VOLUME 2

Application for Permit No. 63-32573

M3 EAGLE, LLC EXHIBITS 21-33

Original

IDWR Hearing
April 15,16, 22-24, May 4-5, 2009

Givens Pursley LLP
601 W. Bannock Street
Boise, Idaho 83702
(208) 388-1200

M3 EAGLE
EXHIBIT INDEX

EXHIBIT NO.	EXHIBIT DESCRIPTION
	M3 EAGLE'S TECHNICAL REPORTS AND SUPPORTING DOCUMENTATION (submitted 11/26/08)
1	Drillers Logs Location Map For M3 Eagle 09-13-2007 small
2	M3 Eagle Regional Hydrogeologic Characterization Year One Progress Report
3	Map of Protestants Wells 10-14-2008
4	M3 Eagle SVR #6 Composite - FINAL
5	M3 Eagle SVR #7 Composite by Hydro Logic, Inc. 4-14-2008 - FINAL
6	M3 Eagle SVR #9 Test Well Composite Diagram by Hydro Logic, Inc 07-07-2008 smaller
7	M3 Eagle Test Well #1 Composite by Hydro Logic, Inc. 4-23-2008
8	M3 Eagle Test Well #2 Composite - FINAL
9	M3 Eagle Test Well #3 Composite Diagram by Hydro Logic, Inc. 9-27-2007
10	M3 Eagle Test Well #4 Composite Diagram by Hydro Logic, Inc 4-16-2008
11	Magnetometer Report for M3 Eagle May 20, 2007
12	RE-Analysis of 16 Aquifer Tests in the Greater Eagle-Star Area of North Ada County, Idaho
13	Seismic Reflection Profiling in the Big Gulch Area - Report by John Bradford at CGISS (BSU) - September 2006
14	Star Supply Well #3 Composite - FINAL smaller
15	SVR #10 Test Well Composite Diagram by Hydro Logic, Inc 07-07-2008 smaller
16	Modeling of Ground Water Flow in the Pierce Gulch Sand Aquifer 11-19-2008
17	Well Density by section and Quarter Section 09-13-2007
18	Water Level Measurement Survey Update to M3 Eagle Hydrogeologic Characterization
19	Documentation provided by S. H. Wood, PhD., Professor Emeritus
	19A (Wood geophysical logs)
	19B (Wood May 20, 2007 Qualitative Interpretation of Magnetic Anomalies and Progress Report on Geologic Mapping in the Foothills North of Eagle, Ada and Gem Counties, Idaho)

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UPDATED 4/14/2009

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EXHIBIT NO.	EXHIBIT DESCRIPTION
	19C (Wood/USGS 2004 Geological Field Trips in Southern Idaho, Eastern Oregon, and Northern Nevada)
	19D (Wood/Clemens 2002 Geologic and Tectonic History of the Western Snake River Plain, Idaho and Oregon)
	19E (Wood/Squires 1/8/2001 Stratigraphic Study of the Boise (Idaho) Aquifer System Using Borehole Geophysical Logs with Emphasis on Facies Identification of Sand Aquifers)
	19F (Wood August, 1997 Structure Contour Map of Top of the Mudstone Facies, Western Snake River Plain, Idaho)
	19G (Wood January, 1994 Seismic Expression and Geological Significance of a Lacustrine Delta in Neogene Deposits of the Western Snake River Plain, Idaho)
	19H (Wood/Anderson December, 1981 Geothermal Investigations in Idaho, Part II Geological, Hydrological, Geochemical and Geophysical Investigations of the Nampa-Caldwell and Adjacent Areas, Southern Idaho)
20	Test Well #1 Plot - M3 Eagle
21	Monthly Monitoring Hand Measured Water Levels
22	Figures and Tables to be included and described in upcoming Aquifer Test 2008 Report
23	2007 Regional Ground Water Level Contour Map
24	Summary of Water Chemistry Data for M3 Eagle and Select Regional Wells
25	Water Chemistry and Cross-Section Wells Map
26	Cross-Sections from wells with geophysical logs (four total)
27	Cross-Sections of wells near M3 Eagle with well construction and lithology (thirteen total)
28	Hydrographs of United Water Idaho's State and Linder Monitoring Wells (1999-2008)
29	Ground water gradient map in Eagle, Idaho area (USGS 1980)
30	Hydrograph of Vail and Miller domestic wells (1995-1998)
31	Ground Water Gradient Map from Lindholm (USGS 1991)
32	Curriculum Vitae and Summaries of Facts and Opinions of M3 Eagle Experts
	32A (Squires, Ed CV and Summary of Opinion)
	32B (Utting, Mark CV)

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EXHIBIT NO.	EXHIBIT DESCRIPTION
	32C (Pearson, Loren Facts and Opinions)
	32D (Osiensky, James CV and Summary of Opinion)
	32E (Wood, Spencer CV and Facts)
	32F (Jim Rumbaugh - NOT TESTIFYING)
	32G (Dittus, Roger Facts and Opinions, CV)
	32H (Schwartzman, Peter CV and Facts
	32I (Glanzman CV)
	32J (Del Leavitt - NOT TESTIFYING)
	32K (Wonders, Scott Facts and Opinions
	32L (Holt, Steven CV, Nov 26, 2008 Engineering Water Uses Report
	32M (Church, John CV and Facts and Opinions
33	Documentation for the Treasure Valley Hydrologic Project (includes oversize map: Structure Contour Map of Top of the Mudstone Facies, Western Snake River Plain, Idaho, by Spencer H. Wood)
	33A (Petrich Feb 2004 Treasure Valley Hydrologic Project Executive Summary)
	33B (Petrich Feb 2004 Simulation of Ground Water Flow in the Lower Boise River Basin)
	33C (Petrich Feb 2004 Simulation of Increased Ground Water Withdrawals in the Lower Boise River Basin)
	33D (Petrich & Urban Feb 2004 Characterization of Ground Water Flow in the Lower Boise River Basin
	33E (Mar 04 Appendix C: Monitoring Well Diagrams for the Report, Characterization of Ground Water Flow in the Lower Boise River Basin)
	33F (Petrich & Urban 2004 Water Quality Data for Monitoring Well TVHP #4 Municipal Park Addendum to the Report Characterization of the Ground Water Flow in Lower Boise River Basin)
	33G (Hutchings & Petrich Dec 2002 Ground Water Recharge and Flow in the Regional Treasure Valley Aquifer System Geochemistry and Isotope Study)
	33H (Hutchings & Petrich Dec 2002 Influence of Canal Seepage on Aquifer Recharge Near the New York Canal)
	33I (Urban Water Budget for the Treasure Valley Aquifer System for the Years 1996 and 2000)

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	33J (Dittus, Allred, Squires Oct. 1999 Hydrogeology, Geochemistry, and Well Construction of the Treasure Valley Hydrologic Project Monitoring Well #1, Ada County, Idaho)
	33K (Treasure Valley Hydrologic Project #2 Monitoring Well Nov. 1999)
	33L (Scanlan July 2001 Final Report on the Quarry View Park Well Project)
	33M (Municipal Park Monitoring Well (TVHP#4) July 2002)
	33N (Beukelman 1997 Treasure Valley Hydrologic Project Geological and Geophysical Framework of the Treasure Valley Reports on the Ontario, Parma, Notus and Boise Cross Sections)
	33O (Squires & Wood Jan 2001 Stratigraphic Studies of the Boise (ID) Aquifer System Using Borehole Geophysical Logs with Emphasis on Facies Identification of Sand Aquifers)
	33P (Wood Aug 1997 Structure Contour Map of the Base of Quaternary Basalt, Murphy and west part of Mountain Home Map Sheets, Idaho)
	33Q (Wood Aug 1997 Structure Contour Map of Top of the Mudstone Facies, Western Snake River Plain, Idaho)
	33R (Geologic Cross-Section Across the Treasure Valley from 15 Miles Northwest of Star to the Snake River)
	33S (Geologic Cross-Section Across the Treasure Valley from 6 Miles East-Northeast of Star to the Snake River)
	33T (Othberg & Stanford 1992 Geologic map of the Boise Valley and Adjoining Area, Western Snake River Plain, Idaho)
	33U (Liberty & Wood Apr 2001Treasure Valley Seismic Reflection Project - UPRR 2000 Profile)
	33V (Treasure Valley's Water Future, Summary of the Treasure Valley Water Summit, Jan 14-15, 2000 (May 2002))
34	Map and composite diagram of Eagle Pines Water Association well
35	Draft spreadsheet containing information currently known about Protestants' wells (HLI 2008)
36	November 6, 2008 Memorandum from Dale Ralston, PhD and Professor Emeritus to Josephine Beeman
37	Compact disc of ground water level monitoring data and aquifer test data obtained by Hydro Logic, Inc. in the North Ada County Area
38	M3 Eagle Potable Water Facility Planning Progress Update Meeting #3 Presentation Slides, November 25, 2008, prepared by Stanley Consultants, Inc.
39	Map of Preliminary Sewer Plan, prepared by Stanley Consultants, Inc.
40	Demographic Forecast: Economic & Fiscal Impact Analysis, October 2008, prepared by Dr. John Church
41	Development of a Numerical Ground Water Flow Model for the M3 Eagle Development Area Near Eagle Idaho, Douglas, Stacey L., Master's Thesis (December 2007).

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EXHIBIT NO.	EXHIBIT DESCRIPTION
	M3 EAGLE'S SECOND AMENDED APPLICATION FOR PERMIT (last amended April 2008)
42	M3 Eagle's Second Amended Application for Permit No. 63-32573 with Attachments and Exhibits (filed February 1, 2008; last amended April 2008)
	M3 EAGLE'S SUPPLEMENTAL REPORTS BY HLI (submitted in 2009)
43	Ground Water Geochemistry of Wells in the North Ada County Area of Idaho (Jan. 20, 2009)
44	A Nine-Day Constant-Rate-Discharge Aquifer Test of the SVR #7 Test Well In Big Gulch, North Ada County, Idaho (Jan. 20, 2009)
45	Technical Memorandum re Response to IDWR's March 2, 2009 Staff Memorandum On M3 Eagle Hydrogeologic Studies (with exhibits), prepared by Hydro Logic Inc., dated April 1, 2009 (submitted April 3, 2009)
	DOCUMENTS SUBMITTED BY NACGUA
46	Memorandum from Dale R. Ralston to Jo Beeman regarding Initial Hydrogeologic Analysis, dated November 6, 2008
47	Hydrogeologic Analysis of the M3 Eagle Site, Expert Report Prepared for the North Ada County Groundwater Users Association, by Ralston Hydrologic Services, Inc., dated January 2009
48	Hydrogeologic Analysis of the M3 Eagle Site: Supplement #1 Comments from Review of Geochemistry Report, Expert Report Prepared for the North Ada County Groundwater Users Association, by Ralston Hydrologic Services, Inc., dated January 2009
49	Letter from Dr. Dale Ralston to NACFA c/o David Head re comments relative to IDWR's March 2, 2009 Staff Memorandum, dated March 31, 2009 (submitted April 3, 2009)
	IDWR STAFF MEMORANDUM
50	IDWR Staff Memorandum re Application for Water Right 63-32573, dated March 2, 2009
	OTHER DOCUMENTS OFFERED BY M3
51	Technical Memorandum from Ed Squires, Hydro Logic, Inc., to Dennis Owsley, IDWR, re Written Analysis of Dale Ralston's Technical Report Per Hearing Officer's February 10th, 2009 Order, dated March 2, 2009
52	Refined Analysis of 2008 Water Level Data from TW #1 and TW #4 Using BETCO to better correct for Barometric Effects, M3 Eagle Master Planned Community, dated April 8, 2009
53	M3 Eagle Master Potable Water & Wastewater Study, by Stanley Consultants (04/28/06)
54	M3 Eagle Financial Statement, dated March 30, 2009
55	Letter from J. Fereday to D. Tuthill re M3 Eagle Planned Community, dated March 23, 2007.
56	Letter from J. Fereday to D. Tuthill re M3 Eagle Amended Water Right Application, dated September 24, 2007.
57	Eagle Foothills Comprehensive Plan
58	Pre-Annexation and Development Agreement by and between City of Eagle and M3 Eagle LLC, dated/recorded December 27, 2007.
59	M3 Eagle Average Monthly Residential Housing Additions cmopared to Monthly Residential Dwelling Unit Permits Issued in Ada and Canyon Counties 2000-2008, prepared by Dr. John Church

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EXHIBIT NO.	EXHIBIT DESCRIPTION
60	M3 Eagle: A Summary of Projected 30-Year Buildout Scenario of Residential Housing Units, Households, and Polulation, prepared by Dr. John Church
61	Graphs: The Idaho Economy has Recovered from Severe Recessions in the Past, prepared by Dr. John Church
62	Water Volumes Calculated Using Peak Day Water Production Overstate Annual Water Demand, prepared by Dr. John Church
63	Map based on Figure 1 from Memorandum re Ground Water Geochemistry of Wells in the North Ada County Area of Idaho, dated January 20, 2009, with PGSA wells highlighted and noted.
64	Letter from E. Squires to Nichole Baird Spencer (City of Eagle) re Comments on Letters Submitted by NACFA and Phillip Fry Concerning the M3 Eagle Proposed Planned Community Development North of Eagle, Idaho, dated October 16, 2006.
65	M3 Eagle slide presentation (April 2009)
	OTHER DOCUMENTS BY OR FROM PROTESTANTS
100	Notices of Protest
101	Protestant Questionnaires
102	Affidavit of Dale R. Ralston in Support of NACGUA's Reply to M3 Eagle's Response to NACGUA's Motion for Stay, and Limited Discovery for Purposes of Settlement, dated November 24, 2008
103	Dale Ralston List of References Reviewed, dated Feb. 2, 2009
104	Alan Smith Response to Discovery Request of Applicant M3 Eagle LLC, dated October 27, 2008.
105	Letter from K. Pennisi to Gary Spackman re NACFA's assignment of protest to NACGUA, dated August 26, 2008.
106	David Head notes re water quantity calculations (David Head Deposition Ex. 86)
107	NACGUA bullet list re M3 Eagle water right application (Morgan Masner Deposition Ex. 107)
108	E-mail and attachments from K. Pennisi to "NACFA Supporters" (Conrad Deposition Ex. 24)
109	Letter from David Head to "NACFA Water Group a/k/a . . . . NACGWUA," dated August 12, 2008
110	Letter from David Head to Karl J. Dreher re Request for Comprehensive Groundwater Resource Evaluation and Consideration for New Water Rights Moratorium, dated January 25, 2006
111	Letter from Karl J. Dreher to David Head re Request for Comprehensive Groundwater Resource Evaluation and Consideration for New Water Rights Moratorium, dated May 2, 2006
112	Letter from David Head to David Tuthill re Status of Comprehensive Water Resource Evaluation in North Ada County / Follow-Up on May 12, 2006 Correspondence with Director Dreher, dated January 16, 2007
113	NACFA/NACGUA letter from David Head and John Thornton to M3 Water Protestants re Status on Protest with M3 Municipal water right application, dated September 28, 2008

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EXHIBIT NO.	EXHIBIT DESCRIPTION
114	NACGUA Meeting Presentation (October 2008)
	CITY OF EAGLE WATER RIGHT APPLICATION DOCUMENTS
130	Memorandum from Sean Vincent and Shane Bendixsen to Gary Spackman re Review of City of Eagle, Idaho 7-Day Aquifer Test Report in Support of Applications for Water Right Appropriation 63-32089 and 63-32090, dated November 29, 2006
131	Memorandum from Sean Vincent to Gary Spackman re Review of Addendum to City of Eagle, Idaho 7-Day Aquifer Test Report, dated February 27, 2006 [*sic - should be 2007*]
132	City of Eagle, Idaho 7-Day Aquifer Test Report prepared by Holladay Engineering Company, dated June 2006
133	Addendum to City of Eagle, Idaho 7-Day Aquifer Test Report prepared by Holladay Engineering Company and SPF Water Engineering, dated February 22, 2007
	SUNCOR WATER RIGHT APPLICATION DOCUMENTS
140	Letter from Terry Scanlan (SPF Water Engineering LLC) to Steve Lester (IDWR) re Application for Permit No. 63-32061 - SunCor Idaho, LLC, dated March 3, 2005
141	Lynn Well Water Level Measurement Table and Graph prepared by SPF Water Engineering LLC, dated 10/19/2006 (Application for Permit No. 63-32061, Ex. 38)
142	Maps regarding Avimor and Spring Valley Ranch Resource Area prepared by SPF Water Engineering LLC, all dated January 20, 2006 (Application for Permit No. 63-32061, Exs. 32-34, 36)
143	Letter from Terry Scanlan (SPF Water Engineering LLC) to Bob Taunton (SunCor) re SunCor Water Level Monitoring Program Status, dated October 16, 2006, with enclosed Stipulation to Withdraw Protest between SunCor and NACFA (Application for Permit No. 63-32061, Ex. 42)
144	Aquifer Evaluation in the Big Gulch and Little Gulch Areas of Spring Valley Ranch prepared by SPF Water Engineering LLC, dated October 2004 (Application for Permit No. 63-32061, Ex. 27)

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M3 Eagle Water Levels - Hand measurements (DRAFT November 20, 2008)

Hydro Logic Inc. - WORK IN PROGRESS

This worksheet contains 2006 thru 2008 field measurements and data logger recordings for the M3 Eagle - Test wells (#1, 2, 3, 4), S.V.R. wells (#6, 7, 9), Big Gulch 4-inch stockwater, Kling Domestic, Kling Irrigation, Flack Corral 6-inch, Flack Corral 4-Inch, and Little Gulch 6-inch. Measurement were taken with electrical sounders and calibrated steel tapes.

M3 Eagle Test Well #1

Field Measurements

measuring point (mp) = 3.15' agl

Time (24 hour clock)	Zone #1 Water Level (feet bmp)	Zone #2 Water Level (feet bmp)	Zone #3 Water Level (feet bmp)	Zone #4 Water Level (feet bmp)	Zone #5 Water Level (feet bmp)
10/9/2006 15:59		98.40	104.63	105.80	
01/05/2007 17:41	91.96	92.00	94.65	95.27	93.17
01/08/2007 16:47	91.93	91.93	94.63	95.22	93.06
01/18/2007 12:01	92.13	92.17	94.86	95.47	
04/30/2007 13:31	98.02	98.08	102.61	103.41	92.67
06/01/2007 10:19	104.11	104.12	109.75	110.61	93.58
07/03/2007 11:42	105.17	105.23	110.90	111.91	94.51
07/31/2007 11:34	106.12	106.20	111.72	112.45	95.27
08/30/2007 10:37	105.11	105.16	110.59	111.24	95.48
09/20/2007 13:56	103.47	103.51	108.57	109.23	95.07
11/28/2007 14:04	91.23	91.24	93.47	94.08	
12/06/2007 16:43		90.80	93.02		
01/24/2008 13:37	90.55	90.60	92.79	93.40	92.16
03/04/2008 14:10	91.28	91.33	93.70	94.26	91.79
03/10/2008 10:16	91.46	91.48	93.84	94.40	91.76
03/10/2008 10:19	91.60				
03/20/2008 13:06	91.27	91.30	93.61	94.19	91.83
03/31/2008 13:49	91.55	91.56	94.03	94.56	91.77
05/09/2008 15:39	100.04	100.10	105.10	105.83	92.37
06/13/2008 12:59	100.45	100.51	104.96	105.68	93.73
07/17/2008 12:11	104.45	104.50	110.52	111.64	94.76
08/19/2008 14:00	104.73	104.73	110.38	111.29	94.70
09/19/2008 09:44	102.06	102.12			
09/19/2008 09:49			107.38	108.19	94.59
10/30/2008 13:00	95.84	95.88	99.02	99.64	93.65
11/10/2008 13:54	96.03	96.05	99.85	100.43	93.51

M3 Eagle Test Well #2

Field Measurements

measuring point (mp) = 3.2' agl

Time (24 hour clock)	Zone #1 Water Level (feet bmp)	Zone #2 Water Level (feet bmp)	Zone #3 Water Level (feet bmp)
			"Dry" Zone: Bottom of zone is above water level
11/7/2006 15:37		217.36	
07/24/2007 12:30		217.92	
11/29/2007 14:48		218.30	
01/18/2008 11:18	218.79		
03/06/2008 17:07	218.68		
3/8/2008 15:40	218.40		
03/10/2008 11:36	218.73		
03/20/2008 11:12	218.53		
03/31/2008 16:54		218.98	
05/13/2008 13:32	218.68	219.04	
06/16/2008 12:08	218.65	219.00	
07/16/2008 12:31	218.78	219.12	
08/19/2008 11:20	218.76	219.11	
9/19/2008 12:56	218.81	219.14	
10/30/2008 18:51	218.84		
11/10/2008 16:22	218.88	219.22	

M3 EAGLE LLC
EXHIBIT
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M3 Eagle Test Well #3

Field Measurements

measuring point (mp) = 3.5' agl

Time (24 hour clock)	Zone #1 Water Level (feet bmp)	Zone #2 Water Level (feet bmp)	Zone #3 Water Level (feet bmp)	Zone #4 Water Level (feet bmp)	Zone #5 Water Level (feet bmp)
					"Dry" Zone: Bottom of zone is above water level
11/28/2007 12:38	264.49				
01/24/2008 12:26	263.78				
03/04/2008 15:25	263.84		263.99	264.09	
03/10/2008 09:35	264.15	264.19	264.23	264.44	
03/20/2008 13:06	263.81				
03/31/2008 13:15	263.86	263.85	264.02	264.15	
05/09/2008 12:34	264.05	264.01	264.12	264.31	
06/16/2008 13:35	264.49	264.49	264.54	264.66	
07/17/2008 10:19	264.79	264.79	264.87	265.03	
08/20/2008 14:07	264.89	264.84	264.93	265.12	
9/18/2008 15:18		265.06	265.15	265.32	
09/19/2008 15:18	265.08				
11/05/2008 14:54	264.89		264.99		
11/10/2008 13:00	264.66	264.64	264.71	264.93	

M3 Eagle Test Well #4

Field Measurements

measuring point (mp) = 3.5' agl

Time (24 hour clock)	Zone #1 Water Level (feet bmp)	Zone #2 Water Level (feet bmp)	Zone #3 Water Level (feet bmp)	Zone #4 Water Level (feet bmp)
				"Dry" Zone: Bottom of zone is above water level
03/07/2008 14:56	130.42	130.89	135.00	
03/10/2008 11:04	130.49	130.96	135.16	
03/10/2008 11:07	130.49			
03/31/2008 14:51	130.61	130.85	135.14	
05/08/2008 13:01	131.12		135.09	
06/13/2008 11:34	131.69	132.25	135.64	
07/16/2008 13:52	131.98	132.55	135.69	
08/19/2008 12:57	131.95	132.59	135.79	
09/19/2008 11:54	131.79	132.37	135.78	
10/30/2008 14:48	131.10	131.65	135.67	
11/10/2008 15:00	130.86	131.47	135.62	

M3 Eagle S. V. R. Test Well #6 Field Measurements measuring point (mp) = 1' agl		M3 Eagle S.V.R. Well #7 Field Measurements measuring point (mp) = 5.47' agl		M3 Eagle S.V.R. Well #9 Field Measurements measuring point (mp) = 2' agl	
Time (24 hour clock)	Water Level (feet bmp)	Time (24 hour clock)	Zone #1 Water Level (feet bmp)	Time (24 hour clock)	Water Level (feet bmp)
07/10/2006 18:12	456.26	07/10/2006 14:42	166.46	07/10/2006 19:07	196.24
08/21/2006 14:34	456.23	07/20/2006 16:37	166.38	07/20/2006 18:36	196.58
01/08/2007 11:10	456.71	08/22/2006 13:35	166.35	08/21/2006 13:19	196.60
04/30/2007 17:03	456.64	01/18/2008 12:37	166.64	11/29/2007 17:25	197.31
05/22/2007 12:48	456.55	03/31/2008 15:44	166.86	01/24/2008 10:15	196.97
07/31/2007 14:28	456.92	05/08/2008 15:13	166.72	03/04/2008 10:36	197.20
08/30/2007 13:15	456.61	05/08/2008 15:23	166.72	03/10/2008 13:41	197.28
11/29/2007 16:31	456.60	05/09/2008 16:16	166.82	05/13/2008 16:52	197.35
01/18/2008 14:14	456.89	06/13/2008 10:33	167.33	06/16/2008 09:33	196.52
03/04/2008 07:57	456.57	07/16/2008 13:04	167.31	07/16/2008 09:47	197.68
03/10/2008 12:42	456.97	8/19/2008 12:03	167.37	09/19/2008 15:25	198.00
03/10/2008 12:49	456.97	09/19/2008 11:48	167.36	10/31/2008 11:04	198.14
03/31/2008 18:32	456.98	10/30/2008 16:52	167.11	11/10/2008 18:29	198.11
05/13/2008 15:26	457.11	11/10/2008 15:38	167.04		
05/13/2008 15:37	457.11				
06/16/2008 10:22	457.12				
07/16/2008 11:05	457.17				
08/19/2008 10:00	457.09				
09/19/2008 15:38	456.99				
10/31/2008 8:53	457.11				

UWID State and Linder Test Wells #1 Field Measurements measuring point (mp) = ground leve		M3 Eagle Kling Irrigation Well Field Measurements measuring point (mp) = 1.15' agl		M3 Eagle Big Gulch Stock Well Field Measurements measuring point (mp) = 2.2' agl	
Time (24 hour clock)	Test Well #1 Zone #2 Water Level (feet agl)	Time (24 hour clock)	Water Level (feet bmp)	Time (24 hour clock)	Zone #1 Water Level (feet bmp)
03/06/2007 14:54	13.96	6/2/2006 10:30	103.04	04/30/2007 15:02	151.79
04/30/2007 10:48	12.92	08/22/2006 16:49	101.87	01/18/2008 12:08	152.25
07/03/2007 08:53	11.55	09/01/2006 13:19	101.66	03/04/2008 13:17	152.41
07/31/2007 09:46	10.40	01/08/2007 15:53	97.89	05/08/2008 14:06	152.39
09/20/2007 17:23	12.00	08/30/2007 11:14	109.54	06/13/2008 11:06	152.82
11/28/2007 11:48	14.32	03/10/2008 10:35	96.42	07/16/2008 10:13	152.85
01/24/2008 11:42	13.86	03/10/2008 10:35	96.68	08/19/2008 12:30	152.88
03/04/2008 17:17	14.78	03/31/2008 13:28	96.50	09/19/2008 12:28	152.82
3/31/2008 10:55	14.32	05/09/2008 10:02	105.61	09/19/2008 12:35	152.82
5/9/2008 9:07	12.01	06/13/2008 12:33	105.97	10/30/2008 17:35	152.50
7/17/2008 9:15	10.63	07/17/2008 23:12	110.52	11/10/2008 16:03	152.40
8/20/2008 14:07	11.09	08/19/2008 13:39	110.56		
9/19/2008 12:35	11.78	09/19/2008 08:46	107.94		
11/10/2008 11:45	13.86	09/19/2008 08:52	107.76		
		11/10/2008 14:33	101.16		

Flack Corral 4-Inch Well Field Measurements measuring point (mp) = 2.0' agl		Flack Corral 6-Inch Well Field Measurements measuring point (mp) = 2.8' agl		Little Gulch 6-Inch Field Measurements measuring point (mp) = 1.5' agl	
Time (24 hour clock)	Water Level (feet bmp)	Time (24 hour clock)	Zone #1 Water Level (feet bmp)	Time (24 hour clock)	Water Level (feet bmp)
07/03/2007 14:44	207.82	8/21/2006 18:30	214.05	08/30/2007 13:52	177.25
07/31/2007 13:38	207.72	09/08/2006 13:50	214.10	09/19/2007 12:14	176.85
08/30/2007 12:45	207.84	11/06/2006 15:40	214.53	01/24/2008 11:10	178.27
11/29/2007 15:32	207.95	11/07/2006 13:35	214.29	03/04/2008 11:07	178.63
03/08/2008 17:21	208.04	11/29/2007 15:55	214.68	03/10/2008 13:57	175.94
03/10/2008 12:08	208.34	01/18/2008 13:46	215.19	03/31/2008 19:21	175.98
05/13/2008 14:23	208.26	03/04/2008 11:45	215.00	05/13/2008 16:30	176.17
06/16/2008 11:43	208.22	03/10/2008 12:27	215.14	06/16/2008 08:54	176.40
07/16/2008 12:06	208.21	05/13/2008 14:58	215.02	07/16/2008 10:13	176.66
08/19/2008 10:47	208.20	06/16/2008 11:27	215.03	08/19/2008 09:15	176.82
09/19/2008 13:28	215.45	07/16/2008 11:44	215.12	09/19/2008 15:52	177.01
		08/19/2008 10:34	215.07	10/31/2008 10:36	176.73
		11/10/2008 17:15	215.29	11/10/2008 18:11	176.62

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Table 1. Summary of Well and Aquifer Details

M3 EAGLE LLC EXHIBIT 22

Well	WATER: Measurable Test Drawdown?	WATER: Start-of-Test Level DTW btc ft	WATER: Start-of-Test Level Elev. ft amsl	WELL: Well Elev. ft amsl	WELL: Dist. "r" to Well	WELL: Screen Top/Bottom Depth	WELL: Elev	WELL: Radius in /ft	WELL: Length ft	WELL: Dist Aq. Top to Screen top	WELL: % Aquif. Screened	WELL: Borehole Radius in /ft	AQUIFER: Top/Bottom Depth	AQUIFER: Top/Bottom Elev	AQUIFER: BE* %	AQUIFER: Nature of Aquifer	AQUIFER: Thickness ft	AQUIFER: Aquifer
SVR #7 (Pumping Well)	yes	165.21	2544.63	2709.84	0	280	2429.84	4	70	100	21%	6.00	180	2529.84	95%	Confined	340	Pierce Gulch Sand Aquifer
						350	2359.84	0.33				0.50	520	2189.84				
Big Gulch Stock Well	yes	152.13	2546.09	2698.22	845	180	2518.22	2	0	0	<1%	3?	180	2518.22	96%	Confined	340	Pierce Gulch Sand Aquifer
						180	2518.22	0.17				0.25?	520	2178.22				
M3-TW#2 Zone 3	dry	dry	dry	2766.01	3636	180	2586.01	1	10	120	3%	4.00	60	2706.01	dry	dry	300	Pierce Gulch Sand (dry)
						190	2576.01	0.08				0.33	360	2406.01				
M3-TW#2 Zone 2	yes	218.96	2547.05	2766.01	3636	230	2536.01	1	20	170	7%	4.00	60	2706.01	99%	Unconfined?	300	Pierce Gulch Sand Aquifer
						250	2516.01	0.08				0.33	360	2406.01				
M3-TW#2 Zone 1	yes	218.62	2547.39	2766.01	3636	270	2496.01	1	50	210	17%	4.00	60	2706.01	99%	Unconfined?	300	Pierce Gulch Sand Aquifer
						320	2446.01	0.08				0.33	360	2406.01				
M3-TW#4 Zone 4	no	dry	dry	2673	4489	61	2612	1	10	na	na	4.00	180	2493	na	na	20	dry sand
						71	2602	0.08				0.33	200	2473				
M3-TW#4 Zone 3	yes	134.96	2538	2673	4489	181	2492	1	20	1	100%	4.00	180	2493	85%	Confined	20	**unnamed fluvial sand aquifer**
						201	2472	0.08				0.33	200	2473				
M3-TW#4 Zone 2	yes	130.94	2542	2673	4489	325	2348	1	231	25	89%	4.00	300	2373	39%	Confined	260	Pierce Gulch Sand Aquifer
						556	2117	0.08				0.33	560	2113				
M3-TW#4 Zone 1	yes	130.23	2543	2673	4489	625	2048	1	21	325	53%	4.00	300	2373	33%	Confined	40	**may be part of PGSA**
						646	2027	0.08				0.33	560	2113				
Flack Corral 4-in	?	208.25	2551.98	2760.23	5974	?	?	2	?	?	?	3?	210	2550	?	?	120	?
						?	?	0.17				0.25?	330	2430				
Flack Corral 6-in	yes	215.01	2555.24	2770.25	6749	74	2696.25	3	312	0	100%	3?	220	2550.25	95%	Unconfined?	120	Pierce Gulch Sand Aquifer
						386	2384.25	0.25				0.25?	340.25	2430				
M3-TW#3 Zone 5	no	dry	dry	2786.63	8173	238	2548.63	1	20	na	na	4.25	265	2521.63	na	na	235	Pierce Gulch Sand (dry)
						258	2528.63	0.08				0.35	500	2286.63				
M3-TW#3 Zone 4	no	264.36	2522.27	2786.63	8173	334	2452.63	1	20	69	9%	4.25	265	2521.63	na	Unconfined?	235	Pierce Gulch Sand Aquifer
						354	2432.63	0.08				0.35	500	2286.63				
M3-TW#3 Zone 3	no	264.25	2522.38	2786.63	8173	369	2417.63	1	10	104	4%	4.25	265	2521.63	82%	Unconfined?	235	Pierce Gulch Sand Aquifer
						379	2407.63	0.08				0.35	500	2286.63				
M3-TW#3 Zone 2	no	264.09	2522.54	2786.63	8173	399	2387.63	1	20	134	9%	4.25	265	2521.63	na	Unconfined?	235	Pierce Gulch Sand Aquifer
						419	2367.63	0.08				0.35	500	2286.63				
M3-TW#3 Zone 1	no	263.98	2522.65	2786.63	8173	432	2354.63	1	10	167	4%	4.25	265	2521.63	81%	Unconfined?	235	Pierce Gulch Sand Aquifer
						442	2344.63	0.08				0.35	500	2286.63				
SVR #6	no	456.75	2358.88	2815.63	8189	560	2244	4	170	103	<37%	4.00	457	2358.63	84%	Unconfined?	>283	**Willow Creek Aquifer**
						730	2084	0.33				0.33	>740	<2064				
Little Gulch Stock Well	yes	176.02	2552.77	2728.79	9740	220	2508.79	2	3	44	3%	3?	176	2552.79	99%	Unconfined?	112.79	Pierce Gulch Sand Aquifer
						223	2505.79	0.17				0.25?	288.79	2440				
Kling-Irrigation well	no	96.66	2516.94	2613.6	9908	198	2415.6	8	210	0	76%	11?	300	2313.6	45%	Confined	275	Pierce Gulch Sand Aquifer
						408	2205.6	0.67				0.92?	575	2038.6				
M3-TW#1 Zone 5	no	92.03	2514.36	2606.39	10916	97	2260	1	40	12	73%	4.00	85	2521.39	93%	Confined?	55	**unnamed fluvial sand aquifer**
						137	2056	0.08				0.33	140	2466.39				
M3-TW#1 Zone 4	no	94.54	2511.85	2606.39	10916	353	2260	1	30	0	13%	4.00	353	2253.39	33%	Confined	237	Pierce Gulch Sand Aquifer
						383	2056	0.08				0.33	590	2016.39				
M3-TW#1 Zone 3	no	93.97	2512.42	2606.39	10916	395	2260	1	30	42	13%	4.00	353	2253.39	na	Confined	237	Pierce Gulch Sand Aquifer
						425	2056	0.08				0.33	590	2016.39				
M3-TW#1 Zone 2	no	91.57	2521.77	2606.39	10916	467	2260	1	40	114	17%	4.00	353	2253.39	27%	Confined	237	Pierce Gulch Sand Aquifer
						507	2056	0.08				0.33	590	2016.39				
M3-TW#1 Zone 1	no	91.54	2521.77	2606.39	10916	514	2260	1	42	161	18%	4.00	353	2253.39	na	Confined	237	Pierce Gulch Sand Aquifer
						556	2056	0.08				0.33	590	2016.39				
SVR #9	yes	197.22	2555.84	2753.06	11660	235	2518.06	3	28	38	38%	6.00	197	2556.06	99%	Unconfined?	73	Pierce Gulch Sand Aquifer
						263	2490.06	0.25				0.50	270	2483.06				
UWID State and Linder TW#1 (East) Zone 2	no	-14.67	2533.63	2518.96	22302	280	2238.96	1	90	70	17%	4.00	210	2308.96	20%	Confined	525	Pierce Gulch Sand Aquifer
UWID State and Linder #1A" in HLI, 2007)		(above ground)				370	2148.96	0.08				0.33	735	1784				

NOTES: All wellheads surveyed by ISG during Aug 2007 except M3-TW #4 which has well elevation estimated based on TOPO. " BE" = Barometric Efficiency. "na" = Not Analyzed. Confined nature of aquifer based on comparisons of water levels with geology (interpreted from geophysics and geologic logs).

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Table 2. Summary of SVR #7 Test Aquifer Analyses

Well	Distance from SVR #7	Maximum Measured Drawdown		Calculated Transmissivity	Calculated Storativity	Theis	Cooper-Jacob	Recovery (Theis)	Neuman-Witherspoon	No WL Trend Correction	With WL Trend Correction	Well Loss Removed
		No Trend Adjustment	With Trend Adjustment	T (gpd/ft)	S (unitless)							
	ft	ft	ft									
Five-Well Composite - "Best-Fit"	varies	-	-	430,000	2.1E-03	x				x		
Five-Well Distance Drawdown	varies	-	-	380,000	7.0E-03	x				x		
SVR #7 (Well Loss Removed)	0	29.79	7.51	450,000	-	x				x		x
				380,000	-		x			x		
				520,000	-			x		x		
Big Gulch Stock Well	842	1.71	-	450,000	1.9E-03	x				x		
				500,000	1.2E-03		x			x		
				460,000	-			x		x		
M3-TW#2 Zone 2	3,636	0.17	0.05	240,000	9.1E-02	x				x		
				370,000	2.7E-02	x					x	
				Invalid	Invalid		x			x	x	
				Invalid	-			x		x	x	
M3-TW#2 Zone 1	3,636	0.17	0.08	350,000	6.2E-02	x				x		
				230,000	1.6E-01	x					x	
				Invalid				x		x	x	
M3-TW#4 Zone 3 (as upper part of PGSA)	4,489	0.15	0.08	Invalid	Invalid	x	x	x		x	x	
M3-TW#4 Zone 3 (as overlying, unnamed aquifer)		0.15	0.08	Invalid	Invalid				x			
M3-TW#4 Zone 2	4,489	0.67	0.60	570,000	3.0E-03	x				x		
				580,000	3.0E-03	x					x	
				"700,000?"	-			x		x		
				"840,000?"	-			x			x	
M3-TW#4 Zone 1 (as lower part of PGSA)	4,489	0.58	0.59	170,000	2.4E-03	x				x		
				160,000	2.2E-03	x					x	
				"690,000?"	-			x		x		
				"790,000?"	-			x			x	
M3-TW#4 Zone 1 (as underlying aquifer)				60,000	3.5E-04				x	x		
				60,000	3.5E-04				x		x	
Flack Corral 4-in	5,974	?	?	Invalid	Invalid	x	x	x		x	x	
Flack Corral 6-in	6,749	0.08	0.08	Invalid	Invalid	x	x	x		x	x	
M3-TW#3 Zones 1-4	8,173	none	none	-	-							
SVR #6 (Willow Creek Aquifer)	8,189	none	none	-	-							
Little Gulch Stock Well	9,740	0.08	0.14	180,000	1.3E-02	x				x		
				270,000	1.2E-02	x					x	
				Invalid	-			x		x		
				"670,000?"	-			x			x	
Kling-Irrigation well	9,908	none	none	-	-							
M3-TW#1 Zones 1-5	10,916	none	none	-	-							
SVR #9	11,660	0.09	0.15	250,000	8.7E-03	x				x		
				320,000	7.1E-03	x					x	
				Invalid	-			x		x		
				"780,000?"	-			x			x	
UWID State & Linder TW#1 Zone 2	22,302	none	none	-	-							

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Table 3. Well Loss and Well Efficiency Comparison

	Theoretical	Actual	Well Loss -Efficiency		Means	
Pumping Time	DD	DD	(difference)	(ratio)	Well Loss	Efficiency
min	ft	ft	ft	%	22.92	14%
12	3.34	25.83	22.49	13%		
18	3.43	26.07	22.64	13%		
28	3.53	26.49	22.96	13%		
43	3.63	26.57	22.94	14%		
66	3.72	27.14	23.42	14%		
101	3.82	27.70	23.88	14%		
156	3.92	26.83	22.91	15%		
240	4.02	26.13	22.11	15%		

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Figure 1. Well Location Map

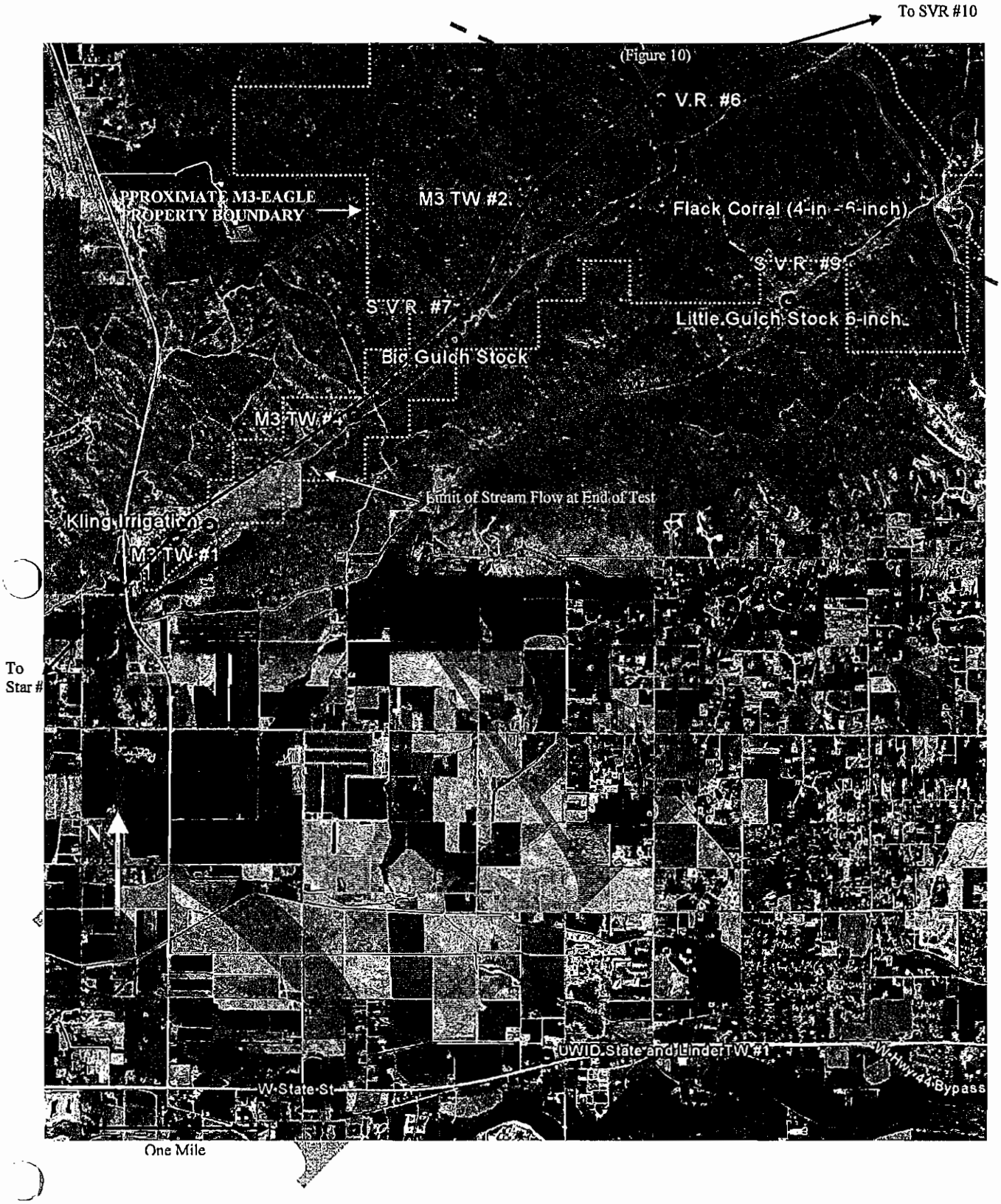


Figure 2. Composite Diagram for Well SVR #7 (the Pumping Well)

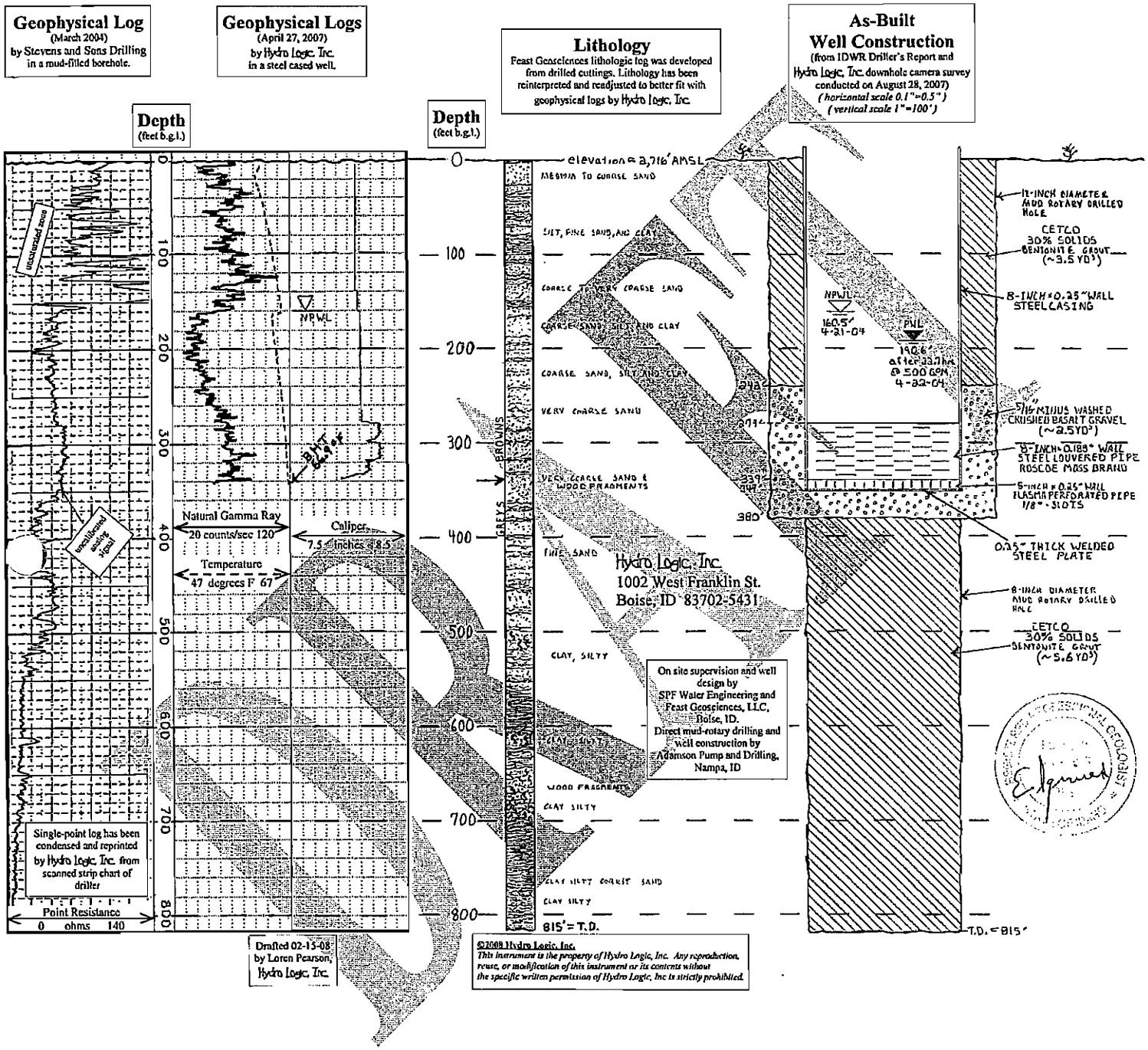


Figure 3. Composite Diagram for Well M3-TW #1

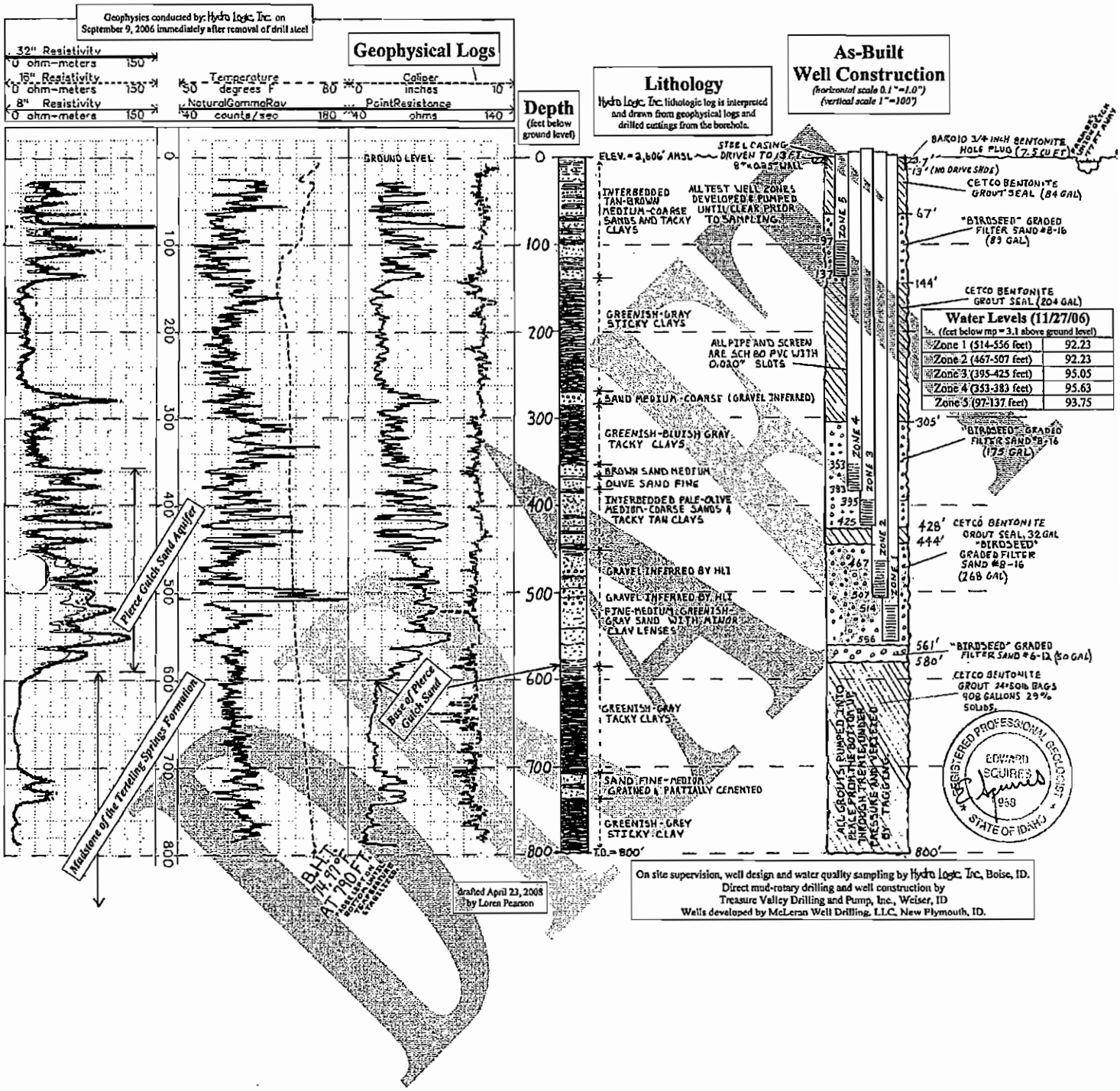


Figure 4. Composite Diagram for Well M3-TW #2

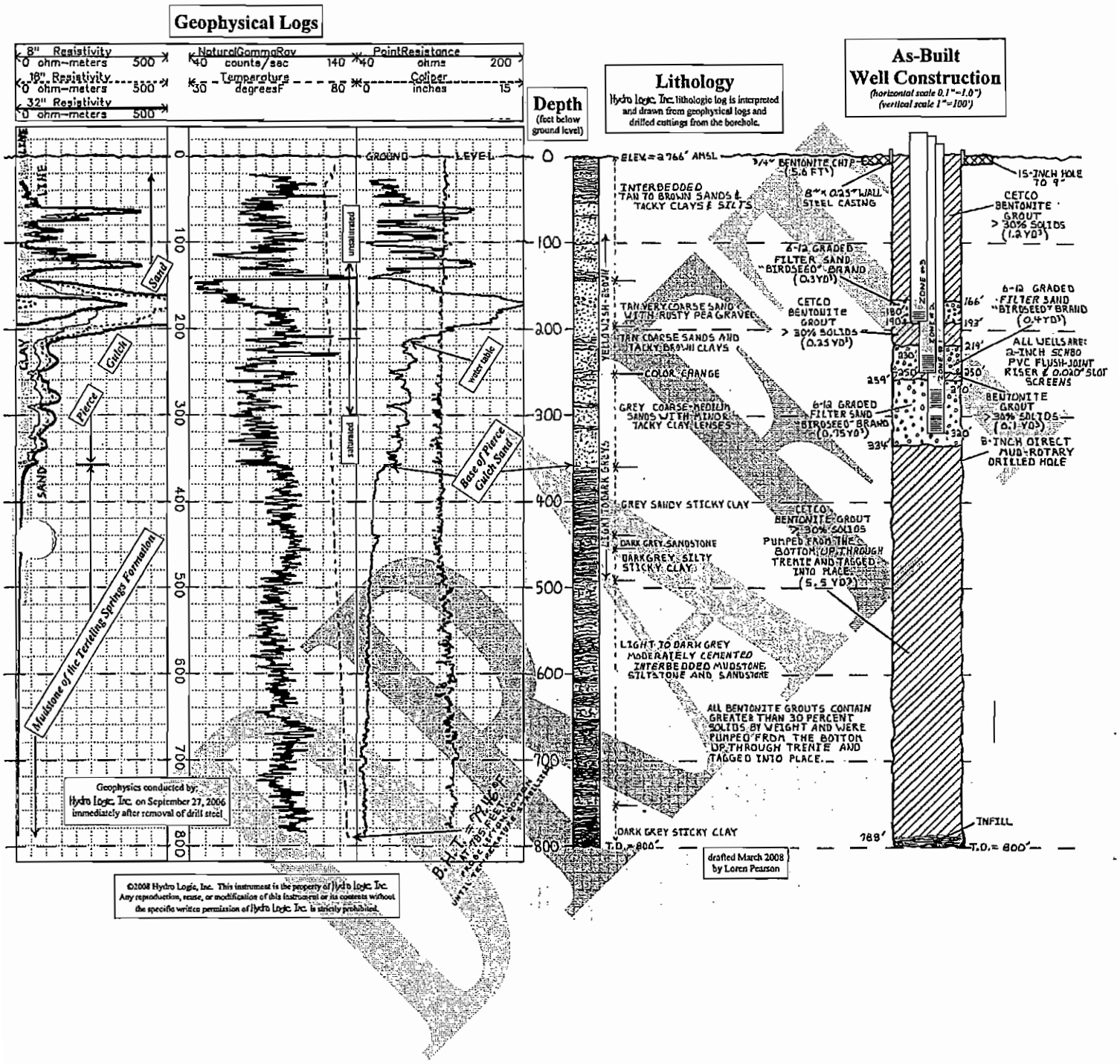


Figure 5. Composite Diagram for Well M3-TW #3

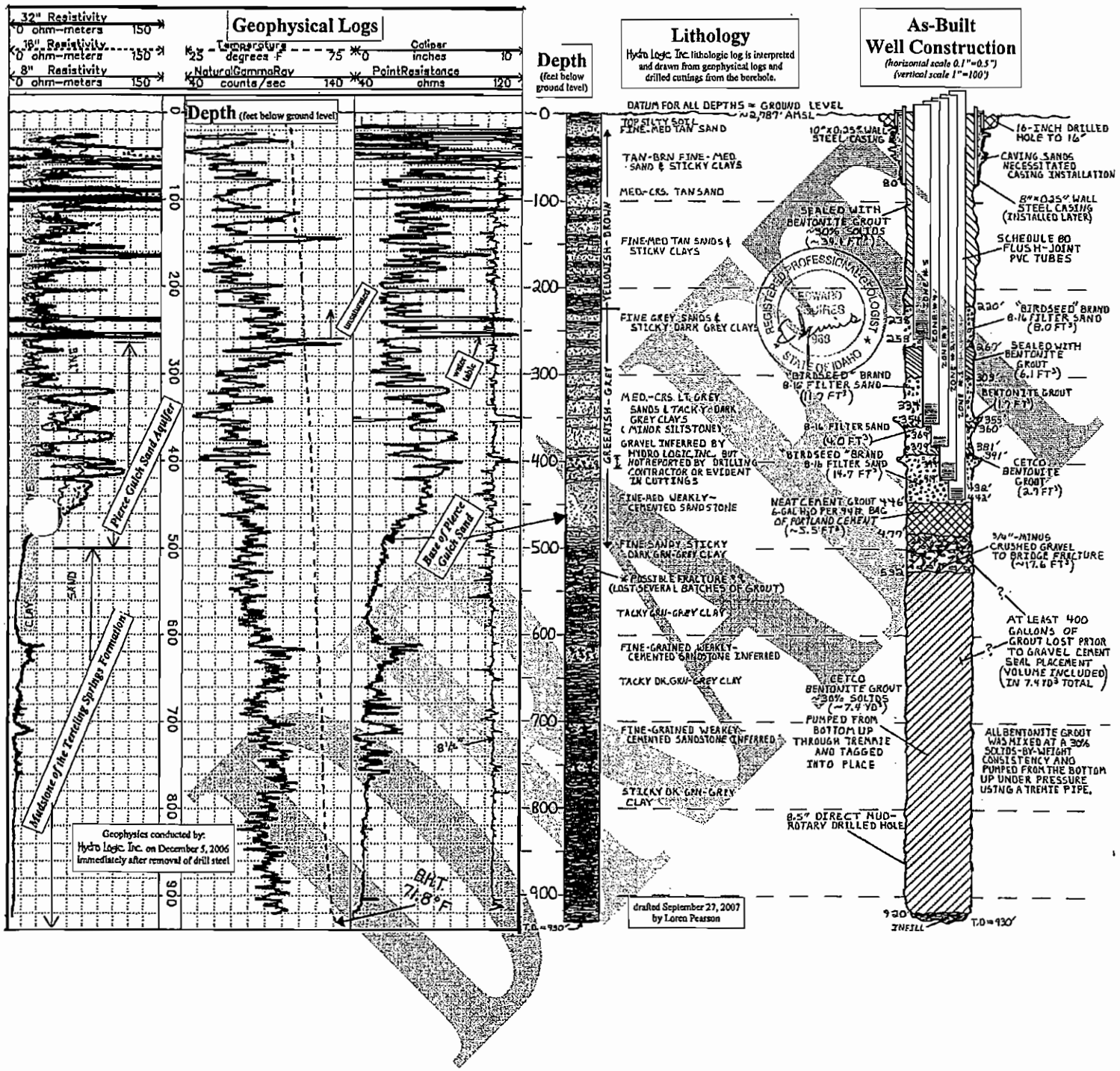


Figure 6. Composite Diagram for Well M3-TW #4

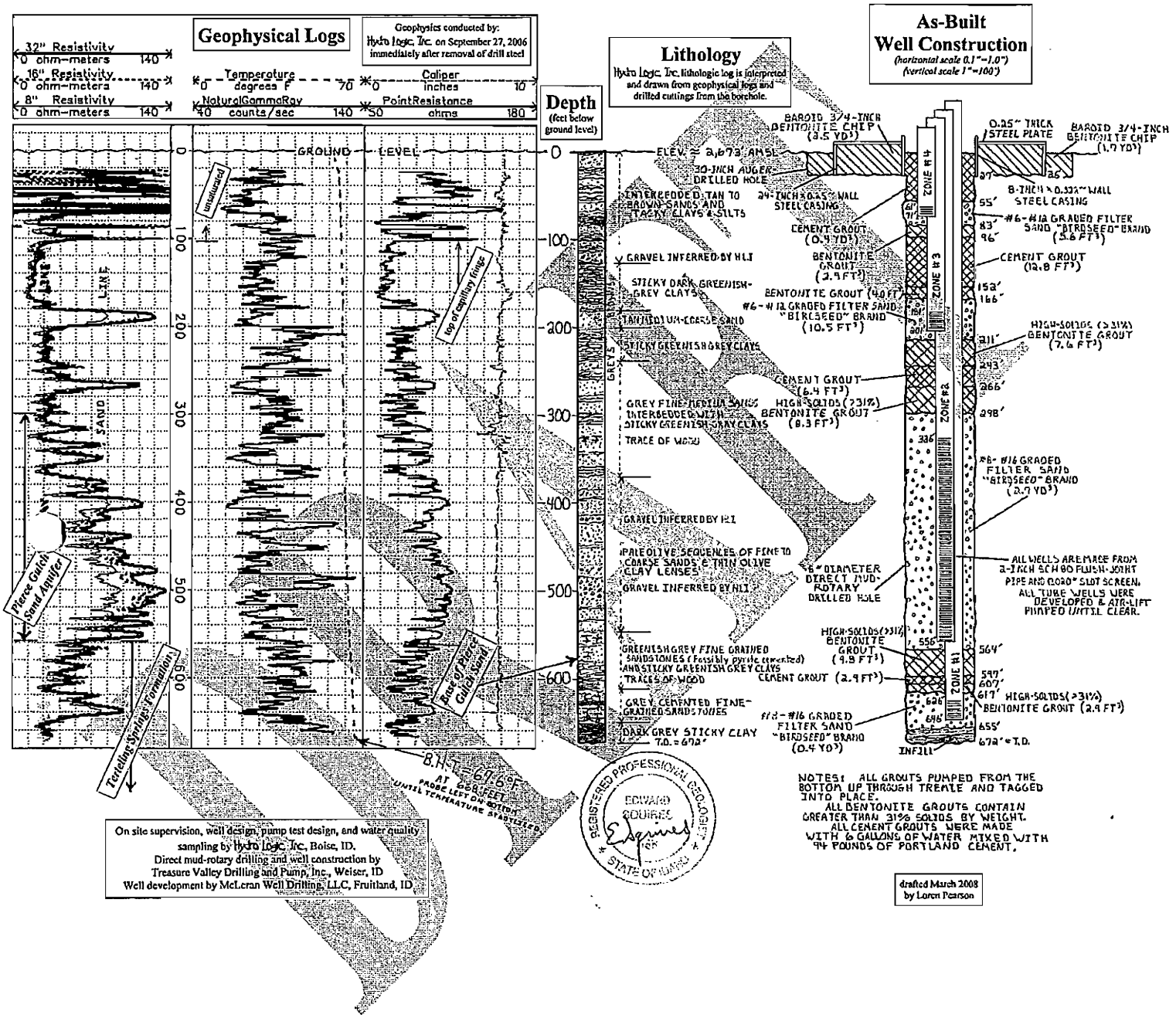


Figure 7. Composite Diagram for Well SVR #9

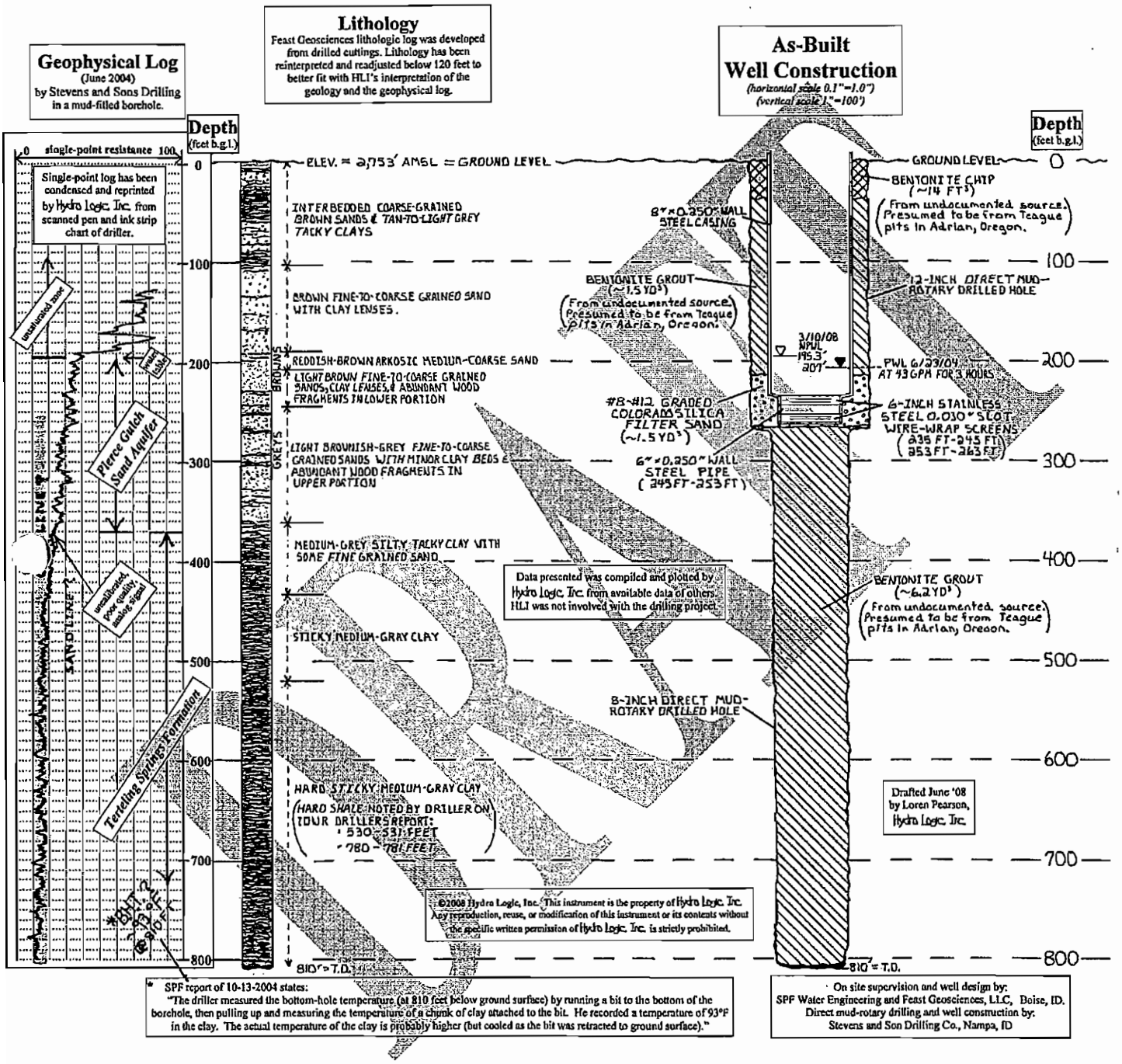


Figure 8. Composite Diagram for Well SVR #6

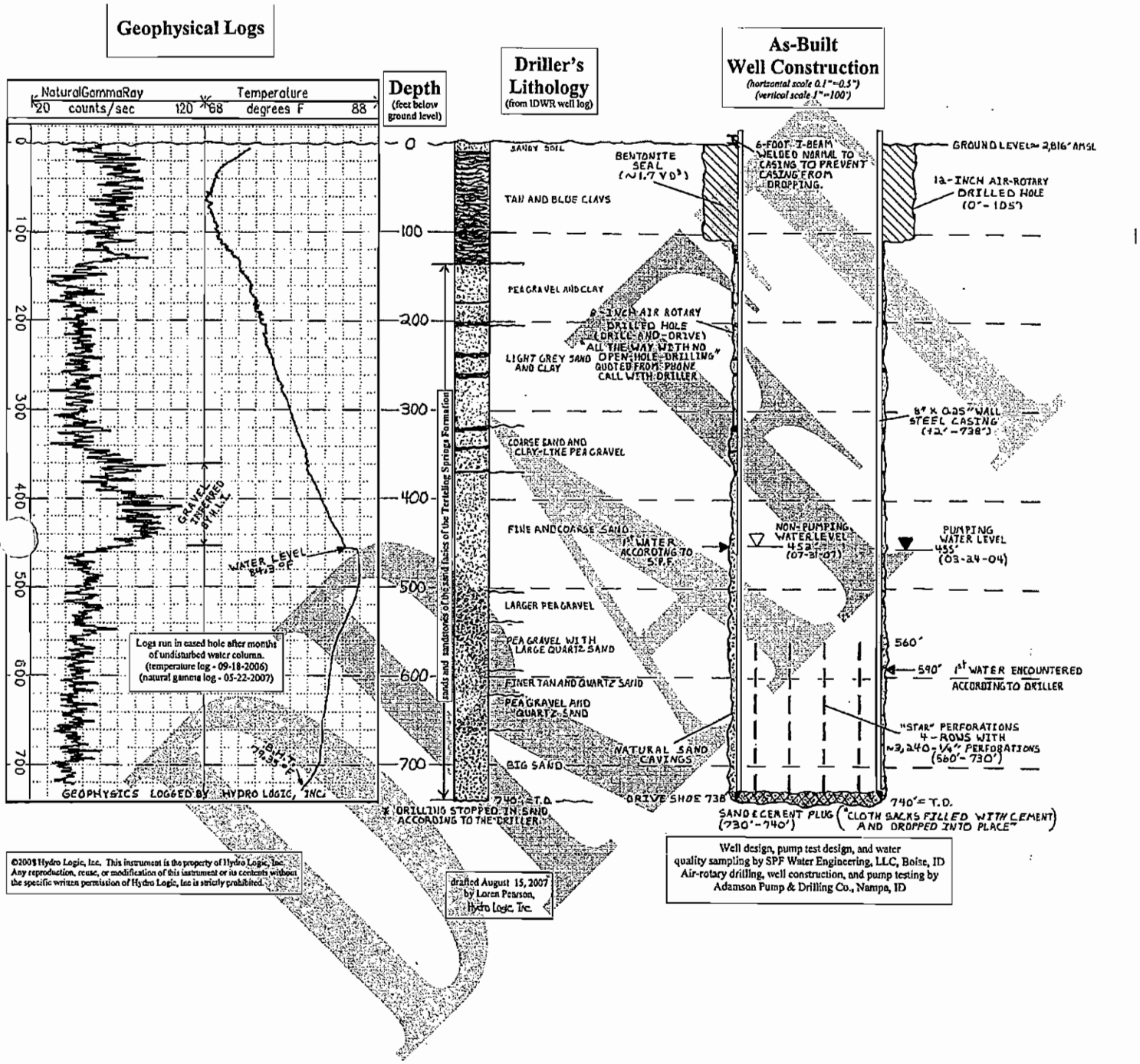


Figure 9. Composite Diagram for Well UWID State and Linder #1A

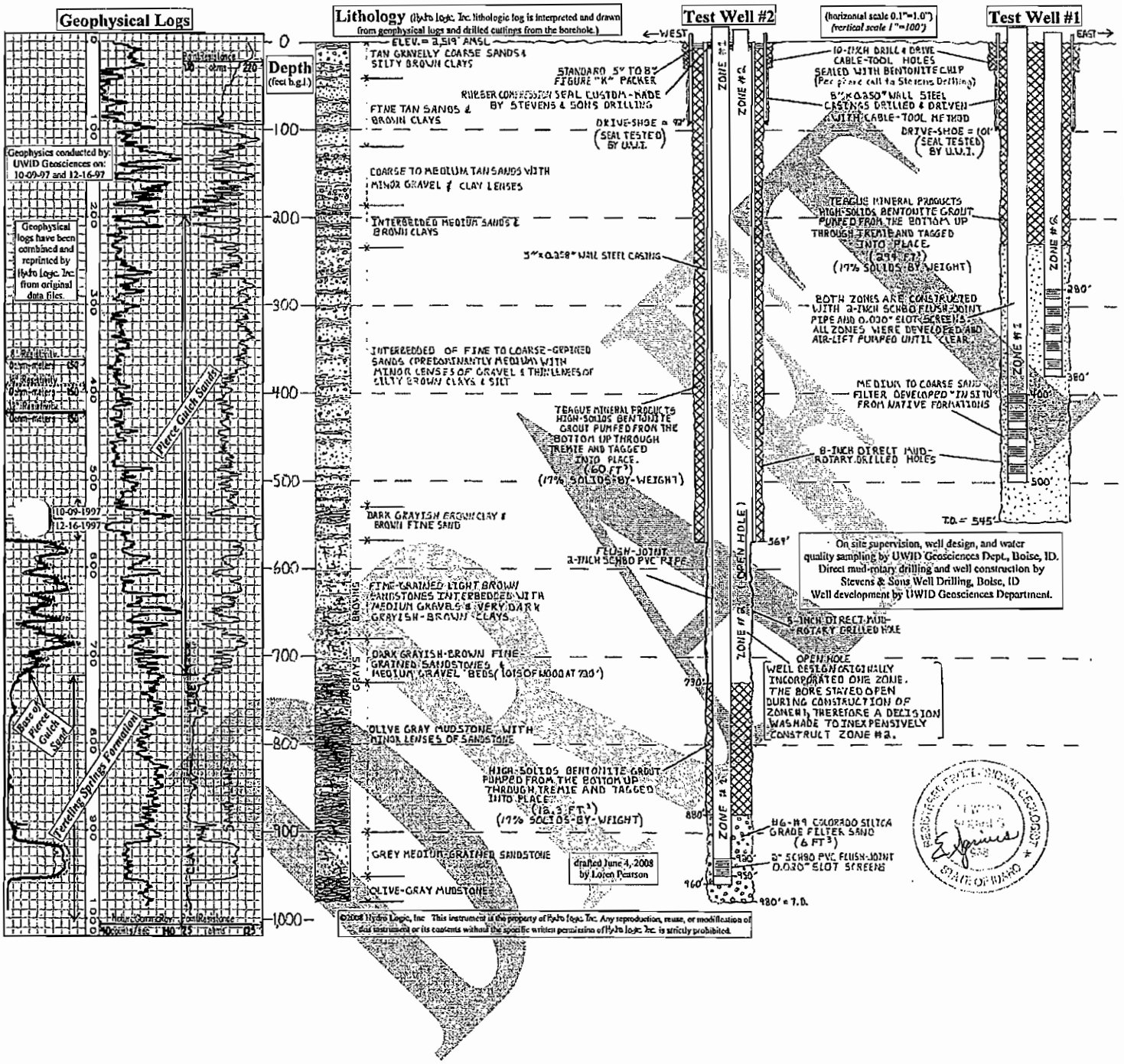
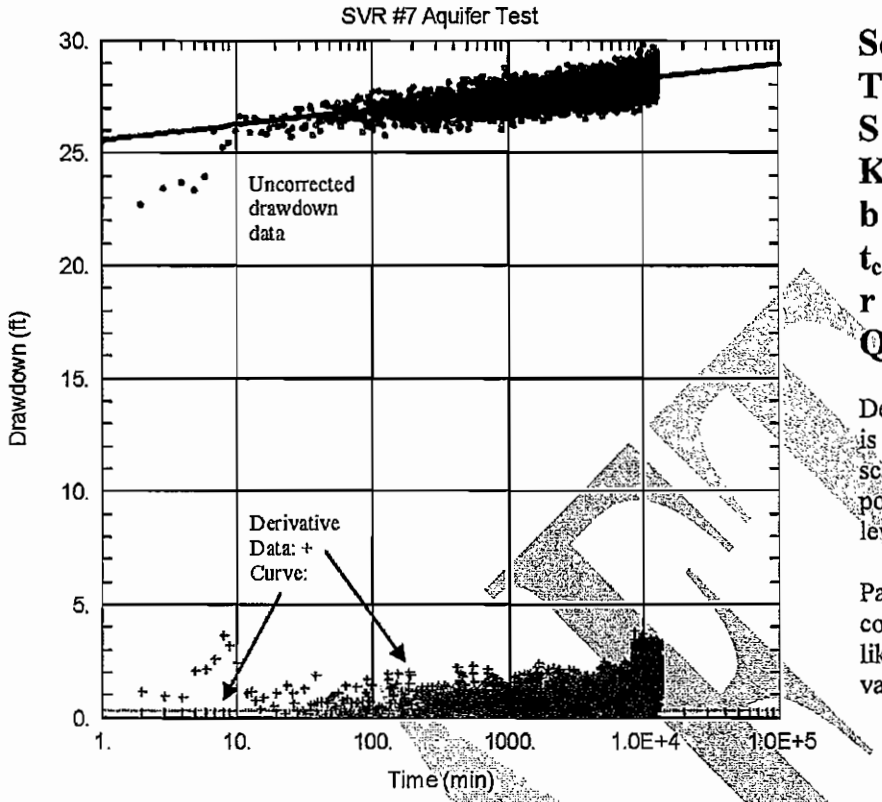


Figure 10. Southwest to Northeast Hydrogeologic Cross Section Beneath the M3 Site

[Insert figure here, rotated 90 degrees]

Figure 12. Cooper-Jacob Analysis for Well SVR #7



Screen = 279-349 ft
T=400,000 gpd/ft
S = Not Calculable
Kv/Kh=0.1
b = 340 ft
t_c < 1 min
r = 0.5ft
Q = 917gpm

Derivative analysis indicates method is valid for data after 20 min. Wide scatter of drawdown and derivative points the results of surging water levels in tight well casing.

Partial penetration correction corrections not applied. Analysis likely underestimates transmissivity value without PP correction.

$T = 264Q/\Delta s$ Where:

T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

t_c = critical time where "u assumption" is met (where u = 0.05) such that method may be valid, is less than 1minute.

$u = 1.87r^2S/Tt$

t = time in days
r = effective radius of pumping well (ft)

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Based on the analytical method of Cooper and Jacob (1946).
No partial penetration corrections.

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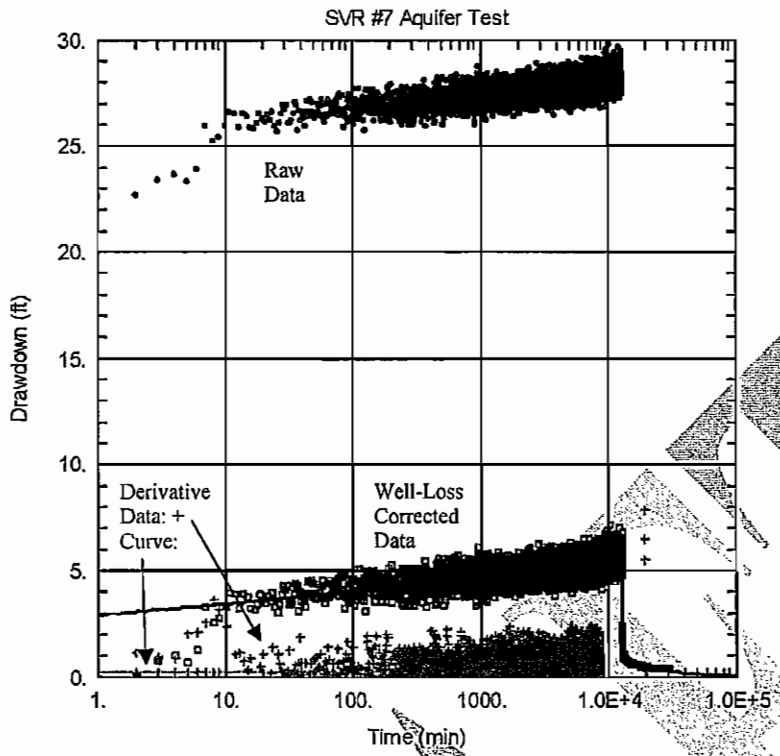
Figure 13. Theis Analysis for Well SVR #7



Screen = 279-349 ft
T=450,000 gpd/ft
S = Not Calculable
Kv/Kh=0.1
b = 340 ft
r = 0.5ft
Q = 917gpm

Derivative analysis indicates method is valid for data after 20 min. Wide scatter of drawdown and derivative points the results of surging water levels in tight well casing.

Well-loss correction of 23 feet applied derived from back-calculated theoretical-drawdown based on observation well analysis. See text for details.

Linear vertical (drawdown) scale used to allow better curve fit to data and less-exaggerated derivative data plot.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

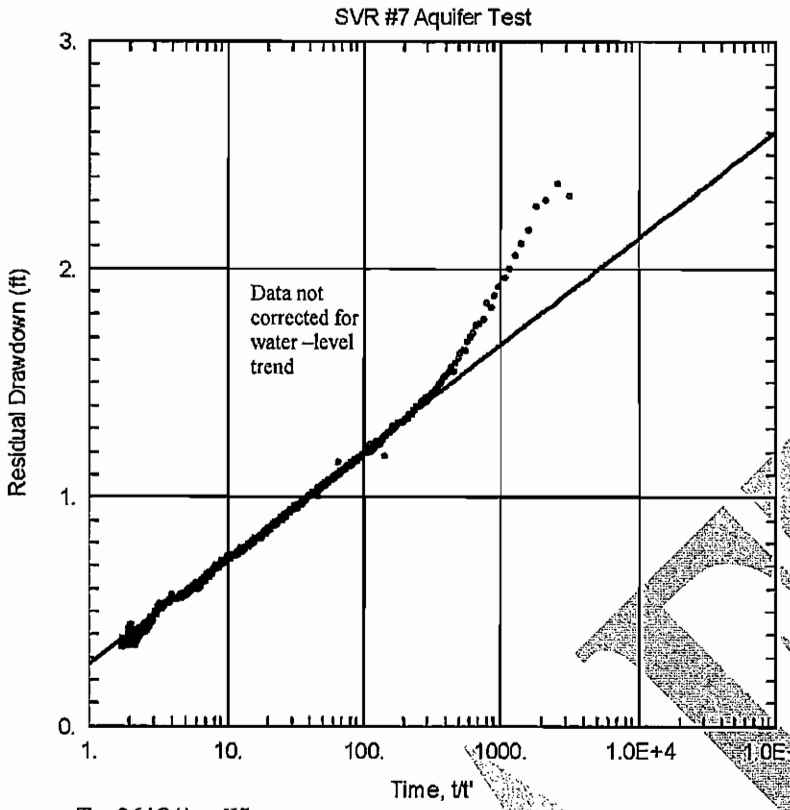
$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = effective radius of pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), estimated from geophysical and well logs in the area

Solid Line represents "type curve" where T and S best match observed drawdown. Variations from "smooth," semi-log curve the result of Aqtesolv® generating type curve based on variations in reported pumping rate.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 14. Theis Recovery Analysis for Well SVR #7



Screen = 279-349 ft
T=520,000 gpd/ft
S/S' =0.3
Kv/Kh=0.1
b = 340 ft
r = 0.5 ft
Q = 917gpm

S/S' less than 1 suggests "late" or "incomplete" recovery, often indicative of an aquifer no-flow boundary, as is present beneath the M3 site (see green line in Figure 1). However, seasonal (declining), regional, water- level trend over 11+ days of recovery may also be a cause of the apparent incomplete recovery.

T = 264Q/Δs Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

t = time since pumping started (minutes)
t' = time since pumping stopped (minutes)

S/S' = storativity ratio (unitless) where:
S/S' < 1 indicates no-flow boundary ("late" recovery)
S/S' = 1indicates no recharge or discharge boundaries ("normal" recovery)
S/S'>1 indicates recharge boundary ("early" recovery)

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), calculated from geophysical log of well.
r = effective radius of pumping well (ft)

Based on the analytical method of Theis (1935).

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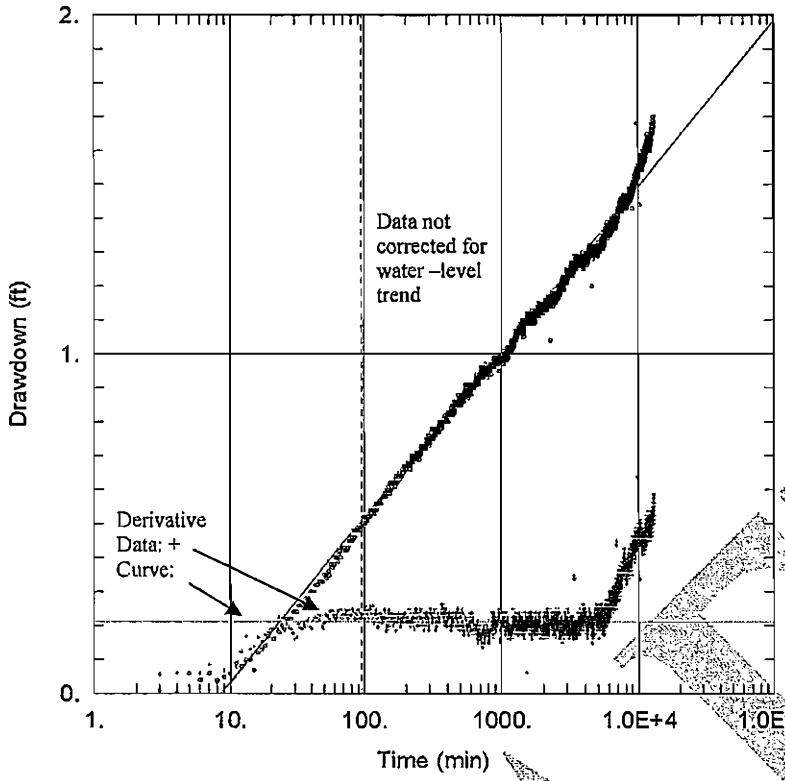
Figure 15. Cooper-Jacob Analysis for the Big Gulch Stock Well



Screen = 180 ft (Open hole)
T=500,000 gpd/ft
S = 1.2x 10^{-3}
Kv/Kh=0.1
b = 340 ft
t_c = 95 min
r = 845 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 100 and 6,000 min. Rise in apparent drawdown and derivatives after 6,000 minutes caused by declining regional aquifer water level trend. Data are uncorrected for this trend.

Partial penetration corrections not needed.

$T = 264Q/\Delta s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

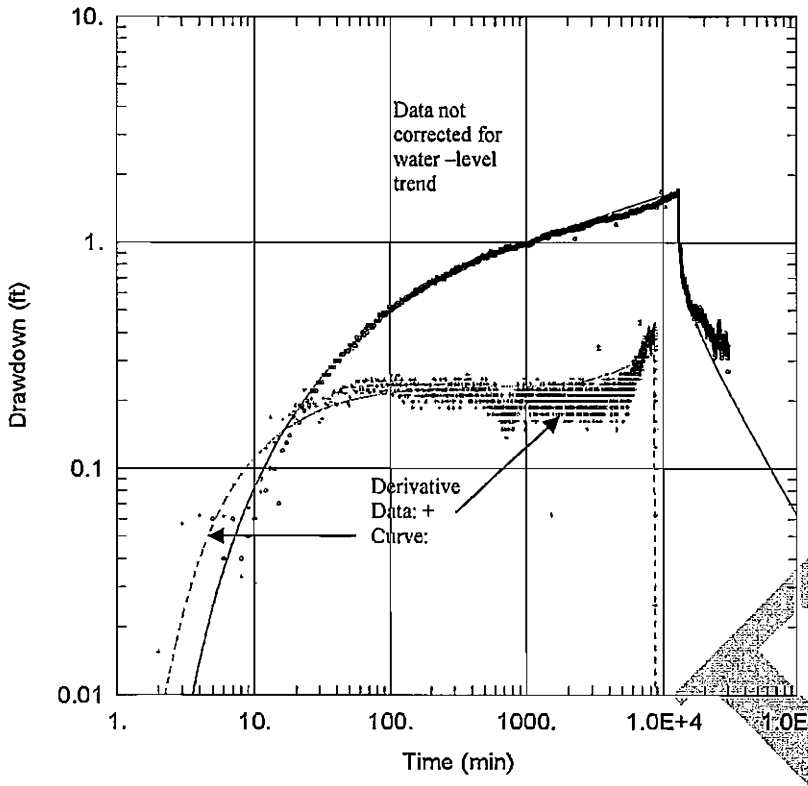
t_c = critical time where "u assumption" is met (where u = 0.05) such that method may be valid, is 95 minutes as shown by dashed vertical line.

$u = 1.87r^2S/Tt$
t = time in days
r = distance to pumping well (ft)

b = aquifer thickness in feet (ft), estimated from geophysical log of well SVR #7.

Based on the analytical method of Cooper and Jacob (1946).
No partial penetration corrections needed.

Figure 16. Theis Analysis for the Big Gulch Stock Well



Screen = 180 ft (Open hole)
T=450,000 gpd/ft
S = 1.8x 10^{-3}
Kv/Kh=0.1
b = 340 ft
r = 845 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 100 and 5,000 min. Rise in apparent drawdown and derivatives after 6,000 minutes caused by declining regional aquifer water level trend. Data are not corrected for this trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

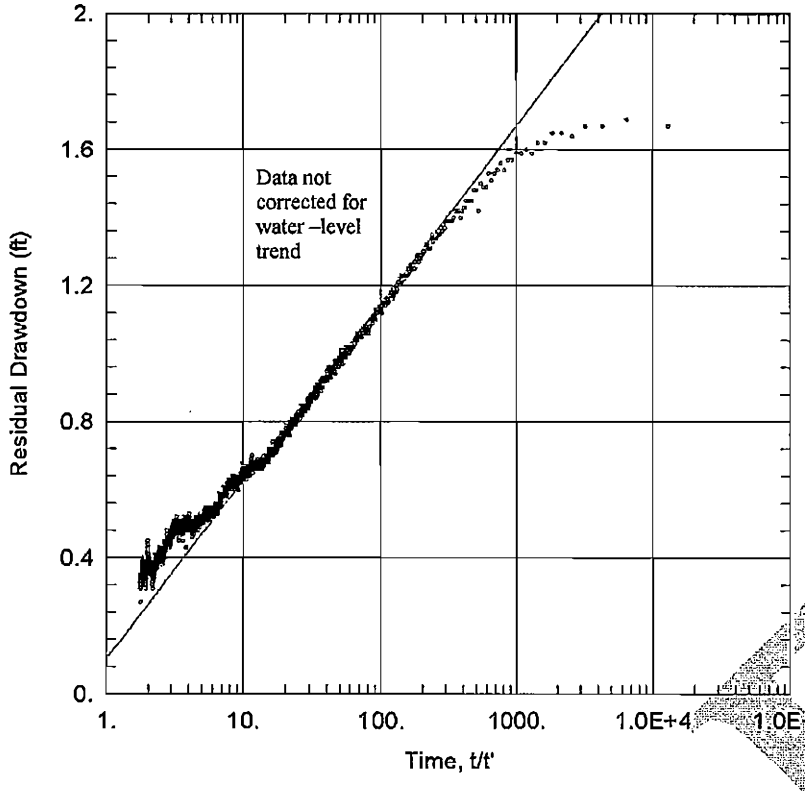
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), estimated from geophysical log of well SVR #7.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 17. Theis Recovery Analysis for the Big Gulch Stock Well



Screen = 180 ft (Open hole)
T=450,000 gpd/ft
S/S' =0.6
Kv/Kh=0.1
b = 340 ft
r = 845 ft
Q = 917gpm (at SVR #7)

S/S' less than 1 suggests "late" or "incomplete" recovery. However, seasonal (declining), regional, water-level trend over 11+ days of recovery is most probable cause of apparent incomplete recovery.

Partial penetration corrections not needed.

T = 264Q/Δs Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

t = time since pumping started (minutes)
t' = time since pumping stopped (minutes)

S/S' = storativity ratio (unitless) where:
S/S' < 1 indicates no-flow boundary ("late" recovery)
S/S' = 1indicates no recharge or discharge boundaries ("normal" recovery)
S/S' >1 indicates recharge boundary ("early" recovery)

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), estimated from geophysical log of well SVR #7.
r = distance to pumping well (ft)

Based on the analytical method of Theis (1935).

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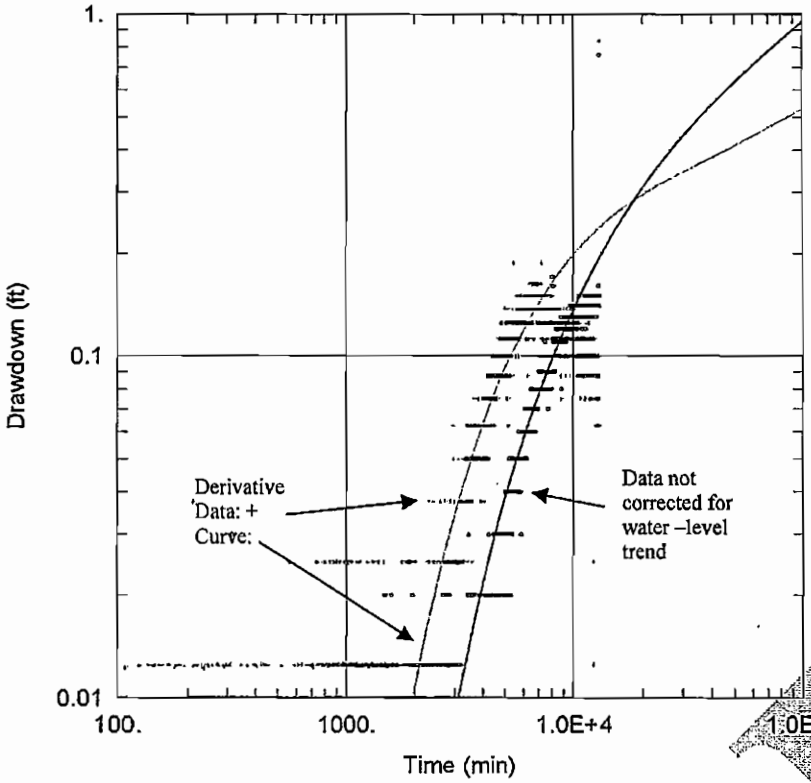
Figure 18. Theis Analysis for the M3-TW #2 Zone 2 – No Trend Correction



Screen = 230-250 ft
T=240,000 gpd/ft
S = 9.0x 10^{-2}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 2,000 and 7,000 min. Fall in apparent drawdown and derivatives after 6,000 minutes caused by end of rising regional aquifer water level trend. Data are uncorrected for this trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

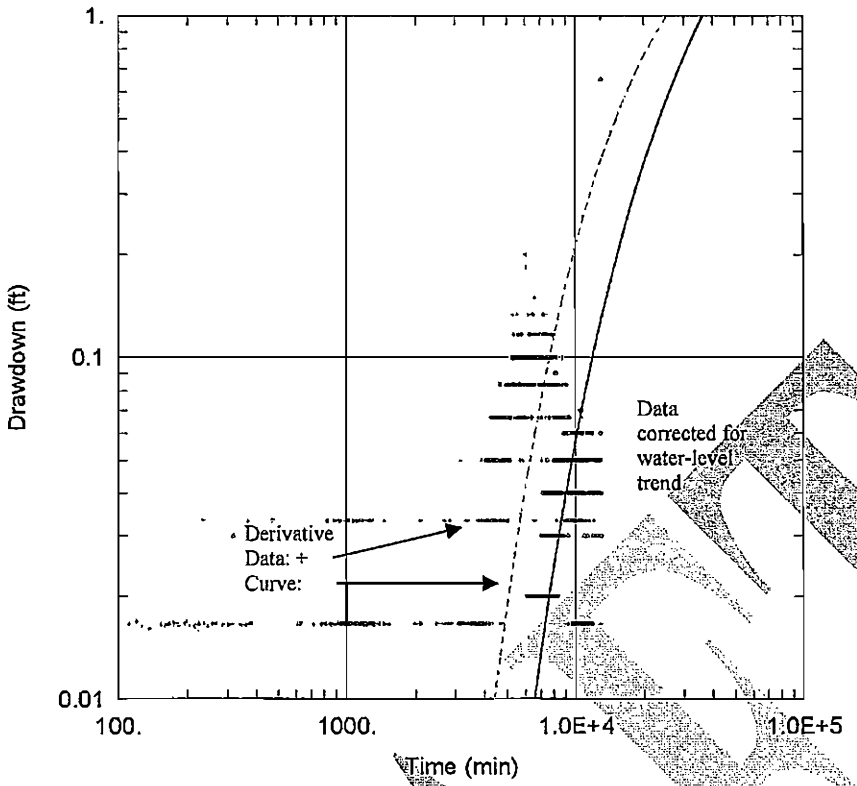
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 19. Theis Analysis for the M3-TW #2 Zone 2 – With Trend Correction



Screen = 230-250 ft
T=370,000 gpd/ft
S = 2.7x 10^{-2}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 2,000 and 5,000 min. Fall in apparent derivatives after 6,000 minutes may be caused in part by relatively large range for calculating derivative (0.4 log cycles) that extends beyond data collection period.

Partial penetration corrections not needed.

$T = 114.6\ Q\ W(u)/s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

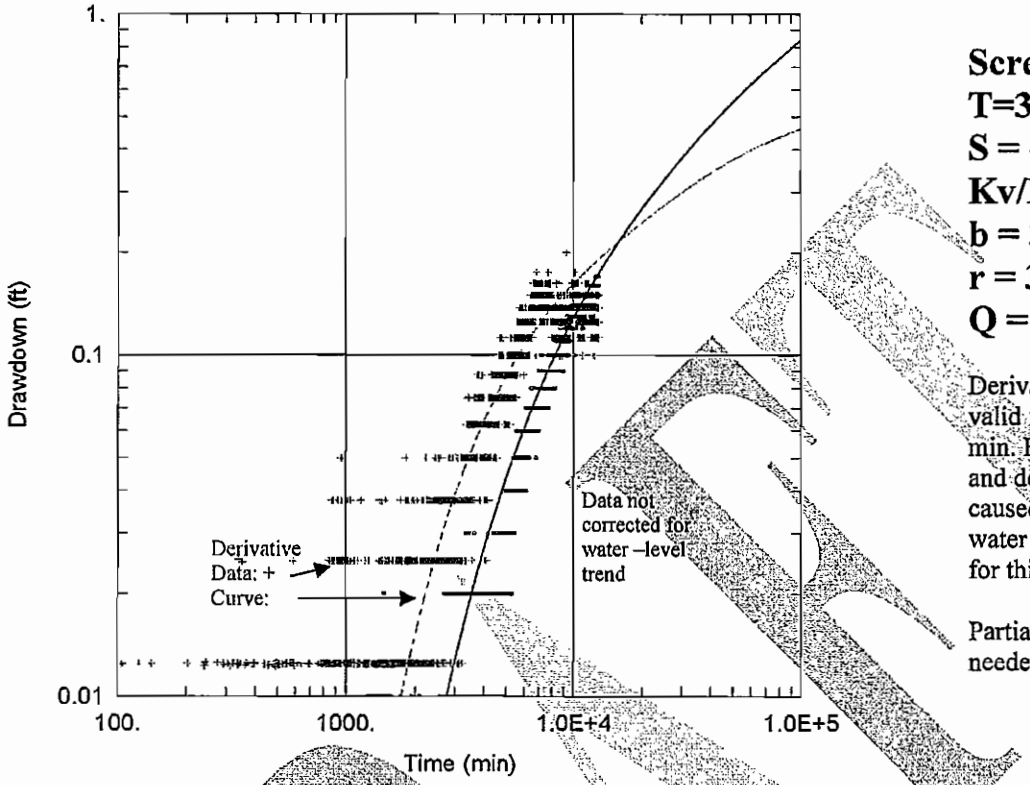
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 20. Theis Analysis for the M3-TW #2 Zone 1 – No Trend Correction



Screen = 270-320 ft
T=350,000 gpd/ft
S = 6.2x 10^{-2}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 2,000 and 7,000 min. Flattening in apparent drawdown and derivatives after 7,000 minutes caused by end of rising regional aquifer water level trend. Data are uncorrected for this trend.

Partial penetration corrections not needed.

$T = 114.6\ Q\ W(u)/s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
$W(u)$ = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

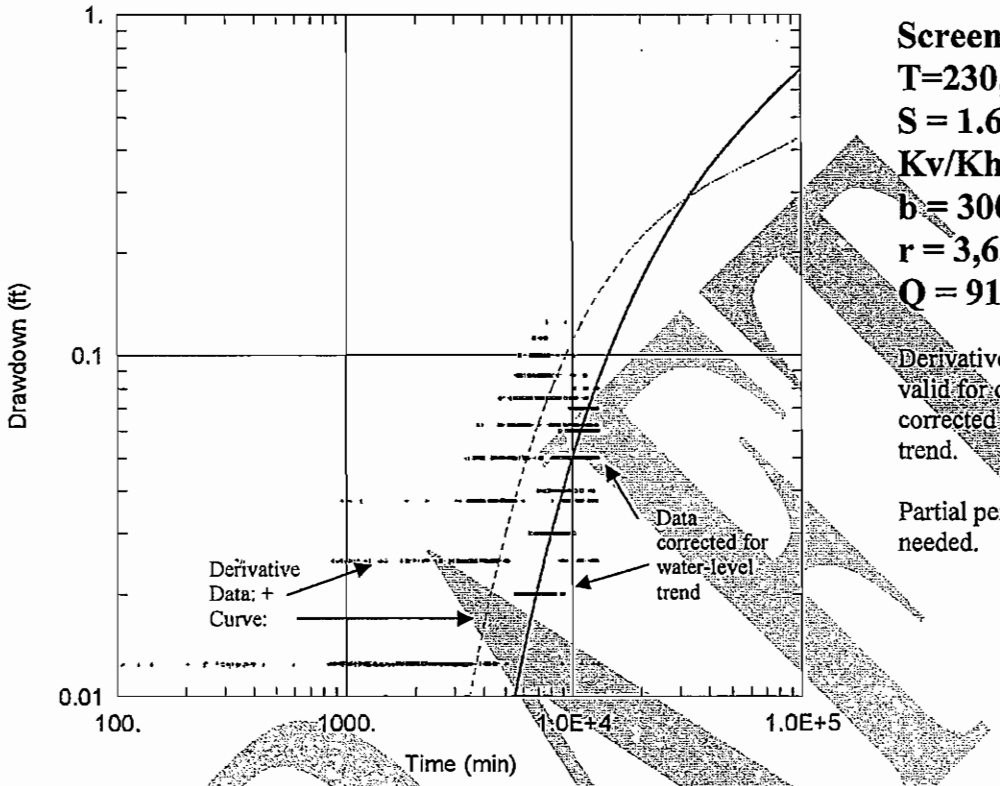
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 21. Theis Analysis for the M3-TW #2 Zone 1 – With Trend Correction



Screen = 270-320 ft
T=230,000 gpd/ft
S = 1.6x 10^{-1}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data for entire test. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

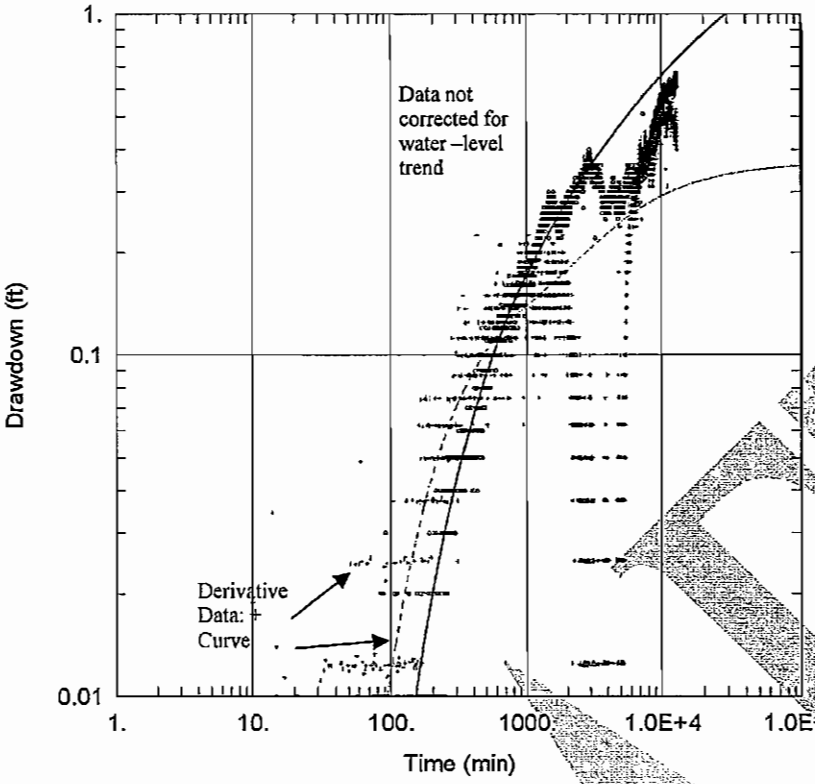
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 22. Theis Analysis for the M3-TW #4 Zone 2 – No Trend Correction



Screen = 325-556 ft
T=570,000 gpd/ft
S = 3.0x 10^{-3}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 1,000 minutes of test. Afterward, incomplete barometric corrections and lack of water level trend corrections make analysis only approximate. Data are uncorrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

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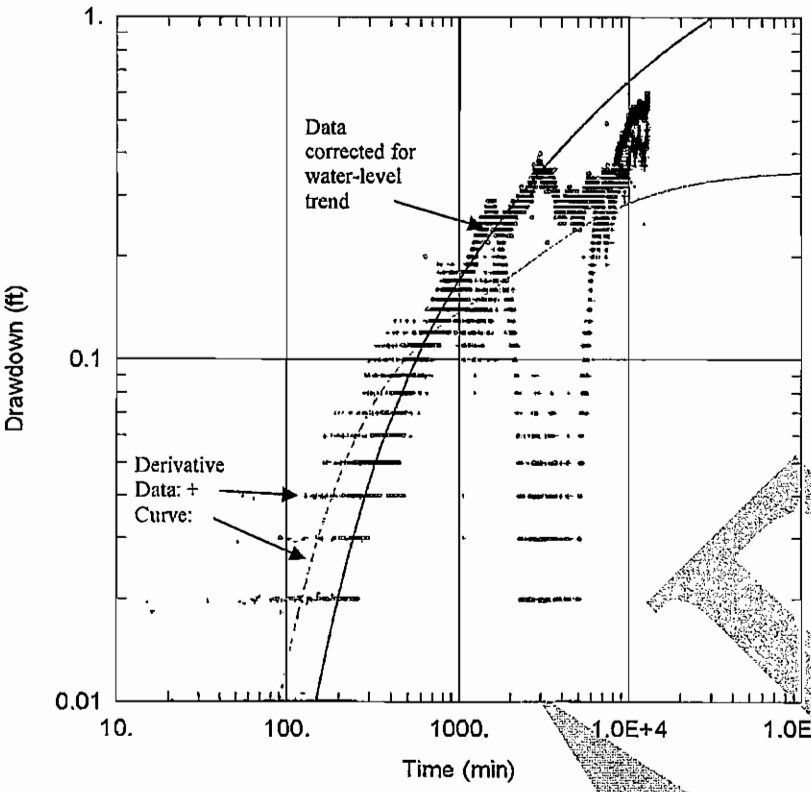
Figure 23. Theis Analysis for the M3-TW #4 Zone 2 – With Trend Correction



Screen = 325-556 ft
T=580,000 gpd/ft
S = 3.0x 10^{-3}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 1,000 minutes of test. Afterward, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

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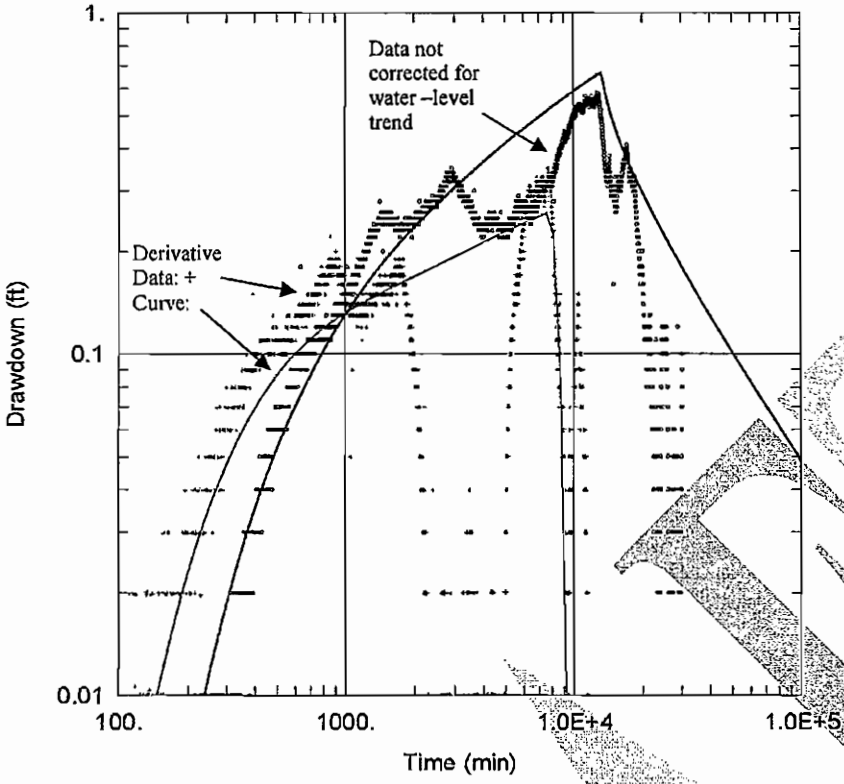
Figure 24. Neuman-Witherspoon Analysis for the M3-TW #4 Zone 1 – as an Aquifer Separate from the PGSA, No Trend Correction



Screen = 625-646 ft
T_{PGSA}= 500,000 gpd/ft
S_{PGSA} = 2.3x 10^{-3}
Kv/Kh=0.1
b_{PGSA} = 260 ft
$T_{zone\ 1}$= 80,000 gpd/ft
$S_{zone\ 1}$ = 1 x 10^{-3}
$b_{zone\ 1}$ = 30 ft
$b_{aquitard}$ = 30 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates only fair match for method. After 200 minutes, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

*Partial penetration corrections not needed.

Based on the analytical method of Neuman and Witherspoon (1972) derived from the original method of Theis (1935). Based on assumption of flow to the pumped aquifer, through a leaky aquitard, from a second aquifer. Flow through the aquitard is assumed to be vertical. See Appendix D for equations and illustrations.

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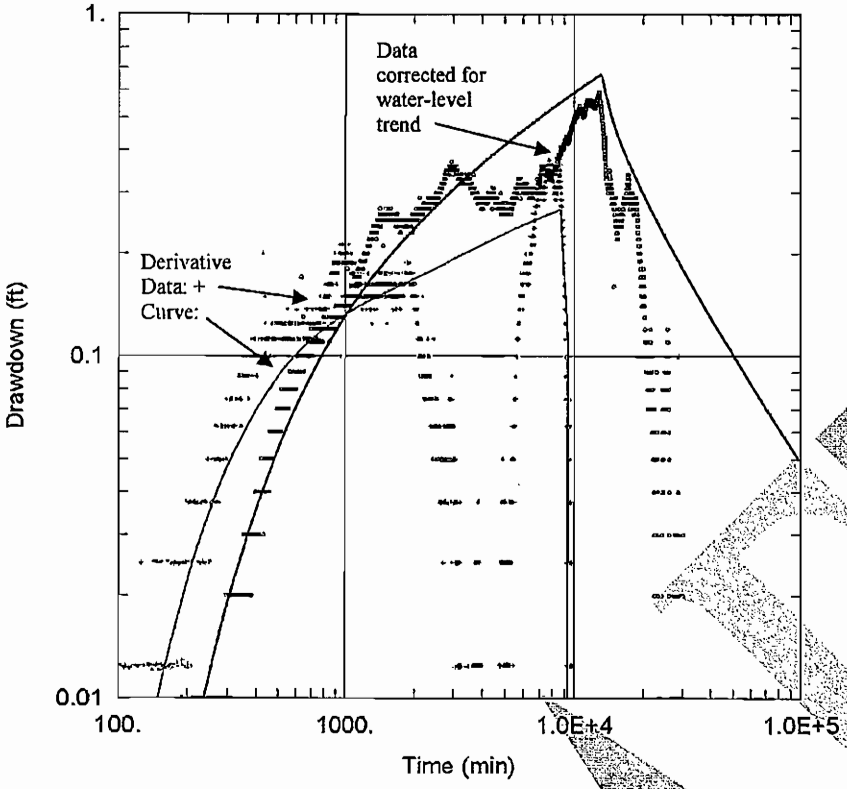
Figure 25. Neuman-Witherspoon Analysis for the M3-TW #4 Zone 1 – As Aquifer Separate From PGSA, With Trend Correction



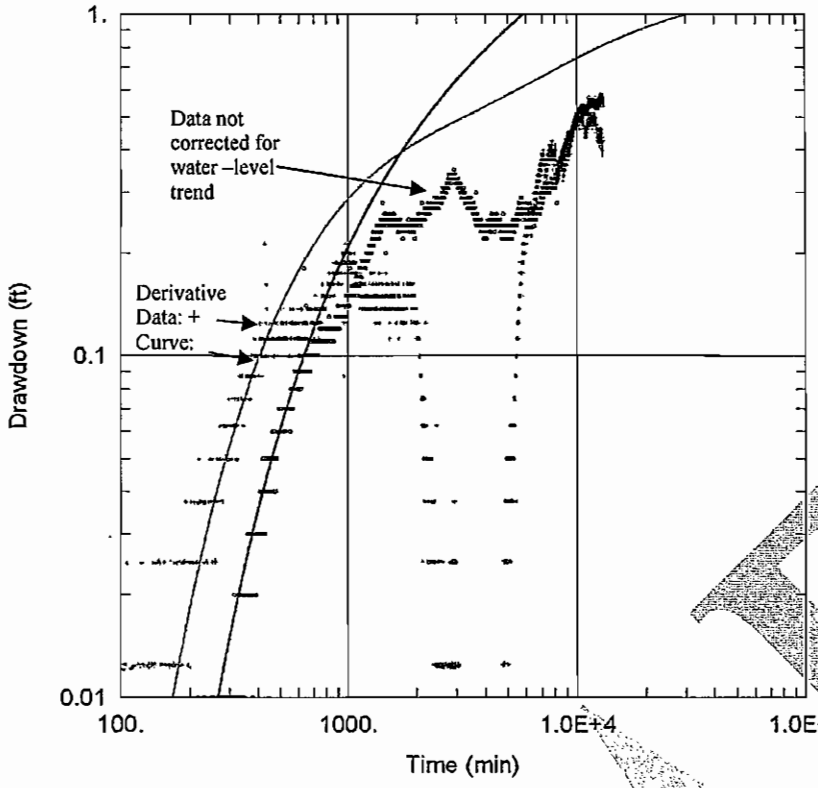
Screen = 625-646 ft
T_{PGSA}= 500,000 gpd/ft
S_{PGSA} = 2.3x 10^{-3}
Kv/Kh=0.1
b_{PGSA} = 260 ft
$T_{zone\ 1}$= 80,000 gpd/ft
$S_{zone\ 1}$ = 1 x 10^{-3}
$b_{zone\ 1}$ = 30 ft
$b_{aquitard}$ = 30 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates only fair match for method. After 300 minutes, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

Based on the analytical method of Neuman and Witherspoon (1972) derived from the original method of Theis (1935). Based on assumption of flow to the pumped aquifer, through a leaky aquitard, from a second aquifer. Flow through the aquitard is assumed to be vertical. See Appendix D for equations and illustrations.

Figure 26. Theis Analysis for the M3-TW #4 Zone 1 – As a part of the PGSA, No Trend Correction



Screen = 625-646 ft
T= 170,000 gpd/ft
S = 2.4x 10^{-1}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 500 minutes of test. Afterward, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$, Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

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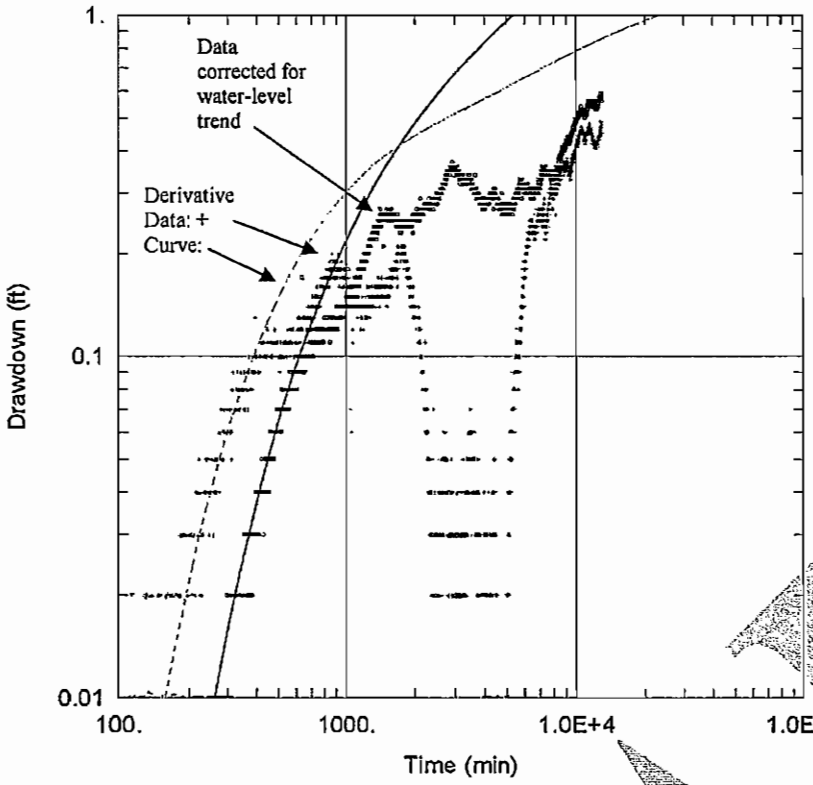
Figure 27. Theis Analysis for the M3-TW #4 Zone 1 – As a part of the PGSA, With Trend Correction



Screen = 625-646 ft
T= 160,000 gpd/ft
S = 2.4x 10^{-1}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 500 minutes of test. Afterward, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

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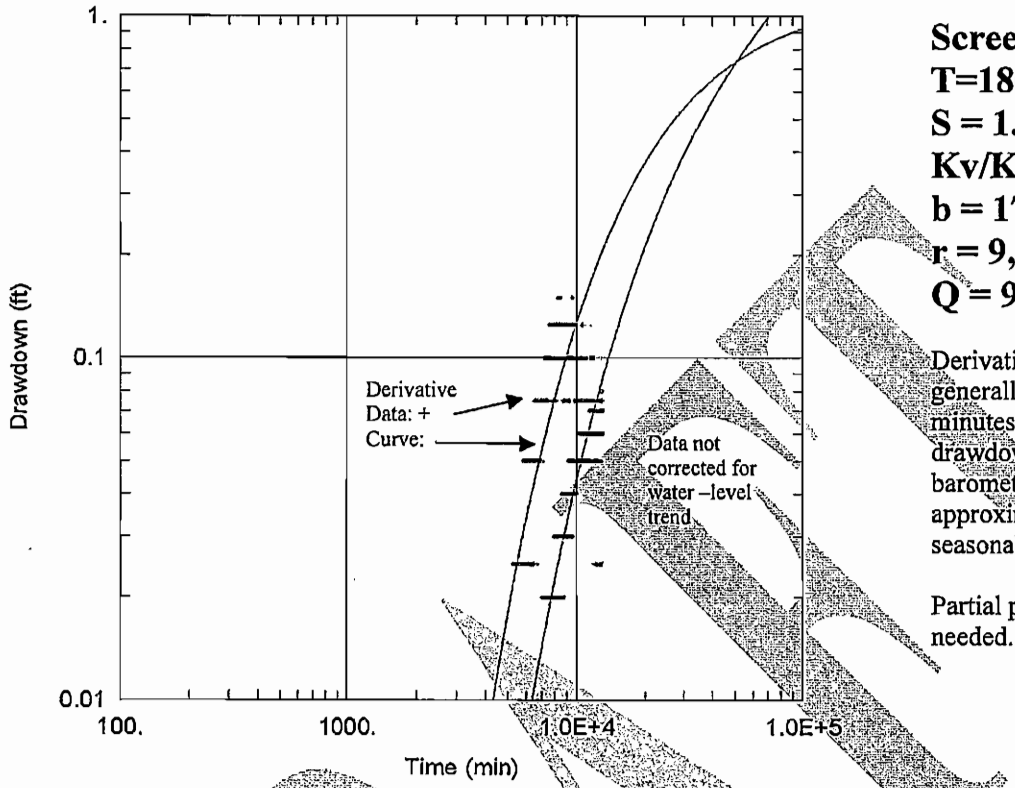
Figure 28. Theis Analysis for the Little Gulch Stock Well – No Trend Correction



Screen = 220-223 ft
T=180,000 gpd/ft
S = 1.3x 10^{-2}
Kv/Kh=0.1
b = 176 ft
r = 9,740 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 8,000 minutes of test. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = 1.87r^2S/Tt Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

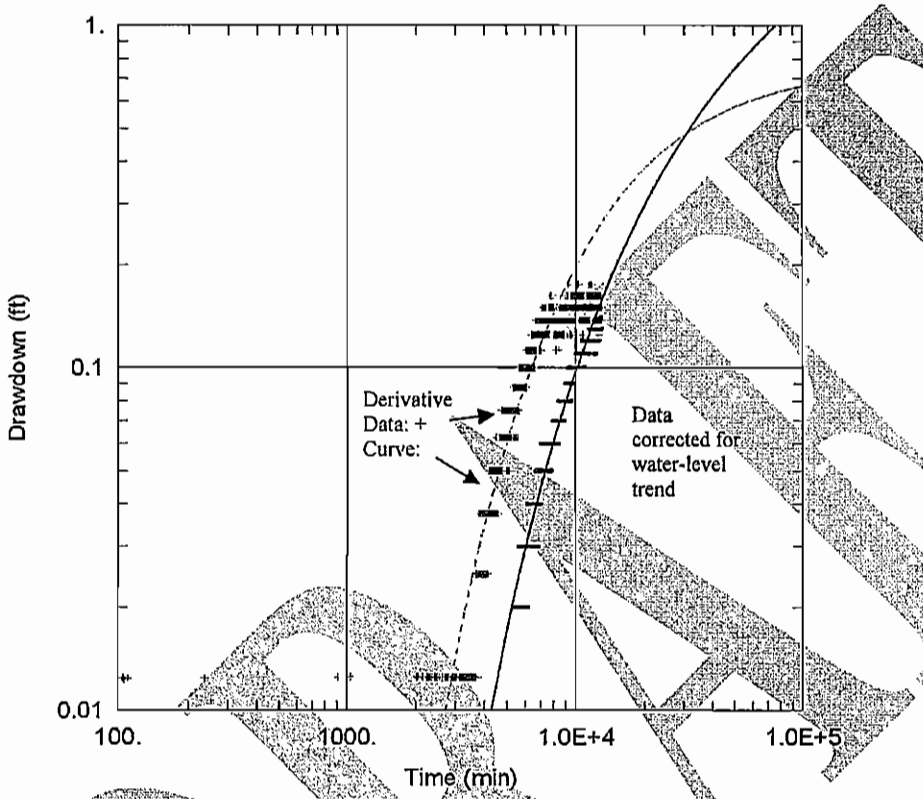
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 29. Theis Analysis for the Little Gulch Stock Well – With Trend Correction



Screen = 220-223 ft
T=270,000 gpd/ft
S = 1.1x 10^{-2}
Kv/Kh=0.1
b = 176 ft
r = 9,740 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 8,000 minutes of test. Fit is better than analysis without trend correction. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

$T = 114.6\ Q\ W(u)/s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
$W(u)$ = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

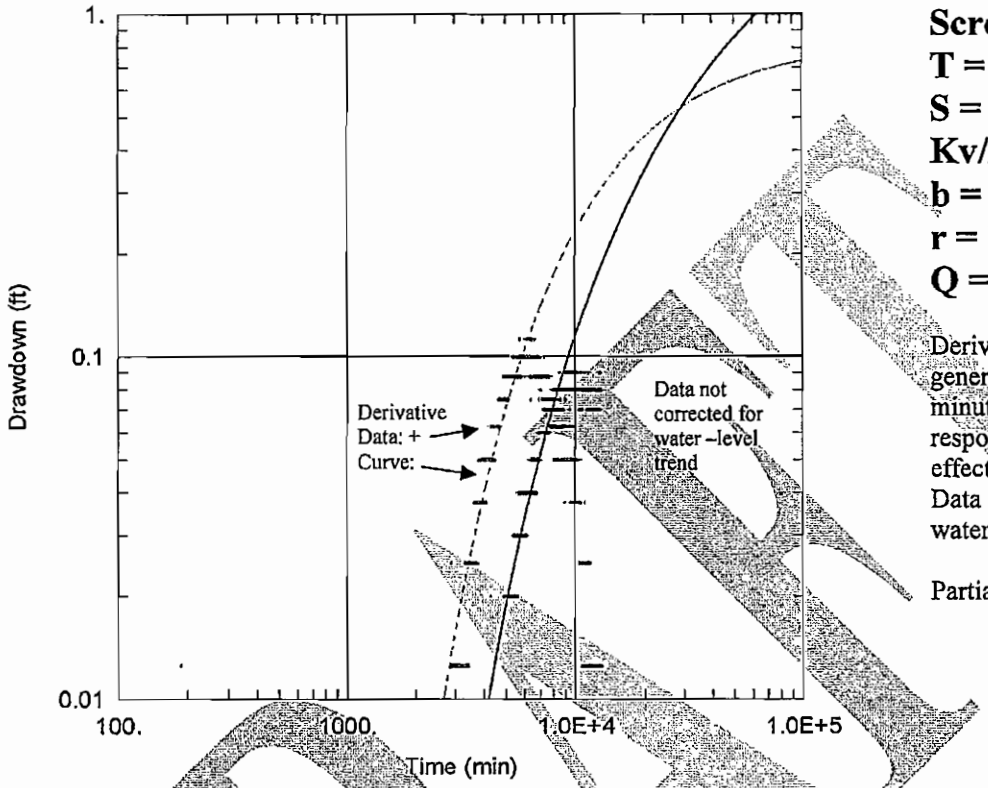
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 30. Theis Analysis for Well SVR #9– No Trend Correction



Screen = 235-263 ft
T = 250,000 gpd/ft
S = 8.7x 10^{-3}
Kv/Kh=0.1
b = 73 ft
r = 11,660 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 6,000 minutes of test. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

$T = 114.6\ Q\ W(u)/s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
$W(u)$ = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

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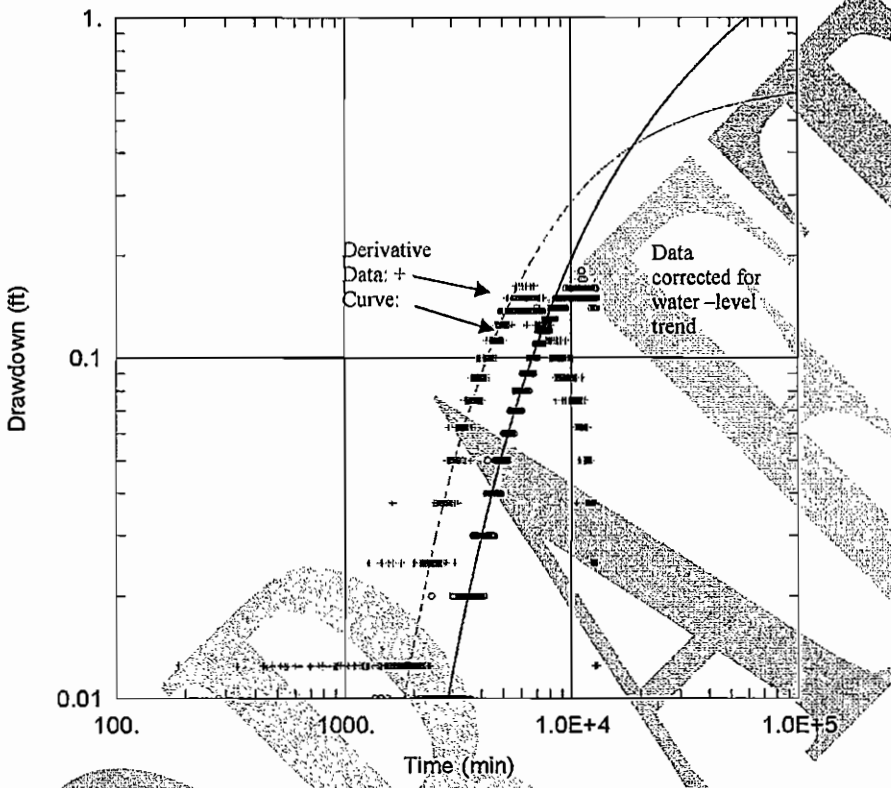
Figure 31. Theis Analysis for Well SVR #9 – With Trend Correction



Screen = 235-263 ft
T = 320,000 gpd/ft
S = 7.1x 10^{-3}
Kv/Kh=0.1
b = 73 ft
r = 11,660 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 6,000 minutes of test. Fit is better than analysis without trend correction. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

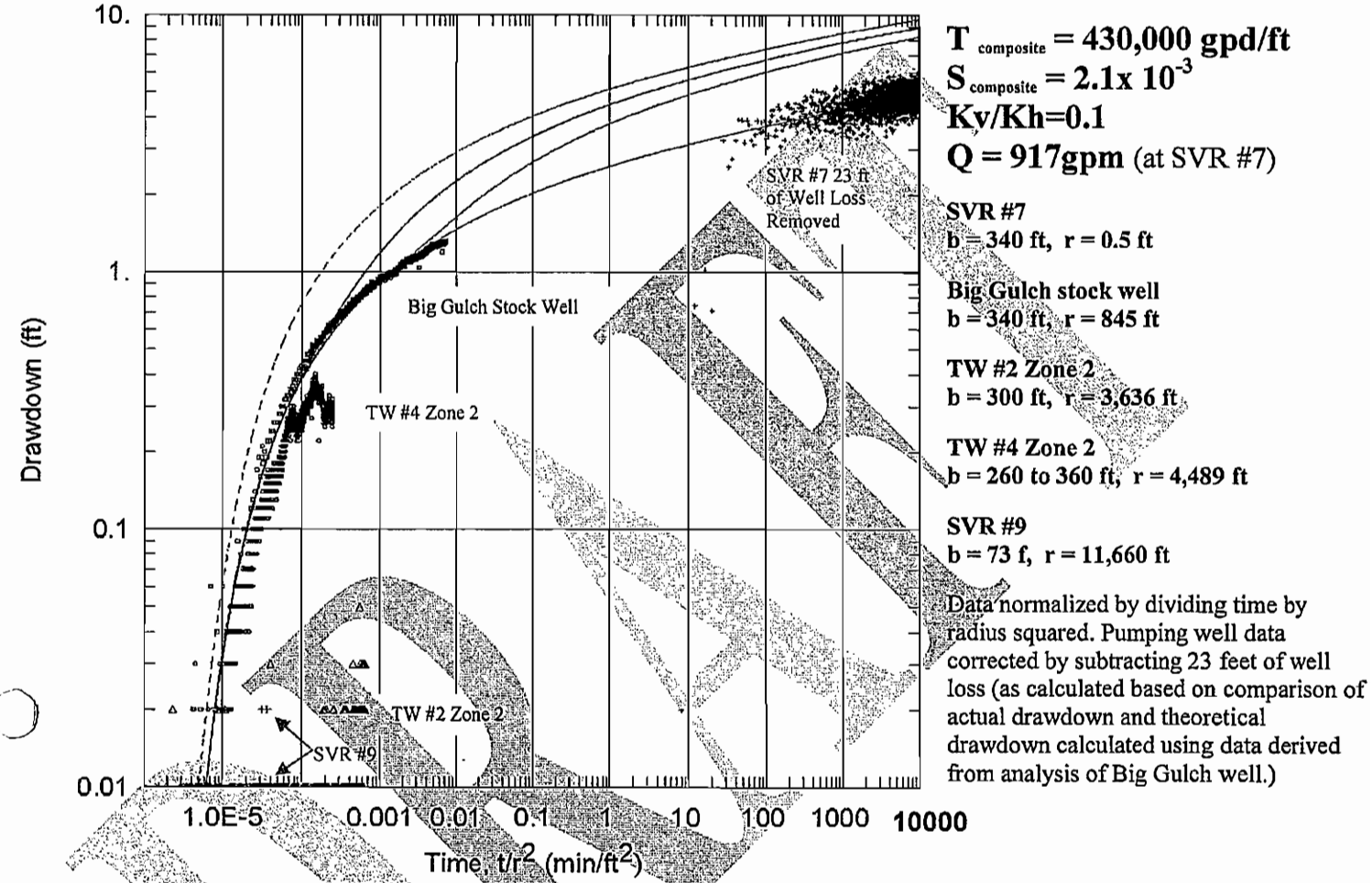
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 32. Composite Theis Analysis for Five Observation Wells



Composite plot for five wells with time normalized by distance such that data would plot on similar curves in a uniform, homogeneous aquifer. The pumping well (SVR #7), nearest observation well ("Big Gulch") and observation well to west (TW #4) plot on curve. Wells to the east of the pumping well (TW #2 and SVR #9) where the Pierce Gulch Sand Aquifer becomes unconfined, show a delayed response caused by thinner aquifer (lower transmissivity) and unconfined conditions (larger storativity).

$T = 114.6\ Q\ W(u)/s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
$W(u)$ = "well function" (defined below)

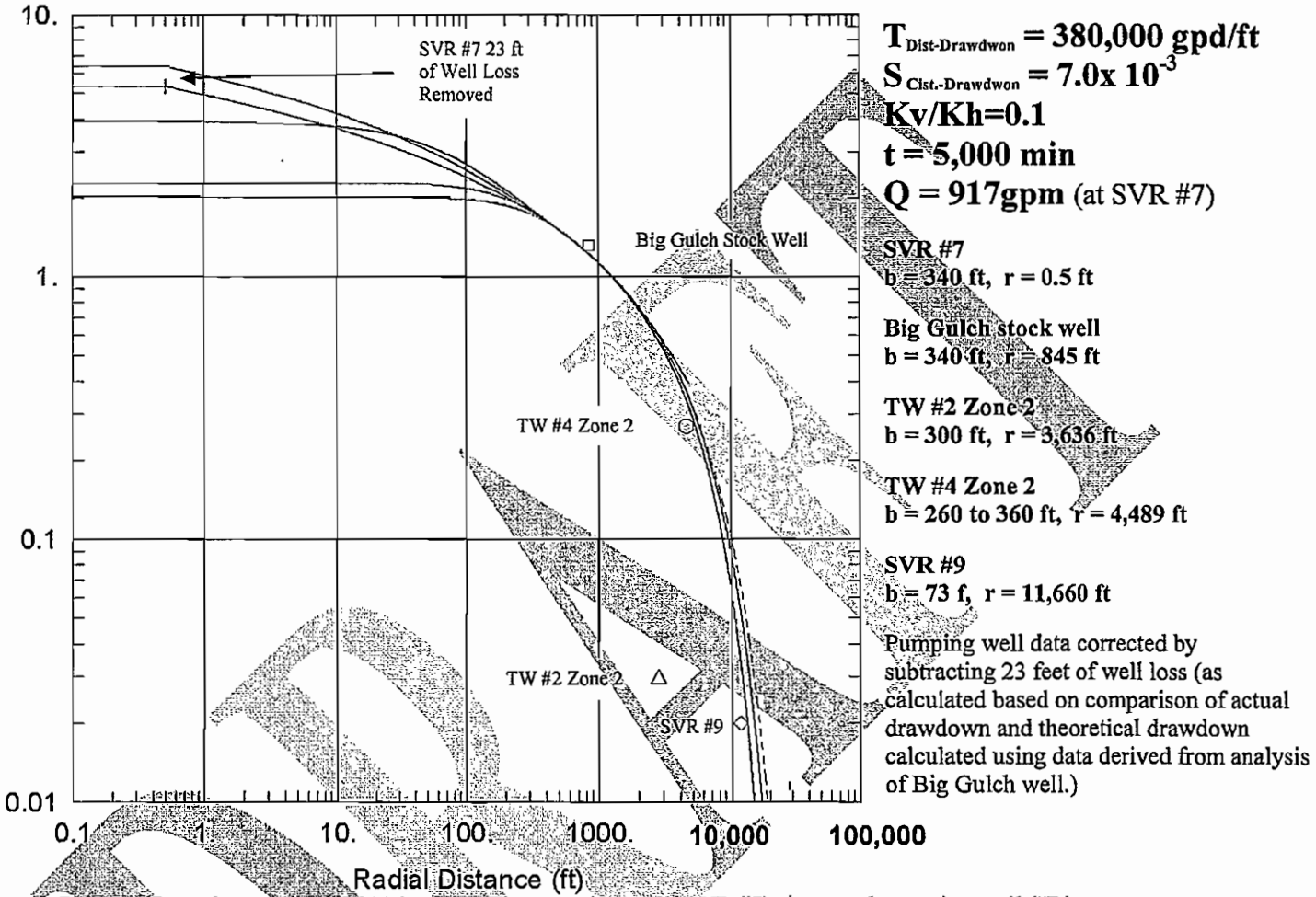
$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 33. Theis Distance Drawdown Analysis



Distance Drawdown plot at 5,000 into test. The pumping well (SVR #7), nearest observation well ("Big Gulch") and observation well to west (TW #4) plot on curve. Wells to the east of the pumping well (TW #2 and SVR #9) where the Pierce Gulch Sand Aquifer becomes unconfined, show a different response caused by thinner aquifer (lower transmissivity) and unconfined conditions (larger storativity).

$T = 114.6\ Q\ W(u)/s$ Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
$W(u)$ = "well function" (defined below)

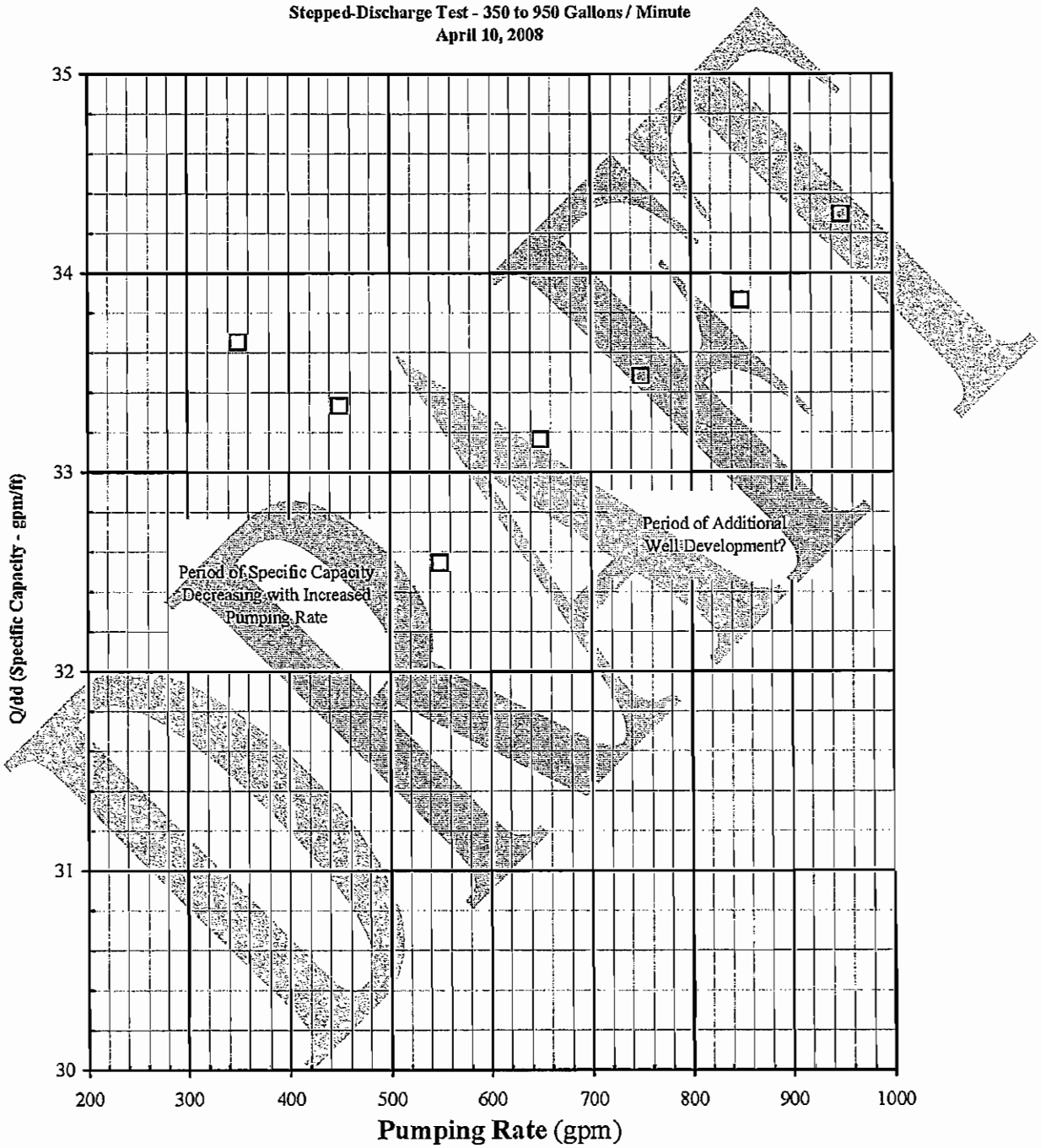
$W(u) = 1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 34. Specific Capacity at Various Pumping Rates During the Step-Discharge Test



APPENDICIES

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Appendix A - Well Driller's Reports for Wells without Additional Information

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Appendix B – Barometric Efficiency Analyses

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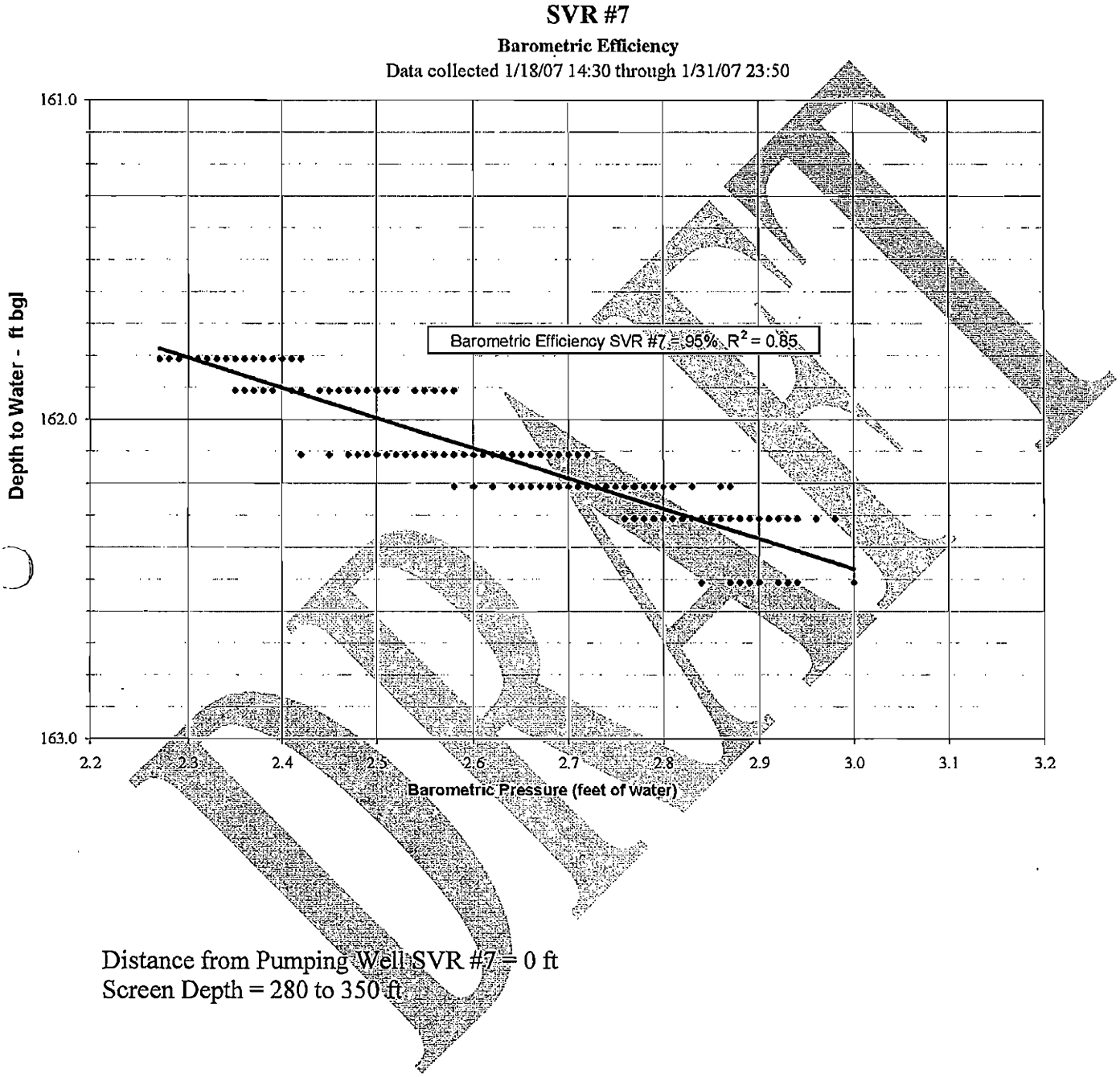
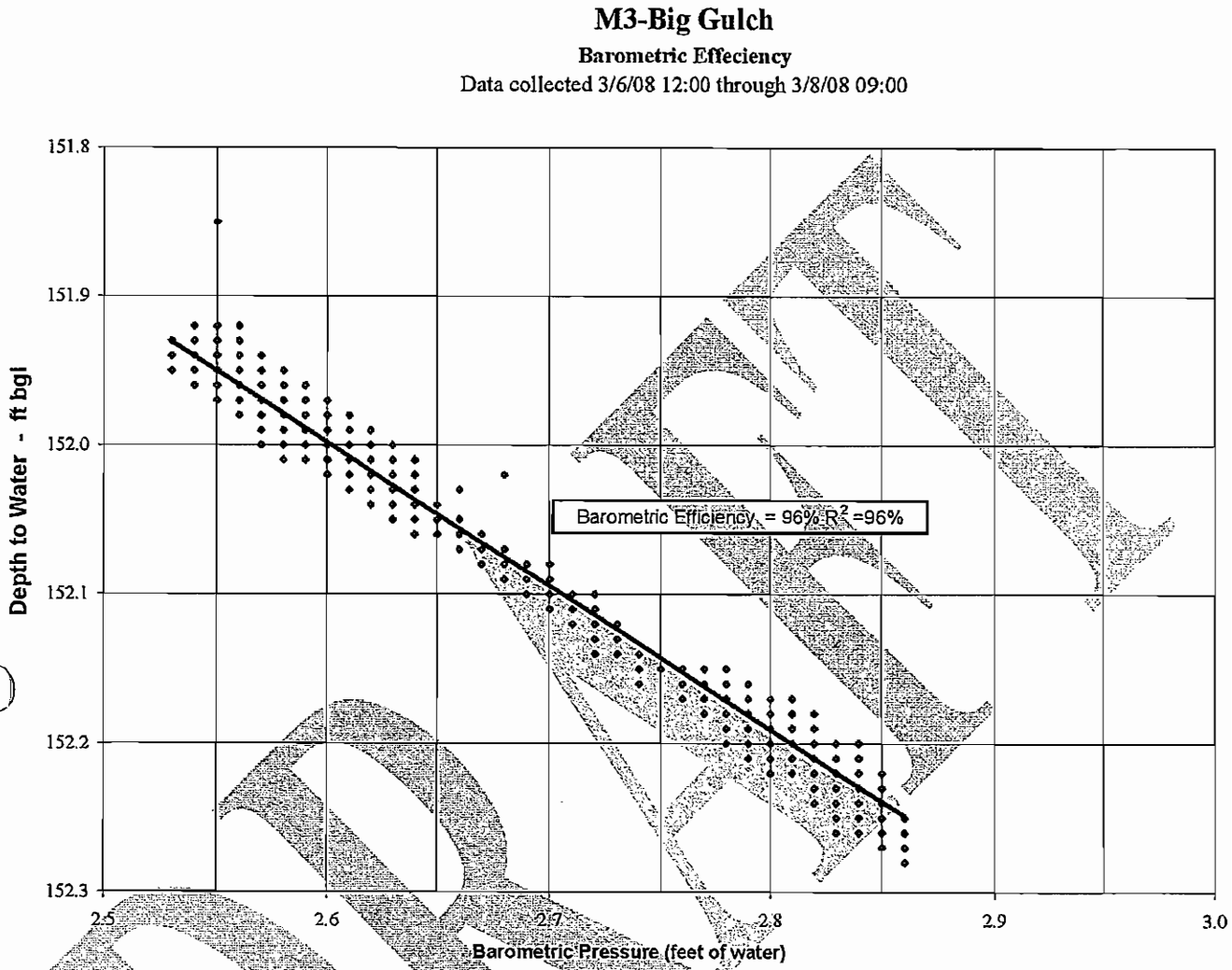
Figure B-1. Barometric Efficiency Plot for SVR #7



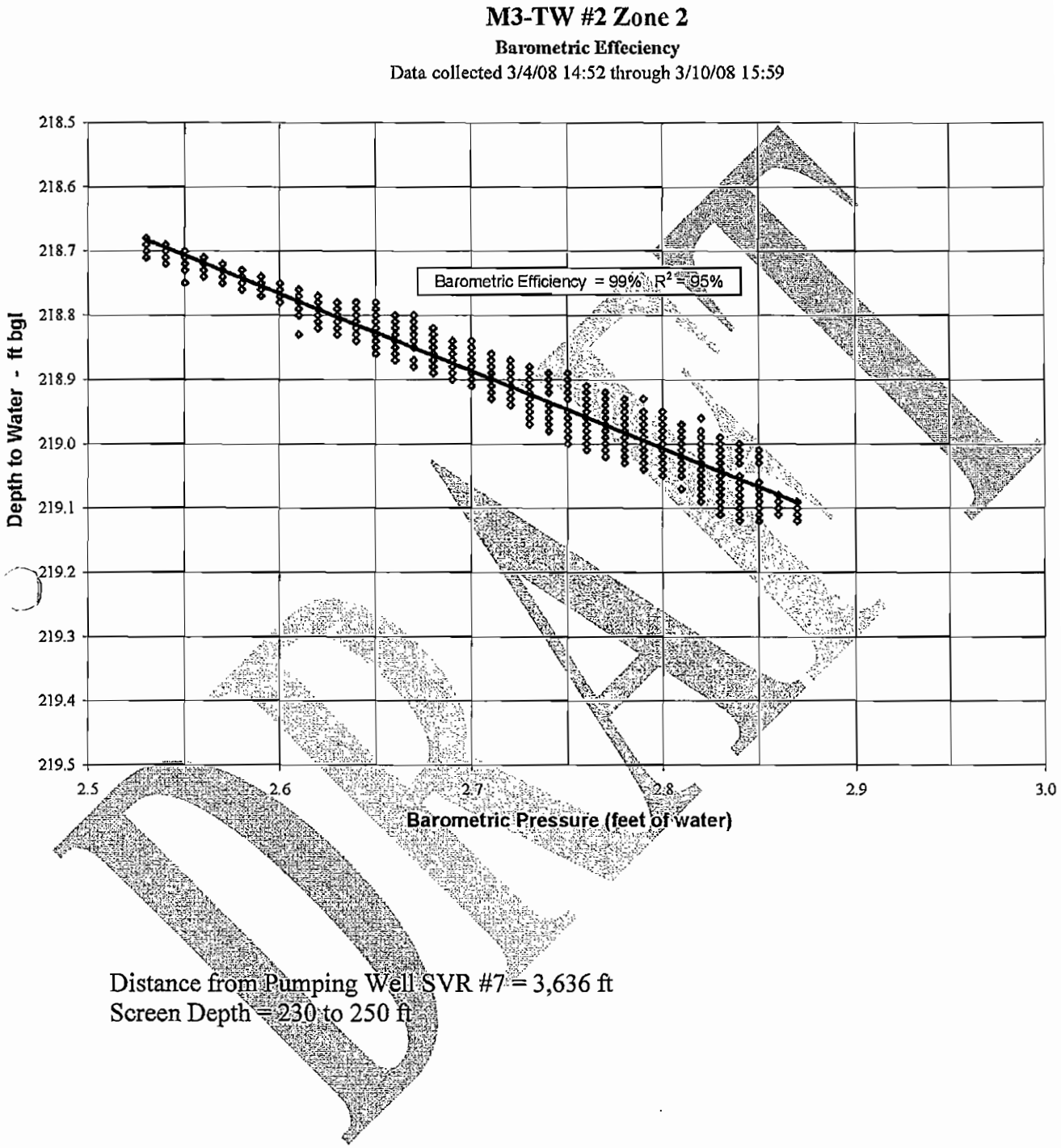
Distance from Pumping Well SVR #7 = 0 ft
Screen Depth = 280 to 350 ft

Figure B-2. Barometric Efficiency Plot for Big Gulch Stock Well



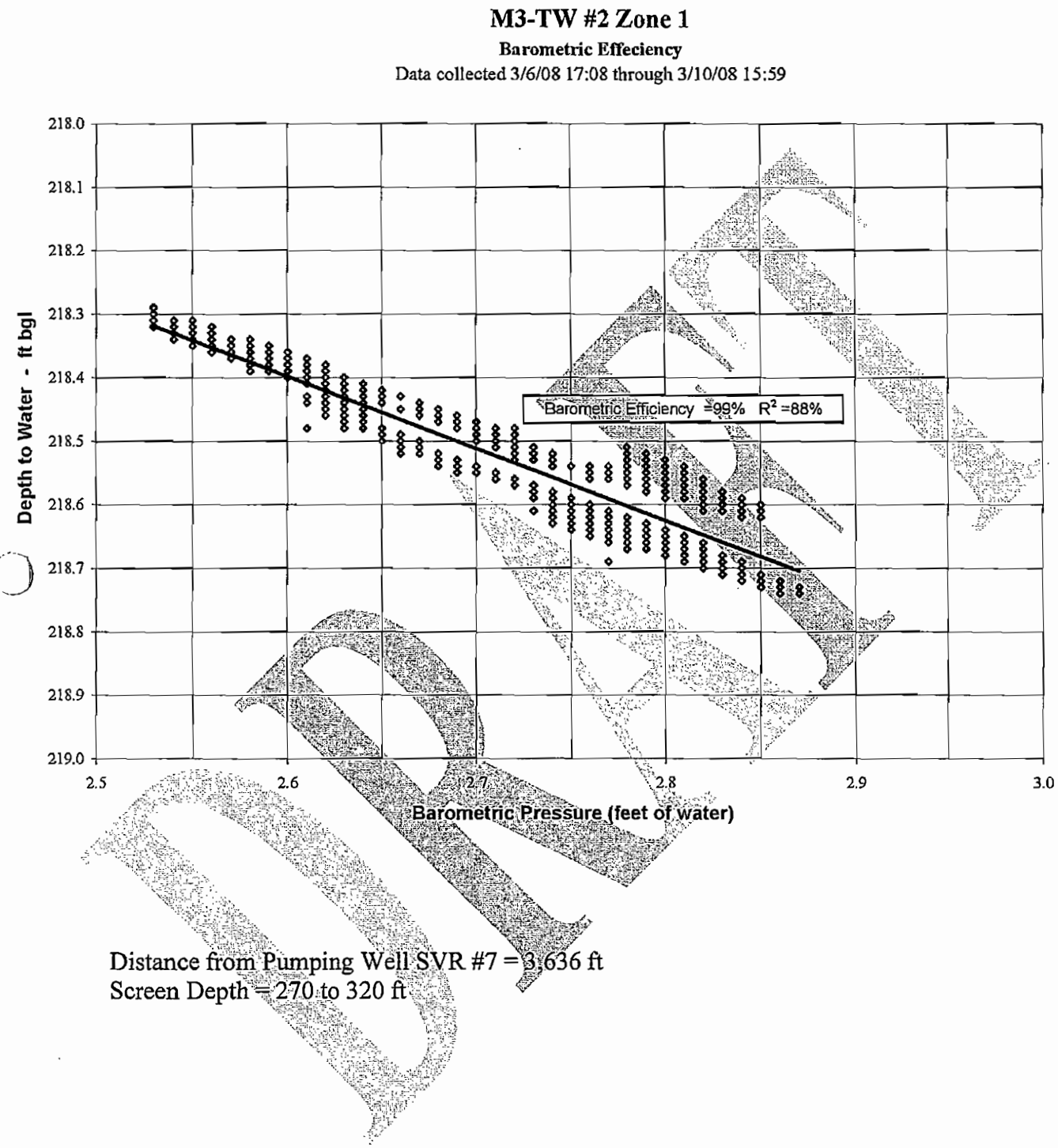
Distance from Pumping Well SVR #7 = 845 ft
Screen Depth = 180 to 180 ft ("open hole," no well screen)

Figure B-3. Barometric Efficiency Plot for TW #2 Zone 2



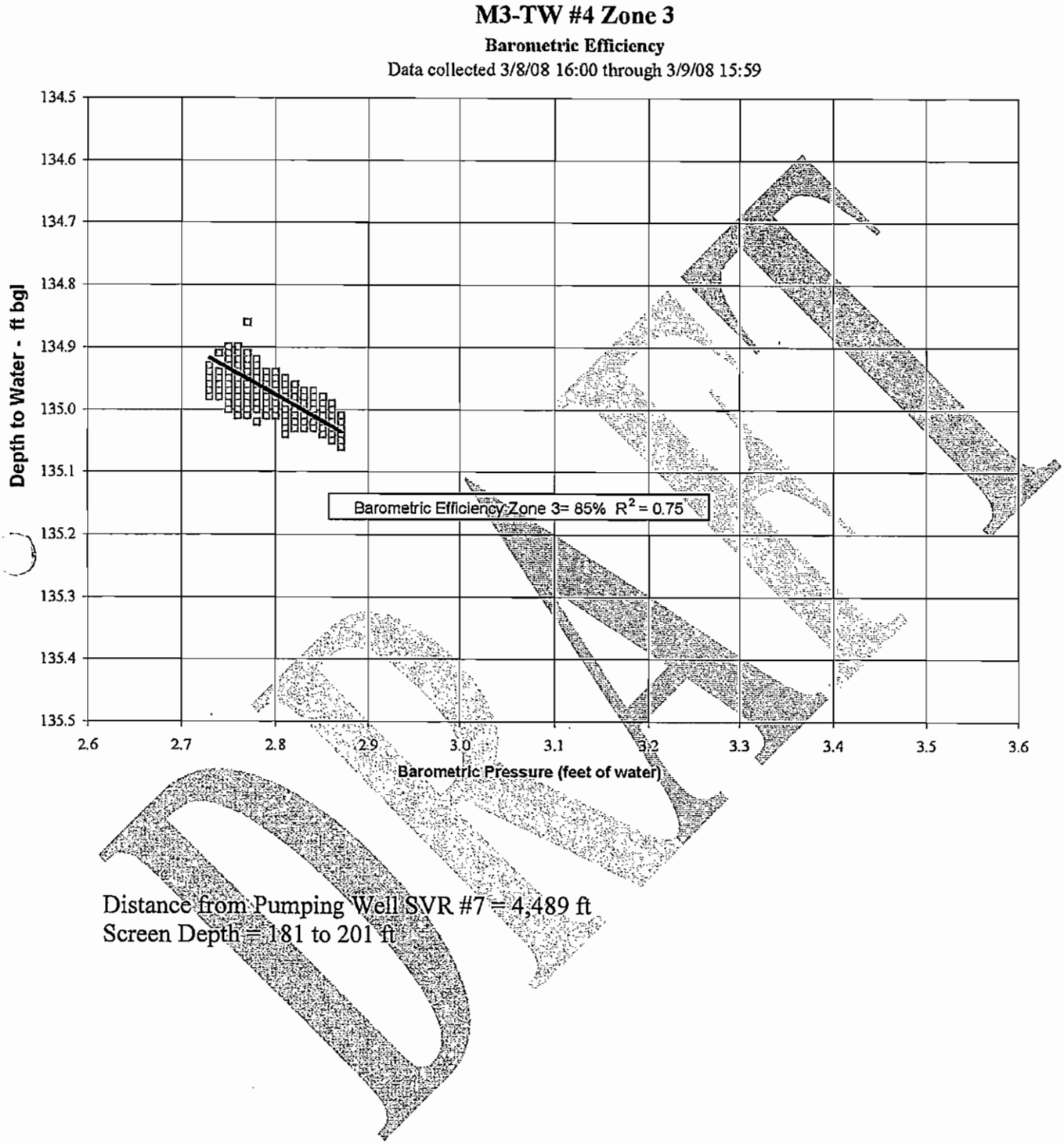
Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 230 to 250 ft

Figure B-4. Barometric Efficiency Plot for TW #2 Zone 1



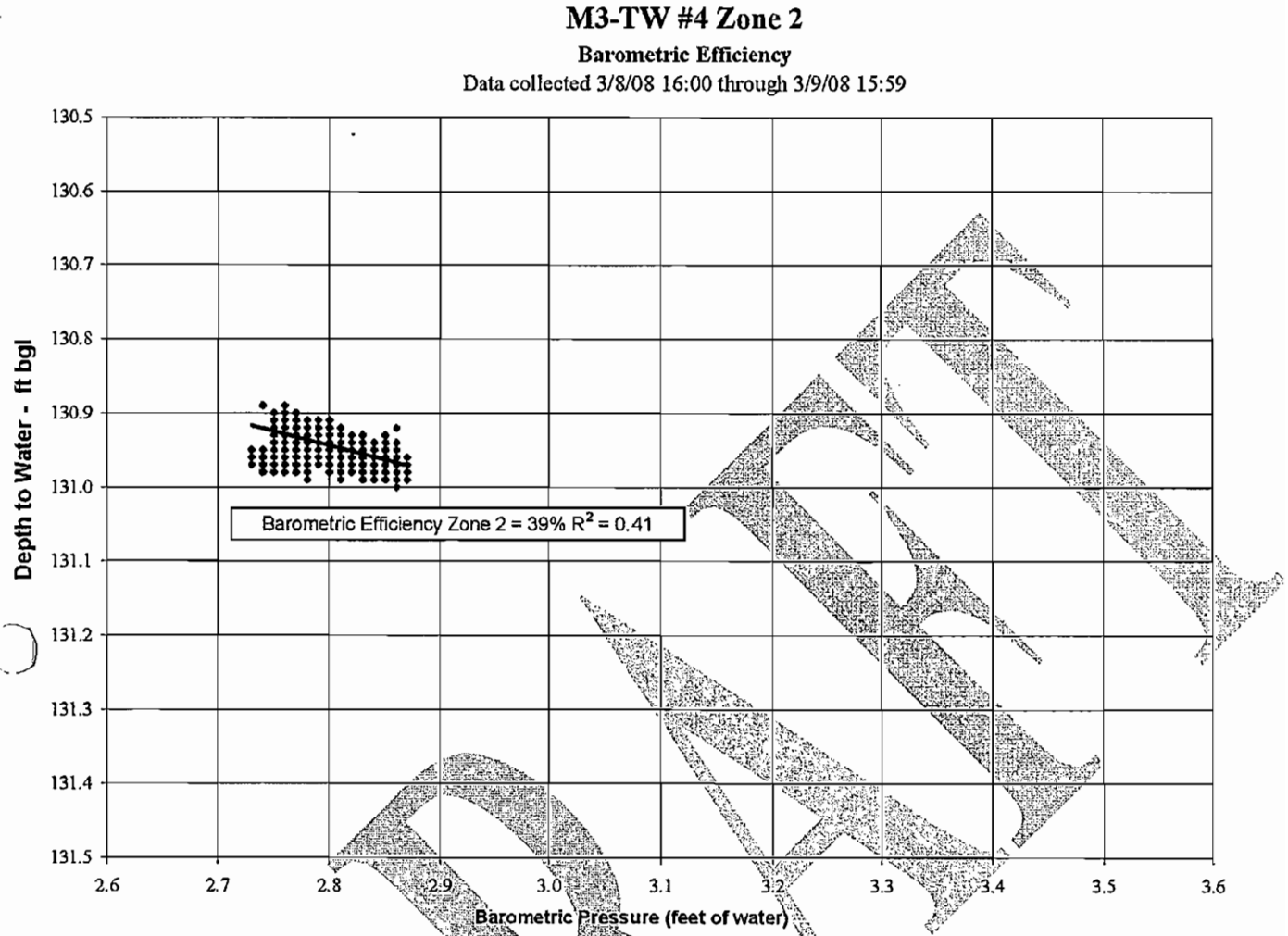
Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 270 to 320 ft

Figure B-5. Barometric Efficiency Plot for TW #4 Zone 3



Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 181 to 201 ft

Figure B-6. Barometric Efficiency Plot for TW #4 Zone 2



Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 325 to 556 ft

DRAFT

Figure B-7. Barometric Efficiency Plot for TW #4 Zone 1

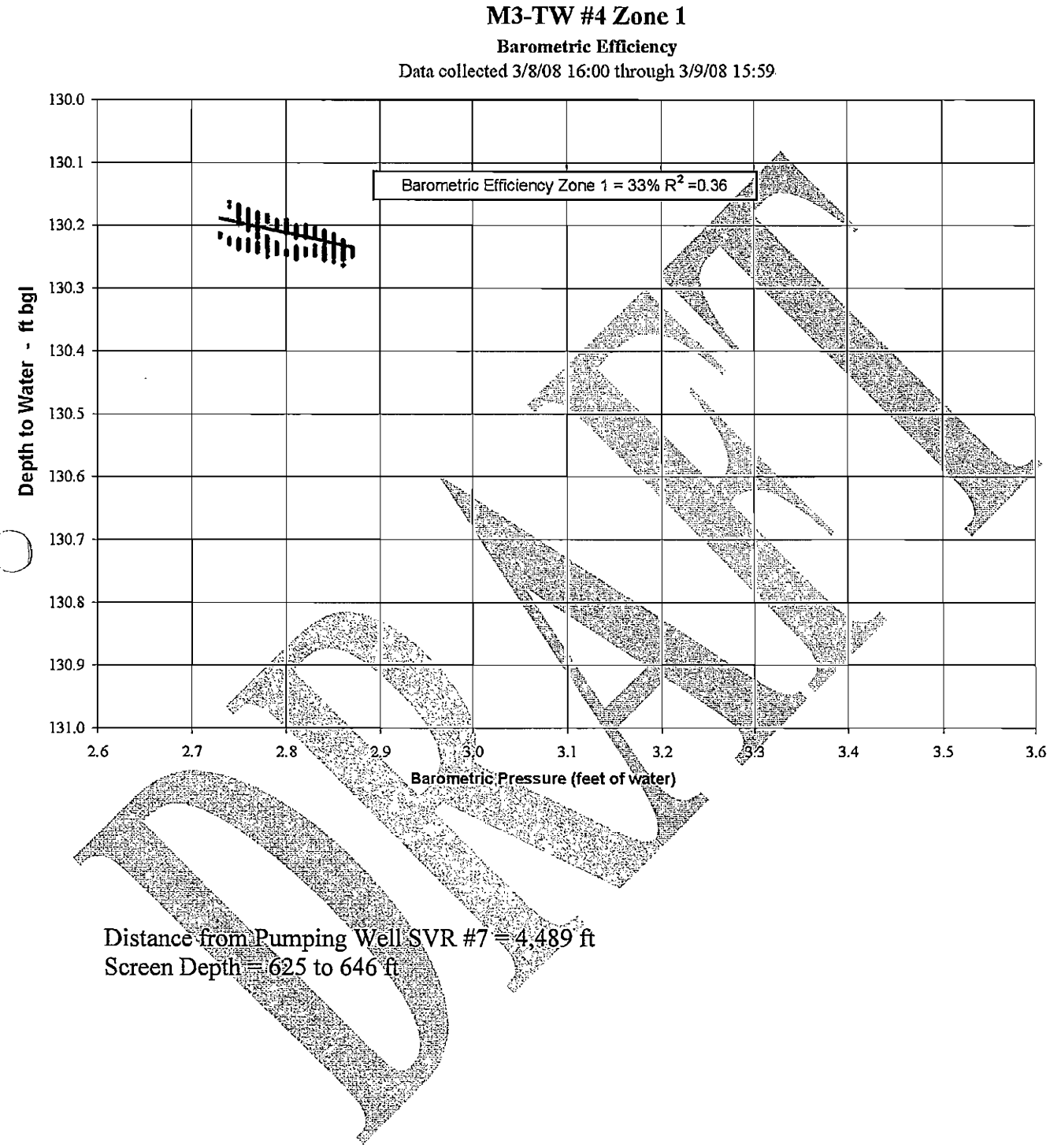
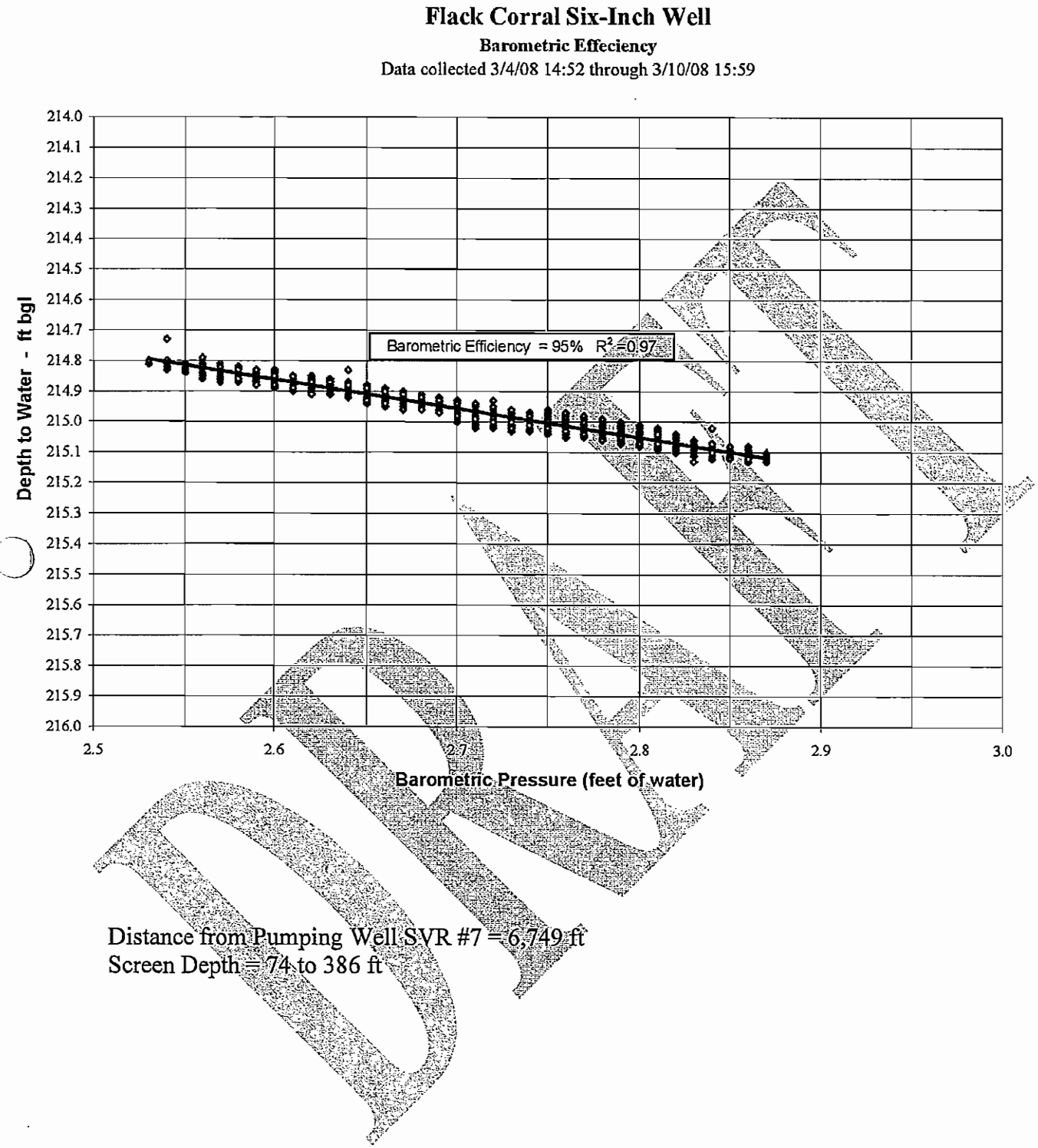
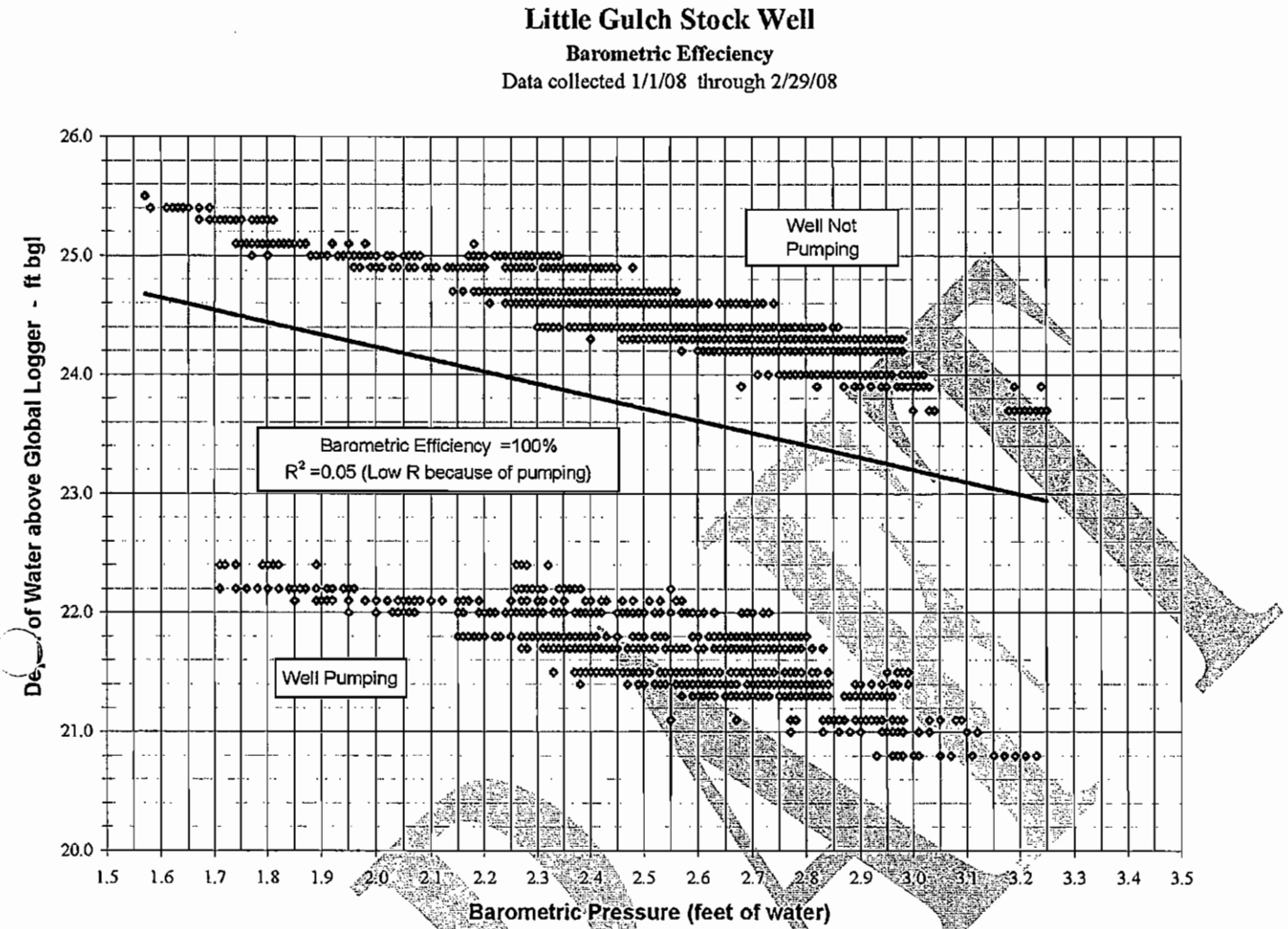


Figure B-8. Barometric Efficiency Plot for Flack Corral 6-Inch Well



Distance from Pumping Well SVR #7 = 6,749 ft
Screen Depth = 74 to 386 ft

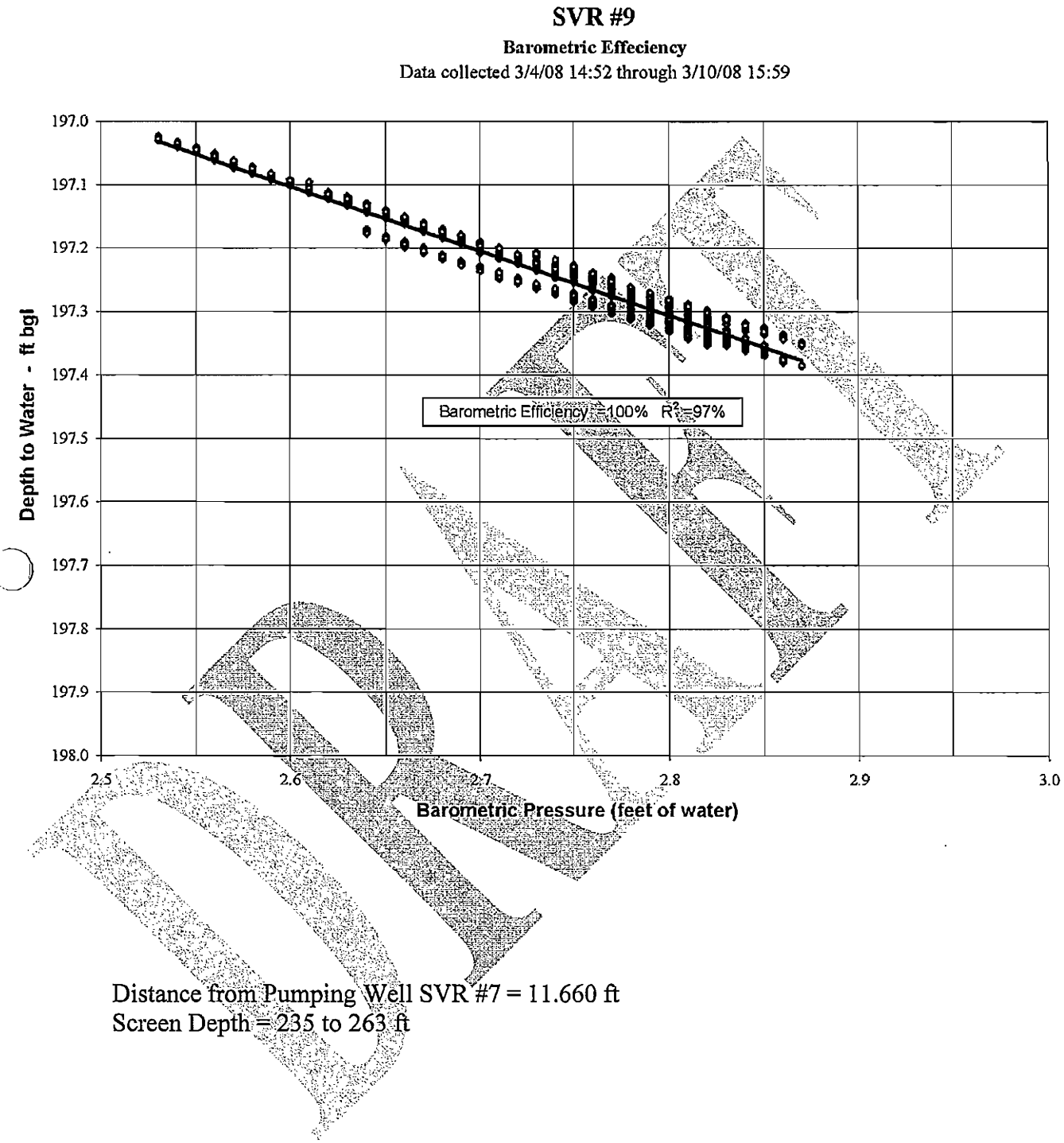
Figure B-9. Barometric Efficiency Plot for Little Gulch Stock Well



Distance from Pumping Well SVR #7 = 9,740 ft
Screen Depth = 220 to 223 ft

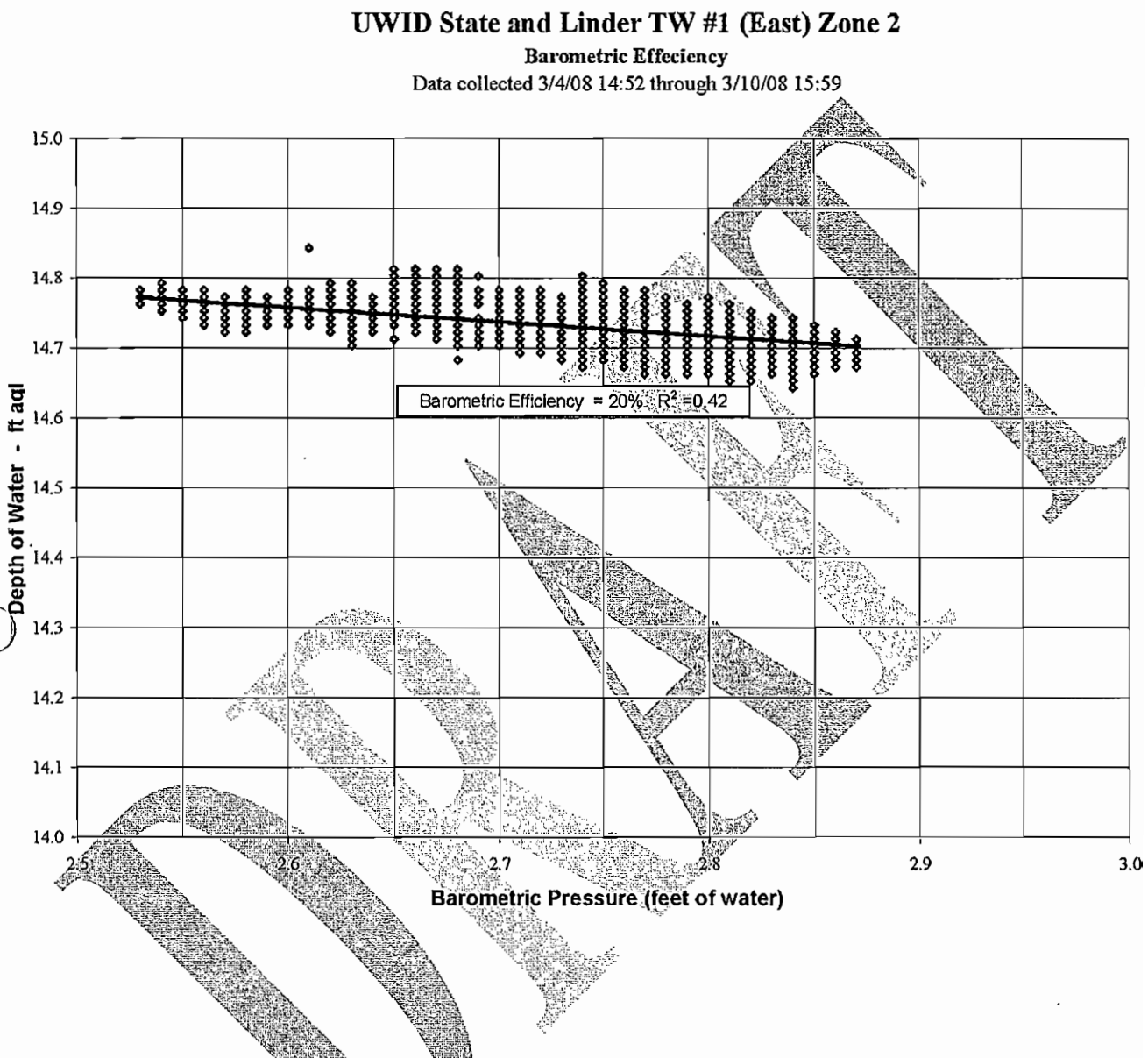
SVR

Figure B-10. Barometric Efficiency Plot for SVR #9



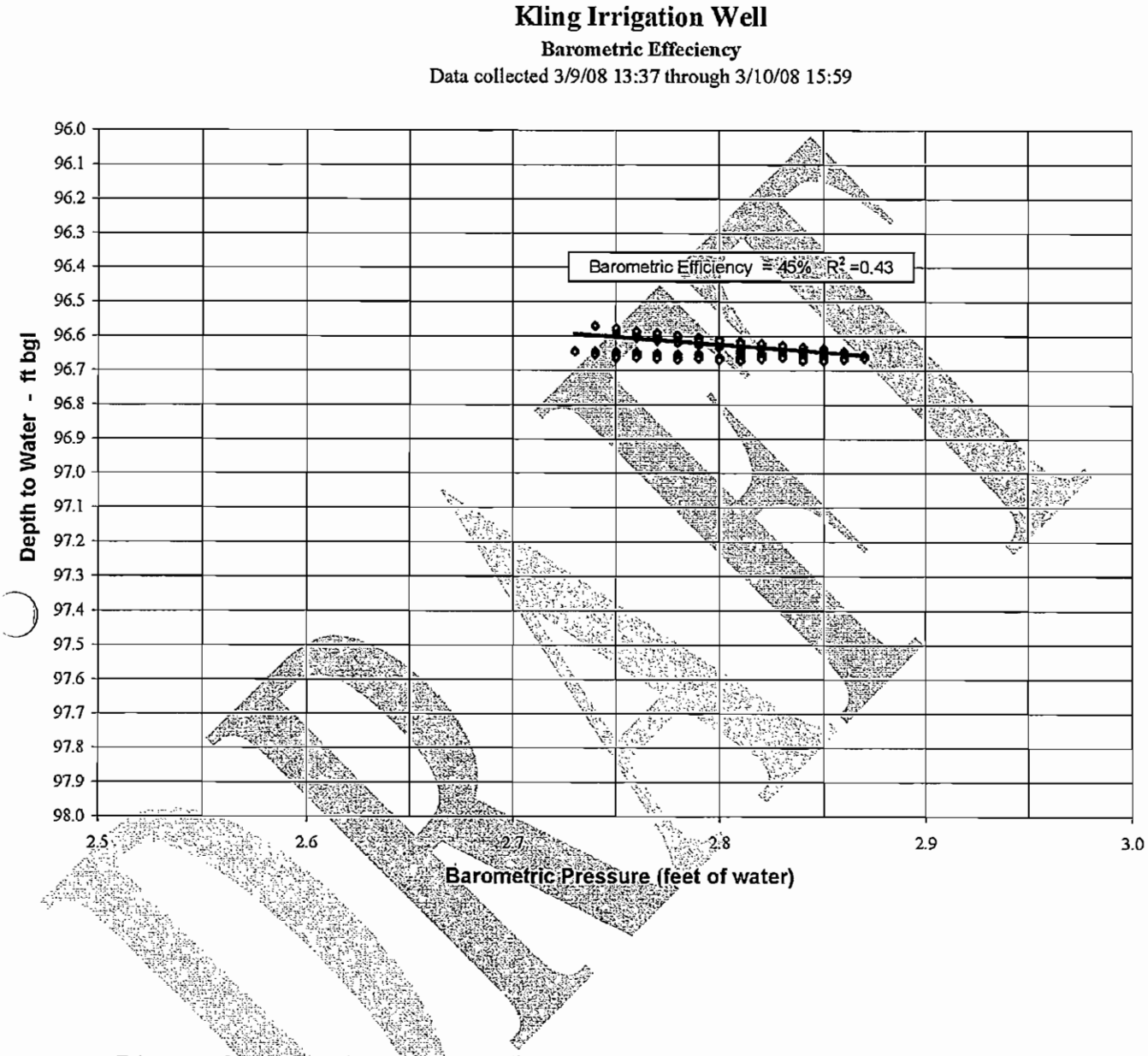
Distance from Pumping Well SVR #7 = 11.660 ft
Screen Depth = 235 to 263 ft

Figure B-11. Barometric Efficiency Plot for UWID State and Linder TW #1 Zone 2



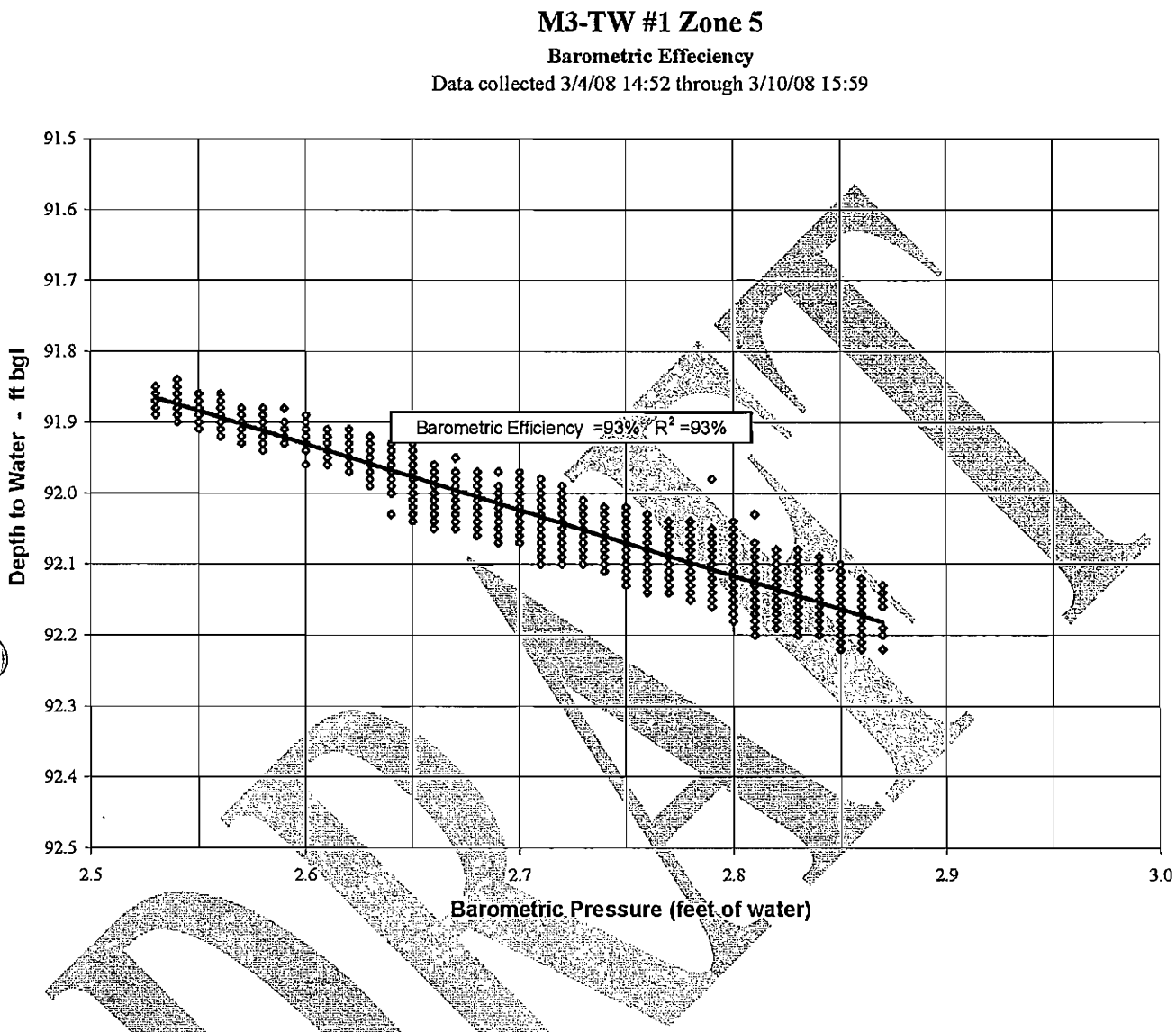
Distance from Pumping Well SVR #7 = 22,302 ft
Screen Depth = 280 to 370 ft

Figure B-12. Barometric Efficiency Plot for the Kling Irrigation Well



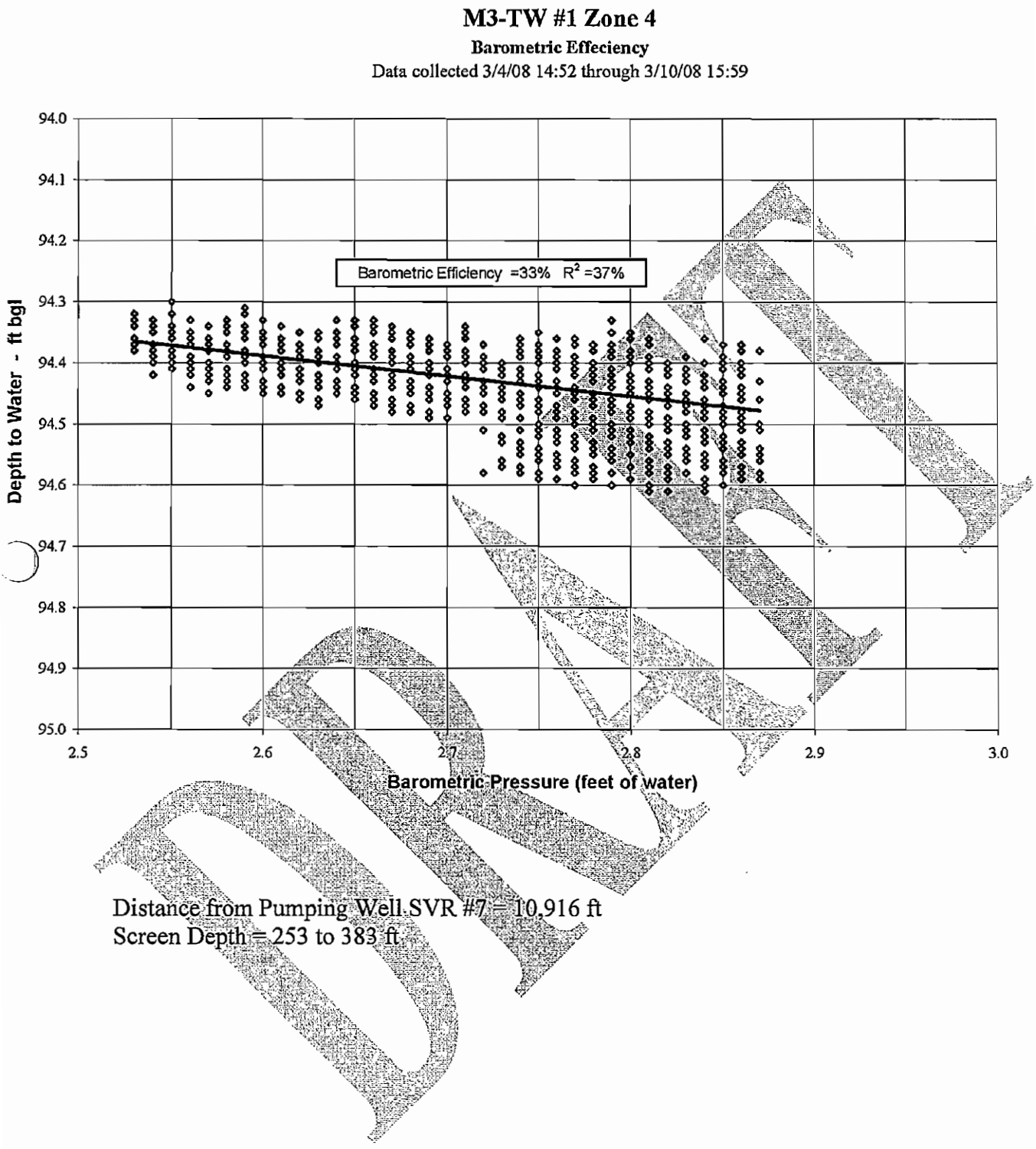
Distance from Pumping Well SVR #7 = 9,908 ft
Screen Depth = 198 to 408 ft

Figure B-13. Barometric Efficiency Plot for TW #1 Zone 5



Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 97 to 137 ft

Figure B-14. Barometric Efficiency Plot for TW #1 Zone 4



Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 253 to 383 ft

Figure B-15. Barometric Efficiency Plot for TW #1 Zone 2

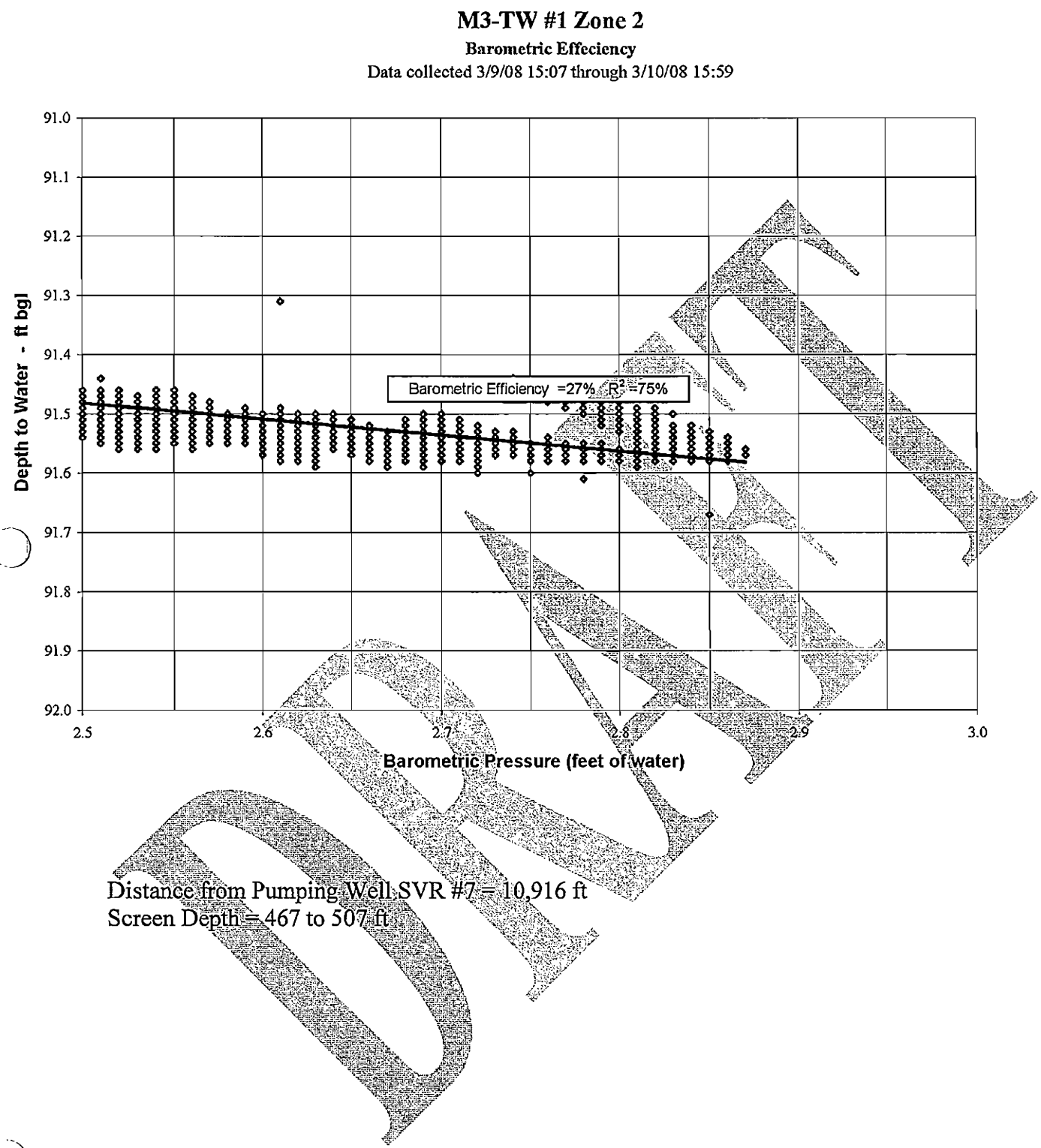
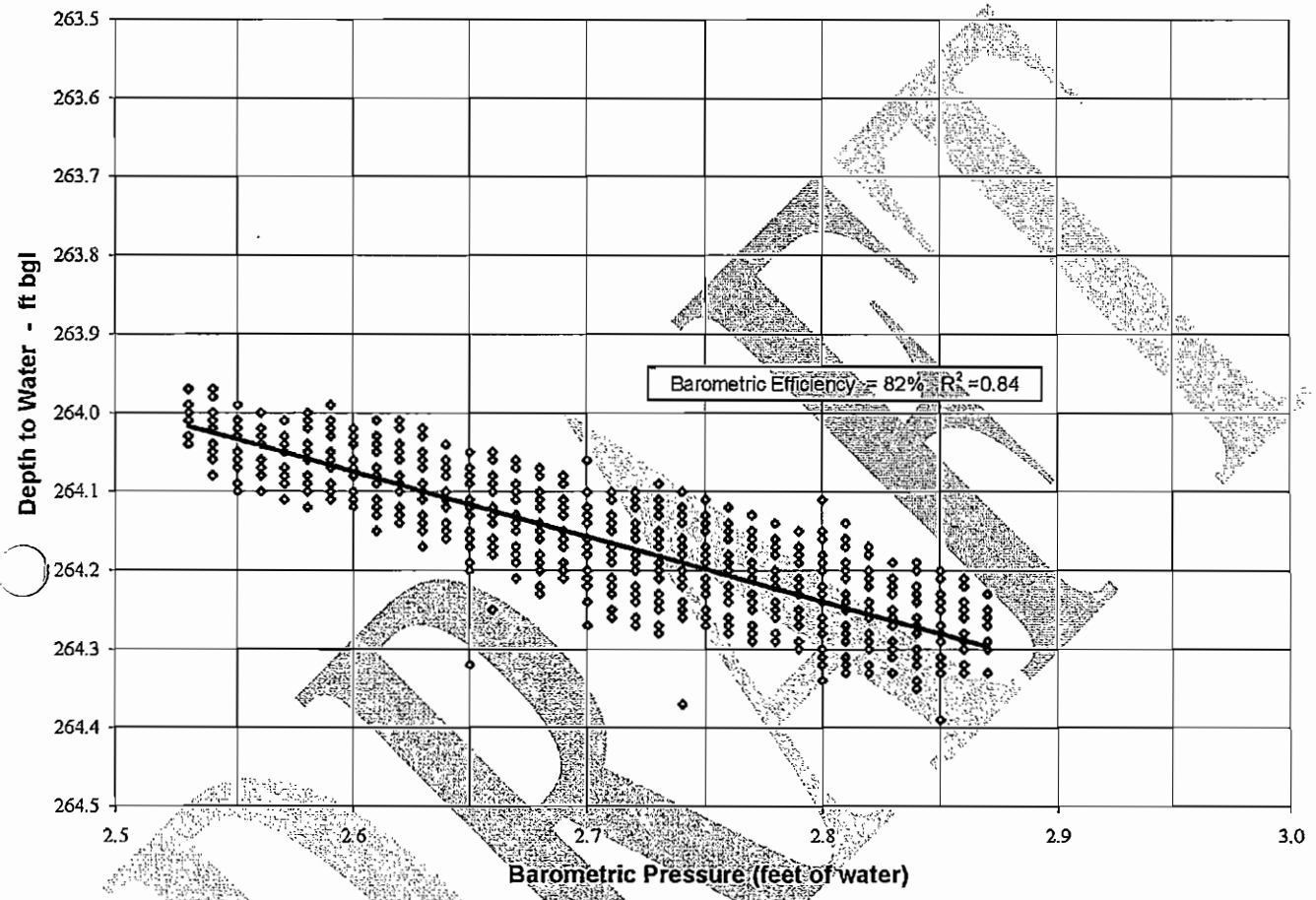
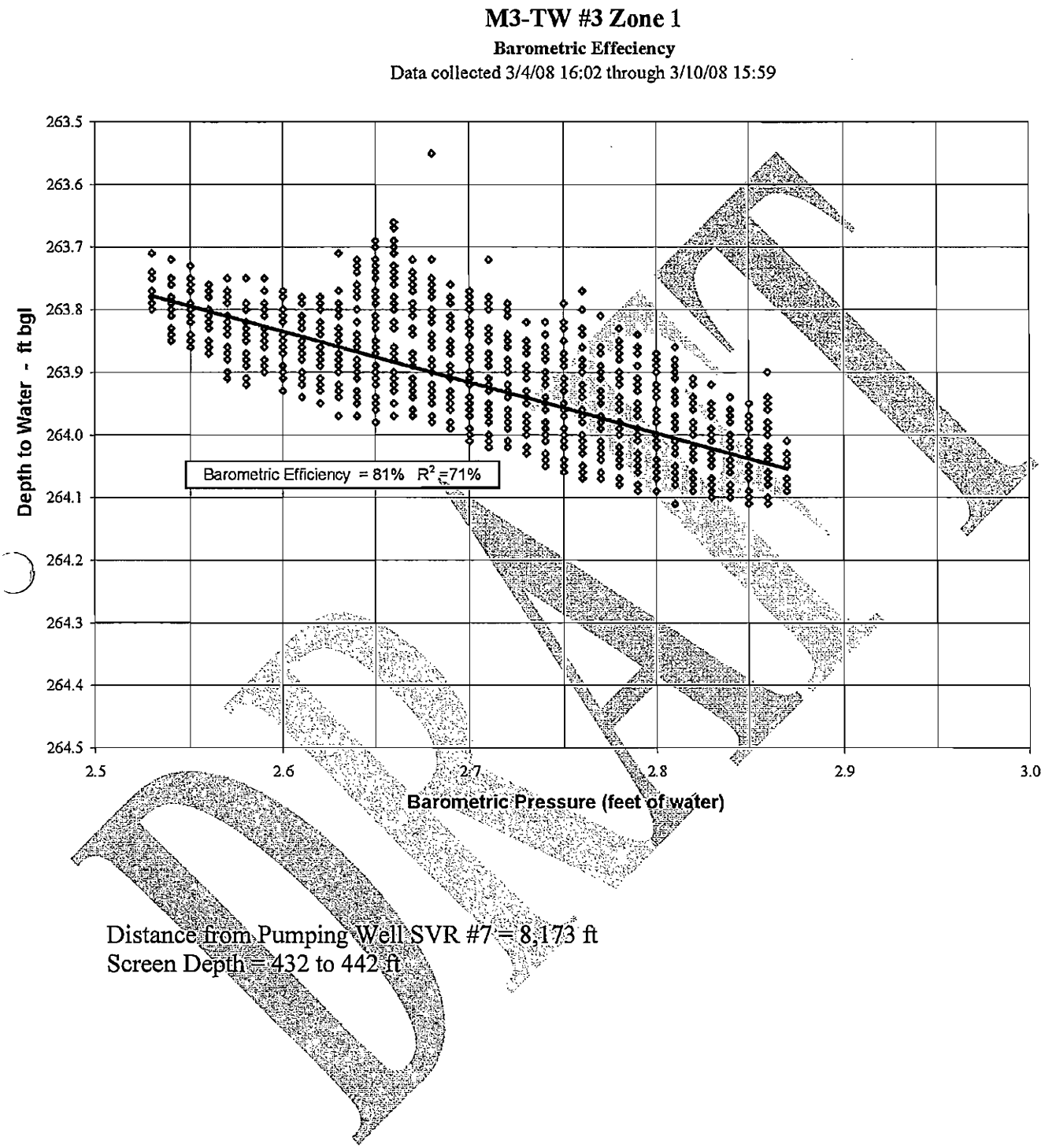


Figure B-16. Barometric Efficiency Plot for TW #3 Zone 3



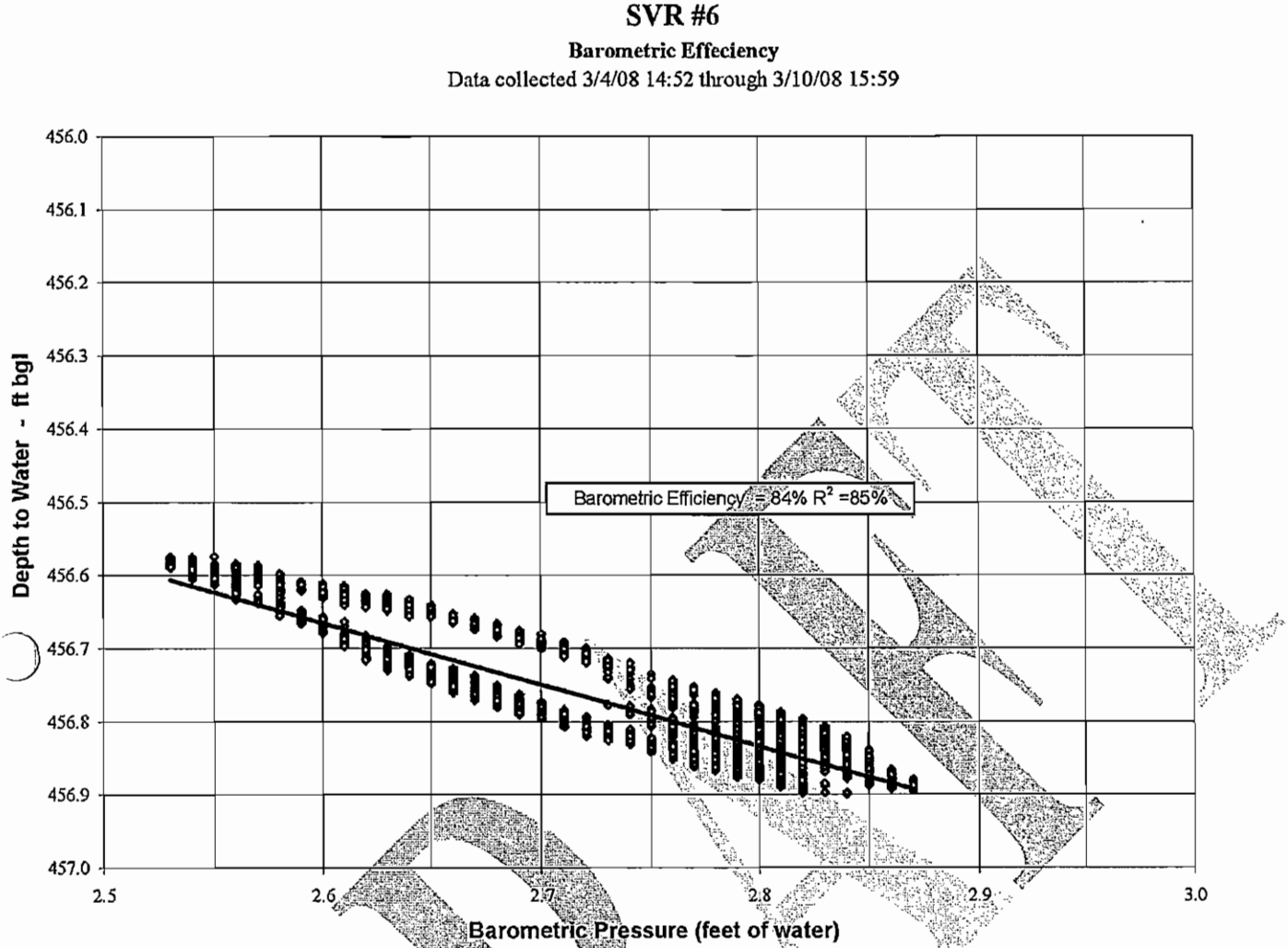
Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 369 to 379 ft

Figure B-17. Barometric Efficiency Plot for TW #3 Zone 1



Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 432 to 442 ft

Figure B-18. Barometric Efficiency Plot for SVR #6



In Willow Creek Aquifer - NOT in Pierce Gulch Sand Aquifer
Distance from Pumping Well SVR #7 = 8,189 ft
Screen Depth = 560 to 730 ft

Appendix C – Actual and BE-Corrected Water Levels

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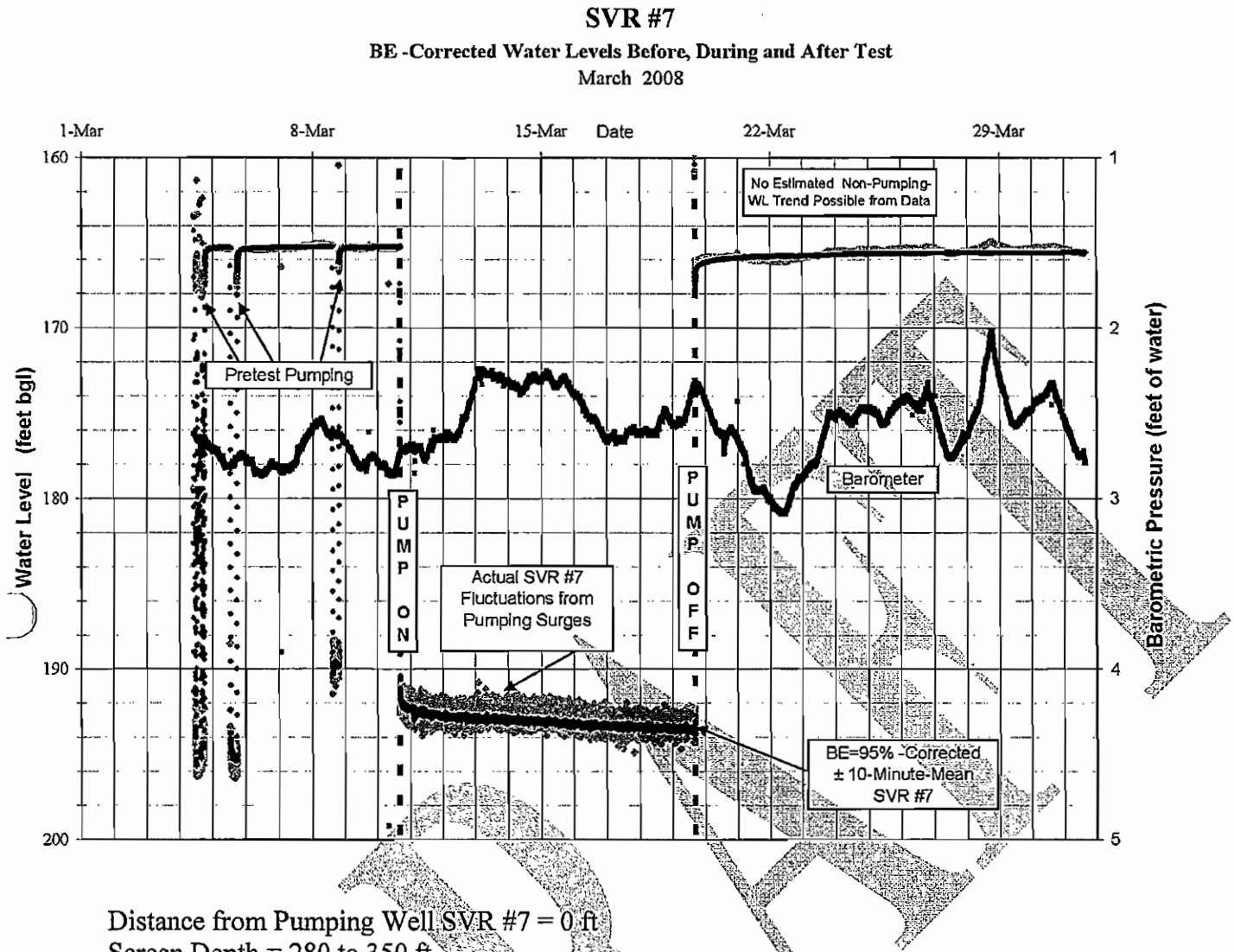
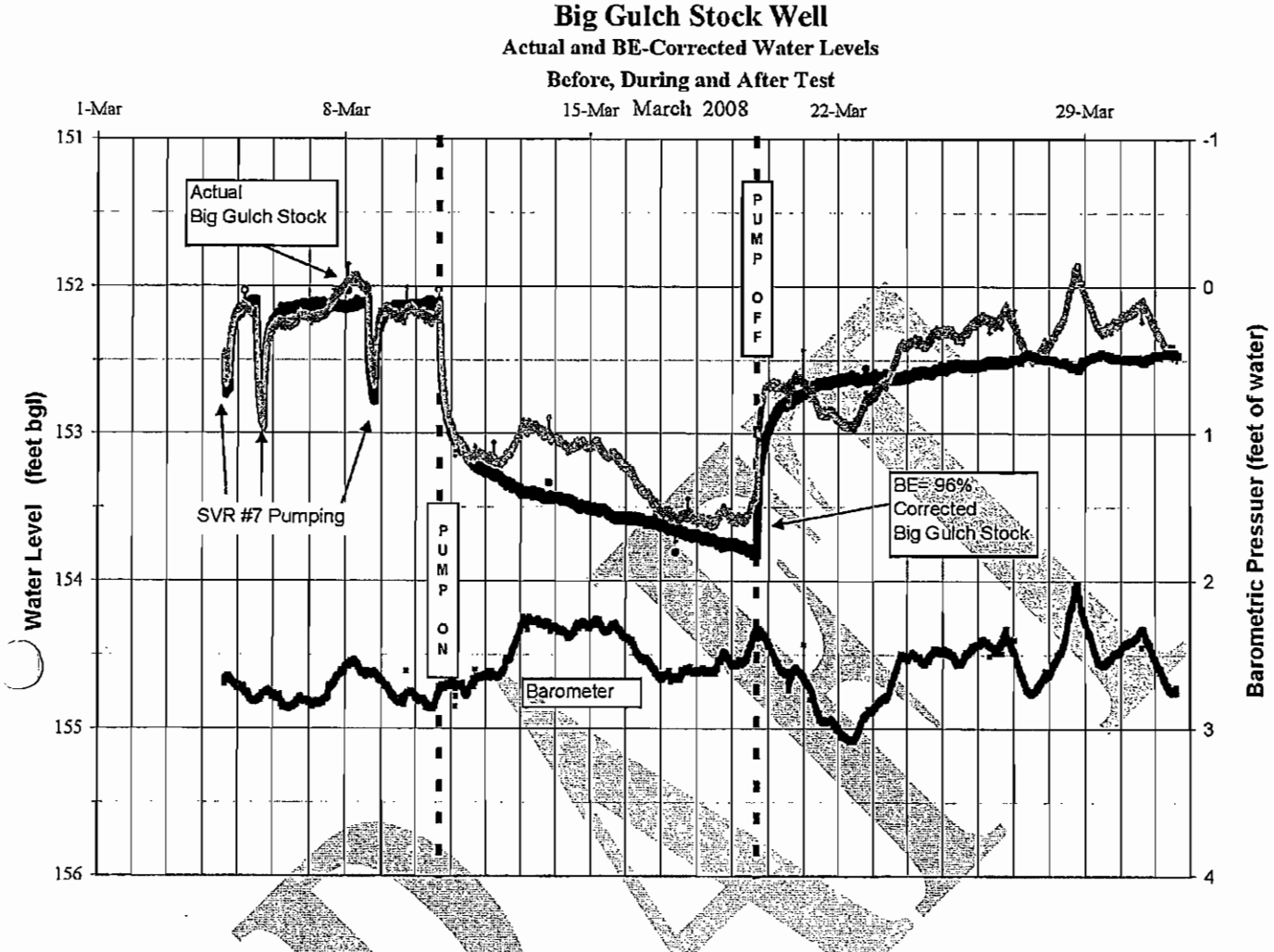
Figure C-1. Actual and BE-Corrected Water Levels for SVR #7



Distance from Pumping Well SVR #7 = 0 ft
Screen Depth = 280 to 350 ft

DRAFT

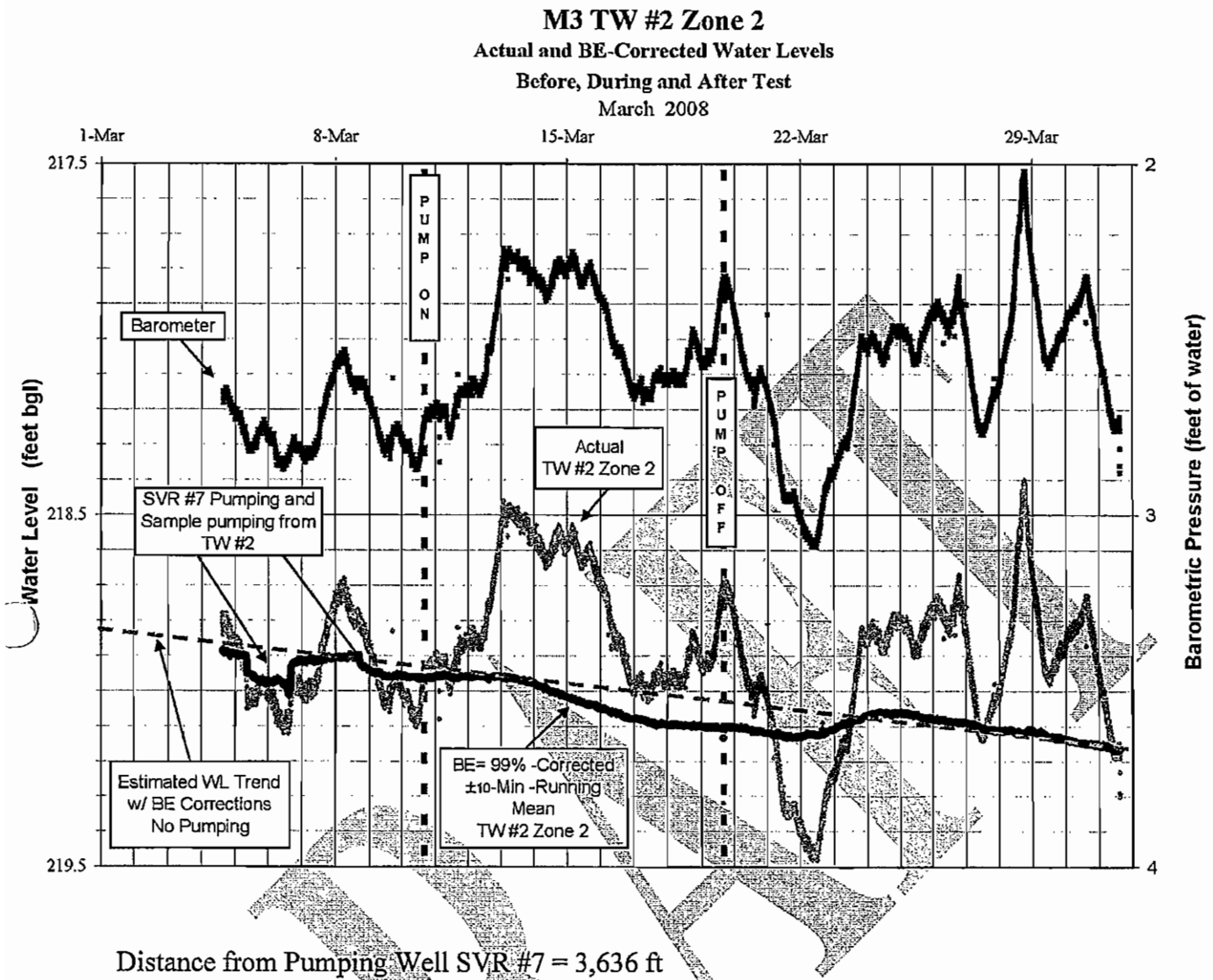
Figure C-2. Actual and BE-Corrected Water Levels for Big Gulch Stock Well



Distance from Pumping Well SVR #7 = 845 ft
Screen Depth = 180 to 180 ft ("open hole," no well screen)

DRAFT

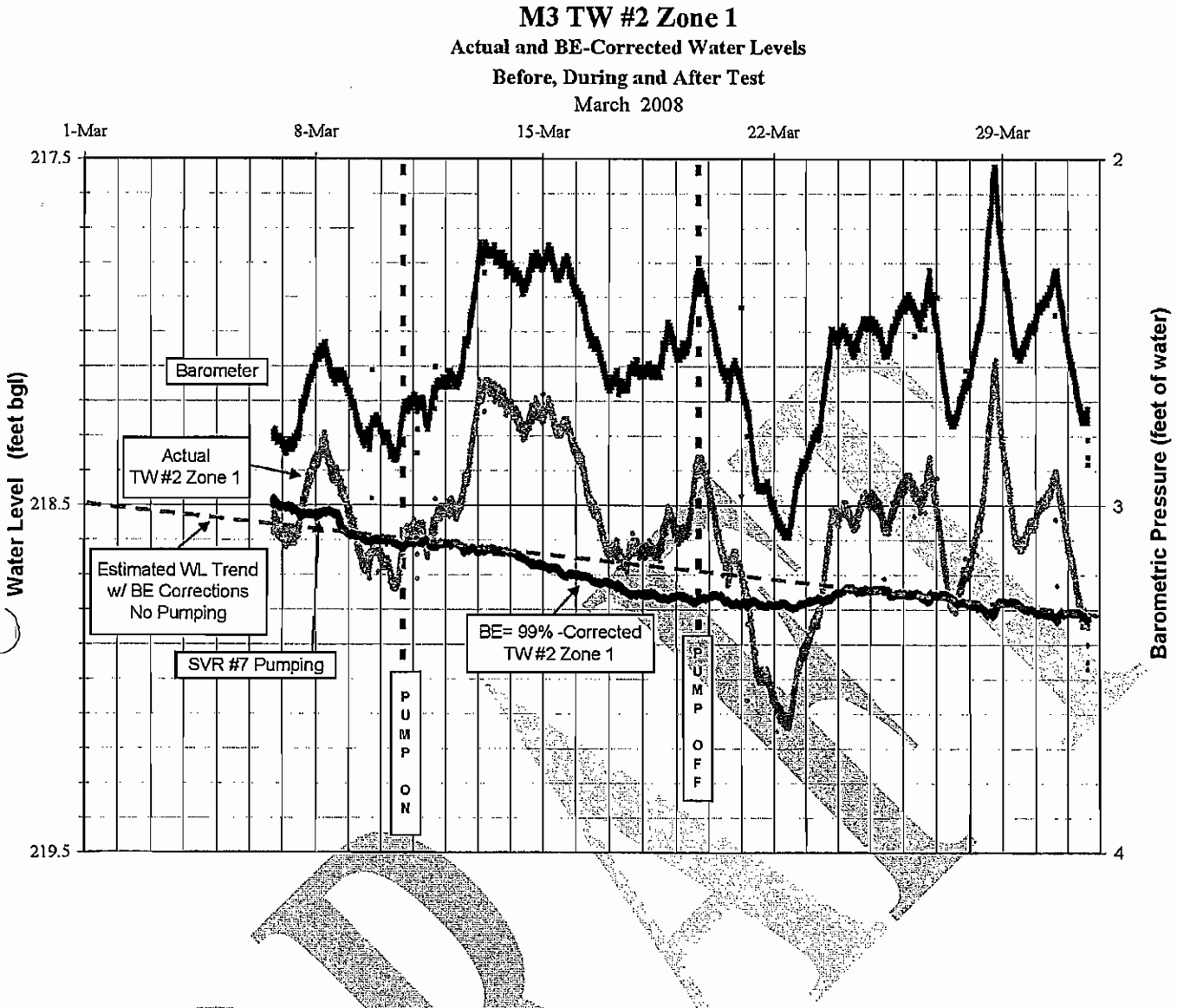
Figure C-3. Actual and BE-Corrected Water Levels for TW #2 Zone 2



Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 230 to 250 ft

DRAFT

Figure C-4. Actual and BE-Corrected Water Levels for TW #2 Zone 1



Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 270 to 320 ft

SVR

Figure C-5. Actual and BE-Corrected Water Levels for TW #4 Zone 3

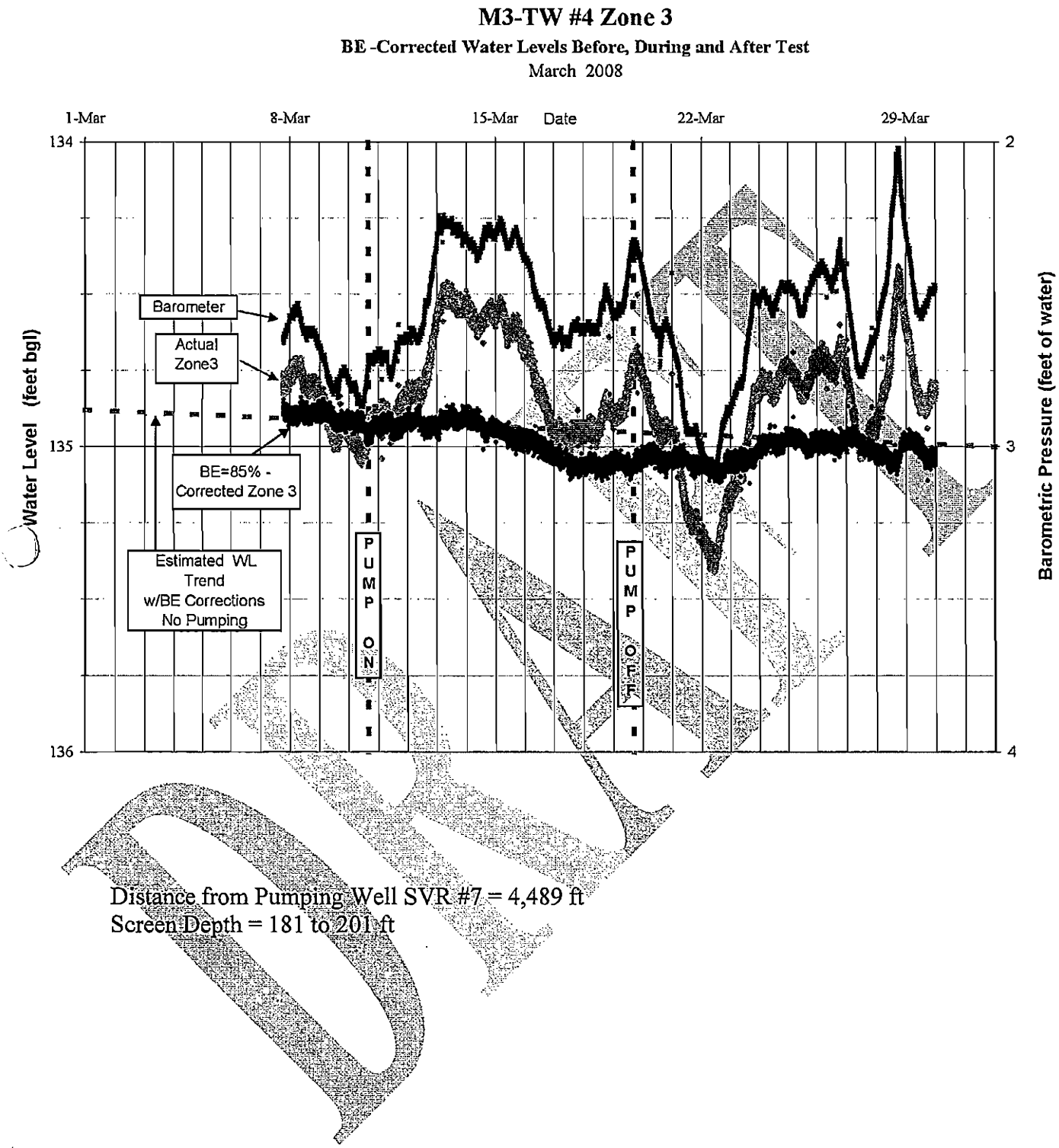


Figure C-6. Actual and BE-Corrected Water Levels for TW #4 Zone 2

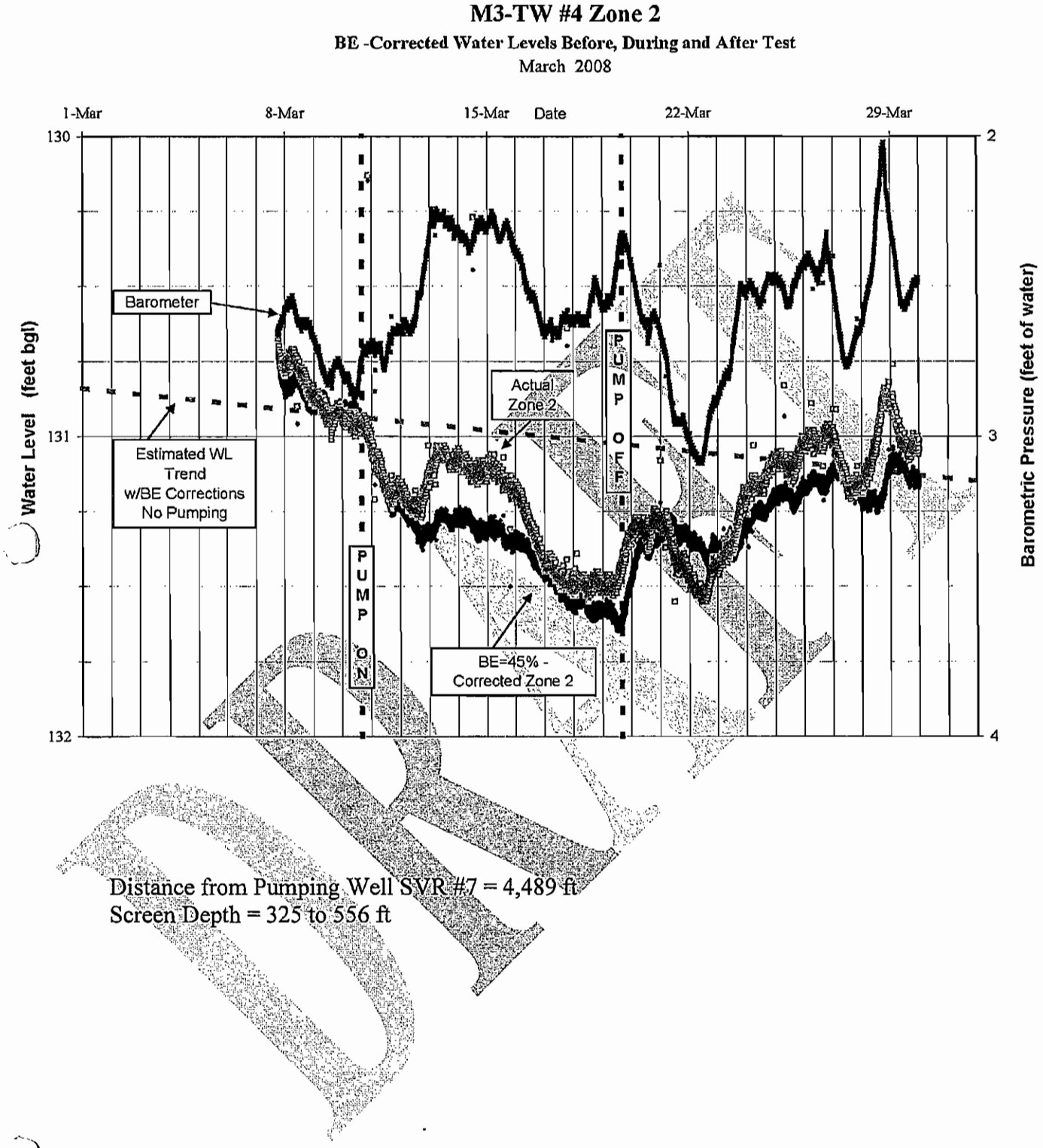


Figure C-7. Actual and BE-Corrected Water Levels for TW #4 Zone 1

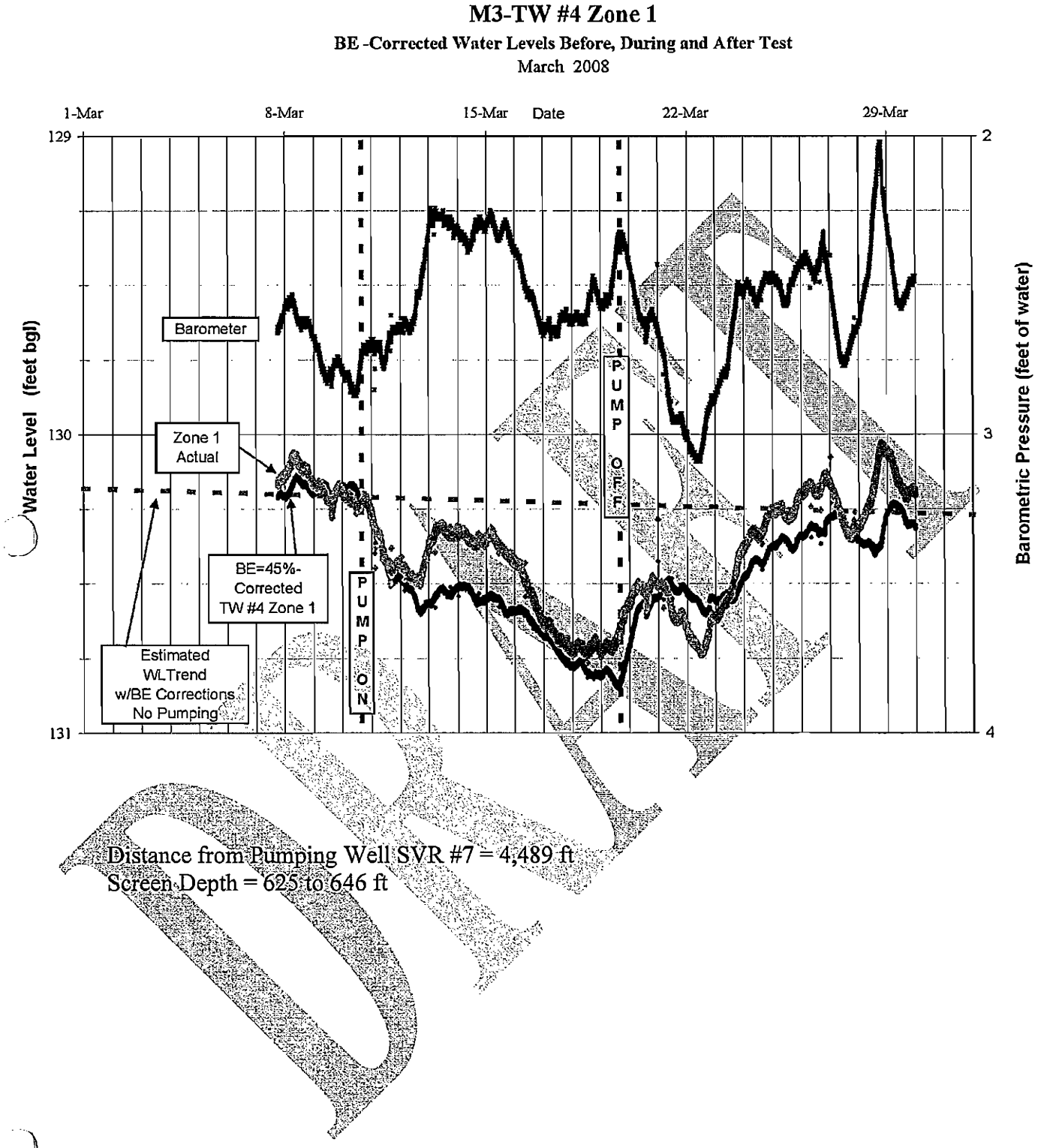
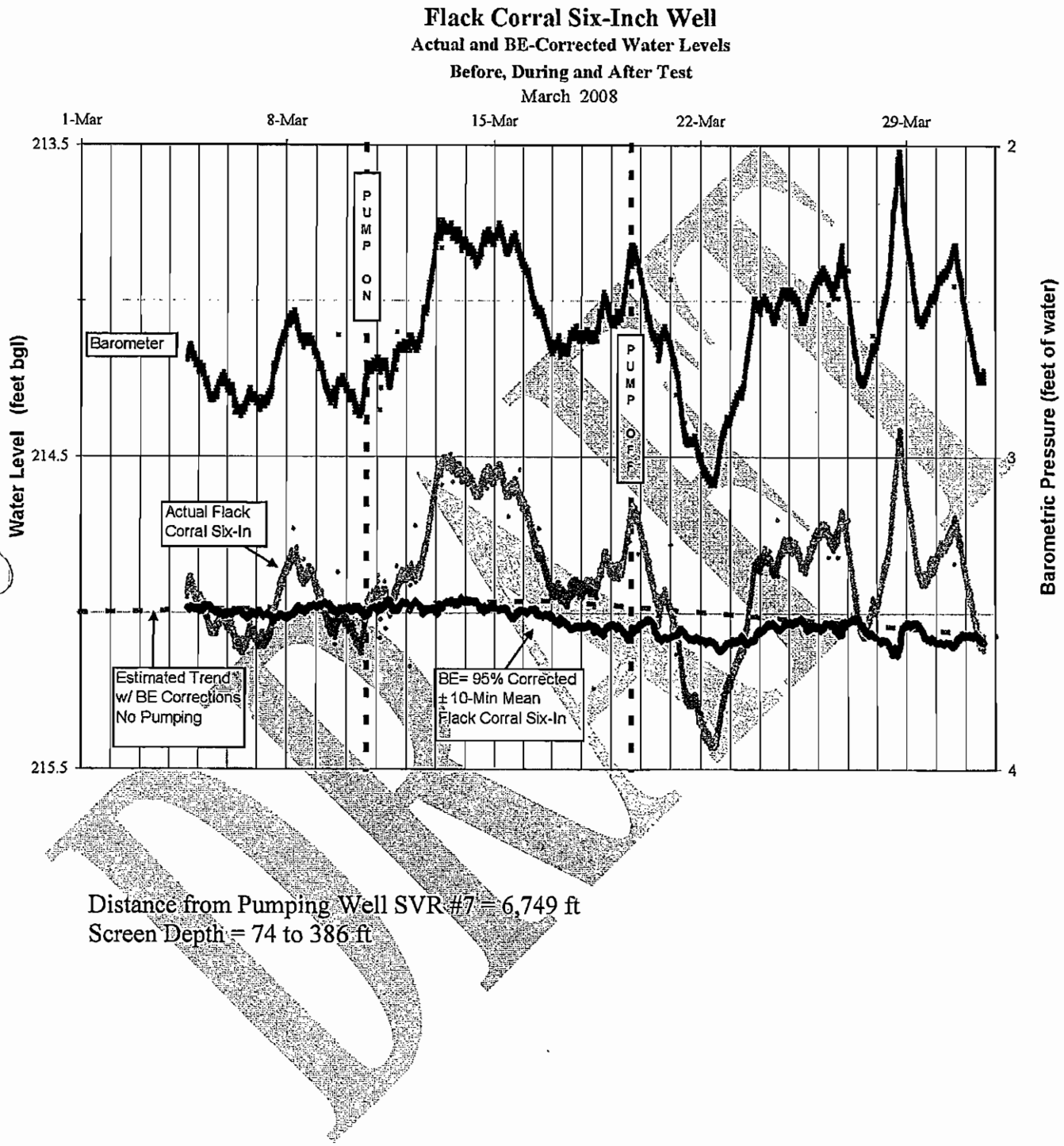


Figure C-8. Actual and BE-Corrected Water Levels for Flack Corral 6-Inch Well



Distance from Pumping Well SVR #7 = 6,749 ft
Screen Depth = 74 to 386 ft

Figure C-9. Actual and BE-Corrected Water Levels for Little Gulch Stock Well

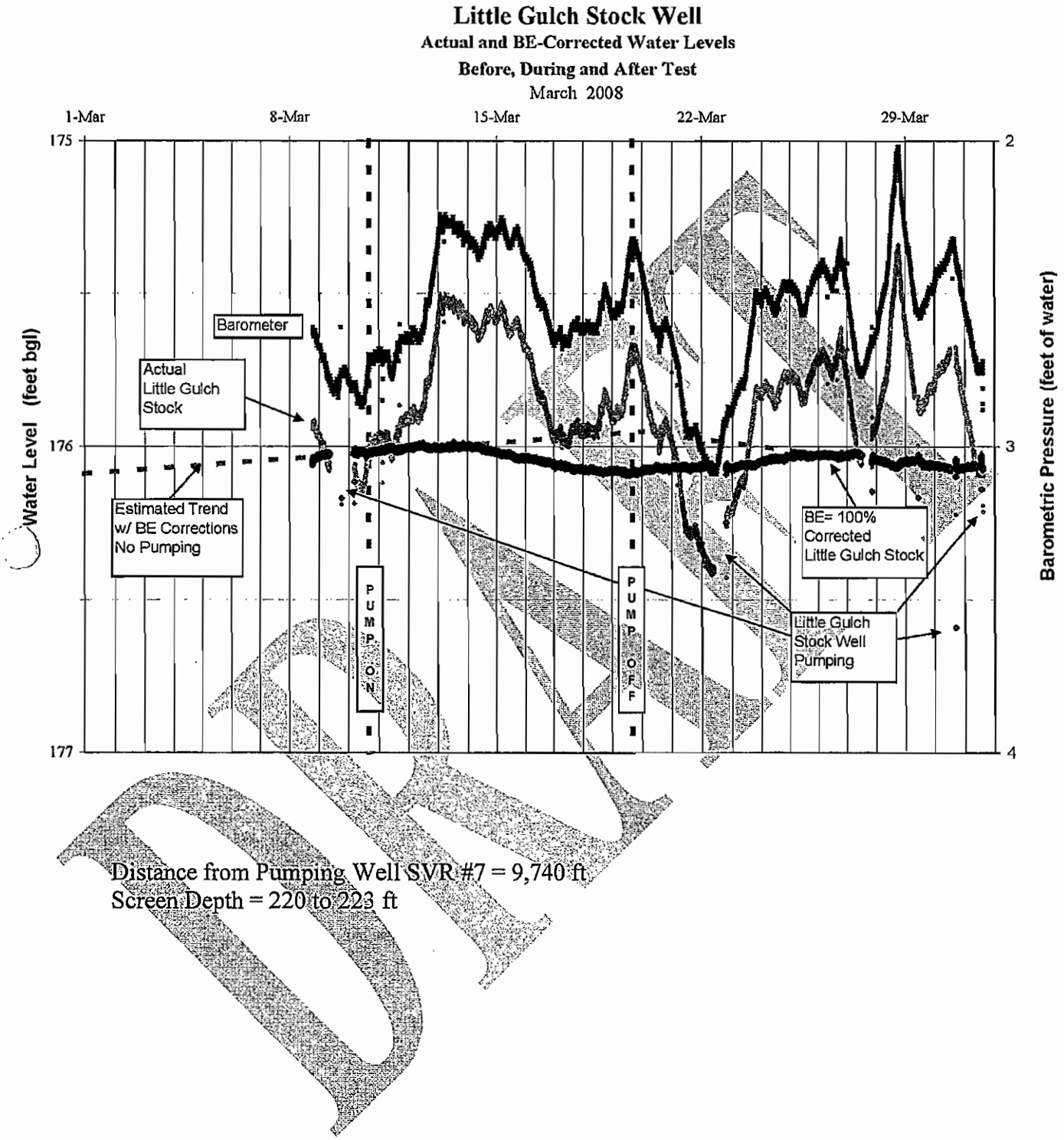
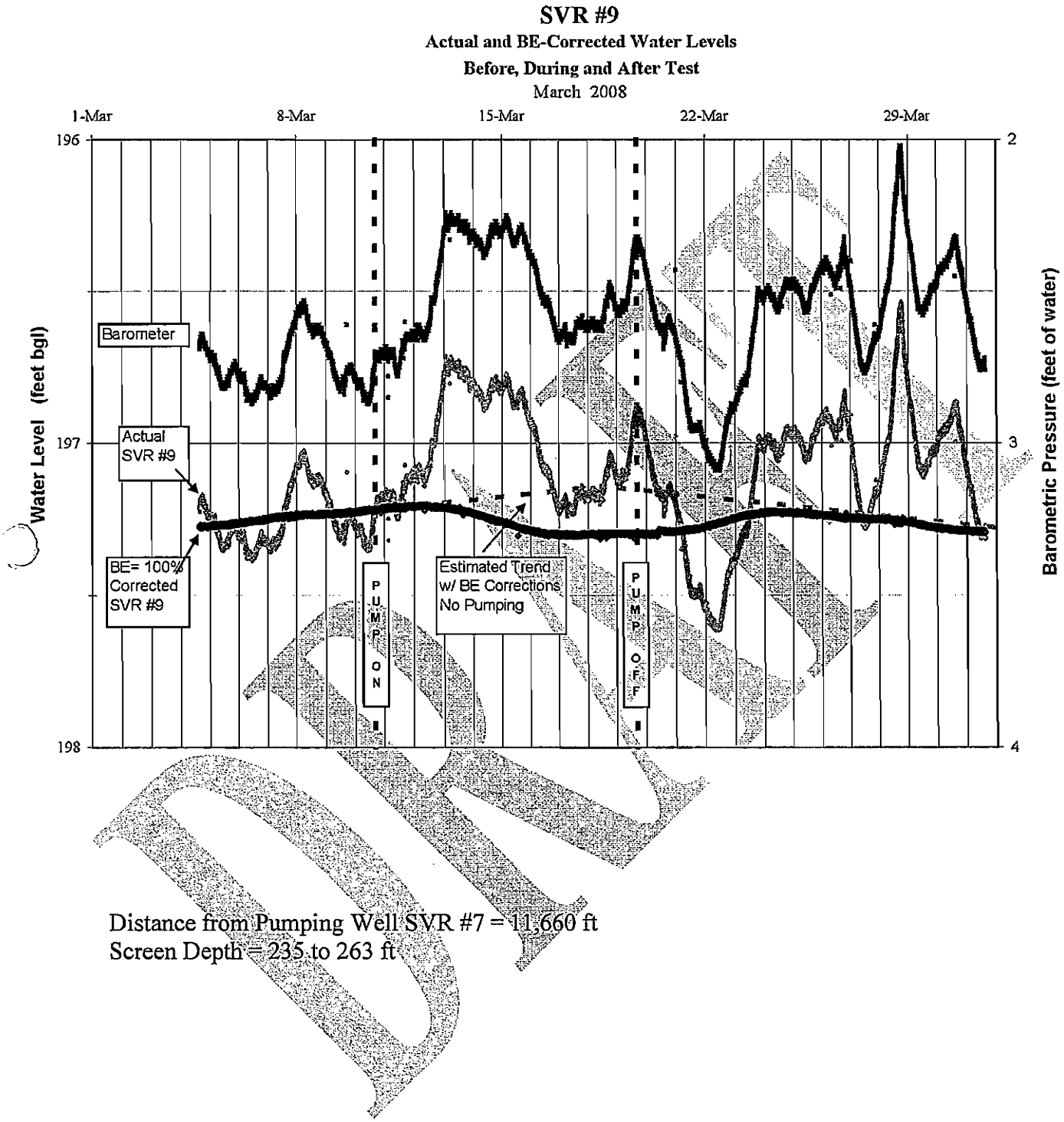
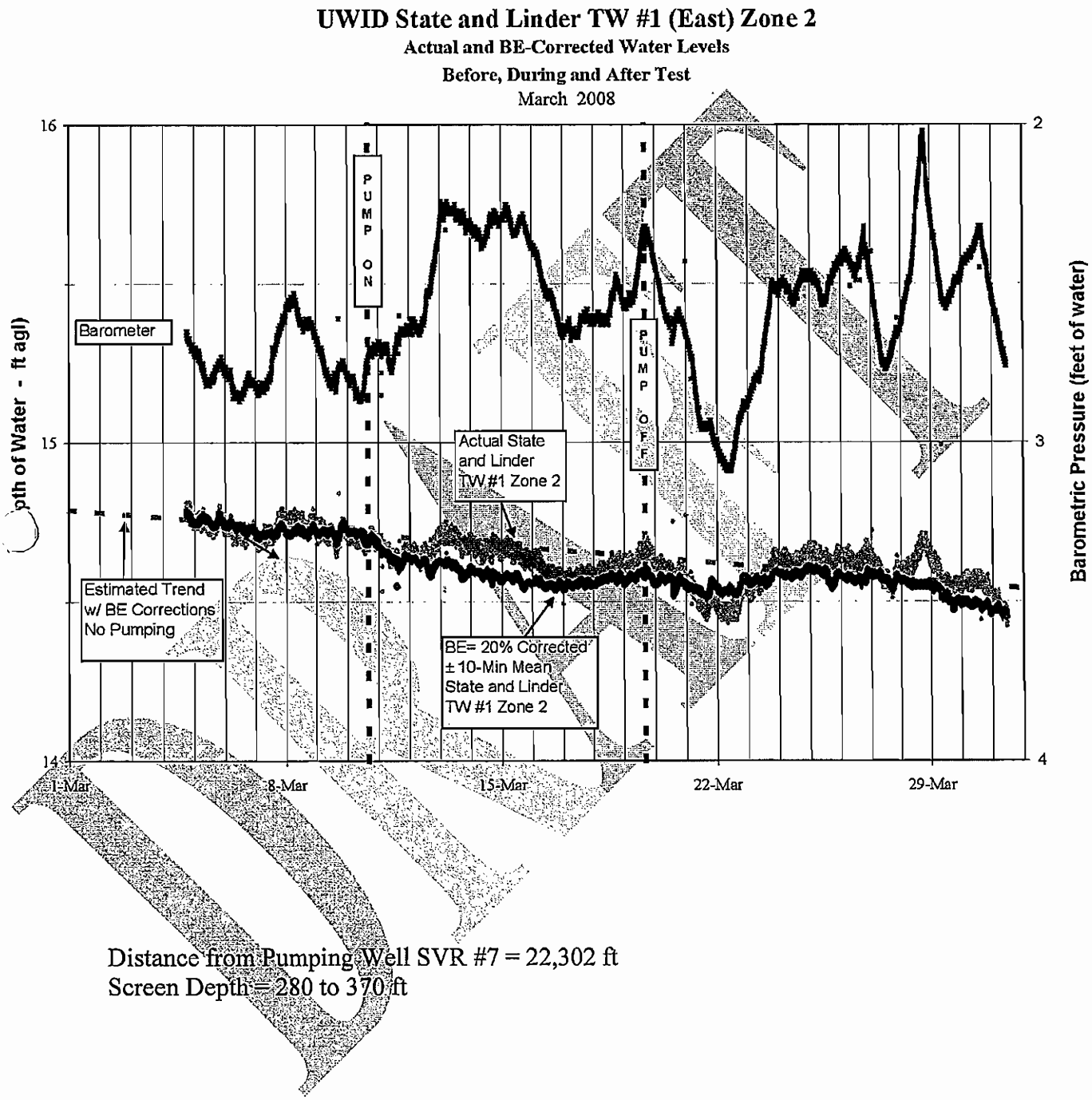


Figure C-10. Actual and BE-Corrected Water Levels for SVR #9



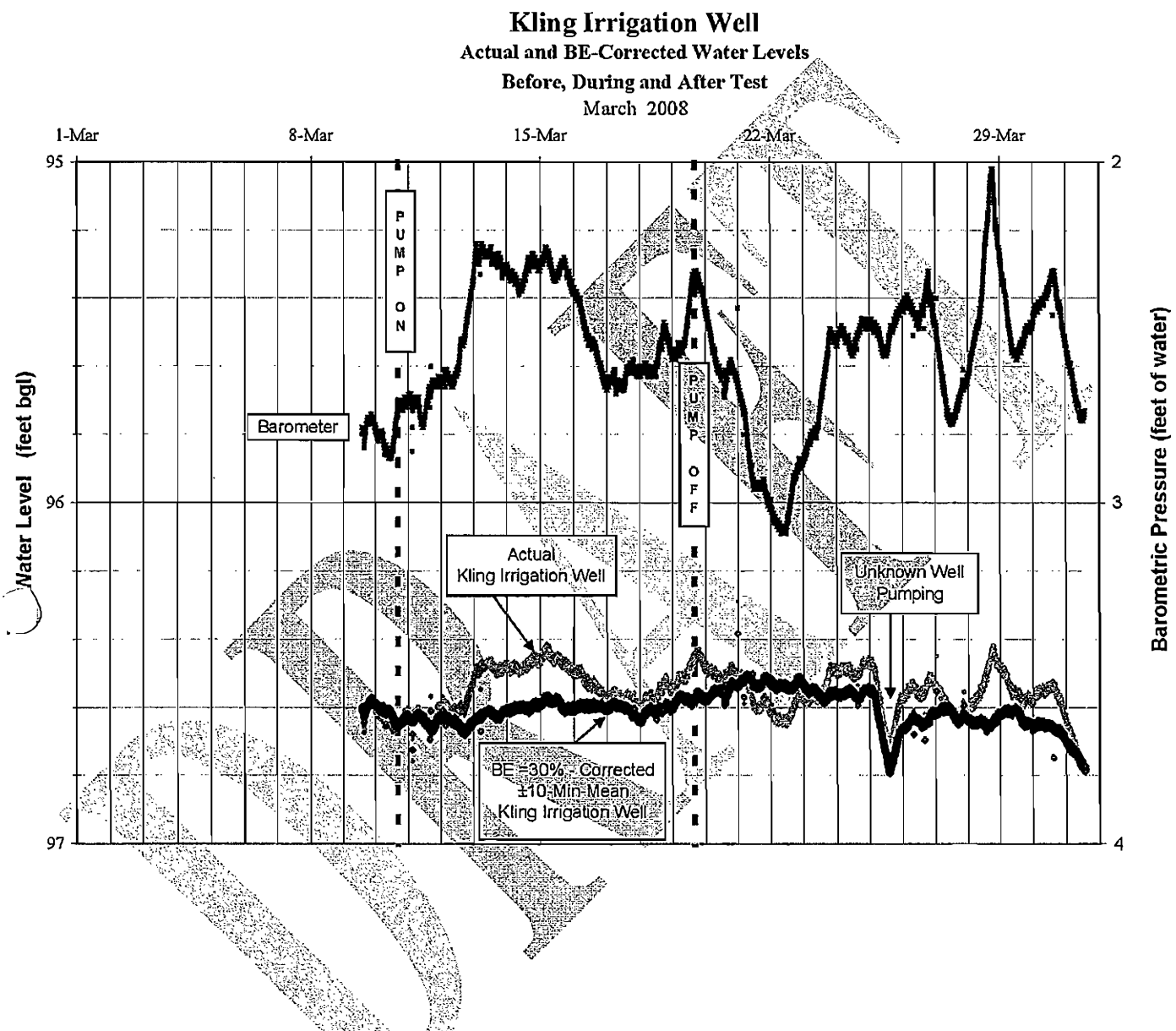
Distance from Pumping Well SVR #7 = 11,660 ft
Screen Depth = 235 to 263 ft

Figure C-11. Actual and BE-Corrected Water Levels for UWID State and Linder TW #1 Zone 2



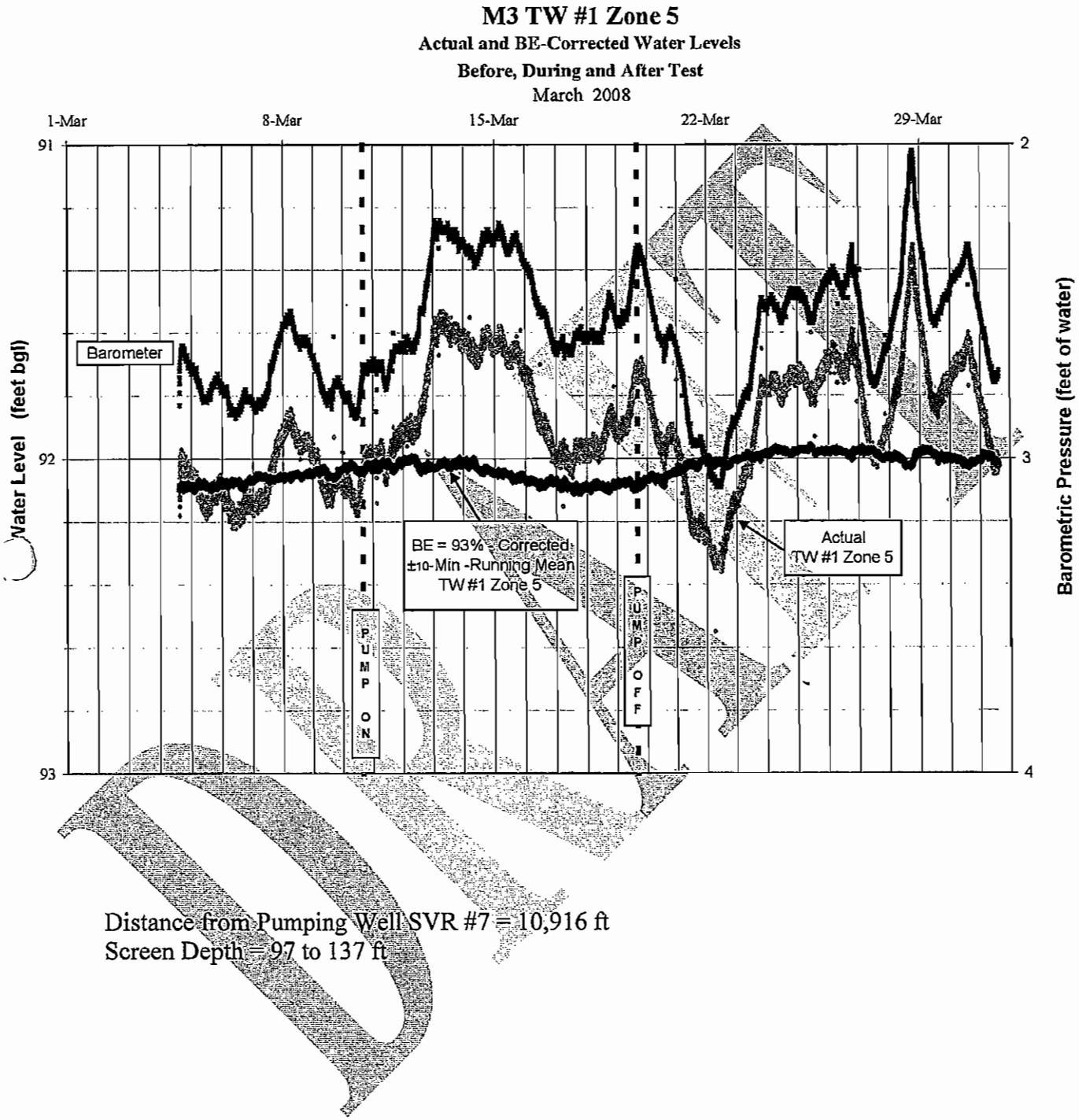
Distance from Pumping Well SVR #7 = 22,302 ft
Screen Depth = 280 to 370 ft

Figure C-12. Actual and BE-Corrected Water Levels for the Kling Irrigation Well



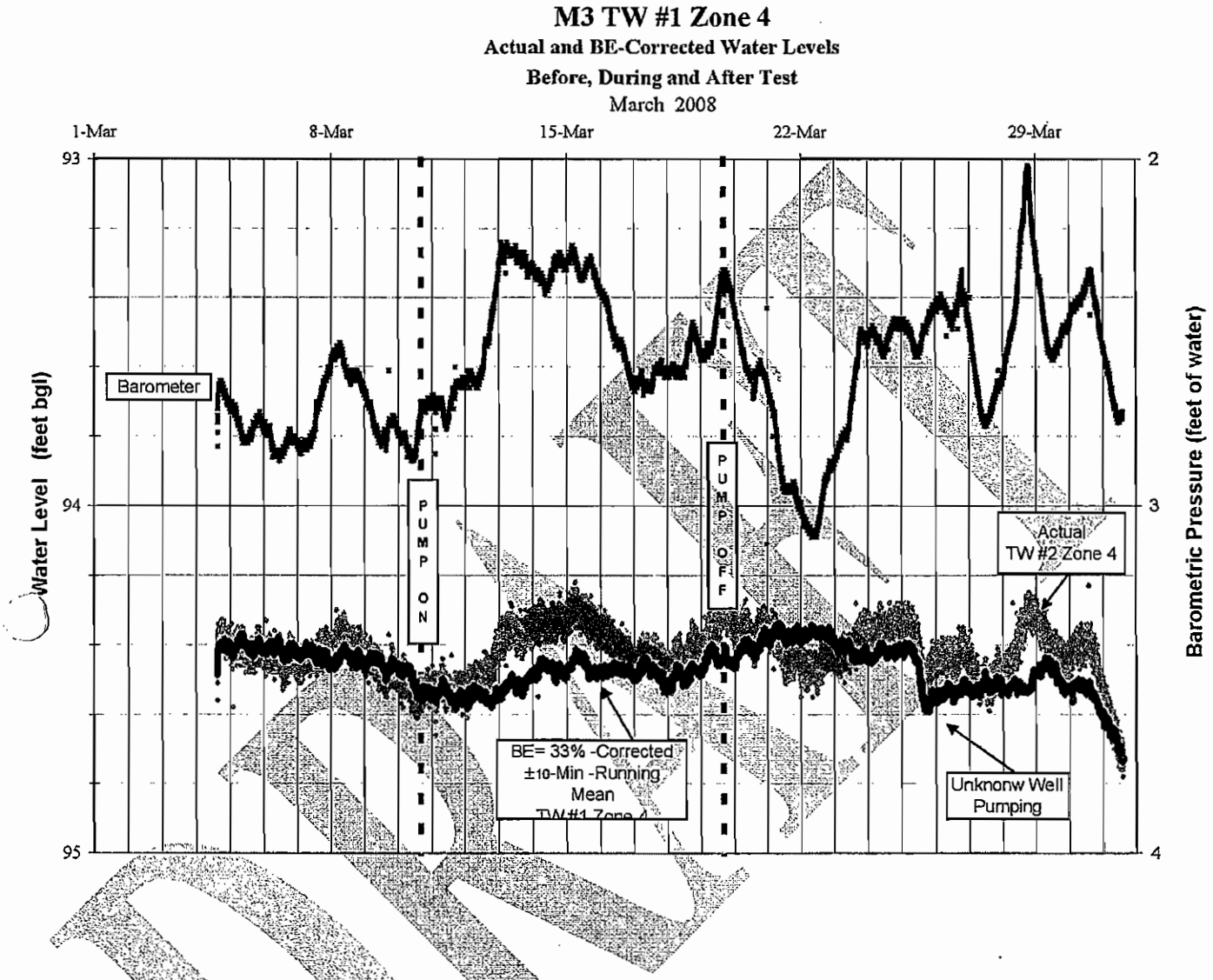
Distance from Pumping Well SVR #7 = 9,908 ft
Screen Depth = 198 to 408 ft

Figure C-13. Actual and BE-Corrected Water Levels for TW #1 Zone 5



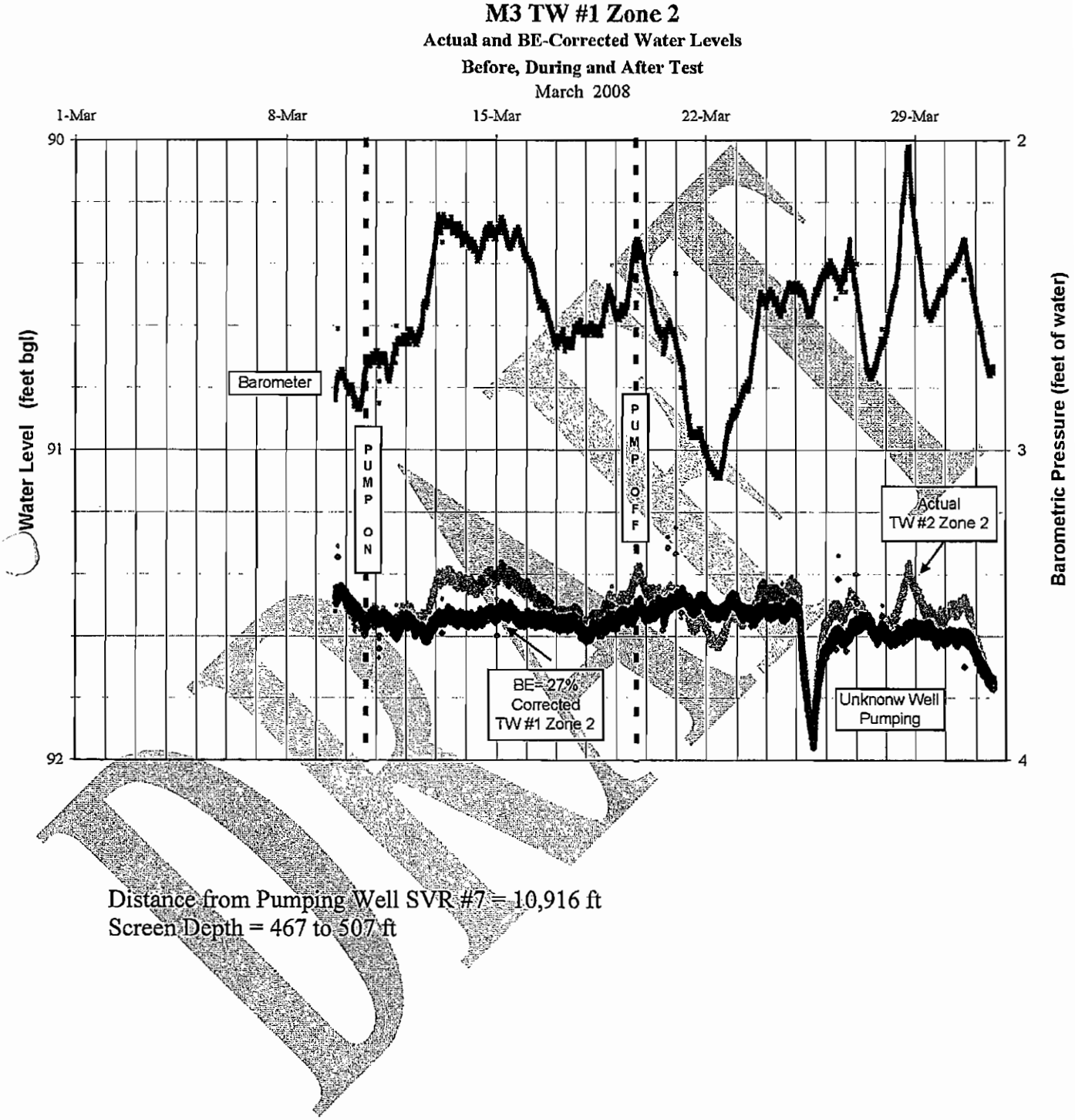
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 97 to 137 ft

Figure C-14. Actual and BE-Corrected Water Levels for TW #1 Zone 4



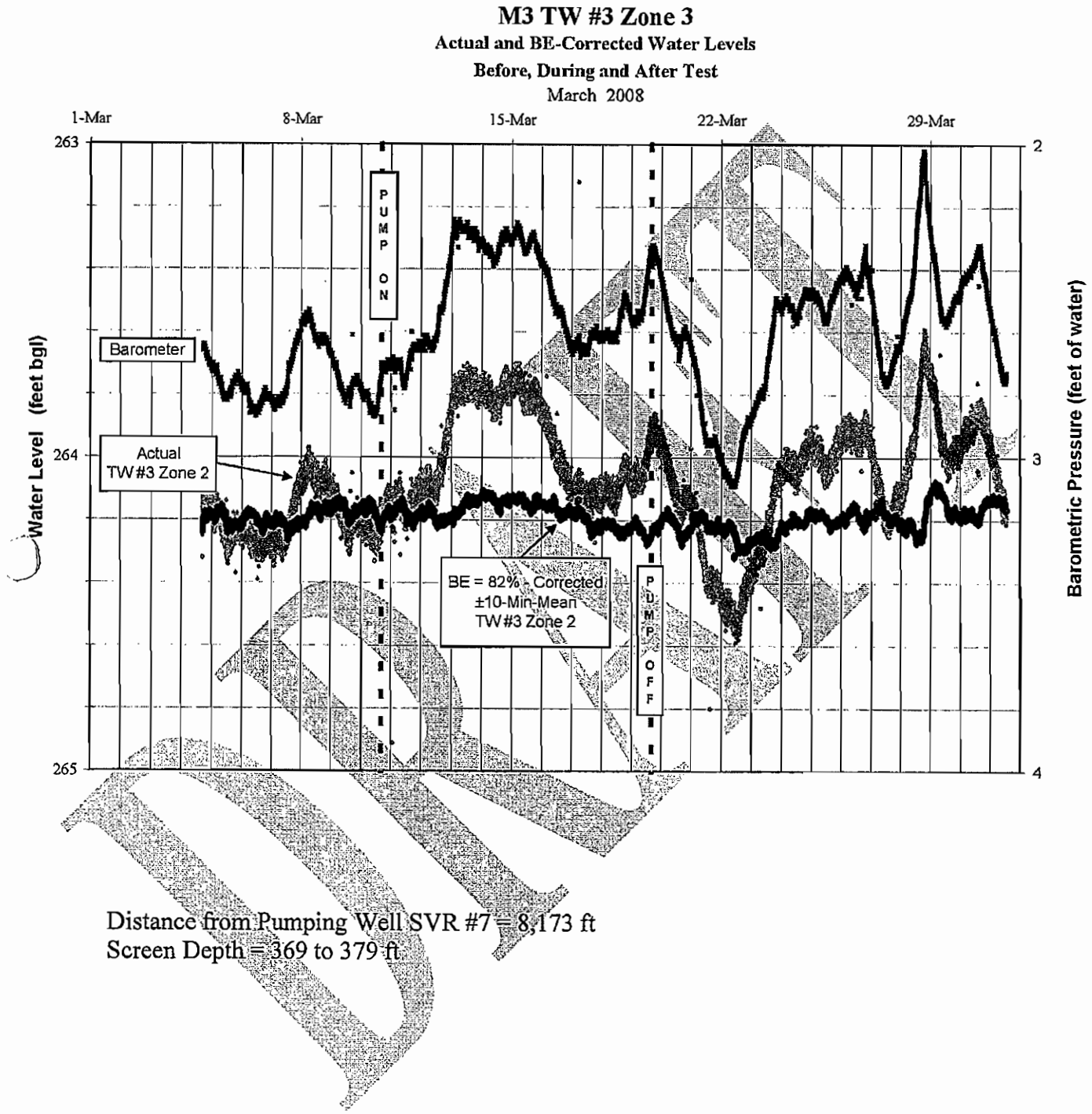
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 253 to 383 ft

Figure C-15. Actual and BE-Corrected Water Levels for TW #1 Zone 2



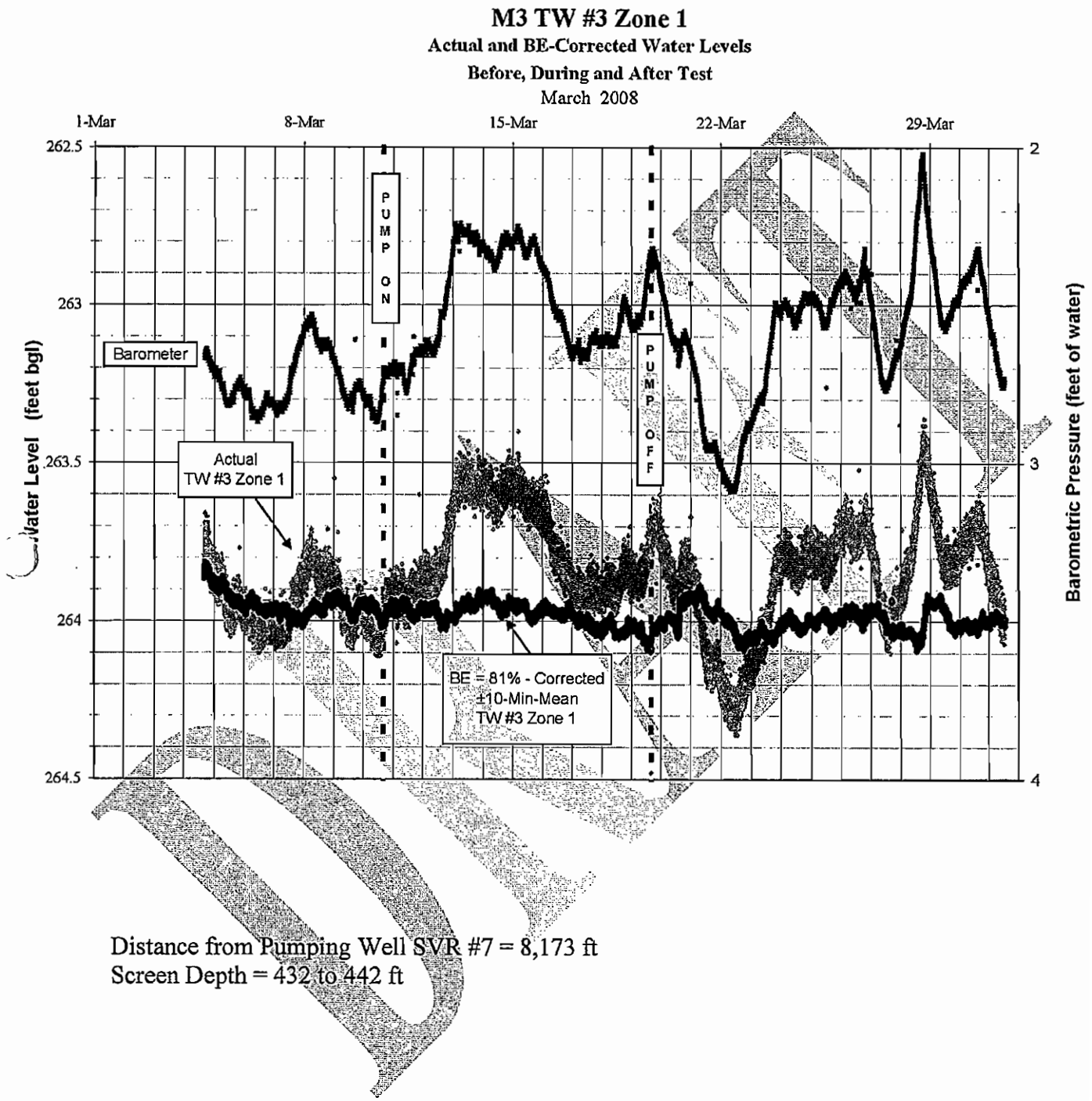
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 467 to 507 ft

Figure C-16. Actual and BE-Corrected Water Levels for TW #3 Zone 3



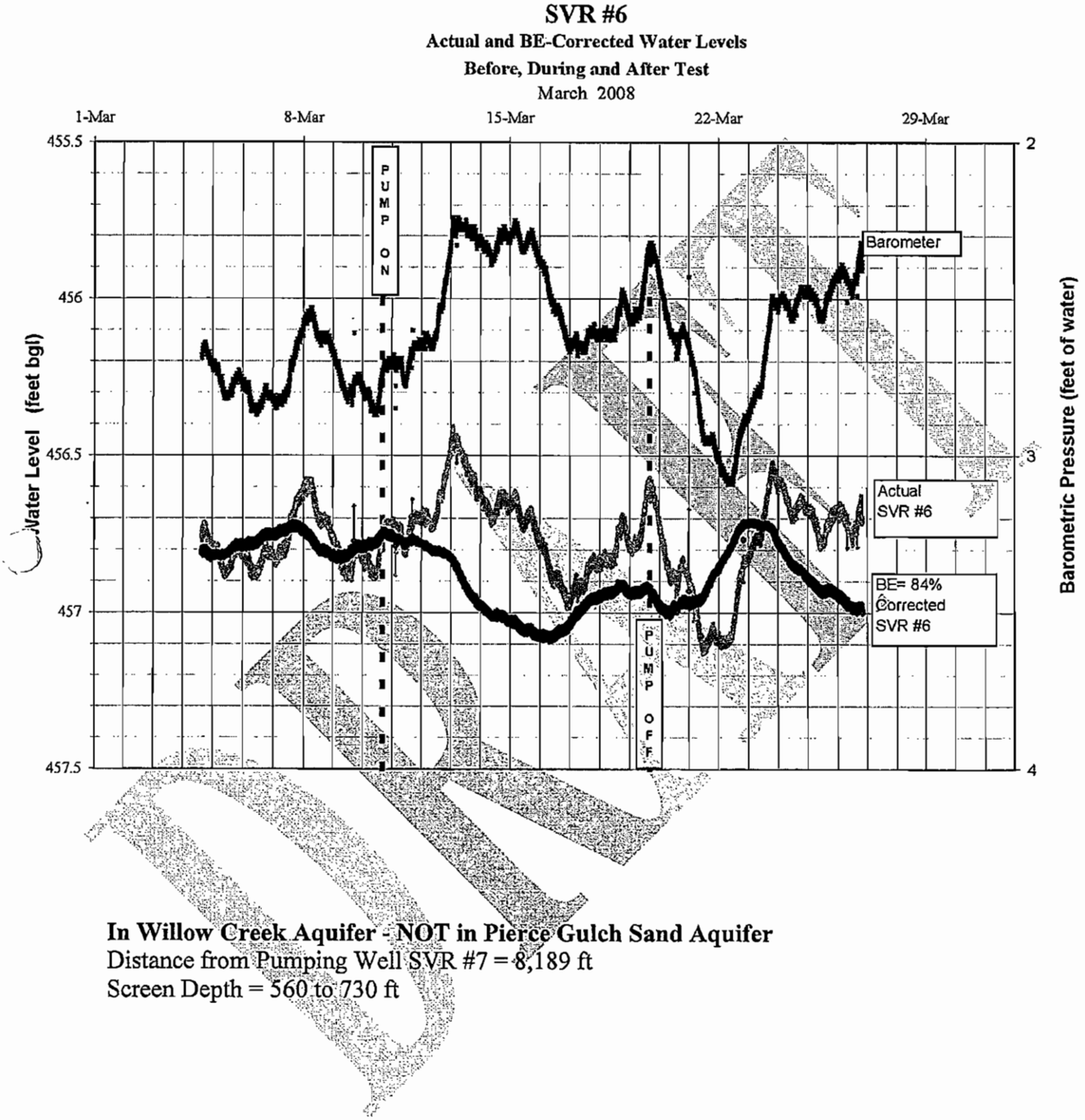
Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 369 to 379 ft

Figure C-17. Actual and BE-Corrected Water Levels for TW #3 Zone 1



Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 432 to 442 ft

Figure C-18. Actual and BE-Corrected Water Levels for SVR #6



In Willow Creek Aquifer - NOT in Pierce Gulch Sand Aquifer
Distance from Pumping Well SVR #7 = 8,189 ft
Screen Depth = 560 to 730 ft

Appendix D – Additional Information on the Analytical Methods Used in this Report

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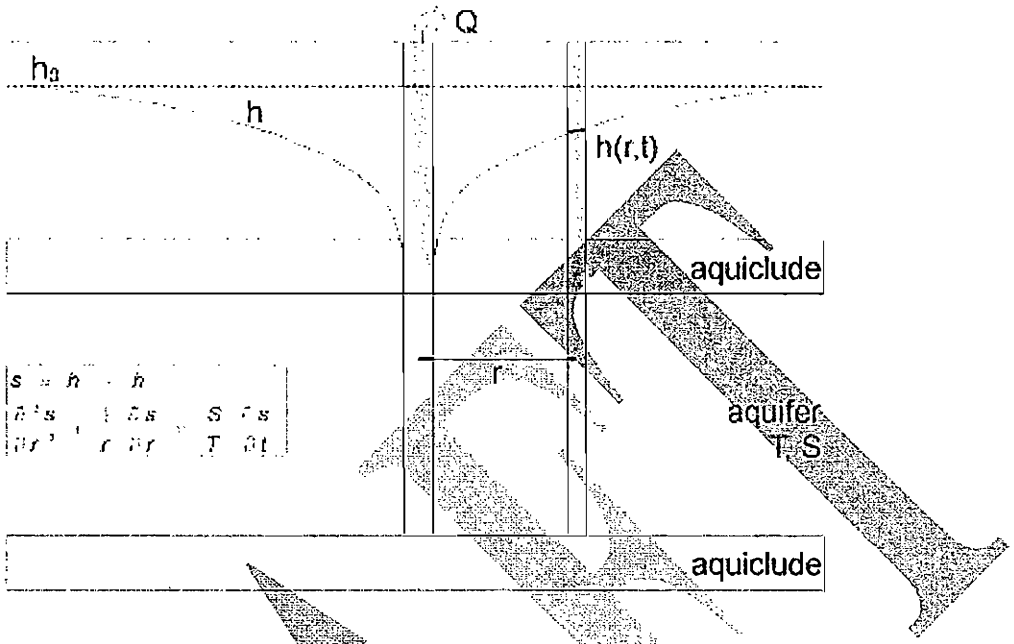
Details on the Method of Cooper, H.H. and C.E. Jacob, 1946. (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic
- diameter of pumping well is very small so that storage in the well can be
- values of u are small (i.e., r is small and t is large)

Equations:

For large values of time, Cooper and Jacob (1946) proposed the following equation for displacement in a confined aquifer in response to pumping:

$$s = \frac{2.303Q}{4\pi T}\log\left(\frac{2.25Tt}{r^2S}\right)$$

$$s_D = \frac{4\pi T}{Q}s$$

$$t_D = \frac{Tt}{r^2S}$$

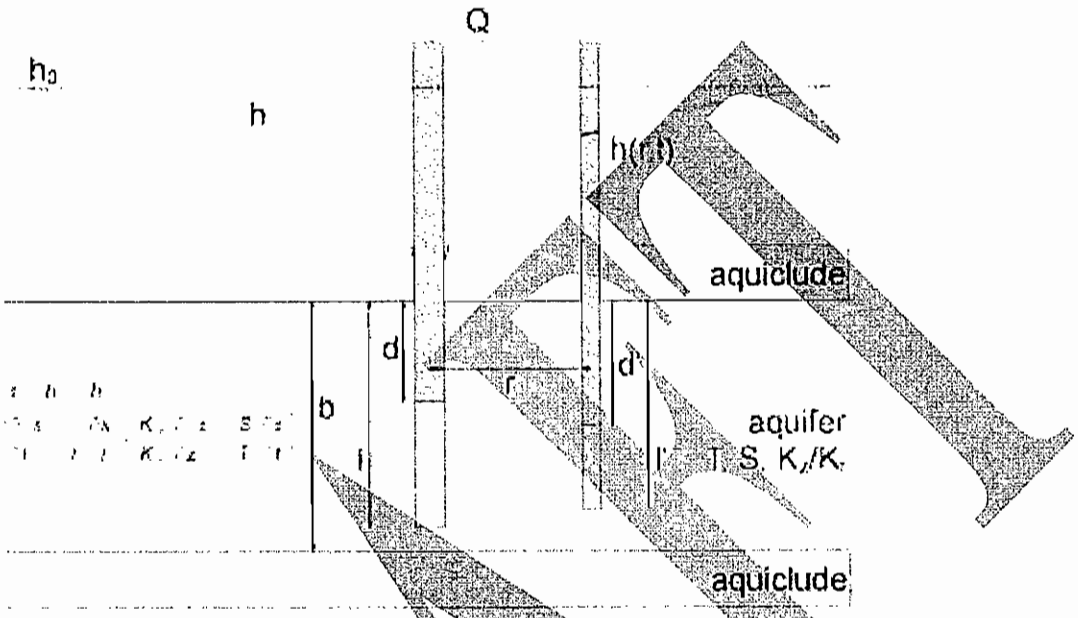
where

- Q is pumping rate [L^3/T]
- r is radial distance [L]
- t is time [T]
- s is drawdown [L]
- S is storativity [dimensionless]
- T is transmissivity [L^2/T]

DRAFT

Details on the Method of Hantush, M.S. 1961a and b (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous and of uniform thickness
- pumping well is fully or partially penetrating
- flow to pumping well is horizontal when pumping well is fully penetrating
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected

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Equations:

Hantush (1961a, b) derived equations for the effects of partial penetration in a confined aquifer. For a piezometer, the partial penetration correction is as follows:

$$s = \frac{Q}{4\pi T}\left(W(u) + \frac{2b}{\pi(l-d)}\sum_{n=1}^{\infty}\frac{1}{n}\left[\sin\left(\frac{n\pi d}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right]\cos\left(\frac{n\pi z}{b}\right)\ W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi}{b}\right)\right)$$

For an observation well, the following partial penetration correction applies:

$$s = \frac{Q}{4\pi T}\left(W(u) + \frac{2b^2}{\pi^2(l-d)(l'-d')}\sum_{n=1}^{\infty}\frac{1}{n^2}\left[\sin\left(\frac{n\pi l}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right]\left[\sin\left(\frac{n\pi l'}{b}\right) - \sin\left(\frac{n\pi d'}{b}\right)\right]\ W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi}{b}\right)\right)$$

where

- b is aquifer thickness [L]
- d is depth to top of pumping well screen [L]
- d' is depth to top of observation well screen [L]
- l is depth to bottom of pumping well screen [L]
- l' is depth to bottom of observation well screen [L]
- K_z/K_r is vertical to horizontal hydraulic conductivity anisotropy (dimensionless)
- w(u,ß) is the Hantush-Jacob well function for leaky confined aquifers
- z is depth to piezometer opening [L]

At large distances, the effect of partial penetration becomes negligible when

$$r > 1.5b\sqrt{K_z/K_r}$$

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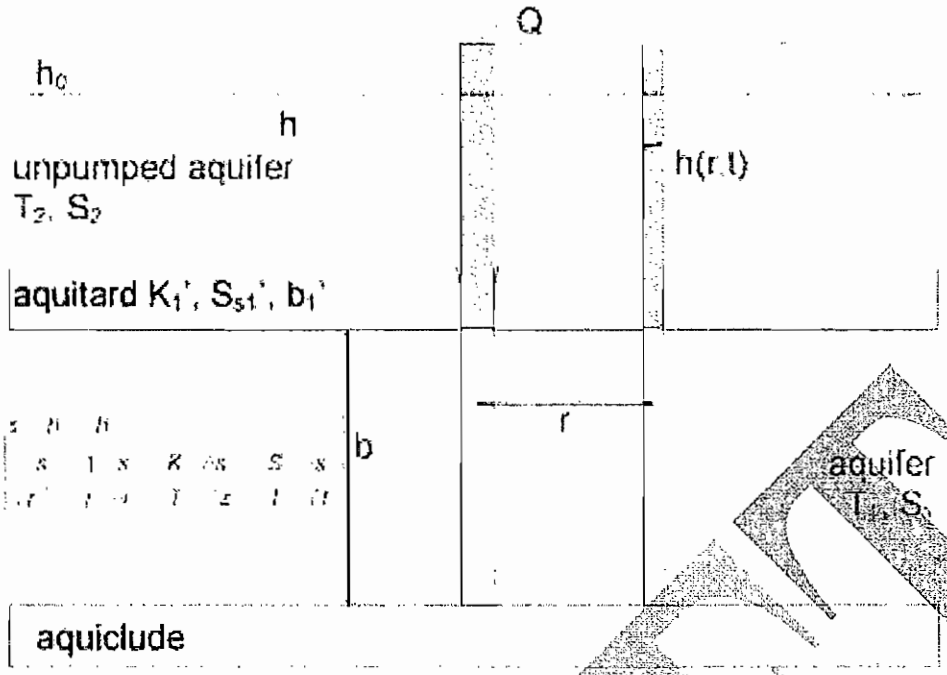
Details on the Method of Neuman, S.P., and Witherspoon, P. 1972. (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is leaky confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected
- confining bed(s) has infinite areal extent, uniform vertical hydraulic conductivity, storage coefficient and thickness
- flow is vertical in the aquitard(s)

Equations:

$$s_1 = \frac{Q}{4\pi T}\int_0^\infty (1-e^{-y^2 t_D})([1+G(y)]J_0(\omega_1(y))+[1-G(y)]J_0(\omega_2(y)))\frac{dy}{y}$$

$$s_1' = \frac{Q}{4\pi T}\frac{2}{\pi}\sum_0^\infty \frac{1}{n}\sin\frac{n\pi z}{b_1'}\int_0^\infty [1-e^{-n^2\pi^2 t_D}+\frac{e^{-n^2\pi^2 t_D}-e^{-y^2 t_D}}{1-y^2/(n^2\pi^2)}]([\frac{2(r/B_{21})^2(-1)^n y}{F(y)\sin y}-G(y)-1]J_0(\omega_1(y))$$

$$-[\frac{2(r/B_{21})^2(-1)}{F(y)\sin y}-G(y)+1]J_0(\omega_2(y)))\frac{dy}{y}$$

$$s_2 = \frac{Q}{4\pi T}\int_0^\infty (1-e^{-y^2 t_D})\frac{2(r/B_{21})^2}{F(y)}[J_0(\omega_1(y))-J_0(\omega_2(y))]\frac{dy}{\sin y}$$

$$t_{D1} = \frac{T_1 t}{r^2 S_1}$$

$$t_{D1}' = t_{D1}(r/B_{11})^4/(4\beta_{11})^2$$

$$r/B_{ij} = r\sqrt{K_i'/T_i b_j'}$$

$$\beta_{ij} = \frac{r}{4b_i}\sqrt{\frac{K_j' S_{sj}'}{K_i S_{si}}}$$

$$G(y) = M(y)/F(y)$$

$$\omega_1^2(y) = \frac{1}{2}[N(y)+F(y)]$$

$$\omega_2^2(y) = \frac{1}{2}[N(y)-F(y)]$$

$$F^2(y) = M^2(y)+\left[\frac{2(r/B_{11})(r/B_{21})y}{\sin y}\right]^2$$

$$M(y) = \left[\frac{(r/B_{11})^4}{(4\beta_{11})^2}-\frac{(r/B_{21})^4}{(4\beta_{21})^2}\right]y^2-\left[(r/B_{11})^2-(r/B_{21})^2\right]y\cot y$$

$$N(y) = \left[\frac{(r/B_{11})^4}{(4\beta_{11})^2}+\frac{(r/B_{21})^4}{(4\beta_{21})^2}\right]y^2-\left[(r/B_{11})^2+(r/B_{21})^2\right]y\cot y$$

$$s_D = \frac{4\pi T}{Q}s$$

$$t_D = \frac{Tt}{r^2 S}$$

where

- b_i is thickness of aquifer i [L]
- b_j' is thickness of aquitard j [L]
- J_0 is Bessel function of first kind, zero order
- K_i is horizontal hydraulic conductivity in aquifer i [L/T]
- K_j' is vertical hydraulic conductivity in aquitard j [L/T]
- Q is pumping rate [L^3/T]
- r is radial distance [L]
- s_1 is drawdown in the pumped aquifer [L]

- s'_1 is drawdown in the aquitard [L]
- s_2 is drawdown in the unpumped aquifer [L]
- S, S_1 is storativity in the pumped aquifer [dimensionless]
- t is time [T]
- T, T_1 is transmissivity in the pumped aquifer [L^2/T]

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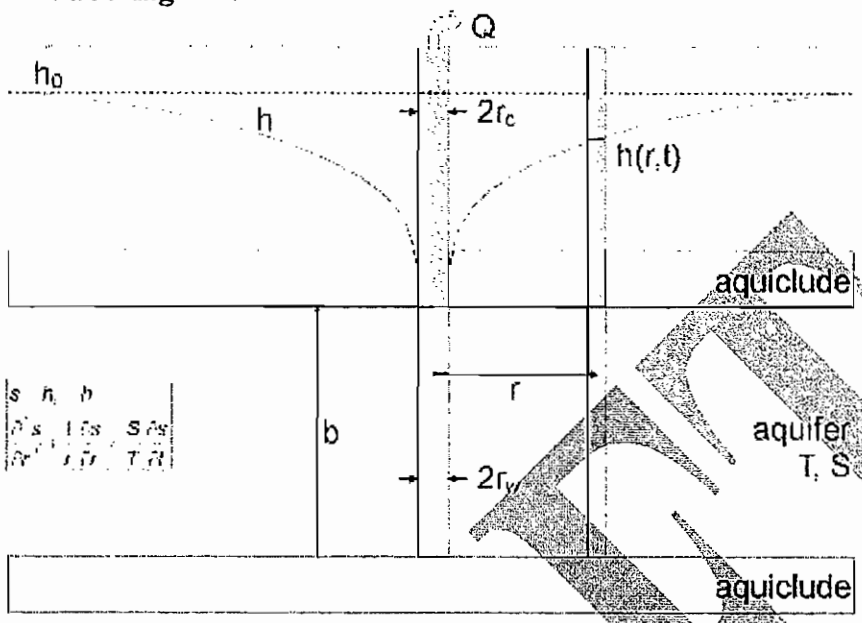
Details on the Method of Papadopulos, I.S. and H.H. Cooper, 1967. (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head

Equations:

Papadopulos and Cooper (1967) derived a solution for a finite-diameter pumping well with wellbore storage in a confined aquifer as follows:

$$s = \frac{Q}{4\pi T} F(u, \alpha, r_D)$$

$$F = \frac{8\alpha}{\pi} \int_0^\infty \frac{(1 - e^{-\beta^2 \alpha / 4u})[J_0(\beta r_D) A(\beta) - Y_0(\beta r_D) B(\beta)]}{([A(\beta)]^2 - [B(\beta)]^2)\beta^2} d\beta$$

$$A(\beta) = \beta Y_0(\beta) - 2\alpha Y_1(\beta)$$

$$B(\beta) = \beta J_0(\beta) - 2\alpha J_1(\beta)$$

$$u = \frac{r^2 S}{4Tt}$$

$$\alpha = \frac{r_c^2 S}{r_w^2}$$

$$r_D = \frac{r}{r_w}$$

where

- J_i is Bessel function of first kind, order i
- Q is pumping rate [L^3/T]
- r is radial distance [L]
- r_c is casing radius [L]
- r_w is well radius [L]
- s is drawdown [L]
- S is storativity [dimensionless]
- t is time [T]
- T is transmissivity [L^2/T]
- Y_i is Bessel function of second kind, order i

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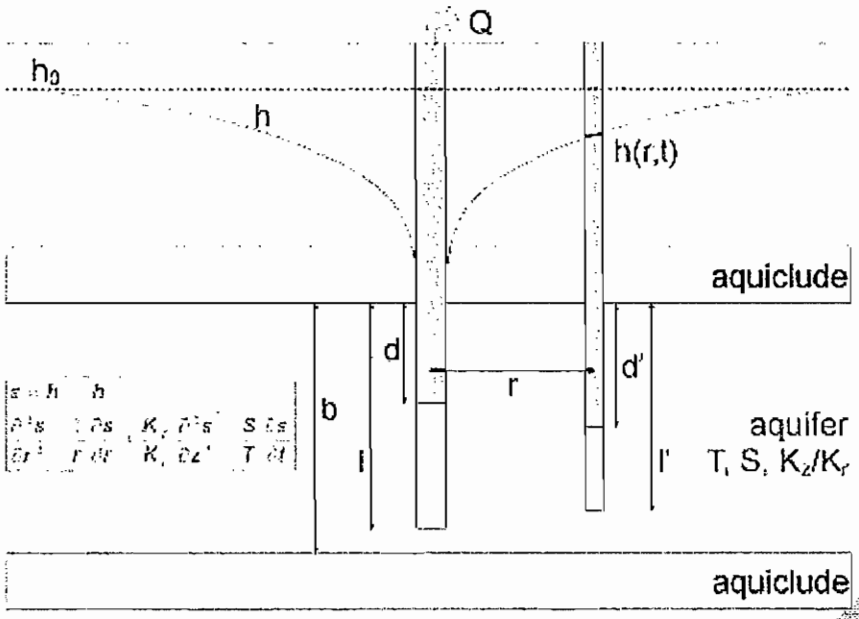
Details on the Method of Theis, C.V., 1935. (Pumping) (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous and of uniform thickness
- pumping well is fully or partially penetrating
- flow to pumping well is horizontal when pumping well is fully penetrating
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected

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Equations:

$$s = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-y}}{y}dy$$

$$u = \frac{r^2 S}{4Tt}$$

where

- Q is pumping rate [L^3/T]
- r is radial distance [L]
- s is drawdown [L]
- S is storativity [dimensionless]
- t is time [T]
- T is transmissivity [L^2/T]

Hydrogeologists commonly refer to the exponential integral in the drawdown equation as the Theis well function, abbreviated as W(u). Therefore, we can write the Theis drawdown equation in compact notation as follows:

$$s = \frac{Q}{4\pi T}W(u)$$

Hantush (1961a, b) derived equations for the effects of partial penetration in a confined aquifer. For a piezometer, the partial penetration correction is as follows:

$$s = \frac{Q}{4\pi T}\left(W(u) + \frac{2b}{\pi(l-d)}\sum_{n=1}^{\infty}\frac{1}{n}\left[\sin\left(\frac{n\pi l}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right]\cdot\cos\left(\frac{n\pi z}{b}\right)\cdot W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right)$$

For an observation well, the following partial penetration correction applies:

$$s = \frac{Q}{4\pi T}\left(W(u) + \frac{2b^2}{\pi^2(l-d)(l'-d')}\sum_{n=1}^{\infty}\frac{1}{n^2}\left[\sin\left(\frac{n\pi l}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right]\cdot\left[\sin\left(\frac{n\pi l'}{b}\right) - \sin\left(\frac{n\pi d'}{b}\right)\right]\cdot W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right)$$

where

- b is aquifer thickness [L]
- d is depth to top of pumping well screen [L]
- d' is depth to top of observation well screen [L]
- l is depth to bottom of pumping well screen [L]
- l' is depth to bottom of observation well screen [L]
- K_z/K_r is vertical to horizontal hydraulic conductivity anisotropy [dimensionless]
- $W(u,\beta)$ is the Hantush-Jacob well function for leaky confined aquifers
- z is depth to piezometer opening [L]

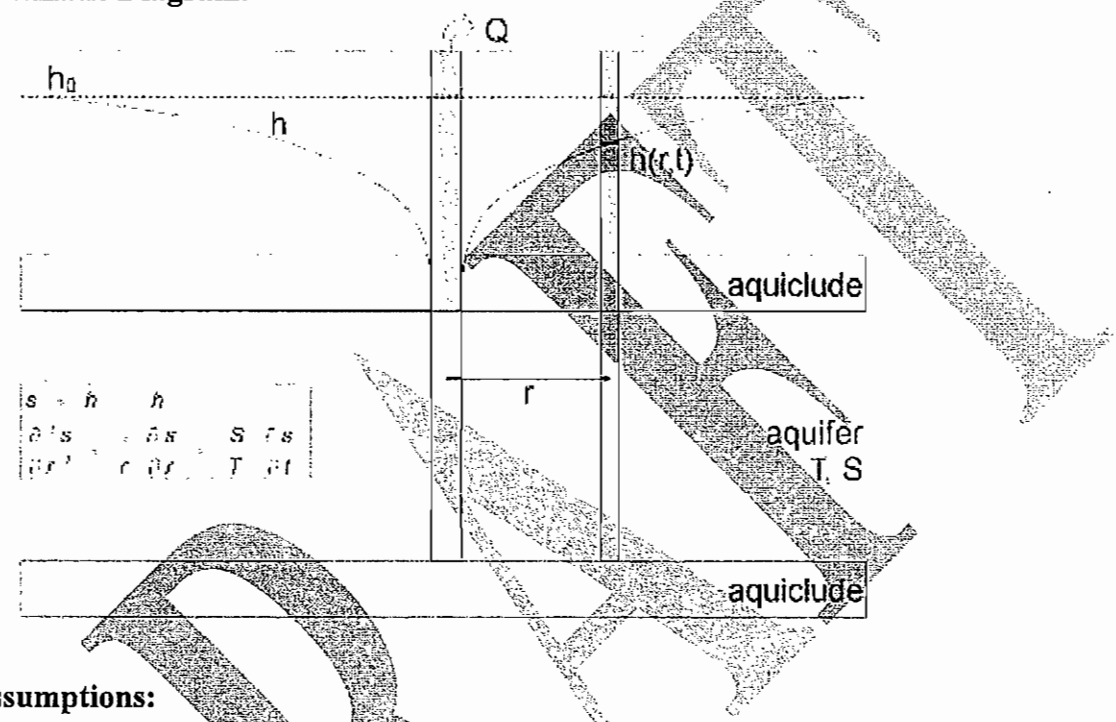
At large distances, the effect of partial penetration becomes negligible when

$$r > 1.5b\sqrt{K_z / K_r}$$

DRAFT

Details on the Method of Theis, C.V., 1935. (Straight-Line Recovery) (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected
- values of u are small (i.e., r is small and t is large)

Equations:

$$s' = \frac{Q}{4\pi T}\left[\ln(t/t') - \ln(S/S')\right]$$

where

- Q is pumping rate [L^3/T]
- s' is residual drawdown [L]
- S is storativity during pumping [dimensionless]
- S' is storativity during recovery [dimensionless]
- t is time since pumping began [T]
- t' is time since pumping stopped [T]
- T is transmissivity[L^2/T]

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Figure 1. 2007 Regional Ground Water Level Contours and Flow Directions

Water Level Data Sources:

M3 Project Area, Eagle, Star and Meridian: Measurements and Survey - Summer of 2007 by HLI

Emmett and Caldwell Areas: Wells from IDWR Data Base. Locations / Elevations From Google Earth®, MapQuest® and TOPO®

Data contoured by Surfer® with manual contouring near Emmett and Caldwell. Dashed contours where sparce or approximate data appear to yield contours that may or may not be representative.

+ Well: surveyed ✦ Well: estimated location

Approximate Ground Water Flow Directions:

Pierce Gulch Sand Aquifer

"Willow Creek Aquifer" and Payette Valley Aquifer

Water Level Contour Elevation in Feet MSL

2400

(Dashed Where Inferred)

West Boise-Eagle Geologic Fault System

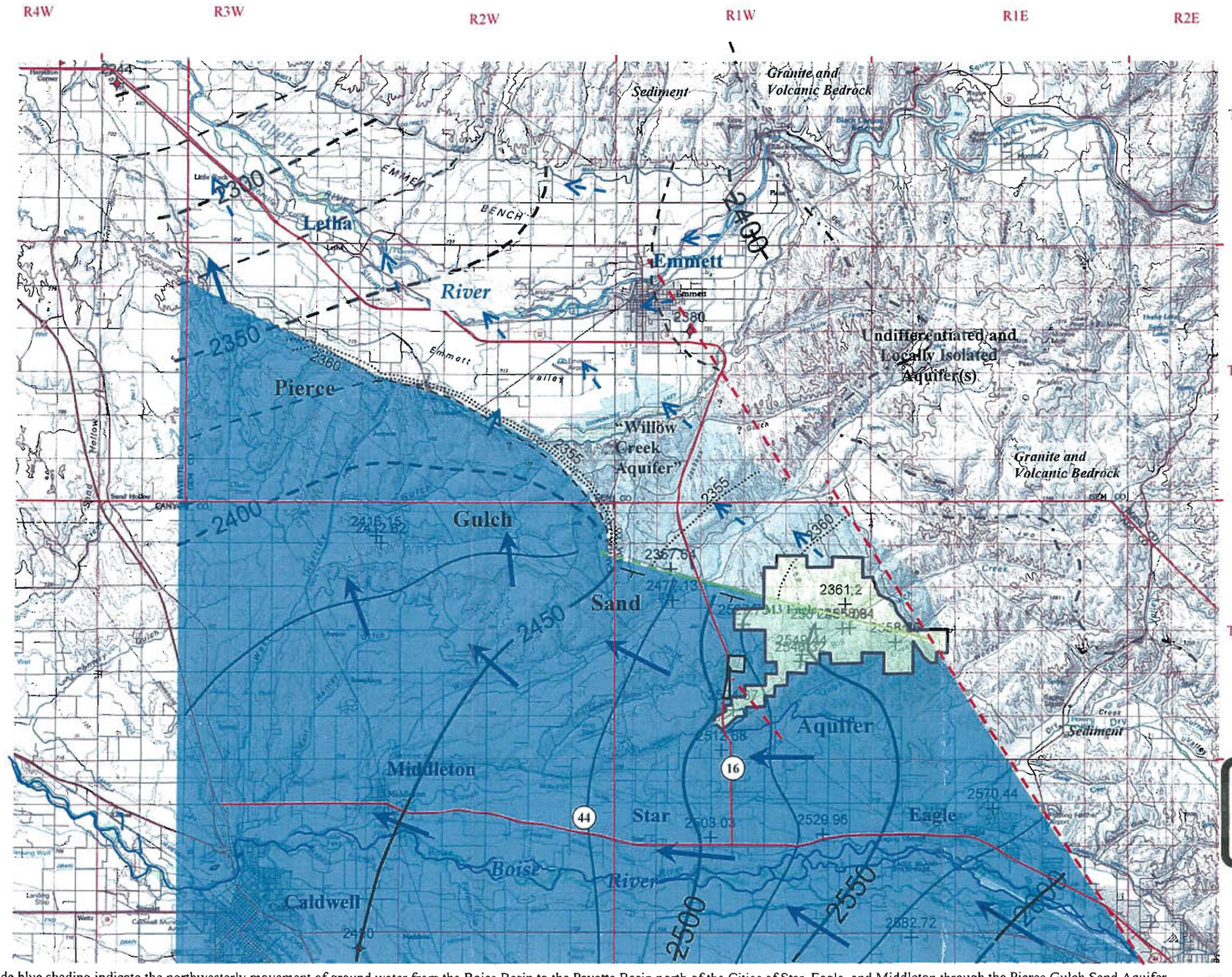
(Dashed Where Inferred)

Contact between bottom of Pierce Gulch Aquifer and underlying mudstone facies of the Terteling Springs Formation (inferred location, dashed where speculative)

Scale: = 1 Mile

North

September 17, 2007



M3 EAGLE LLC EXHIBIT 23

Figure 1.

The black-colored, 50-foot water level contours inside blue shading indicate the northwesterly movement of ground water from the Boise Basin to the Payette Basin north of the Cities of Star, Eagle, and Middleton through the Pierce Gulch Sand Aquifer. The dotted 5-foot water-level contours inside the turquoise area illustrate the relatively flat ground water gradient within the recharge-limited informally named "Willow Creek Aquifer" isolated between low-permeability sediments of the uplands lying to the east of the M3 site and by stratigraphic layering (a day-lighting clay stratum) on the southwest (green solid and dashed line). The boundaries of this aquifer have not been defined as indicated by the "?" symbol.

Hydro Logic, Inc
Boise, Idaho

Figure 2. Locations For Wells Measured During 2007 Regional Ground Water Level Survey

M3 Project Area, Eagle, Star and Meridian: Wells located by GPS Survey Summer of 2007 by HLI and Idaho Survey Group

Emmett and Caldwell Areas: Wells located from maps in HLI files.

Northwest Area: Well located using well log address, MapQuest®,and Google Earth®.

◇ Well water level measured Summer 2007

◆ Well water level from previous periods

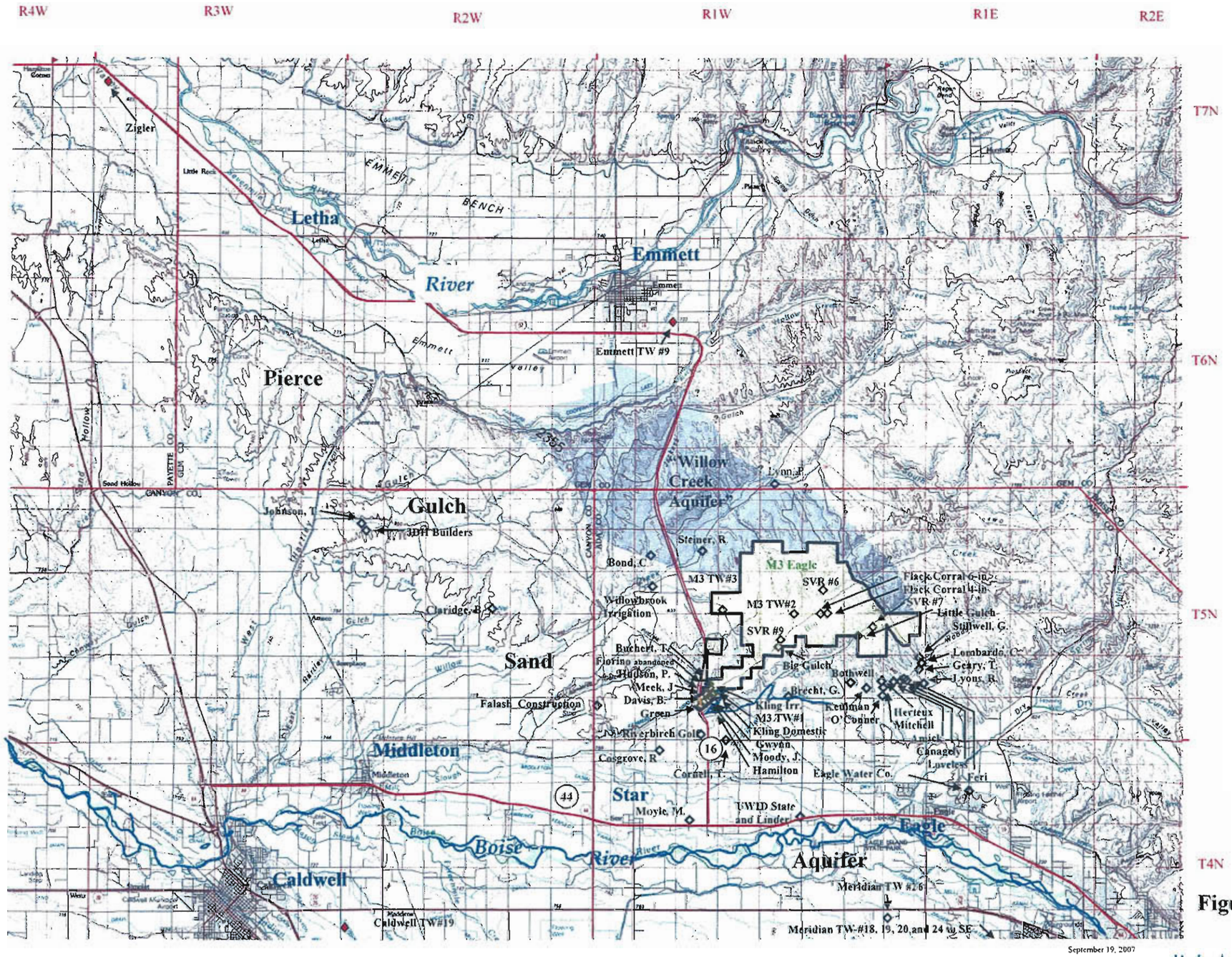


Figure 2.

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Summary of Water Chemistry Data for M3 Eagle and Select Regional Water Supply and Test Wells - DRAFT November 20, 2008

Tabulation of Available Data by Hydro Logic, Inc.

| Well Number | Screened Interval (feet bgl) | Date(s) Sampled | Laboratory | Alkalinity | Aluminum | Aluminum (dissolved) | Ammonia as N | Antimony | Arsenic | Barium | Beryllium | Bicarbonate | Carbon Dioxide | Cadmium | Calcium as CaCO3 | Carbonate | Chloride | Chlorine Demand | Chromium | Color (apparent) | Conductivity (umhos/cm) | Copper | Corrosivity (Langelier) | Cyanide (total) | Fluoride | Hardness | Hydrogen Sulfide | Iron | Iron (dissolved) | Lead | Lead (dissolved) | Magnesium | Manganese | Manganese (dissolved) | MBAS | Mercury | Nickel | Nitrate as N (10.0) | Nitrite as N (1.0) | Odor | Orthophosphate | Phenols | Phosphate P (total) | Phosphorus (total) | Potassium | pH (Lab) | Residue (dissolved) | Selenium | Silica | Silicon | Silver | Sodium | Synthetic Organic Compounds (SOC's) | Sulfate | Sulfide | Surfactant | Suspended Solids | Thallium | Thallium Graphite | Total Coliform | Total Dissolved Solids | Total Kjeldahl Nitrogen | Total Organic Carbon | Volatile Organic Compounds (VOC's) |
|---|---|---

Zinc	Field Temperature (degrees F)	Field pH (S.U.)	Field Conductivity (uS)	Field Dissolved Oxygen	Field Oxidation-Reduction Potential (mV)	Tritium (pCi/mL)	Date(s) Sampled	Screened interval	Well Number	Comments
	66.5	7.51	212	0.35	-		8/30/2006	510-643	City of Star #3	
	67.1	7.19	305	1.70	-54		10/9/2006	444-561	M3 Test #1 - Zone #1	
	66.0	7.19	295	2.60	53		10/9/2006	444-561	M3 Test #1 - Zone #2	
	64.7	7.27	274	4.90	84		10/9/2006	305-428	M3 Test #1 - Zone #3	
	63.8	7.27	268	2.63	143		11/27/2006	305-428	M3 Test #1 - Zone #4	* = no H2S data
	57.4	6.72	265	9.51	166		11/27/2006	67-144	M3 Test #1 - Zone #5	* = no H2S data
	68.6	7.23	322	0.56	94		7/24/2007	270-320	M3 Test #2 - Zone #1	* = no H2S data
	68.6	7.23	322	0.56	94		7/24/2007	259-334	M3 Test #2 - Zone #1	Taste high in iron, moderate H2S smell, no sand, no yellowing, minor degassing after 20 min. (tiny bubbles), Water possibly contaminated with drillers water.
	67.8	7.26	280	0.07	-130		3/6/2008	259-334	M3 Test #2 - Zone #1	Clear water, moderate H2S smell,
	64.2	7.62	310	6.64	106		1/30/2007	391-446	M3 Test #3 - Zone 1	* = no H2S data
	63.2	7.22	307	4.89	6		1/30/2007	391-446	M3 Test #3 - Zone 2	* = no H2S data
	62.2	7.46	321	4.87	110		1/30/2007	360-381	M3 Test #3 - Zone 3	* = no H2S data
	68.9	7.64	333	0.09	-122		4/3/2008	617-655	M3 Test #4 - Zone 1	Water started clear, mild H2S smell, slight irony taste, rapid degassing at the surface, mildly foamy
	64.6	7.70	334	2.26	116		4/3/2008	298-564	M3 Test #4 - Zone 2	chlorine demand = 0.25 mg/l, water started slightly cloudy and cleared up in 5 minutes, moderate degassing with medium sized bubbles, no odor, smooth clean taste, no sand, no yellowing.
								166-211	M3 Test #4 - Zone 3	Water contaminated by cement, will sample after more development
							1/11/07	102-415	M3-Kling Irrigation	
	60.3	7.39	282				11/8/02	open 100-400	Spring Valley Ranch #1	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	66.7		815				11/27/02	open 300-846	Spring Valley Ranch #2	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	56.8		142				12/18/02	150-240+	Spring Valley Ranch #3	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	56.0	7.40	590				2/25/03	1,035-1,220	Spring Valley Ranch #4 (deep)	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	66.0	7.40	546				3/6/03	240-320	Spring Valley Ranch #4 (250)	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	57.9	6.46	184					open 38-147		
							3/16/04	455-740	Spring Valley Ranch #6	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2004
							4/21/04	240-380	Spring Valley Ranch #7	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2004
	67.0	7.40	382	1.37	55		3/14/08	240-380	Spring Valley Ranch #7	Water is clear, minor H2S smell, small trace of degassing, chlorine demand = 0.33 mg/l
							6/23/04	215-265	Spring Valley Ranch #9	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2004
	75.9	7.64	160				8/19/04	600-770	Spring Valley Ranch #10	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2004
							12/18/02		Spring Valley Ranch Spring #1	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
							3/19/02			data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	55.9	7.49	514				3/6/03		Spring Valley Ranch Irrigation	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	64.9	7.38	269				2/14/03		Big Gulch #1	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	68.2	7.30	253				2/14/03		Little Gulch #1	data obtained from "Groundwater Exploration Drilling in the Spring Valley Ranch Vicinity of Gem, Ada, and Boise Counties, Idaho' Scanlan Eng, April 2003
	60.0	6.80	255				10/27/97	230-545	State/Linder Test #1 Zone 1	
	60.0	6.80	255				10/27/97			same sample, different labs
										sulfide analysis by Alchem
	59.5	6.92	224				10/27/97	230-545	State/Linder Test #1 Zone 2	
							10/27/97			same sample, different labs
							8/28/00			sulfide analysis by Alchem
	62.0	6.70	242				2/16/1998	569-730	State/Linder Test #2 Zone 2	
	62.0	6.70	242				2/16/1998			
							8/28/2000			sulfide analysis by Alchem
		7.03							State Street UWID Zone 1	
		7.03							State Street UWID Zone 1	
		7.42							State Street UWID Zone 2	
		7.42							State Street UWID Zone 2	
		7.18							State Street UWID Zone 3	
		7.18							State Street UWID Zone 3	
		7.36							State Street UWID Zone 4	
		7.36							State Street UWID Zone 4	
	59.9	6.74					8/4/1995	162-215	Swift #1 Supply UWID	
	59.9						2007 ?	162-215	Swift #1 Supply UWID	data obtained from 2007 UWID WQ Fact Sheet
	59.0		282				11/21/1997	85-280	Swift Test Well Zone 3	
	59.0		282				11/21/1997	85-280	Swift Test Well Zone 3	
	59.0		232				11/21/1997	85-280	Swift Test Well Zone 4	
	59.0		232				11/21/1997	85-280	Swift Test Well Zone 4	
	59.9	6.86						171-346	Floating Feather	data obtained from 2001 UWID WQ Fact Sheet
	54.3							171-346	Floating Feather	data obtained from 2007 UWID WQ Fact Sheet
								451-551	Goddard #2 UWID	Off of 2001 UWID WQ Fact sheet: unkown field measurements, and unknown sample date
	60.6							451-551	Goddard #2 UWID	
	68.0							760-960	Goddard #1 UWID	
<0.005							5/17/1991	575-700	HP UWID	
	57.6	6.05						225-345	Island Woods #1	data obtained from 2001 UWID WQ Fact
	57.6						2007 ?	225-345	Island Woods #1	data obtained from 2007 UWID WQ Fact Sheet
	59.9	6.12						230-355	Island Woods #2	data obtained from 2001 UWID WQ Fact Sheet
	59.9						2007 ?	230-355	Island Woods #2	data obtained from 2007 UWID WQ Fact Sheet
	61.3	6.88						265-415	Redwood Creek	data obtained from 2001 UWID WQ Fact Sheet
	61.7						2007 ?	265-415	Redwood Creek	data obtained from 2007 UWID WQ Fact Sheet
	63.5	6.96						215-385	Lexington Hills #1	data obtained from 2001 UWID WQ Fact Sheet
	63.0						2007 ?	215-385	Lexington Hills #1	data obtained from 2007 UWID WQ Fact Sheet
							6/7/2004	?	Wade Lynn Well	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2004
							6/7/2004	540-580	Corbett Lynn well	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2005
							6/7/2004	?	Lynn Old Irrigation well	data obtained from "Well Construction and Aquifer Testing in the Big Gulch and Little Gulch Areas of Spring Valley Ranch. 10/13/2006

25

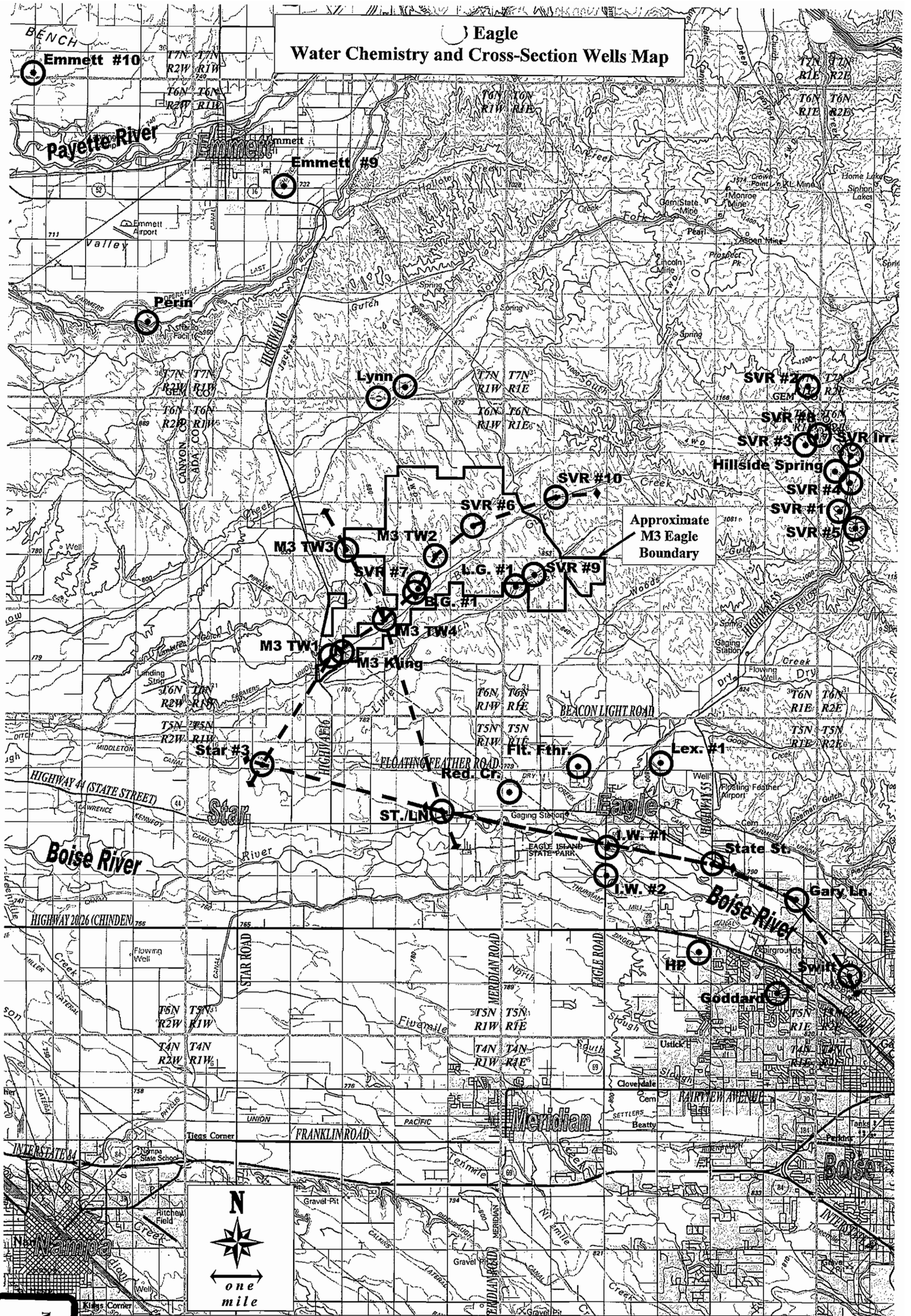

Figure XX Base map is a (1:100,000 scale) USGS map. DRAFT November 20, 2008 Hydro Logic, Inc. Boise, Idaho

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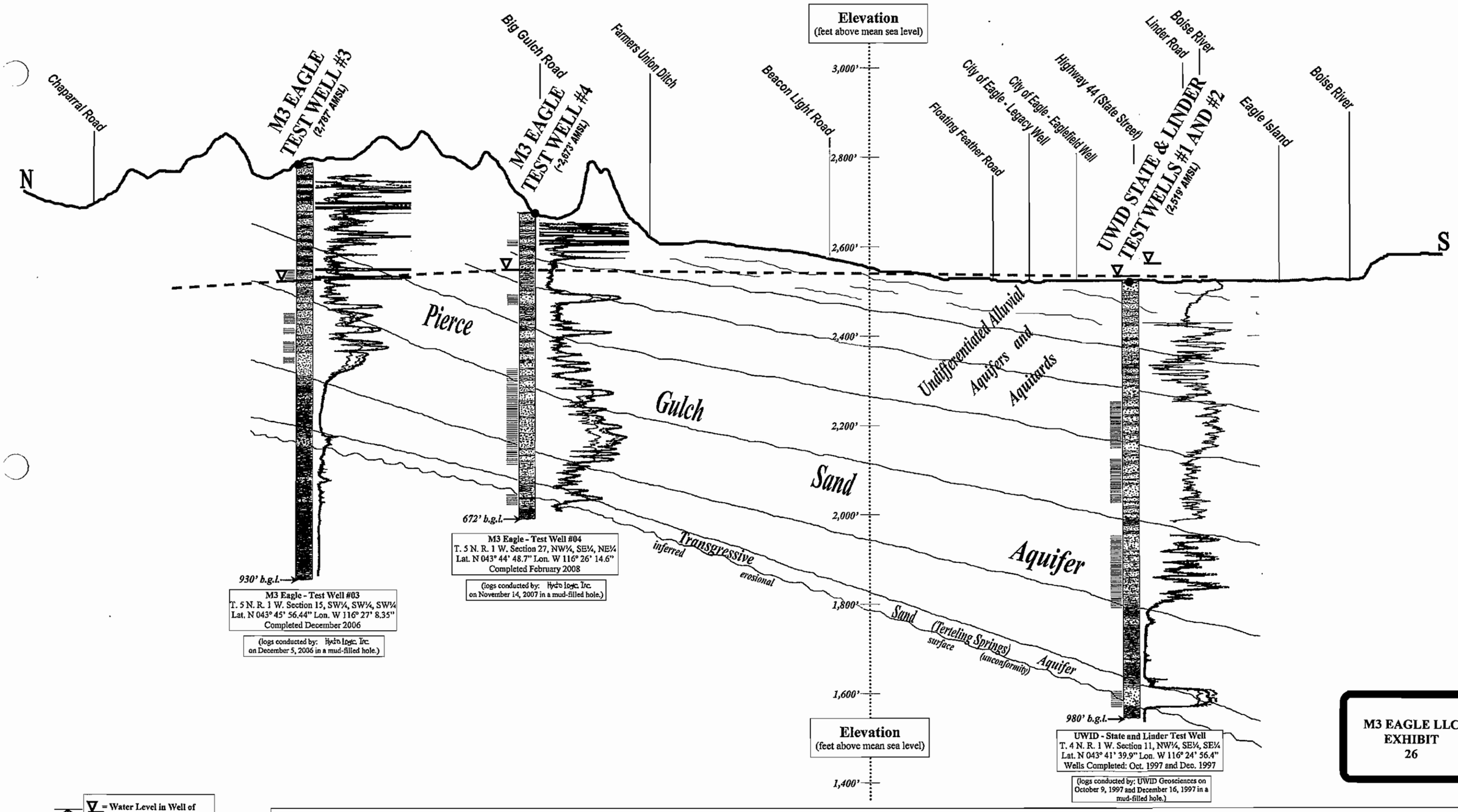

▽ = Water Level in Well of Pierce Gulch Aquifer

▽ = Water Level in Well of Terteling Springs Aquifer

(horizontal scale 1"= 3,000')
(vertical scale 1"= 200')

drawn by: L. Pearson, Hydro Logic, Inc. Boise, ID.

200 FEET

ONE MILE

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Figure XX. Cross-section M3 Eagle Test Well #3 to UWID State and Linder

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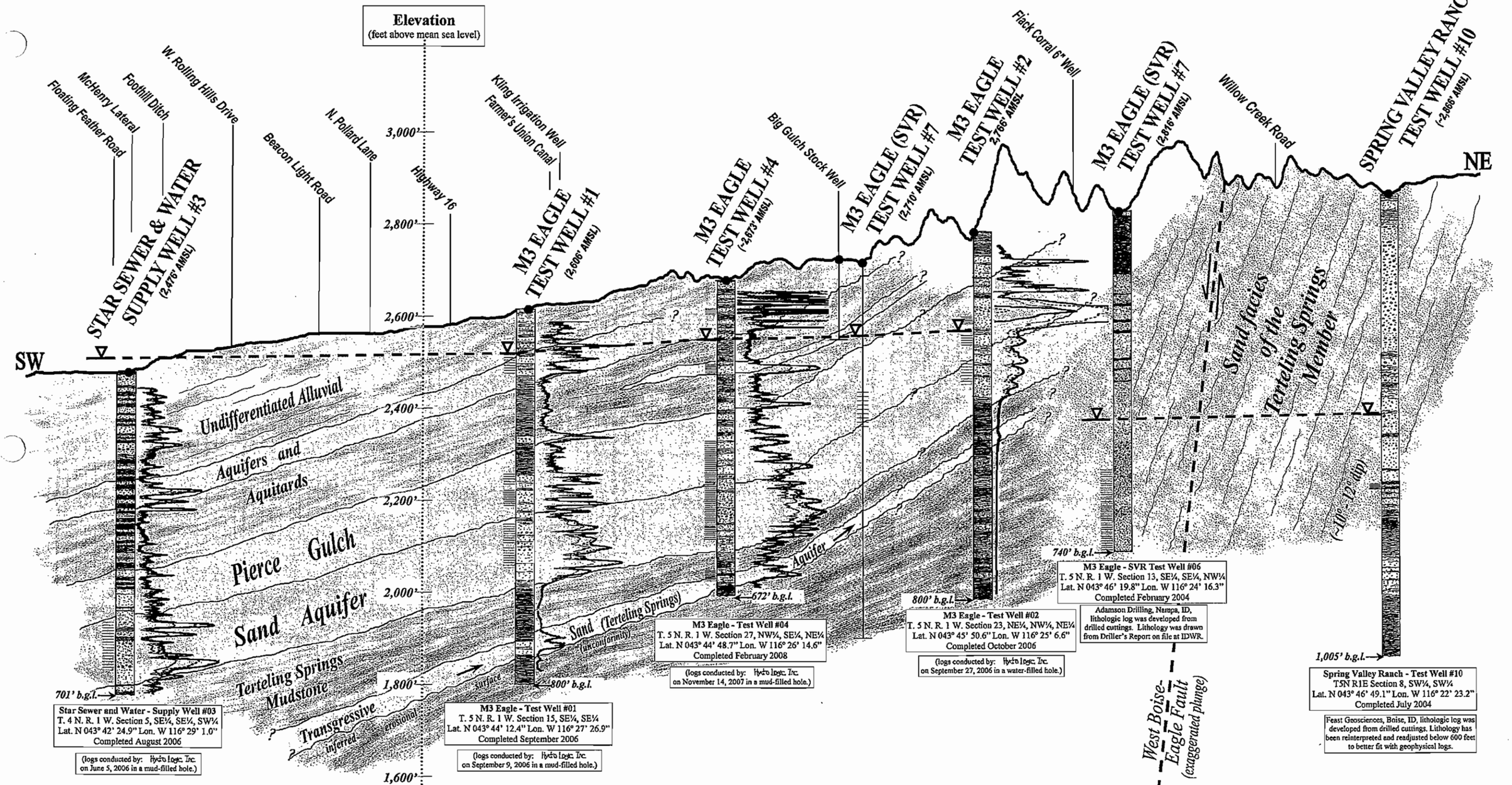

Figure XX. Cross-section in Big Gulch

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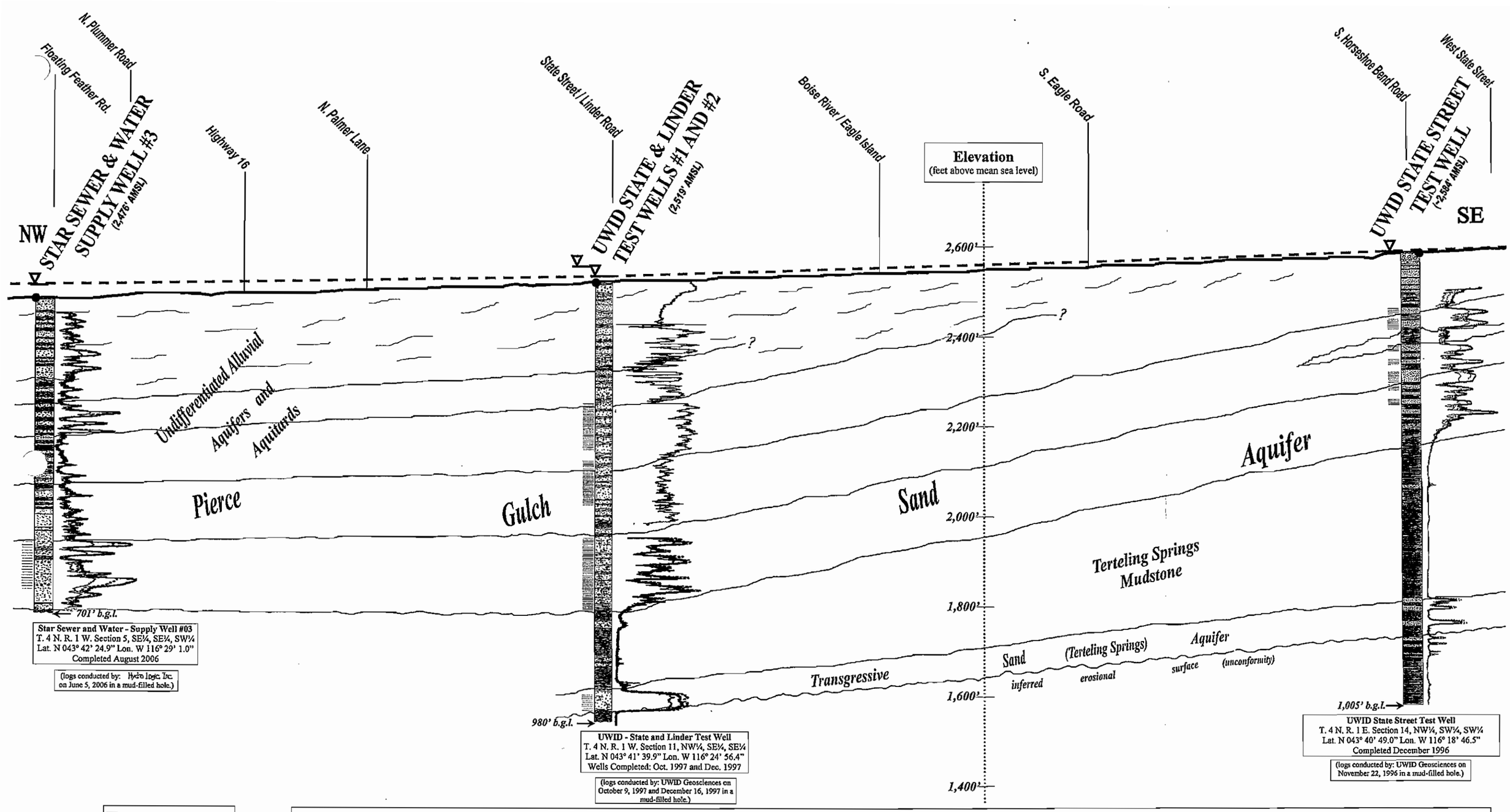

Figure XX. Cross-section Star #3 to State Street Test Well

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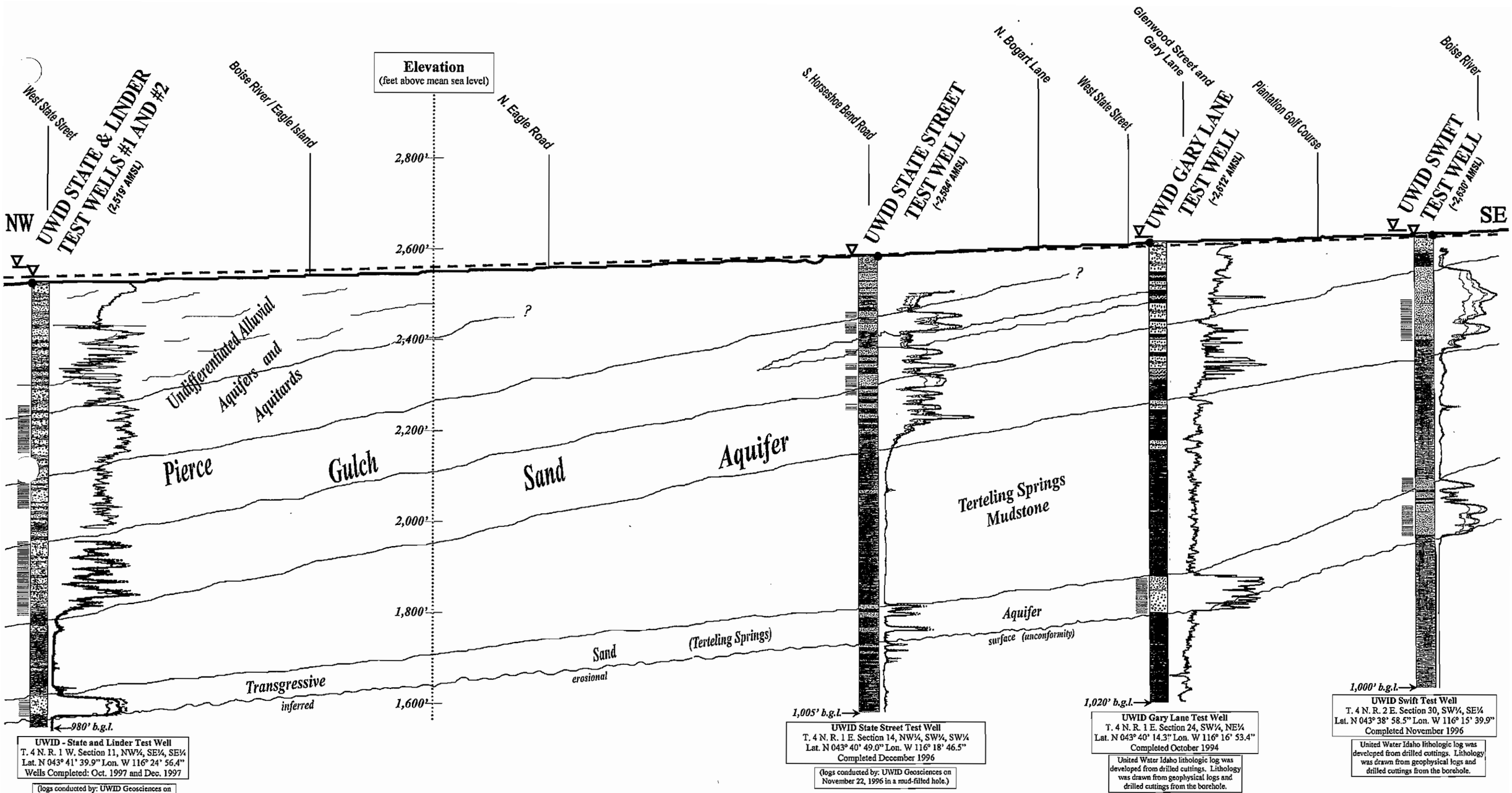

UWID - State and Linder Test Well
T. 4 N. R. 1 W. Section 11, NW¼, SE¼, SE¼
Lat. N 043° 41' 39.9" Lon. W 116° 24' 56.4"
Wells Completed: Oct. 1997 and Dec. 1997
(logs conducted by: UWID Geosciences on October 9, 1997 and December 16, 1997 in a mud-filled hole.)

UWID State Street Test Well
T. 4 N. R. 1 E. Section 14, NW¼, SW¼, SW¼
Lat. N 043° 40' 49.0" Lon. W 116° 18' 46.5"
Completed December 1996
(logs conducted by: UWID Geosciences on November 22, 1996 in a mud-filled hole.)

UWID Gary Lane Test Well
T. 4 N. R. 1 E. Section 24, SW¼, NE¼
Lat. N 043° 40' 14.3" Lon. W 116° 16' 53.4"
Completed October 1994
United Water Idaho lithologic log was developed from drilled cuttings. Lithology was drawn from geophysical logs and drilled cuttings from the borehole.

UWID Swift Test Well
T. 4 N. R. 2 E. Section 30, SW¼, SE¼
Lat. N 043° 38' 58.5" Lon. W 116° 15' 39.9"
Completed November 1996
United Water Idaho lithologic log was developed from drilled cuttings. Lithology was drawn from geophysical logs and drilled cuttings from the borehole.

▽ = Water Level in Well of Pierce Gulch Aquifer
▽ = Water Level in Well of Terteling Springs Aquifer

(horizontal scale 1"= 3,000')
(vertical scale 1"= 200')

200 FEET

drawn by: L. Pearson, Hydro Logic, Inc. Boise, ID.

ONE MILE

Figure XX. Cross-section from UWID State and Linder Test Well to UWID Swift Test Well

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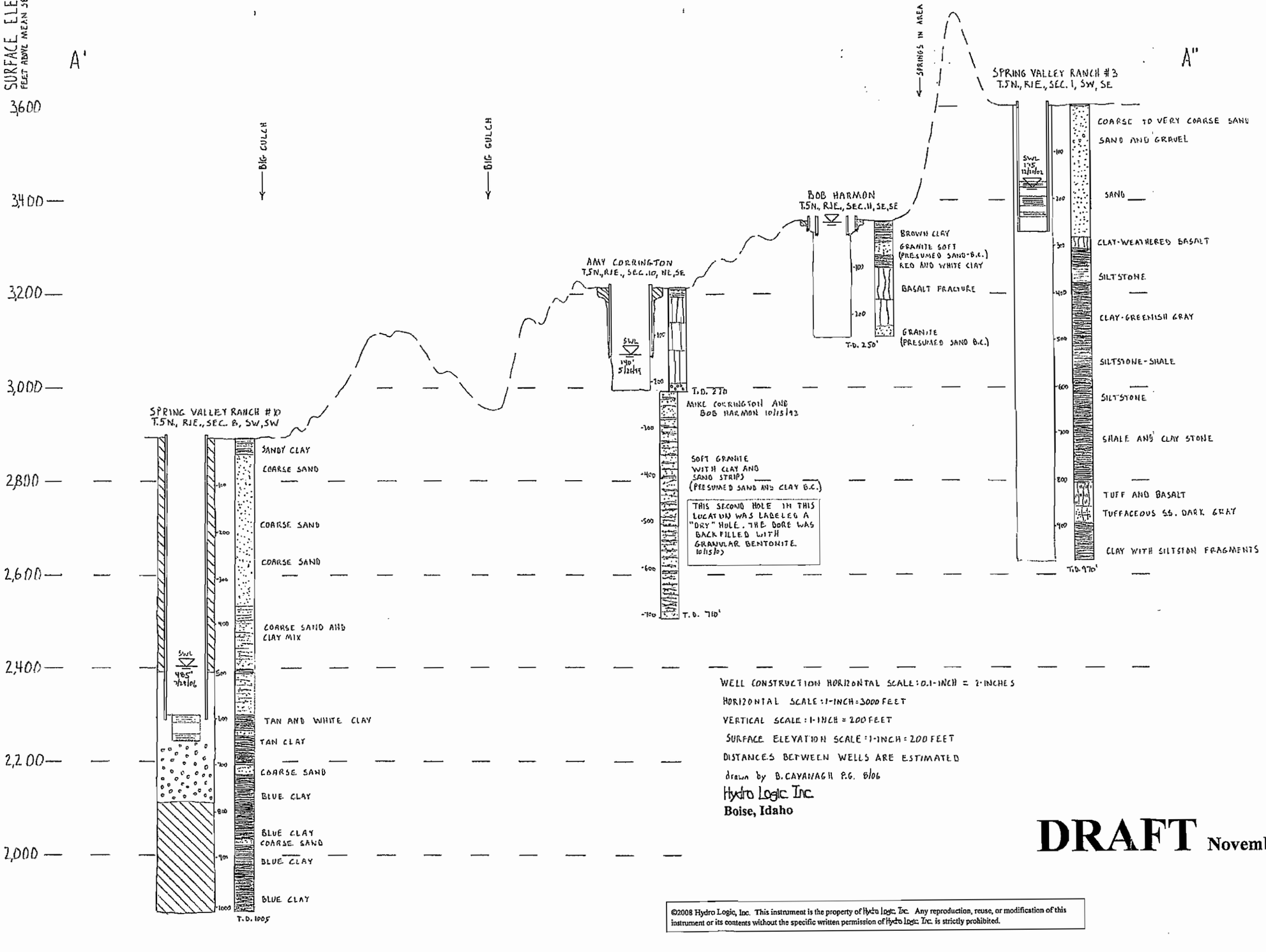
Geologic Cross-Section A'-A''
(SW x NE)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES

HORIZONTAL SCALE: 1-INCH = 3000 FEET

VERTICAL SCALE: 1-INCH = 200 FEET

SURFACE ELEVATION SCALE: 1-INCH = 200 FEET

DISTANCES BETWEEN WELLS ARE ESTIMATED

drawn by B. CAVANAGH P.G. 6/06

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Boise, Idaho

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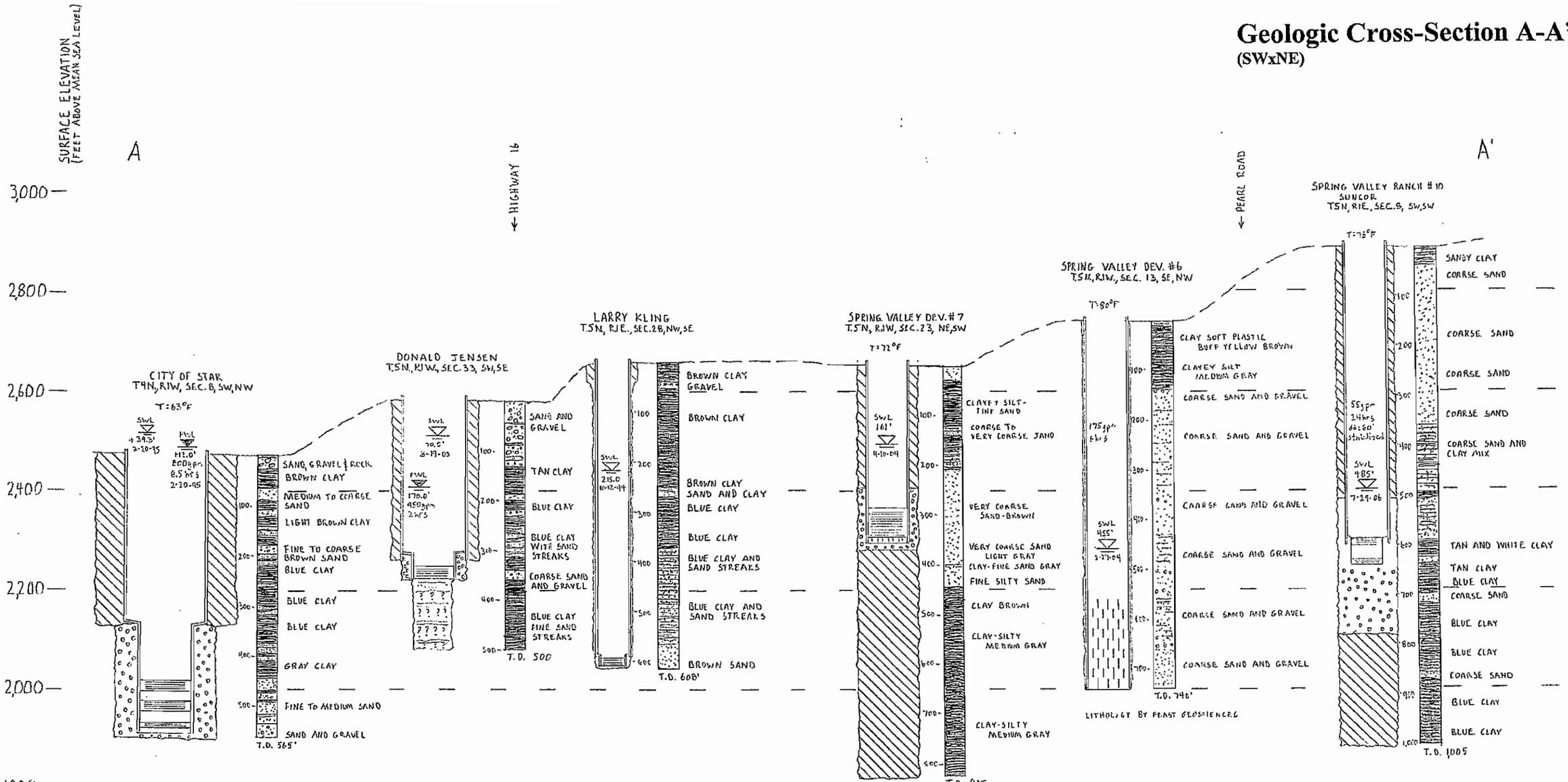
Geologic Cross-Section A-A'
(SWxNE)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES
HORIZONTAL SCALE: 1-INCH = 3000 FEET
VERTICAL SCALE: 1-INCH = 200 FEET
SURFACE ELEVATION SCALE: 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED

drawn by B. CAVANAGH P.G. 8/08

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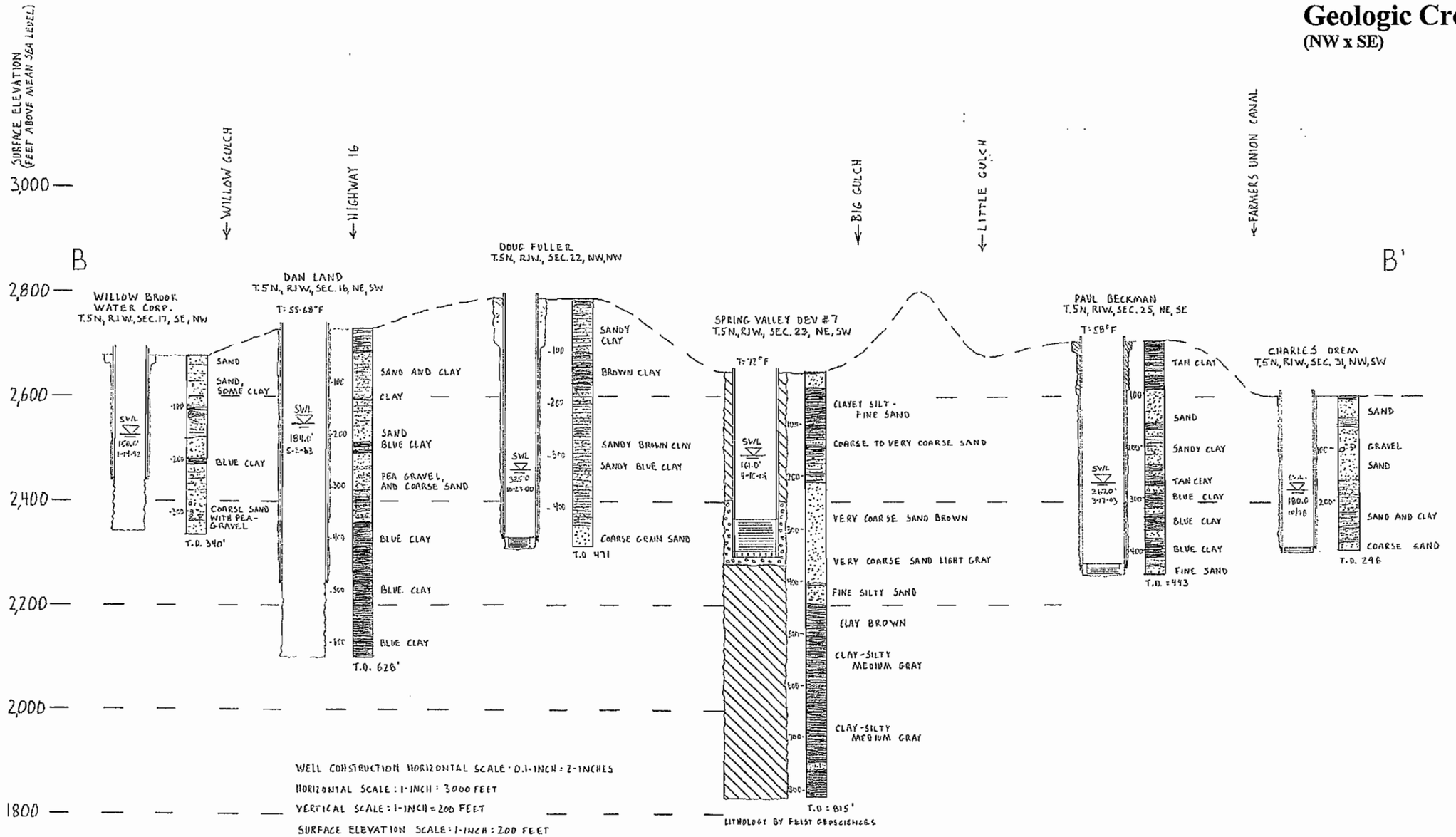
Geologic Cross-Section B-B'
(NW x SE)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES
HORIZONTAL SCALE: 1-INCH = 3000 FEET
VERTICAL SCALE: 1-INCH = 200 FEET
SURFACE ELEVATION SCALE: 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED

drawn by B. CAVANAGH P.G. 8106

LITHOLOGY BY FEIST GEOSCIENCES

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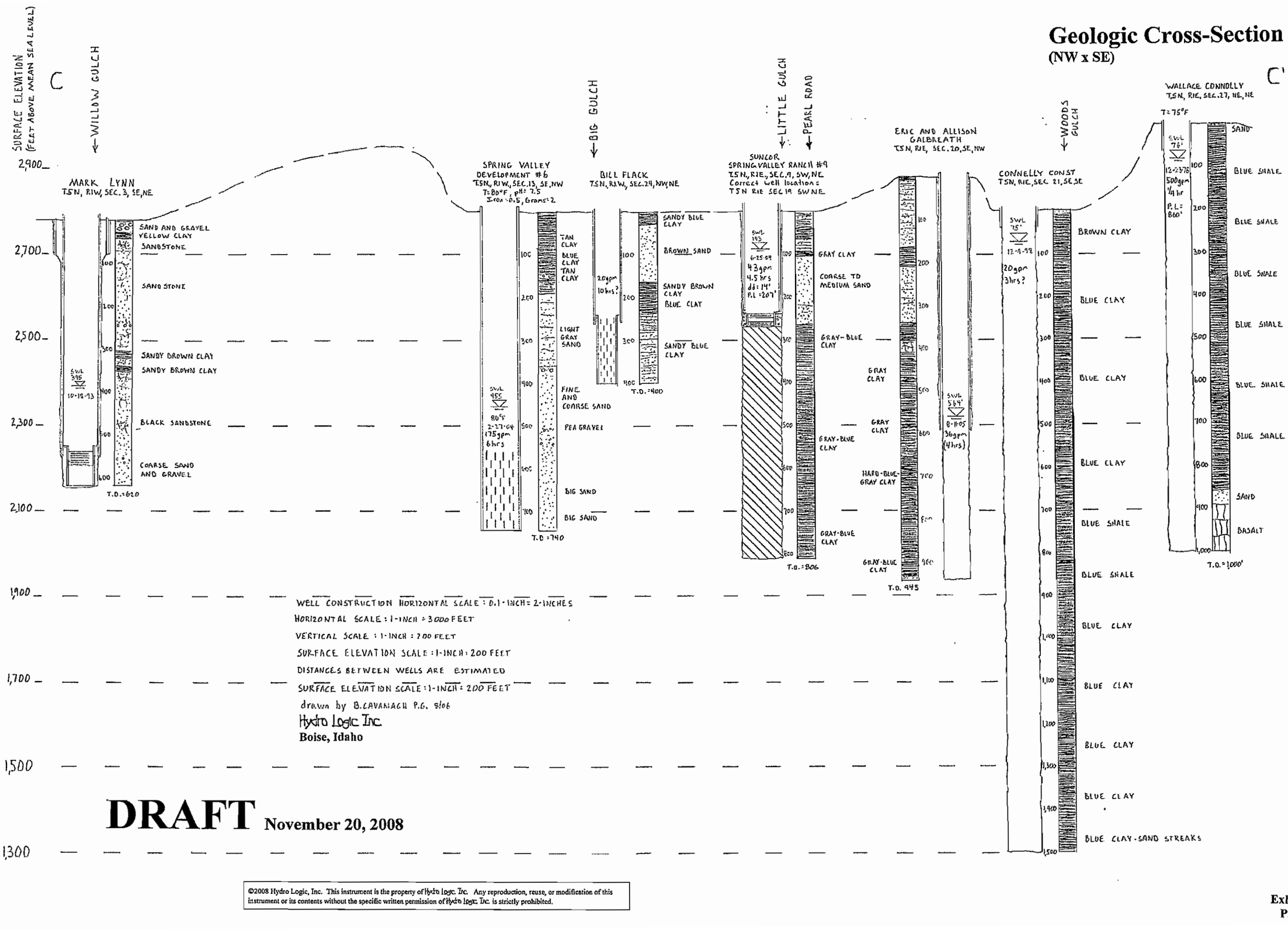
Geologic Cross-Section C-C'
(NW x SE)



WELL CONSTRUCTION HORIZONTAL SCALE : 0.1-INCH = 2-INCHES
HORIZONTAL SCALE : 1-INCH = 3000 FEET
VERTICAL SCALE : 1-INCH = 700 FEET
SURFACE ELEVATION SCALE : 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED
SURFACE ELEVATION SCALE : 1-INCH = 200 FEET
drawn by B.CAVANAGH P.G. 5106

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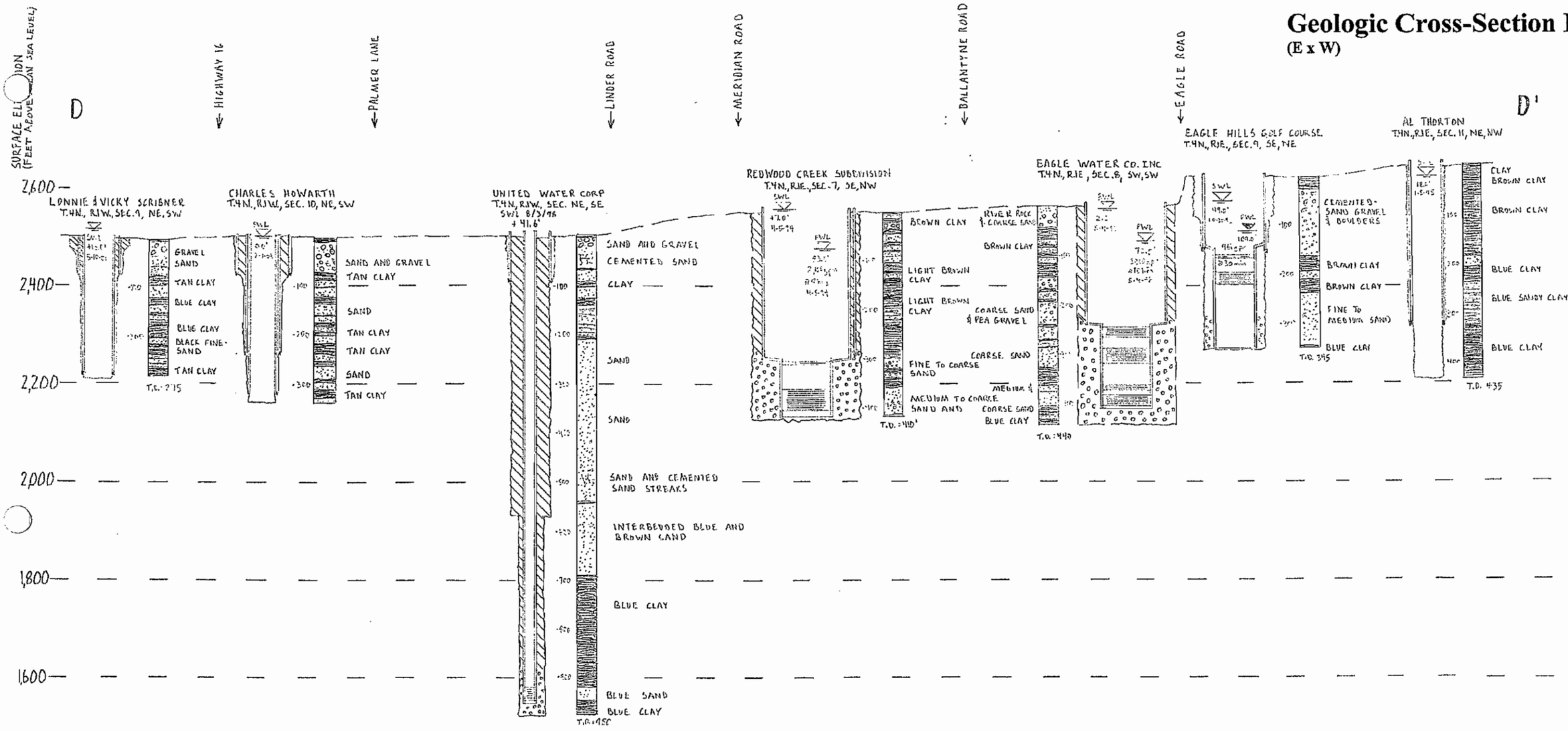
Geologic Cross-Section D-D'
(E x W)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES
HORIZONTAL SCALE: 1-INCH = 3000 FEET
VERTICAL SCALE: 1-INCH = 200 FEET
SURFACE ELEVATION SCALE: 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED

drawn by B. CAVANAGH P.G. 8/06

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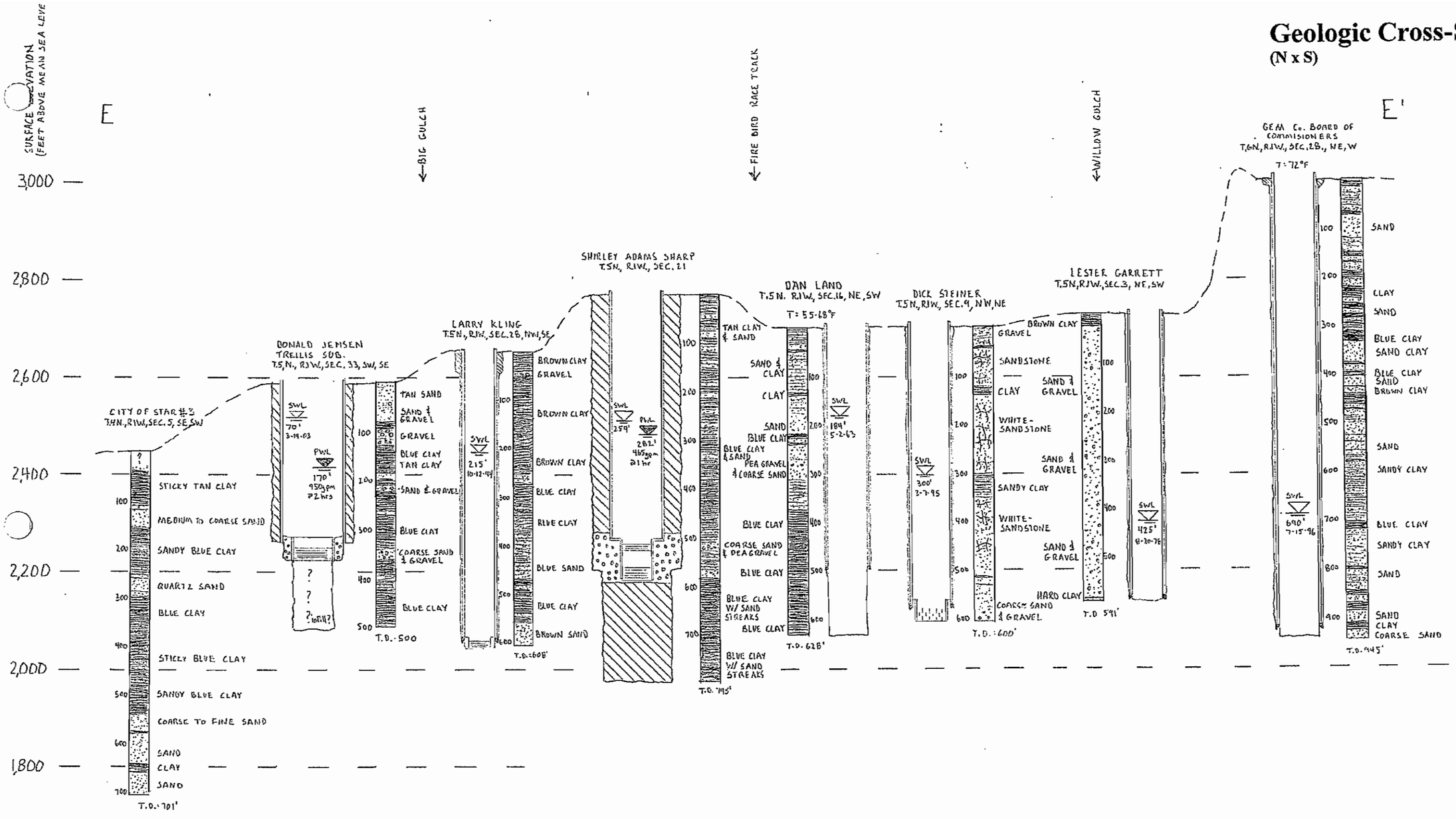
Geologic Cross-Section E-E'
(N x S)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES
HORIZONTAL SCALE: 1-INCH = 4000 FEET
VERTICAL SCALE: 1-INCH = 200 FEET
SURFACE ELEVATION SCALE: 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED

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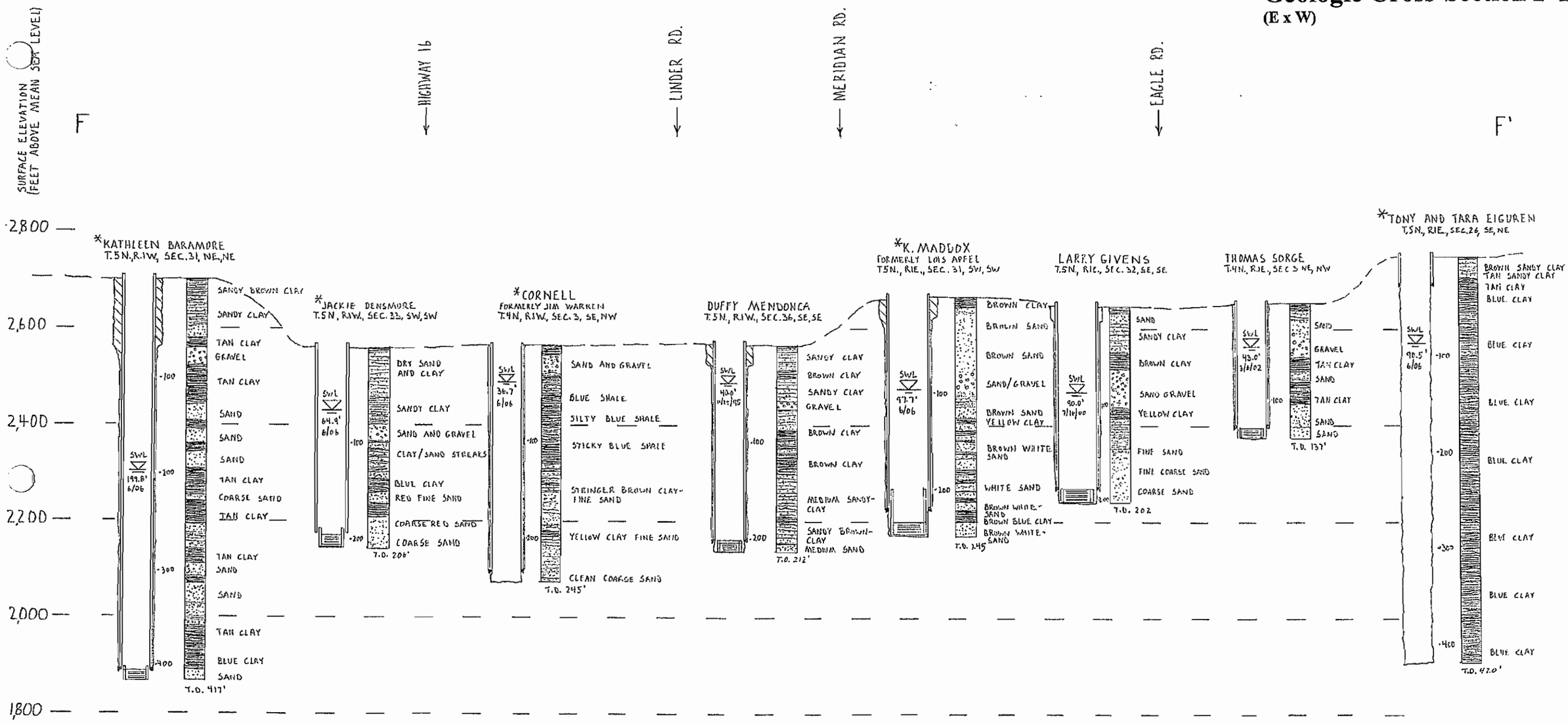
Geologic Cross-Section F-F'
(E x W)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES

HORIZONTAL SCALE: 1-INCH = 4000 FEET

VERTICAL SCALE: 1-INCH = 100 FEET

SURFACE ELEVATION SCALE: 1-INCH = 200 FEET

DISTANCES BETWEEN WELLS ARE ESTIMATED

*WELLS MEASURED BY HYDRO LOGIC INC.

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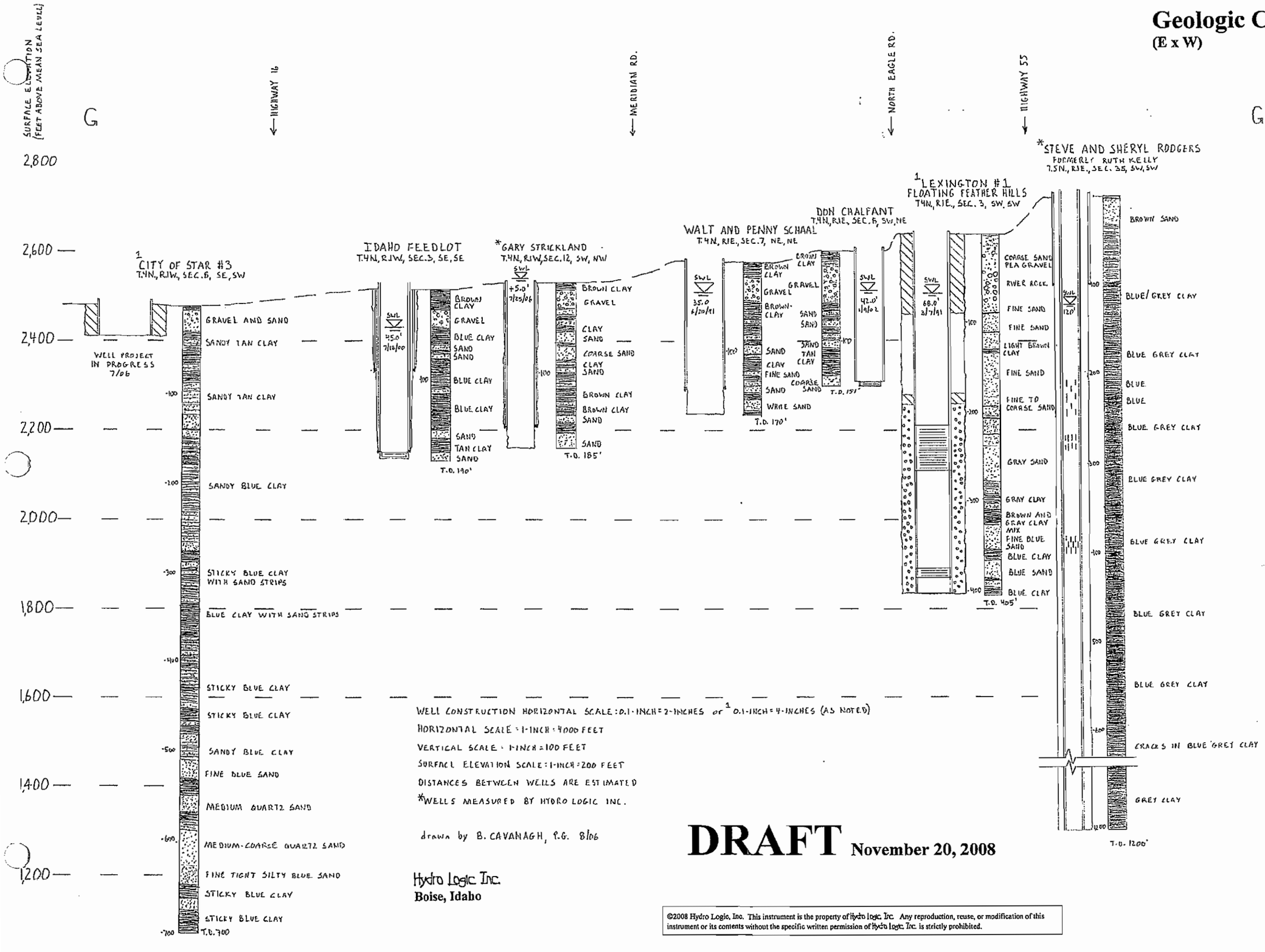
Geologic Cross-Section G-G'
(E x W)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES or [1] 0.1-INCH = 4-INCHES (AS NOTED)
HORIZONTAL SCALE = 1-INCH = 4000 FEET
VERTICAL SCALE = 1-INCH = 100 FEET
SURFACE ELEVATION SCALE = 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED
*WELLS MEASURED BY HYDRO LOGIC INC.

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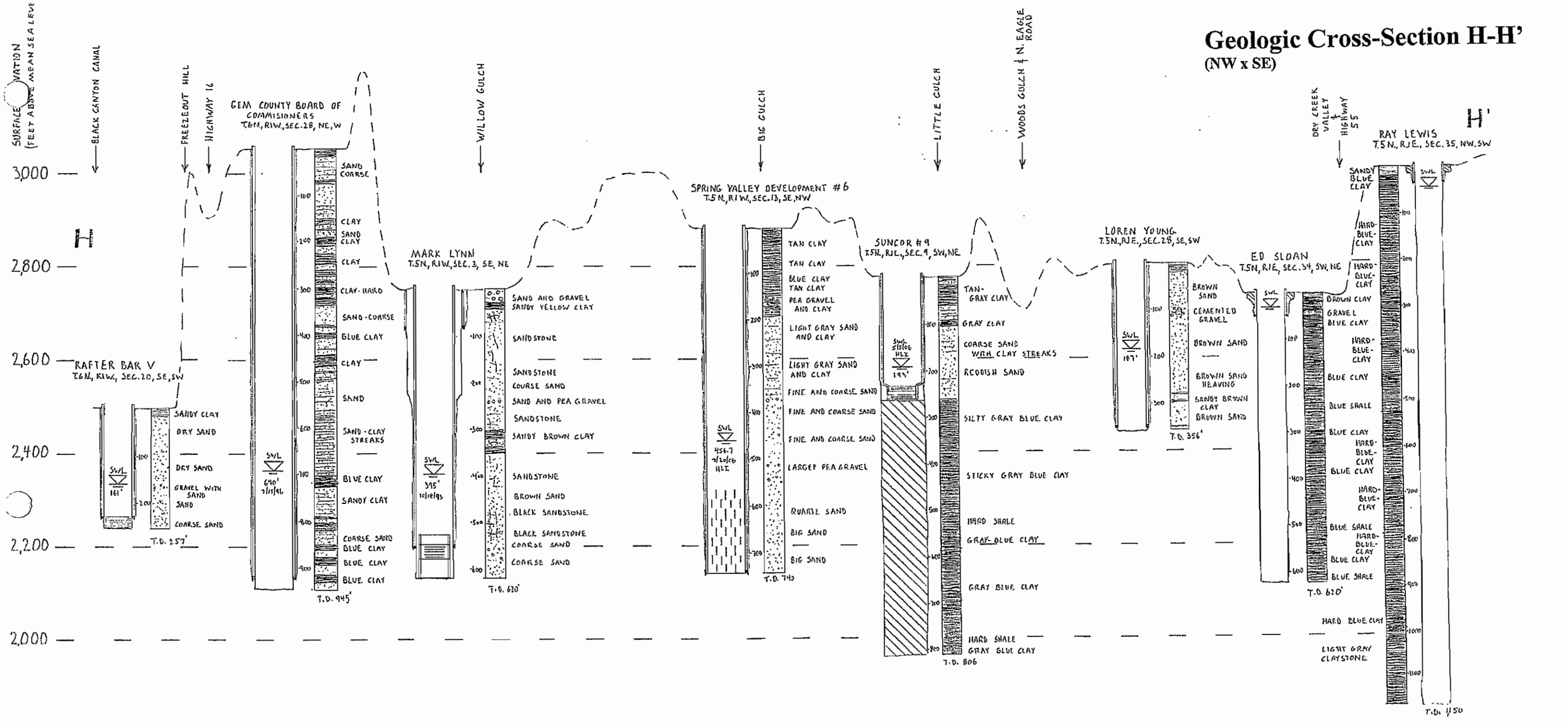
Geologic Cross-Section H-H'

(NW x SE)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES

HORIZONTAL SCALE: 1-INCH = 5000 FEET

VERTICAL SCALE: 1-INCH = 200 FEET

SURFACE ELEVATION SCALE: 1-INCH = 200 FEET

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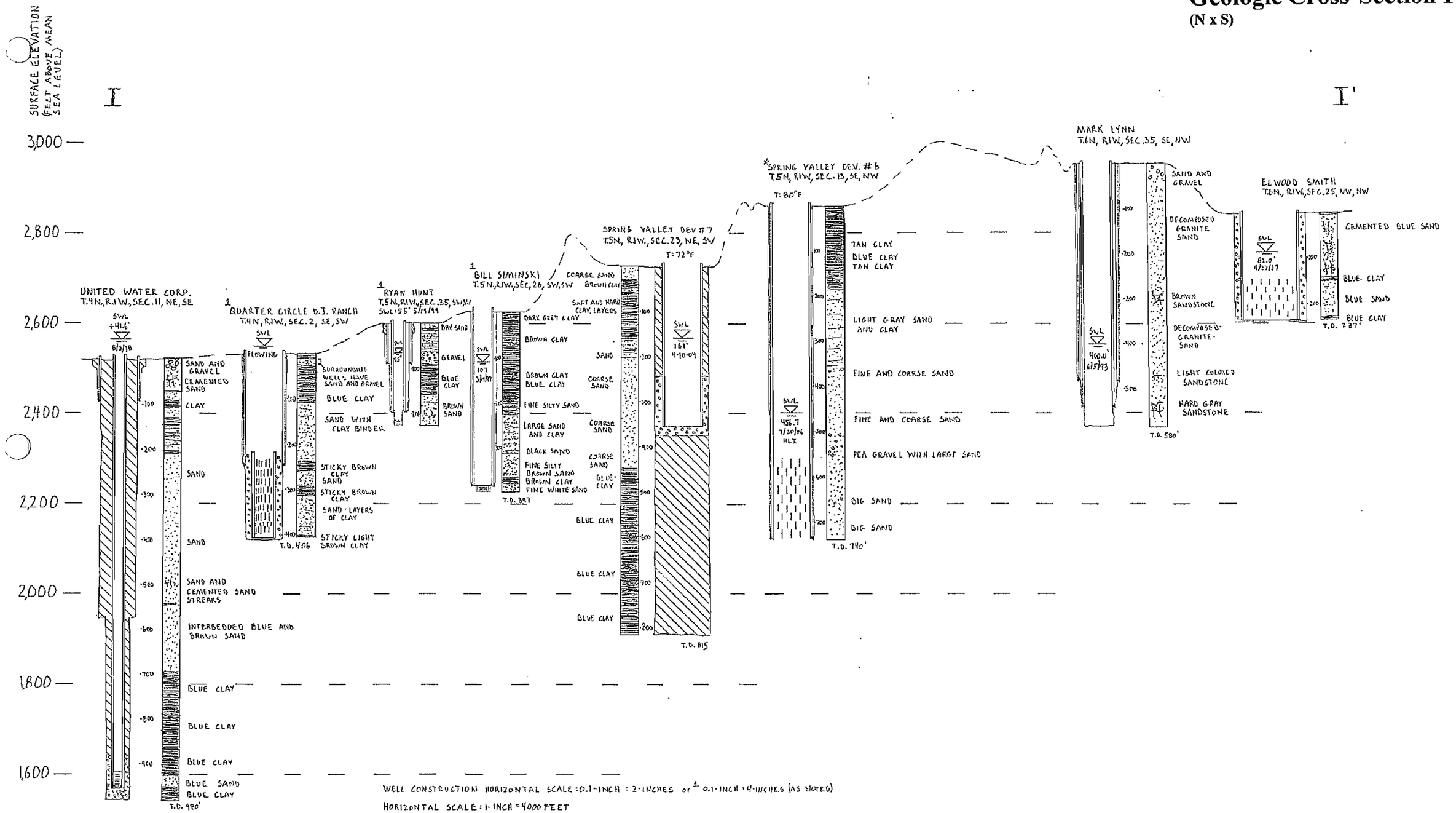
Geologic Cross-Section I-I'
(N x S)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES or ± 0.1-INCH = 4-INCHES (AS NOTED)
HORIZONTAL SCALE: 1-INCH = 4000 FEET
VERTICAL SCALE: 1-INCH = 100 FEET
SURFACE ELEVATION SCALE = 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED
* WELLS MEASURED BY HYDRO LOGIC INC.
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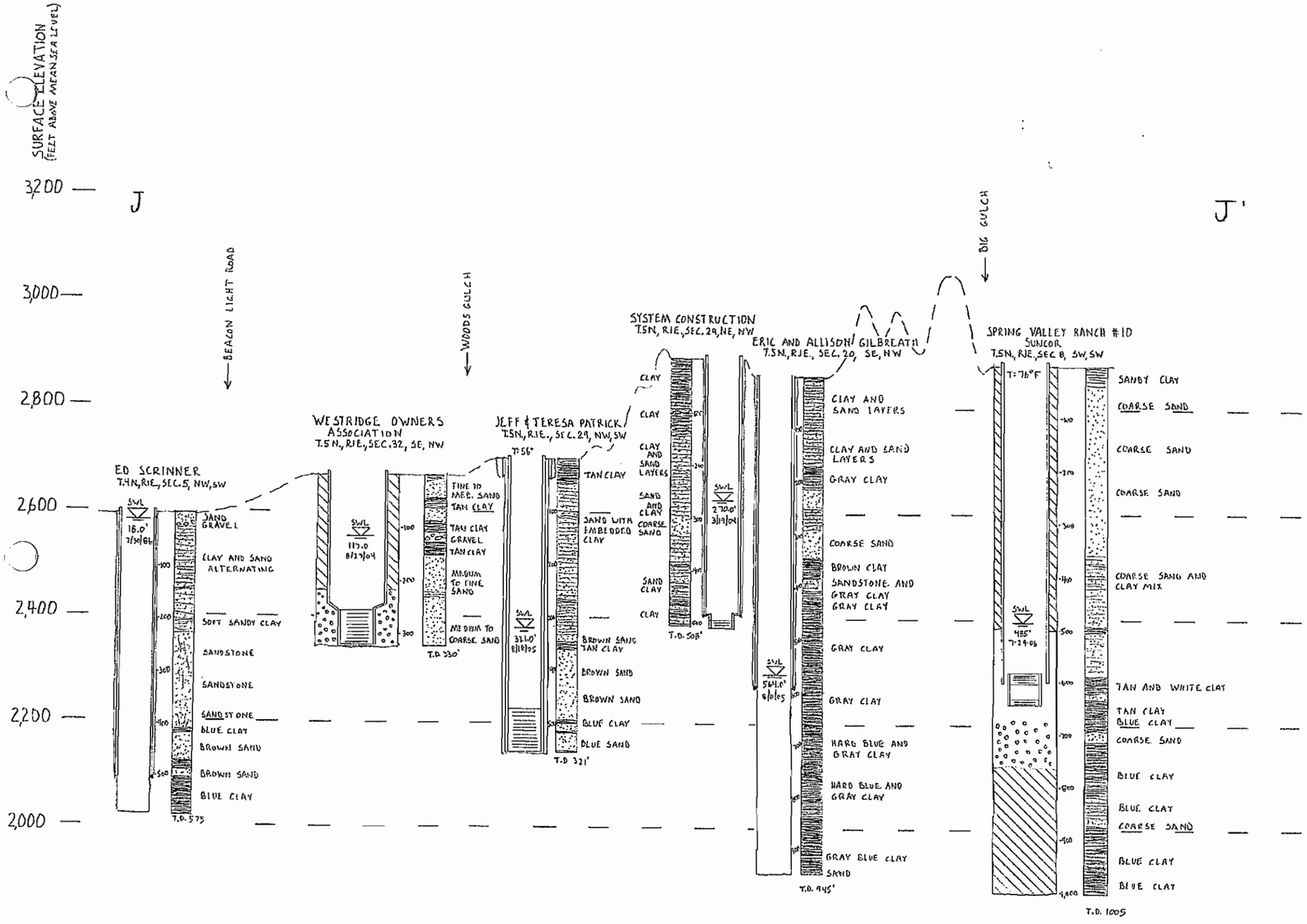
Geologic Cross-Section J-J'
(N x S)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES
HORIZONTAL SCALE: 1-INCH : 3000 FEET
VERTICAL SCALE: 1-INCH = 200 FEET
SURFACE ELEVATION SCALE: 1-INCH: 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED
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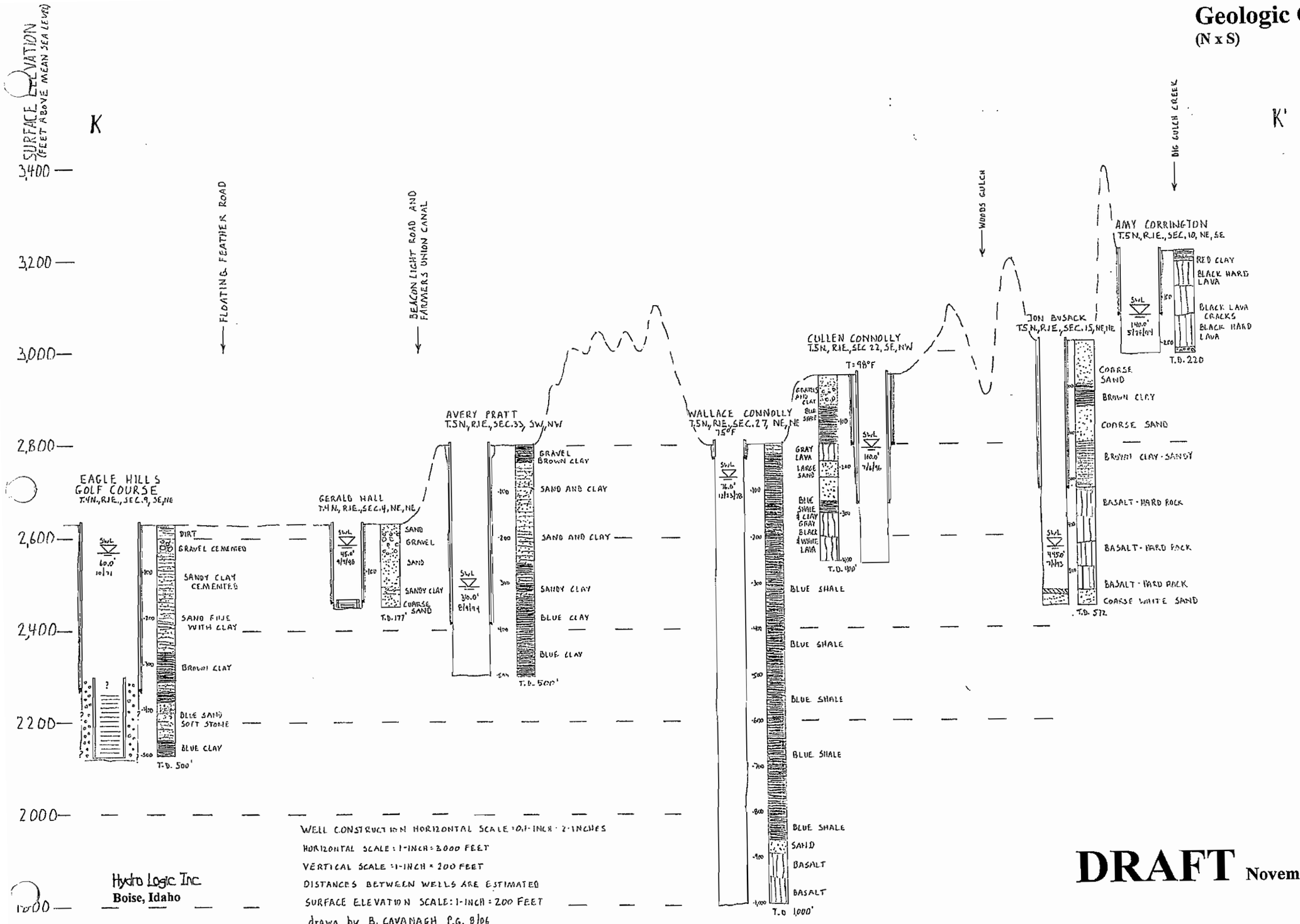
Geologic Cross-Section K-K'
(N x S)



WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES
HORIZONTAL SCALE: 1-INCH = 3000 FEET
VERTICAL SCALE: 1-INCH = 200 FEET
DISTANCES BETWEEN WELLS ARE ESTIMATED
SURFACE ELEVATION SCALE: 1-INCH = 200 FEET
drawn by B. CAVANAGH P.G. 8/06

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Geologic Cross-Section L-L'
(N x S)

L

L'

SURFACE ELEVATION FEET ABOVE MEAN SEA LEVEL

3,600
3,400
3,200
3,000
2,800
2,600
2,400
2,200
(1,600)

HIGHWAY 55 — NORTH HORSESHOE BEND ROAD — HIGHWAY 55 — HIGHWAY 55 — HIGHWAY 55

WILLOW CREEK

UWID LEXINGTON HILLS #2
T4N., R1E., SEC. 3, NW, SW
SWL 900' 4/14/92
COARSE SAND
CEMENTED GRAVEL
BROWN CLAY
GREY CLAY
SANDY GREY CLAY
SANDY GREY CLAY
FINE TO MEDIUM SAND
GREY CLAY
FINE TO MEDIUM SAND
GREY CLAY
T.D. 615'

STEVE AND SHERYL RODGERS
FORMERLY RUTH KELLY
T.5N., R1E., SEC. 35, SW, SW
SWL 120'
BROWN SAND
BROWN SAND AND CLAY STRIPS
BLUE GREY CLAY
BLUE GREY CLAY
BLUE GREY CLAY
BLUE GREY CLAY
GREY CLAY
CRACKS IN GREY CLAY
GREY CLAY
T.D. 1200'

JOHN FERGUSON
T.5N., R1E., SEC. 25, NW, SE
SWL 86.0' 12/15/71
BROWN STICKY CLAY
BLUE CLAY
STICKY BLUE CLAY AND QUARTZ SAND
BLUE CLAY
BLUE CLAY
QUARTZ SAND AND BLUE CLAY
QUARTZ SAND
T.D. 500'

JERRENE PHILLIPS
T.5N., R2E., SEC. 19, SW, SW
SWL 340' 9/26/79
BROWN SAND
BROWN ROCK
BROWN CLAY
BROWN GRAVEL
BROWN HARD SANDSTONE
BROWN BLACK HARD GRANITE
GRAY CRACKED GRANITE
GRAY GRANITE
HARD GRAY GRANITE
SOLID GRAY GRANITE
CRACKS IN GRANITE
SOFT GRANITE
CRACKS IN GRANITE
SOFT GRANITE
HARD GRANITE
HARD GRANITE CRACKS
GRAY GRANITE SOFTER
HARD GRANITE / FRACTURE
T.D. 1936'

VALLEY RANCH #5
T.5N., R2E., SEC. 18, SW, SE
SWL 23.0 2/4/04
COARSE TO VERY COARSE SAND
TUFF WELL CEMENTED LIGHT & DARK BROWN
BRECCIA OR RUBBLE VARIETY OF APHANITIC ROCK TYPES
CLAY (WHITE) TUFFACEOUS SEDIMENTS
BRECCIA OR RUBBLE
DECOMPOSED GRANITE
T.D. 443'
LITHOLOGY BY T. SCANLAN R.E.P.G. & C. FEIST P.G.
TUFF - HARD - BRITTLE
SAND AND GRAVEL
GRANITE COBBLES AND SAND
CLAY
WEATHERED GRANITE
GRANITE CLEAN QUARTZ WHITE FELDSPAR BIOTITE
FRACTURES
GRANITE CLEAN QUARTZ WHITE FELDSPAR BIOTITE
T.D. 1220'
LITHOLOGY BY FEIST GEOSCIENCES

SPRING VALLEY RANCH #4
T.5N., R2E., SEC. 7, NW, SE
SWL 1.1' 3/14/05

SPRING VALLEY RANCH #3
T.5N., R1E., SEC. 1, SE, SE
SWL 175' 11/20/02
COARSE TO VERY COARSE SAND
SAND AND GRAVEL
SAND
CLAY - WEATHERED BASALT
CLAY
SILTSTONE
CLAY - GREENISH GRAY
SILTSTONE SHALE
SILTSTONE
SHALE AND CLAYSTONE
TUFF AND BASALT
TUFFACEOUS SS. DARK GRAY
CLAY WITH SILTSTONE FRAGMENTS
T.D. 970'
LITHOLOGY BY FEIST GEOSCIENCES

SPRING VALLEY RANCH #2
T.6N., R1E., SEC. 36, NE, SE
SWL 31' 1/31/02
SANDY CLAY
SHALE AND CLAY
SANDSTONE AND SAND
CLAY LIGHT BROWN TO GRAY
SANDSTONE
CLAY GREENISH BROWN
SANDSTONE CLAYEY TO SHALEY
STICKY GRAY CLAY
BASALT BLACK APHANITIC
SAND AND SANDSTONE
SANDSTONE LIGHT-DARK GRAY
DECOMPOSED GRANITE
T.D. 800'
LITHOLOGY BY FEIST GEOSCIENCES

* WATER LEVEL MEASURED BY HYDRO LOGIC 7/06

WELL CONSTRUCTION HORIZONTAL SCALE: 0.1-INCH = 2-INCHES EXCEPT WHERE DASHED

HORIZONTAL SCALE: 1-INCH = 3000 FEET

VERTICAL SCALE: 1-INCH = 200 FEET

SURFACE ELEVATION SCALE: 1-INCH = 200 FEET

DISTANCES BETWEEN WELLS ARE ESTIMATED

drawn by B. CAVANAGH P.G. 8/08

Hydro Logic Inc.
Boise, Idaho

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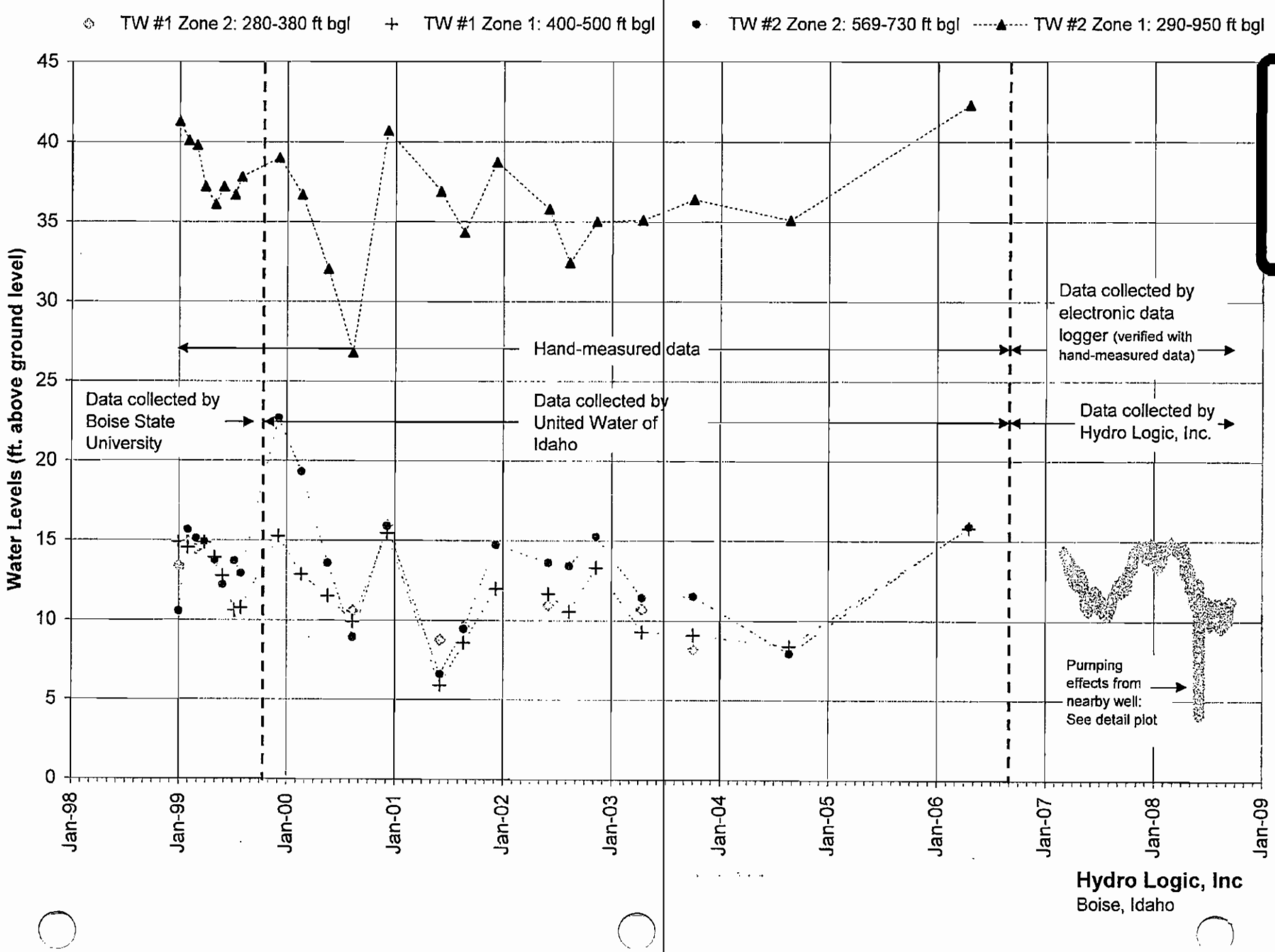
Exhibit XX. Water Levels at UWID State & Linder Monitoring Wells



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Boise, Idaho

M3 EAGLE LLC
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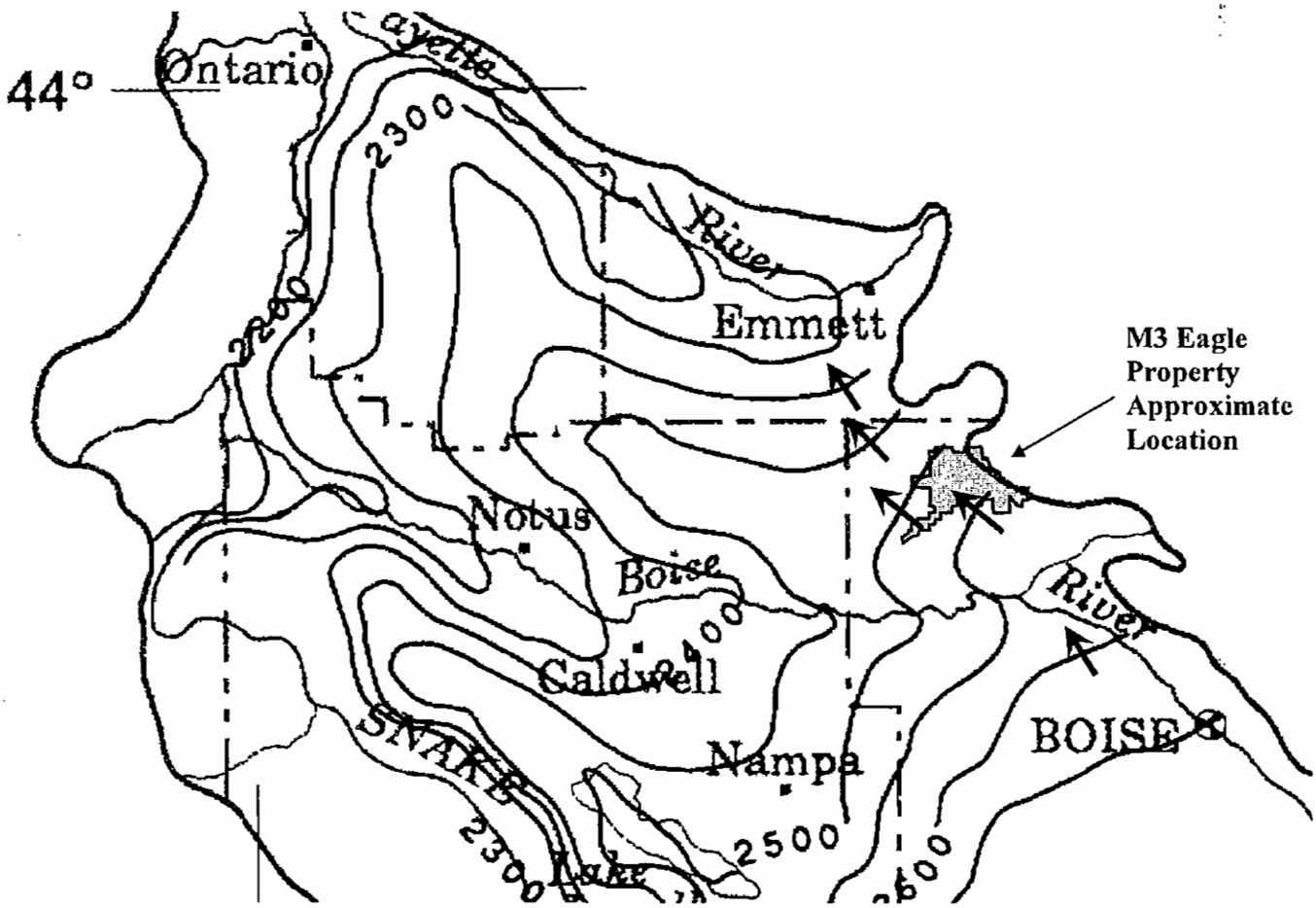
Exhibit xx – Water Level Contours from USGS Model of Treasure Valley Showing Ground-Water Flow toward Payette River Valley Beneath the M3 Eagle Site



Water level contours generated by USGS model. Blue Arrows (added by Hydro Logic, Inc based on flow at right angles to contours) shows ground water beneath the M3 Eagle site flowing to the northwest toward the Payette River Valley. Excerpt from Figure 21 of Newton (1991).

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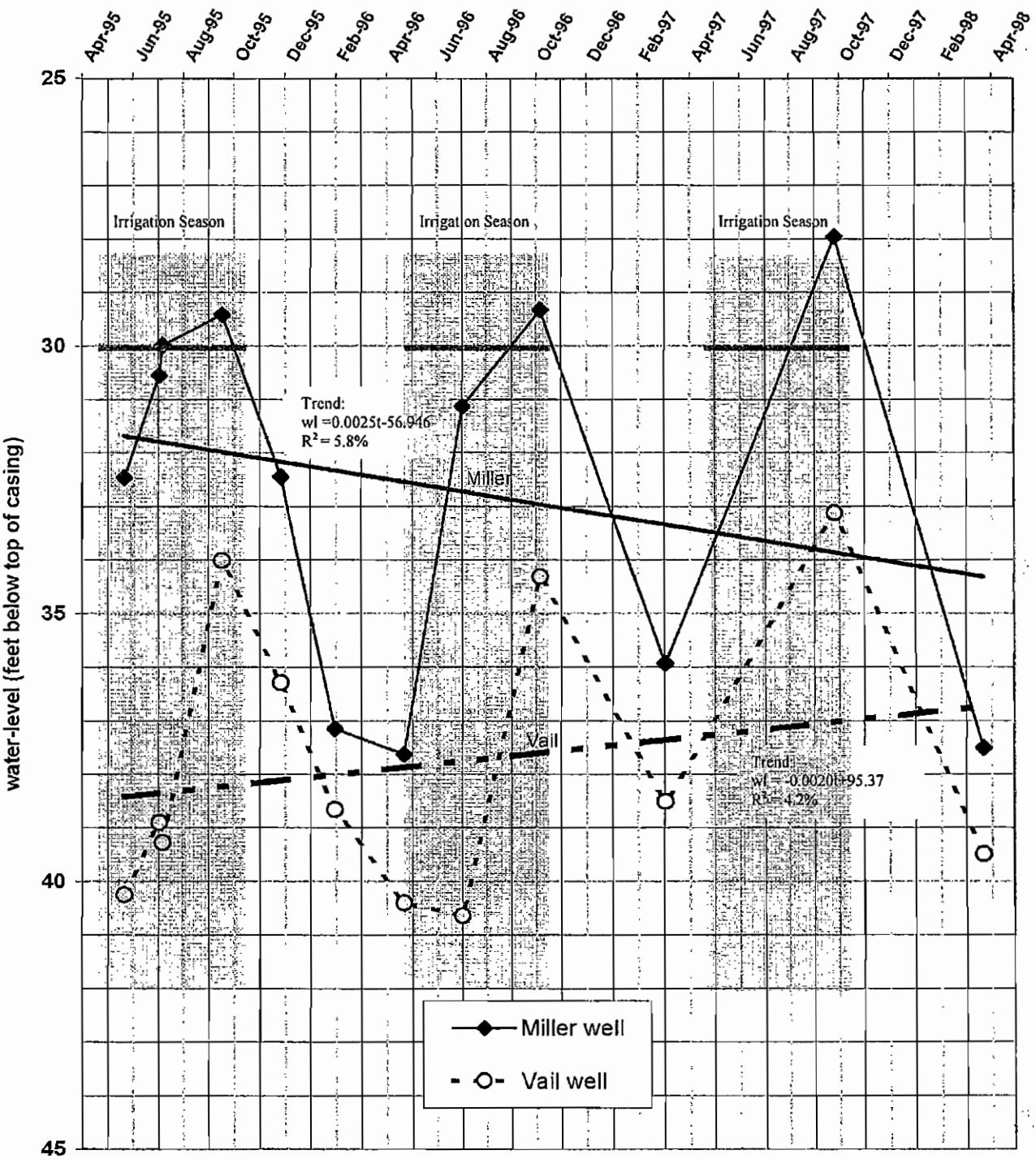
Exhibit XX. Water Levels in the Vail and Miller Wells 6/15/95 – 4/1/98



The data indicate that water levels *rise* in shallow domestic wells during summer when irrigation is applied and the Floating Feather well pumps at higher average rates and *fall* during winter when no irrigation is applied and the Floating Feather well pumps at lower average rates.

No declines in water levels are indicated by pumping at the Floating Feather Well

(based on data provided by United Water of Idaho)

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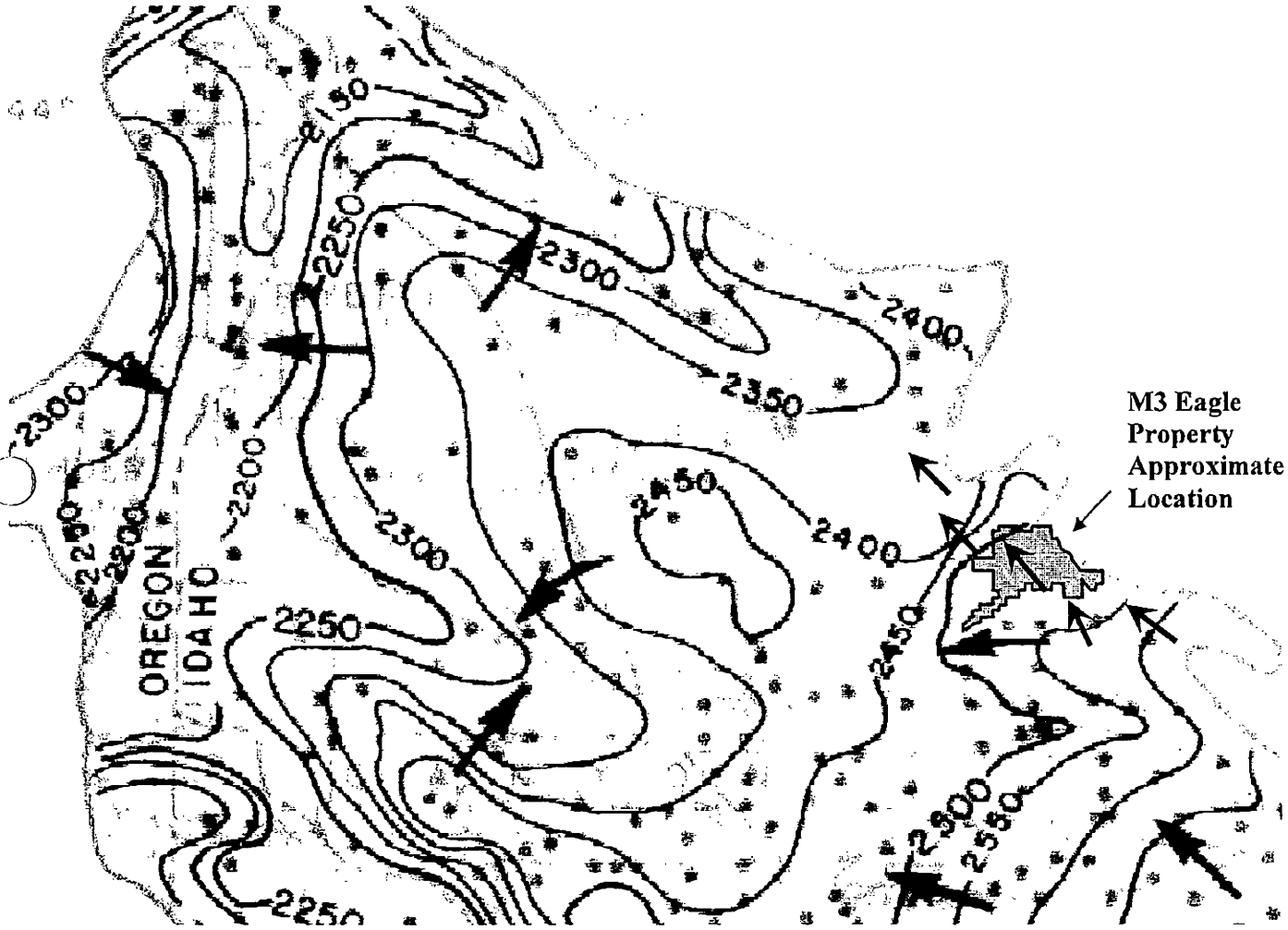
Exhibit xx – Water Level Contours from USGS Study of Snake River Aquifer Showing Ground-Water Flow toward Payette River Valley Beneath the M3 Eagle Site – 1980 Data



Water level contours generated from water levels measured by the USGS during 1980. Blue Arrows (added by Hydro Logic, Inc based on flow at right angles to contours) shows ground water beneath the M3 Eagle site flowing to the northwest toward the Payette River Valley. Excerpt from Lindholm et al, 1982.

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DOCUMENTS CONTAINED IN EXHIBIT A, TAB 32

A. Edward Squires

- Curriculum Vitae ("CV")
- Outline/summary of facts and opinions

B. Mark Utting

- CV
- Outline/summary of facts and opinions

C. Loren Pearson

- Outline/summary of facts and opinions

D. Dr. James L. Osiensky

- CV
- Summary of Comments on Technical Analyses

E. Dr. Spencer Wood

- CV
- Outline/summary of facts and opinions

F. Jim Rumbaugh – NOT EXPECTED TO TESTIFY

G. Roger Dittus

- CV
- Outline of Facts and Opinions Pertaining to M3 Eagle Ground Water Studies

H. Peter Schwartzman

- CV
- Outline/summary of facts and opinions

I. Richard Glanzman

- CV
- Outline/summary of facts and opinions

J. Del Leavitt – NOT EXPECTED TO TESTIFY

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K. Scott Wonders

- Summary of Facts and Opinions

L. Steven E. Holt

- CV
- Engineering Report, November 26, 2008

M. Dr. John Church

- CV
- Outline of Facts and Opinions

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Edward Squires, R.P.G.

EDUCATION

M.S. Interdisciplinary Hydrogeology, 1992, Boise State University, Boise, Idaho.
Advisors: Dr. S.H. Wood (BSU) and Dr. J.L. Osiensky (U of I) advisors.

B.S. Geology, groundwater emphasis, cum laude, 1990, Boise State University, Boise, Idaho.
Advisor: Dr. C. M. White.

Thesis: Hydrogeologic Framework of the Boise Aquifer System, Ada County, Idaho.

REGISTRATION

Registered Professional Geologist, since 1999, Certificate No. 968
Professional Well Log Analyst, since 1995
Certified Water Right Examiner, Certification No. 06-125

OVERVIEW

Ed Squires is the President and Managing Hydrogeologist for Hydro Logic, Inc. of Boise, Idaho. Before starting his own consulting firm in 1999, he served for 6 years as Manager of the Geosciences Department and Senior Project Hydrogeologist for United Water Idaho, Inc. In that capacity, Mr. Squires has consulted on a variety of water resource projects to the United Water Resources group of companies around the United States. He has been part of the adjunct graduate faculty at Boise State University's Department of Geosciences since 1995, regularly teaching a curriculum course in Field Hydrogeology and serving as a guest lecturer for other water-related coursework. Prior to his tenure at United Water Idaho, Mr. Squires worked as a hydrogeologist for S.H. Wood and Associates and has over eighteen years of hands-on groundwater experience.

Mr. Squires' professional career and current practice emphasizes all aspects of responsible groundwater development, water rights, and resource protection. He has conducted extensive research and published several reports on the groundwater and subsurface hydrogeology of the Boise River Valley since publication of his Masters Thesis, entitled "Hydrogeologic Framework of the Boise Aquifer System, Ada County, Idaho". Mr. Squires served three years on the Technical Advisory Committee of the Treasure Valley Hydrologic Project and has been a member of the Southeast Boise Groundwater Management Area Committee, formed as a result of his research in Southeast Boise, since 1994. He recently served on the Technical Advisory Committee for the Hydrogeologic Framework and Computer Modeling Project for the Boise Front Geothermal Groundwater Management Area and has been appointed by the Director to the Negotiated Rulemaking Committee to draft new administrative rules for well drilling in the State of Idaho.

Mr. Squires has designed and supervised the construction of over 300 large bore, high capacity water supply wells averaging 500 feet deep in sedimentary and volcanic aquifers. He has designed, supervised the construction, developed, and tested more than 60 deep (500-to-1000 feet) exploratory test/observation wells in addition to multiple geothermal and irrigation well development projects. In addition to new well installations, Mr. Squires has run down hole camera surveys and borehole geophysical logs in hundreds of wells throughout the Western States and has been in charge of rehabilitative maintenance/reconstruction of over 100 older wells.

Mr. Squires is a registered Professional Geologist (No. 968) and a Professional Well Log Analyst. He is a member of the National Groundwater Association, the Association of Ground Water Scientists and Engineers, and is a Certified Water Rights Examiner in the State of Idaho (05-125).

REPRESENTATIVE PROJECT EXPERIENCE

Groundwater Development

1) Design, construction oversight, development, and testing of over 100 large bore, high capacity production supply wells for public drinking water systems, municipalities, and private utilities.

2) Designed, organized, and supervised 11 regional scale, long-term aquifer tests including those for the State of Idaho Department of Corrections, United Water Idaho, Inc., Water District 63-S, Mesa Water Corporation, Tamarack Resort, and Crane Creek Country Club,

3) Conducted and interpreted borehole geophysical logs in newly drilled wells and provided design information for hundreds of well projects for industrial, commercial, agricultural, and municipal wells in the western U.S.

4) Testing/analysis of United Water Idaho's infiltration galleries (Ranney Collectors) along the Boise River.

5) Pumping test analysis and pumping plant design of municipal supply wells for the Cities of Caldwell, Meridian, and Garden City.

6) Ground water quality and water geochemistry evaluations for the Cities of Meridian, Caldwell, and Garden City, United Water Idaho, Capitol Water Corp., Tamarack Resort, and SSI Food Industries.

7) Hydrogeologic and geophysical investigations for groundwater supply projects for the Idaho cities of Boise, Meridian, Caldwell, Mountain Home, Nampa, Greenleaf, Kuna, Marsing, Buhl, Rupert, Eagle, Cascade, Donnelly, Victor, Star, Emmett, Glenns Ferry, and Notus. Also the Cities of Hawthorne NV, Mt. Vernon OR, LaGrande OR, Island City OR, and Walla Walla WA

Geothermal

1) Water-level monitoring and data analysis of the BWSWD Well #3, Kanta-Yanke, Behrman, Quarryview Park, Koch, and BLM geothermal wells 1984-1987.

2) Water-level monitoring of the Terteling Ranch and Flora Nursery geothermal wells 1993- present.

3) Geophysical investigations of the BWSWD #1 and #2, Kanta, BLM, Terteling (6 wells) Ranch, UWID Cartwright, Crane Creek Country Club, Simplot Ranch, Jeker Ranch wells.

4) Large scale, 11-well aquifer test of the Stewart Gulch geothermal aquifer using the Terteling Windsock well as the pumping well. Basis for IDWR Order changing Water District 63-S boundary (1994).

5) Large scale, long-term aquifer testing of the Stewart Gulch geothermal wells using the Quail Hollow Golf Course well as the pumping well (1993).

6) Six-well, aquifer testing of the Crane Creek area geothermal wells using the Simplot Ranch, Crane Creek GC, and UWID wells as pumping wells. Settled UWID/Simplot water rights dispute – (194-1995).

7) Specific capacity testing of the Flora Nursery and Edwards Nursery geothermal wells 2000-2002.

8) Conducted and interpreted down hole camera surveys of the BWSWD, Flora, Crane Creek Country Club, Terteling Ranch wells.

9) Project manager for design, drilling, completion, and testing of the Peaceful Cove Nursery and Tom Terteling residence deep geothermal supply wells in Stewart Gulch – 1994 & 1995).

10) Project manager for the rehabilitation of the Terteling Ranch Pool, Motorcycle Club, and Windsock geothermal wells – 1990's.

11) Evaluation of historical weir flow data and geothermal water use at Flora Nursery – 1921- 2002.

12) Project manager for reconstruction, and sealing of the Flora Nursery Silkey geothermal well.2001.

13) Co-leader of the Treasure Valley Hydrologic Project Foothills Field Trip to view exposed geothermal aquifer rocks along the Boise Front 1998.

14) Project manager Stewart Gulch seismic profiling project to site, drill, and complete a new cold-water irrigation well above the geothermal aquifer – 1996

15) Conducted geophysical surveys for the J.R. Simplot Co.'s Aquaculture Project in Caldwell, ID.

16) Expert witness for Flora Nursery during protested geothermal Transfer application 2001-2002.

17) Expert witness for The Terteling Company during protested Petition by the City of Boise to increase geothermal water withdraws from the Boise Geothermal Aquifer 2002.

18) Hydrogeologic Framework Refinement and Simulation of Hydraulic Head and Temperature in the Boise Geothermal Aquifer -Technical Advisory Committee member 2002.

19) Co-author of the Boise Front Geothermal Aquifer Monitoring Plan June 2002.

20) Project manager for the geothermal exploration drilling and seismic reflection surveys project at Tamarack Resort 2005.

Aquifer Recharge

1) Project manager for the United Water Idaho, Inc.'s Swift Aquifer Storage and Recovery project (aquifer recharge) in West Boise, Idaho, 1996-1999.

2) Consulting hydrogeologist to United Water Resources for various aquifer recharge projects along the east coast 1996-1999.

3) Geophysical and hydrogeological consultant to the State of Idaho Department of Water Resources' Managed Recharge Project including providing open-hole geophysical logs and borehole video 2000.

4) In-situ Aquifer Storage and Recovery project for dissolved iron concentrations in ground water in the Tamarack Resort municipal supply Well #7 ; successful elimination of iron 2004.

5) Attended two international ARR conferences and two recharge conferences in the US.

Water rights

1) Preparation, filing, and follow-though of numerous water right transfers and water right permit applications and transfers for public utilities, municipalities, the State of Idaho, commercial, and agricultural water users in Idaho.

2) Evaluation of surface water rights and filing of transfer applications in Little Salmon River Valley.

3) Expert witness in Basinwide Issue #5 – Conjunctive Management of Water Resources in Idaho.

4) Expert witness in all manner of water right disputes, protests, and well interference issues before the Idaho Department of Water Resources including groundwater/surface water interactions

5) Evaluations and filing of claims in the Snake River Basin Adjudication.

6) Certified Water Right Examiner in the State of Idaho regularly conducting field licensing examinations and evaluations of pumping systems including determination of historical use.

7) Continual involvement in the interpretation and application of the tenets of the State of Idaho Water Code with respect to groundwater resource development and management.

8) Project manager for United Water Idaho, Inc. concerning the implementation of the 1996 Municipal Water Rights Statute 1994-1999.

9) Successful "Municipal" water rights application for the Idaho Dept. of Transportation for their Issac's Canyon Rest Area near Boise. 1st use of 1996 Municipal Water Rights Statute for the State of Idaho.

10) Co-author of the first successful municipal "future needs' water right application in Idaho.

Groundwater Development Feasibility Studies

1) Design, construction oversight, development, water quality testing , and monitoring of over 50 deep (500-1000 feet) exploratory test-well and piezometer nest installations for municipal and industrial water providers in Southwest Idaho..

2) Groundwater Feasibility Study For Idaho Power Co.'s Pahsimeroi Fish Hatchery, Lemhi, County, Idaho.

3) Reconnaissance Level Groundwater Feasibility Study for the Idaho Power Company's Oxbow Fish Hatchery atv the Confluence of Pine Creek With the Snake River in the Hells Canyon Reach, Baker County, Oregon.

4) Hydrogeologic Evaluation of Groundwater Quality and Yield Beneath the Idaho Power Company's Pahsimeroi Fish Hatchery – Upper Facility.

5) Analysis of the 2001 Aquifer Testing for the Municipal Water Supply of the Proposed WestRock Resort, Donnelly, Valley County, Idaho.

6) Groundwater Conditions and Hydraulic Testing of the Boise Fan-Aquifer of Southeast Boise River Valley, Ada County, Idaho.

1) Evaluation of the Hydrogeologic Framework and Groundwater Production Potential of the Kings River Valley, Nevada.

Resource Protection

1) Investigation, design and oversight of the decommissioning and proper abandonment of 35 aging and unsealed large-bore production well using perforate-and-pressure grouting techniques.

2) Design and oversight of the pressure grout sealing and rehabilitation of four high-yield unsealed wells.

3) Development and implementation of a baseline (pre-development) surface water quality monitoring plan for the proposed Tamarack Resort, Donnelly, ID.

EMPLOYMENT

1999-present	President and Managing Hydrogeologist; Hydro Logic, Inc.
1994-1999	Sr. Hydrogeologist (RPG) United Water Idaho, Inc.; Geosciences Department Head.
1995-present	Adjunct graduate faculty; Boise State University Department of Geosciences.
1992-1994	Consulting Hydrogeologist. S.H. Wood and Associates, Boise, Idaho.
1990-1993	Staff Technician; Geophysical Well-logging Unit, Boise State University.
1989 summer	Idaho Geological Survey; Idaho Initiative. Albion Range field-mapping.
1989	Internship; Boise Water Corp.; Digital Data Acquisition for Groundwater Studies.
1988 summer	White/Naslund National Science Foundation Research Expedition to Kangerslugsuaag region of arctic East Greenland. Team member in charge of field mapping.
1987 summer	Research assistant at BSU on hydrogeological studies. Design, construction, and operation of Boise State University's truck-mounted geophysical well-logging unit. Thin-section and X-ray diffraction laboratory manager.

PUBLICATIONS AND REPRESENTATIVE PROFESSIONAL REPORTS

Movement of Dissolved Constituents From Surface to Groundwater and Analysis of Hydrochemical Trends in the Boise Aquifer, 2006, research paper in preparation with D. Glanzman.

Baseline Surface Water Quality Estimation For Streams In the Tamarack Resort Area, Donnelly, Valley County, Idaho: 2006, a four-year study to develop baseline geochemical signatures and annual flow rates/volumes for six area streams using the Probability Plot Analysis method.

Hydrogeologic Evaluation of the Feasibility for Ground Water Development Beneath the Miller Gulch Area of the Terteling Ranch in the Boise Foothills, Ada County, Idaho With Emphasis on Water Quality / Geochemistry: 2005, a report on the drilling, design, construction, and sampling of the Miller Gulch exploratory test-well bore and piezometer nest.

Options for Additional Ground Water Development and Replacement of the City of Caldwell's #7 Supply Well: 2005, a report on the drilling, design, construction, and sampling of an exploratory test-well and long-term dedicated piezometer nest/monitoring well at the City of Caldwell's existing municipal water supply well site, prepared for the City of Caldwell, Idaho Department of Public Works.

Boise Valley Groundwater Geochemistry – Origin, Infiltration Rate, and Transport Characteristics: 2005, abstract submitted to the 15th Annual Goldschmidt Meeting of international geochemists, co-author with Dick Glanzman, CH2M-Hill Denver.

Treasure Valley Hydrologic Project Seismic Survey and Hydrogeologic Framework Study, 2003, research paper in preparation with Dr. S.H. Wood, and Lee Liberty of BSU.

Compilation of Drilling, Geological, Geophysical, Geochemical, and Hydraulic Testing Data for the City of Meridian, Idaho's Groundwater Supply; Including Detailed Well-Construction Information and Aquifer Pressure Measurements From a Long-Term Groundwater Monitoring Well Network, 2003, data compilation from a ten-year hydrogeologic study funded by the City of Meridian.

City of Meridian, Idaho Source Water Protection Plan: 2003, prepared for the Idaho Department of Environmental Quality and the City of Meridian Department of Public Works.

Details of Drilling, Construction, and Hydraulic Testing of the Idaho State Correctional Institution #4 Supply Well, 2002, a report prepared for the Idaho Division of Public Works.

Results and Analysis of the 2001 Aquifer Testing for the Municipal Water Supply of the Proposed WestRock Resort, Donnelly, Valley County, Idaho: 2002, A report prepared for the Idaho Department of Water Resources.

Causative Factors of Detachment of the Mountain Home #1 Municipal Supply Well Pump With Details of the Recovery Effort: 2002, A report prepared for Ringert Clark Chartered Lawyers.

Evaluation, Abandonment, and Proposed Replacement of the Capitol Water Corporation's #5 (Lubkin) Municipal Supply Well 1999-2002: 2001, A report on the history of repair, the occurrence of volatile organic compounds, and the abandonment of an aging supply well in preparation for replacement of the #5 well with a new facility.

Preliminary Evaluation of the Well Construction, Present Down Hole Conditions, and Sustainable Yield of the Garden City #5 Municipal Well: 2001, A report the Garden City Public Works Department.

Stratigraphic Studies of the Boise (Idaho) Aquifer System Using Borehole Geophysical Logs With Emphasis on Facies Identification of Sand Aquifers: 2000, Report to the Treasure Valley Hydrologic Project, Idaho Department of Water Resources, (co author with Dr. S.H. Wood).

Hydrogeology, Geochemistry, and Well Construction of the Treasure Valley Hydrologic Project Monitoring Well #1, Ada County, Idaho: , 1999, Final report to the Technical Advisory Committee (co-author).

Supporting Data for the Groundwater Conditions and Aquifer Testing of the Tenmile Ridge Area of South Boise, Ada County, Idaho: 1998.

Implications of Well-Construction to Aquifer Water-Quality: Some Observations: (principal author), 1997, Southwest Idaho Subsection – Pacific Northwest Section of the American Water Works Association; in Southwest Idaho As An Example of Ground Water Development in the Northwest Intermountain Region, Speakers Expanded Abstracts

City of Meridian #15 Production Well; Discovery of a New, Good-Quality Aquifer: 1994, Professional report to the City of Meridian, Idaho.

Groundwater Conditions and Hydraulic Testing of the Boise-Fan Aquifer of Southeast Boise River Valley, Ada County, Idaho: 1993, Report to Boise Water Corporation. (principal author).

City of Meridian #14 Production Well: 1993, A new large-capacity municipal-supply well is completed in response to unprecedented 18% growth. Report to City of Meridian, Idaho.

Hydrogeologic Framework of the Boise Aquifer System, Ada County Idaho: 1992, Project Completion Technical Report, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho, 109 pages. (principal author)

An Irrigation Well for the Les Bois Invitational Soccer Tournament Incorporated, 1992, professional report to Boise Water Corporation, 42 pages. (sole author)

Hydrogeologic Investigation for the Proposed State of Idaho, Department of Transportation Blacks Creek Rest Area, Ada County, Idaho: 1992, report to Idaho Department of Transportation, 38 pages. (principal author)

Investigation of Groundwater in the Tenmile Ridge Area of South Boise, Idaho: 1989. Report to Boise Water Corporation. (principal author)

Origin of Granophyres in the Vandfaldalen Macrodike, East Greenland: 1989, Evidence for Assimilation and Magma Mixing. GSA Abs. with Programs. (co-author)

Crustal Assimilation and Coexisting Silicic and Mafic Magmas in the Vandfaldalen Macrodike, East Greenland: Continental Magmatism Abstracts (IAVCEI): New Mexico Bureau of Mines and Mineral Resources Bulletin 131. (co-author)

Analysis of Historical and Current Water-level and Production Data from the Boise Geothermal System: 1988, Geological Society of America Abstracts. (co-author)

Preliminary Geology and Hydrogeology of the Mayfield/Orchard Area, Elmore and Ada Counties, Southwest Idaho: 1988, (Best Undergraduate Paper in Physical Sciences), in Program and Abstracts, 30th Annual Meeting of the Idaho Academy of Science. (sole author)

Geologic Study of Groundwater in Deep Wells, Southeast Boise Area: 1987. Report to Boise Water Corporation.

Summary of Principal Opinions, Data, and Exhibits

Ed Squires
Hydro Logic, Inc.
November 26, 2008

Background information and opinions.

1. My resume is attached. I am the owner of Hydro Logic, Inc. ("HLI"), a consulting firm specializing in hydrogeology. I have 22 years of experience conducting ground water analyses, designing and testing water wells, and studying the subsurface geology in the Ada, Canyon, and Gem County areas of Idaho. My 1992 Master's thesis focused on the hydrogeologic framework of the Boise aquifer system. I have been fortunate to have two of southern Idaho's pre-eminent geologists, Dr. S.H. Wood (Boise State University professor emeritus) and the late Willis Burnham (USGS retired) as my mentors in studying the exposed outcrop geology of the local foothills and the history of depositional processes for the resultant stratigraphy of this area.

2. I have personally designed, supervised the construction of, and tested at least 200 large water supply wells (most of which have been in the Treasure Valley), at least a few dozen smaller diameter water supply wells, and more than 50 deep exploratory wells including many that have been completed as long-term designated piezometer nest monitoring stations. I have collected information from many more wells that I did not construct, and have monitored ground water levels in many wells during all of this time. I have personally measured water levels in hundreds of water wells, and have conducted down-hole camera surveys of hundreds of wells in the intermountain west.

3. I routinely conduct geophysical and lithologic logging of wells using several techniques, and am very familiar with the interpretation and use of such logs. I have reviewed many thousands of well driller reports, in Idaho and elsewhere, and compared them to geophysical data in several hundred instances. In my opinion, driller's reports most often do not provide an accurate depiction of the subsurface drilled geologic section. While driller reports are somewhat useful and important in providing general information about a well or a well bore (such as its date drilled, its depth, its drilling method, casing length, and any attempt at sealing), and sometimes can provide some evidence for explaining why a given well behaves the way it does, these records are generally incomplete and uneven in quality such that more rigorous evaluation usually is needed to determine actual characteristics of a well or the subsurface it penetrates.

4. I have been involved with several seismic investigations and other geophysical surveys of subsurface geology in the Treasure Valley. I am familiar with the general use of seismic equipment, and have consulted on the interpretation and correlation of seismic analysis in various types of geologic settings.

5. I have a great deal of experience in water well drilling techniques and the methods needed to seal wells against leakage between aquifers and from surface land use activities. I have observed many times, and often am asked to help solve, problems well owners encounter due to such things as poor well construction, inefficiency, improper

well completion, improper screening, lack of well seals, invasion of various types of bacteria, and other issues.

6. I have conducted hundreds of well tests and at least a dozen large-scale regional aquifer tests which have involved pumping properly-constructed and examined wells to determine a variety of things such as effects on aquifer pressures, movement of water in the subsurface, aquifer boundary conditions, aquifer coefficients, and effects on recharge and discharge. I have assisted in the construction and use of ground water models in my work, and have consulted on the construction of models by others. I frequently use geochemical analyses in my work.

7. Most domestic and irrigation wells in the Treasure Valley (and elsewhere in my experience) are not sealed, and most often (in my opinion) are not properly constructed or completed. Water level measurements from such wells, while useful for limited purposes and a necessary data point in a thorough study, can yield data that inaccurately portrays ground water conditions or well interference effects. For example, a well bore that is open outside the casing to three separate water-bearing zones usually will not provide an accurate water level of any of the three. A well casing that has corroded through (another common problem, especially with thin-wall steel casings) usually will defeat any common casing seals that may be in place. A well that fills with sand due to improper screen or perforation sizing will yield water level and drawdown profiles that are different from an adjacent well that does not have this problem. Sand-producing wells also often create voids outside the casing that can result in caving of overlying materials that can then clog screens and impede water flow into the well. Nevertheless, measurements of water levels in such wells cannot be avoided because they are most often all we have to work with.

8. Each of the domestic and irrigation wells of the Protestants in this case, based on the Protestants' Questionnaires and Well Driller's Reports I have reviewed, is an unsealed well. In my opinion, most, if not all, of these wells are of poor-quality construction.

Hydrogeological Investigations and Opinions Relative to the M3 Eagle Water Right Application

Several of my opinions in this matter are based on extensive hydrogeological investigations, analyses, and data collection undertaken by HLI or others pertaining to water supply for the proposed M3 Eagle planned community. These efforts include the following:

9. HLI measured the Aquifer's surface and gradient.
   a. June 2006: researchers and graduate student interns at the University of Idaho, working under contract to HLI, measured ground water levels in 169 domestic wells in the Eagle area.

   b. June 2007: HLI reviewed records of these domestic wells and selected a group of them for re-measurement. The selection was based on those wells that are better constructed and completed into the Pierce Gulch Sand Aquifer. On this basis, ground water levels in 57 wells were measured again.

c. August 14-16, 2007: To confirm accuracy of measured ground water levels (and thus, aquifer gradients); HLI hired a professional surveyor to determine well head elevations of these 57 wells to survey-grade accuracy (within).

d. March 7, 2007: HLI compiled this measurement data, produced a contour map based on it, and submitted both to IDWR.

e. March 19, 2007: HLI provided a Technical Memorandum to IDWR describing and enclosing the ground water contour map.

f. Data from all of the above well measurements have been provided to IDWR and posted to the Department's North Ada County ("NAC") website.

This information shows that ground water within the Pierce Gulch Sand Aquifer ("Aquifer") flows northwest from the Boise River Basin to the Payette River Basin.

g.

Baseline, pre-M3 Eagle water level measurements now exist for domestic wells in the area from which to gauge future changes in the Aquifer.

10. On behalf of M3 Eagle, HLI began a monitoring network in M3 Eagle area on May 5, 2006 and is now monitoring 23 wells in the area, including multiple piezometer nests.

11. Each of the 23 observation wells has been designed and constructed so that it could be used for long-term monitoring. For example:

    a. Each existing well bore was cleaned, re-habilitated, and inspected with a down-hole camera to ensure it will provide meaningful monitoring data.

    b. Each newly constructed piezometer within the exploratory bores is fully developed, sealed, and equipped with a separate digital data logger that continuously measures water level and barometric pressure; this data is downloaded monthly.

    c. Each piezometer also is measured by hand monthly to calibrate and double-check the digital data logger.

12. HLI has obtained and reviewed all other available water level monitoring data in the area maintained by the U.S. Geological Survey, IDWR, and United Water Idaho, Inc.

13. M3 Eagle also measured water levels in Eagle Water Company wells, City of Eagle wells, and United Water Idaho wells in the Eagle area.

14. Accordingly, M3 Eagle has over two years of ground water level measurements from its own monitoring network. This provides a further baseline against which to measure future pumping effects and to check the accuracy of ground water modeling.

15. Existing data show no significant decline of aquifer pressures or ground water levels in the Eagle area over the last ten years, despite steadily increasing ground water development in the area.

16. M3 Eagle contracted with Boise State University's Center for the Geophysical Investigation of the Shallow Subsurface ("CGISS") to conduct seismic reflection surveys on M3 Eagle property in Big Gulch during July 2006 (led by Director John Chapman).

    a. CGISS and students and faculty in BSU's Department of Geological Sciences conducted approximately 25 miles of magnetometer surveys during the summer of 2006 (led by Dr. Paul Donaldson and interpreted by Dr. S.H. Wood).

    b. Seismic reflection profiling of the subsurface was of limited success, but magnetometer surveys detected and confirmed structural faulting that HLI also has described through its work, including in HLI's May 2007 Report attached as Exhibit 4 to Attachment A of the M3 Eagle Second Amended Water Right Application ("HLI 2007 Report").

17. M3 Eagle contracted with the University of Idaho's Geosciences Department in June 2006 to develop a computer model of the ground water system for North Ada County. M3 Eagle funded a Masters Thesis as part of this effort.

    a. This was done in response to a request by the North Ada County Foothills Alliance ("NACFA"), a citizens group concerned about development in the Eagle area.

    b. U of I geology graduate student Stacey Douglas, working under Dr. James Osiensky, completed the model and report in December 2007.

    c. U of I post-doctoral researcher Dr. Robin Nimmer contributed to water budget analyses for the Douglas/Osiensky model.

    d. The December 2007 Master's Thesis model report is available on the NAC website.

    e. The U of I Master's Thesis model report supports the description of the hydrogeological basin in the HLI 2007 Report. The model report also confirms that, in the area it reviewed (which includes the M3 Eagle planned community area of the foothills north of Eagle) ground water flows toward the Payette River Basin.

18. During the past two and a half years, and in addition to the work described above, HLI conducted hydrogeologic framework studies and carried out an exploratory drilling program consisting of the following principal elements:

    a. HLI reviewed every available Well Driller's Report for the area, a total of over 3,000 records.

b. During August 2006, HLI used more than 70 of the better quality driller's reports from area wells to develop 12 draft sub-surface cross-sections of the Eagle-area subsurface. Quality was evaluated based on HLI's familiarity with the well in question, with the driller, and with observed conditions or other data that validated entries in the driller's reports.

c. Between September 2006 and April 2008, M3 Eagle drilled four exploratory test wells (ranging from 800 to 1,000 feet deep), sampled the geologic section, and geophysically logged the open bores before completing these as multi-level piezometer nests for long-term monitoring (the same piezometers that are discussed above).

d. HLI produced composite diagrams showing the geological, geophysical, geochemical, hydraulic, and well construction data for 13 existing wells of significance and for which good-quality data were available. HLI's July 4, 2008 report containing these composite diagrams was submitted to IDWR and is posted on the NAC website.

e. HLI obtained borehole geophysical records dating back over fifteen years from a number of entities and used these to map the 3-D geometry of the base of the Pierce Gulch Sand Aquifer in the M3 Eagle area. The HLI 2007 report contains HLI's preliminary findings from this effort.

f. This information, in concert with other deep well data and geophysical records within the Boise and Payette basins from petroleum exploration projects, supports HLI's conclusion in 2007 that the Pierce Gulch Sand Aquifer, which has been mapped in three-dimensions, is regionally extensive and highly productive.

g. The Pierce Gulch Sand Aquifer is so named because it consists of the extensive layer of lake-deposited sands first identified and described as the "Pierce Gulch Sand" in the research reports by Dr. S. H. Wood of BSU.

h. Since HLI completed the cross-sectional analysis described here, it has obtained additional geophysical logs from three additional deep well drilling projects conducted by oil companies in the Boise and Payette Valleys. This additional information shows that the Aquifer extends at least as far as Payette to the northwest, Boise to the south east, and Caldwell to the west.

i. Based on this data, HLI has constructed four additional cross-sections of the Aquifer within the Boise basin that traces it from across the M3 Eagle site and into Eagle, Star, and West Boise.

19. Working with Pacific Ground Water Group ("PGG") of Seattle, Washington, M3 Eagle, LLC recently completed its own numerical, three-dimensional ground water model of the Aquifer ("PGG Model") and conducted several simulations using it.

a. Developing this model first involved review of four existing ground water models for the basin. These include 1) the Lindgren Model, 2) the Newton Model, 3) the TVHP Model, and 4) the U of I Model.

b. PGG Model predictions were based upon an assumed pumping rate within the M3 Eagle planned community of approximately 16 cfs; pumping full-time year-round.

c. The PGG Model was the first that has been able to duplicate (i.e., calibrate to) the data from the Lexington Hills and Eaglefield aquifer tests (both discussed in 16 Aquifer Test report described below).

d. The model also successfully predicted (i.e., calibrated to) the results of the Spring Valley Ranch Well #7 aquifer test (discussed below) conducted by HLI in winter 2008.

e. The PGG Model shows that simulated ground water pumping (at ~10% above the average annual projected withdrawal rate for the M3 Eagle project at full build-out) is projected to cause Pierce Gulch Sand Aquifer drawdowns of 10 to 15 feet within ½ mile of M3 Eagle's property boundary after 50 years of continuous pumping. Drawdowns in shallower zones are predicted to be less. Within a mile, drawdown is projected to be about 5-to-12 feet after 50 years. In my opinion, these are reasonable predictions, and are supported by the other evidence described herein.

20. HLI conducted two aquifer tests as part of its study of the Aquifer and M3 Eagle's likely effects on ground water levels.

a. Kling Well Aquifer Test.

i. HLI reconstructed, redeveloped, and inspected this supplemental irrigation well during the summer of 2006.

ii. HLI conducted a 48-hour aquifer test of the Kling irrigation well January 9-11, 2007, pumping it at 900 gpm.

iii. HLI monitored 15 observation wells, but effects were observed only in the nearest M3 Eagle monitoring well (M3 TW-#1) approximately 1,050 feet away, where approximately 9 feet of drawdown was measured.

iv. This aquifer test provides strong evidence that large production wells of excellent ground water quality can be completed in Big Gulch area.

b. Spring Valley Ranch Well #7 Aquifer Test:

i. HLI redeveloped and inspected the Spring Valley Ranch test well #7. This well was drilled under the supervision of SunCor's consultants (Scanlan Engineering) in March and April of 2004.

ii. Between March 10th and March 19th of 2008, HLI conducted a 9-day aquifer test at a continuous discharge of 907 gpm.

iii. HLI took water level readings throughout the test in 22 observation wells.

iv. IDWR was informed throughout and participated in some of the test planning and monitoring.

v. HLI measured drawdowns on the order of 0.1 foot in wells in the Aquifer two miles away after 9 days of continuous pumping.

vi. HLI tested the water quality in the well.

vii. From this test, HLI concludes that the Pierce Gulch Sand Aquifer contains excellent ground water quality, suitable for all municipal purposes without treatment. The test is strong evidence of the aquifer's extensiveness and productivity. The test produced no hydraulic response in the Willow Creek Aquifer to the east, and supports the conclusion that the two aquifers are separate geologic formations without a significant hydraulic connection.

21. HLI's re-analysis of 16 previous aquifer tests.

a. Beginning in December of 2007, HLI re-analyzed the data and findings from sixteen previous aquifer tests in light of the new conceptual model as reflected in the HLI 2007 Report. The purpose was to determine whether these past test results are consistent with HLI's current findings.

b. Based on this work, HLI produced its July 4, 2008 report entitled "Re-Analysis of 16 Aquifer Tests in the Greater Eagle-Star Area of North Ada County, Idaho," which has been reviewed by Dr. Osiensky of U of I (the "16 Aquifer Test Report").

c. HLI provided the 16 Aquifer Test Report to IDWR and it was placed on the NAC website.

d. Based on the16 Aquifer Test Report and other evidence, HLI concludes that the Aquifer is a leaky, semi-confined system having some interconnection to shallower ground water on the east side of Eagle, and it has more transmissivity, thickness, and productivity than described in previous consultant's reports.

e. The 16 Aquifer Test Report supports the conceptual model of the Aquifer described herein and in the HLI 2007 Report.

22. Geochemical testing. HLI obtained ground water geochemistry samples from M3 Eagle's exploratory test wells at 15 separate aquifer depths and had them analyzed at Alchem Laboratories in Boise. These geochemical analyses were sent to Richard Glanzman of Glanzman Geochemical in Lakewood, Colorado for interpretation. Mr. Glanzman's

analytical results of the geochemistry have been posted to the IDWR's NAC web-site and HLI will provide the final report from the HLI/Glanzman geochemistry study when it is completed. This report also will be posted on the NAC website.

23. Peer review, agency involvement, and public dissemination of data:

    a. HLI has included Boise State University and the University of Idaho in its studies. As noted, experts from both universities have reviewed HLI's documents and concepts.

    b. Dr. S.H. Wood's decades-long geologic surface mapping, surface and borehole geophysical surveys, and structural studies of the Boise Foothills and Boise Basin were incorporated into M3 Eagle's investigations. Dr. Wood was consulted and included in several field trips evaluating the geology and depositional setting of the area.

    c. At M3 Eagle's direction, HLI has informed IDWR of all of its findings and data, as it is developed, and included IDWR hydrogeologists on field trips (at least four such trips to date).

    d. M3 Eagle has supported and contributed information and comment to the IDWR's newly formed North Ada County Technical Working Group; HLI is a contributing member of that group.

    e. M3 Eagle has shared HLI's aquifer research through public presentations to the Idaho Association of Professional Geologists, Boise State University, City of Eagle City Council, City of Eagle Planning and Zoning, Eagle Mayor's Citizen's Water Committee, North Ada County Foothills Association, Farmer's Union Ditch Co., IDWR North Ada County Technical Working Group, Representative Mike Moyle, Senator Brad Little, United Water Idaho, Holladay Engineering, IDWR's Technical Services Bureau, and NACFA.

    f. All research to date, peer-review, and scientific collaboration has further supported HLI's conceptual model for the ground water system in the Eagle area; no data has contradicted HLI's conclusions.

24. M3 Eagle's Projected Well Field

    a. Simulations using the PGG numerical ground water model are currently being used to model a revised number of wells (fewer) in the center of the planned community.

    b. It is likely that three or four centrally-located production wells, each pumping an average of 1,500 gpm, will form the core of M3 Eagle's production.

    c. Pumping effects from M3 Eagle's wells are now envisioned to be more distant from many existing water users' wells with the newly proposed wells locations

being separated from the current Eagle city boundary by approximately a mile of undeveloped federal land administered by the BLM.

d. Higher capacity production wells with less drawdown are now believed to be possible at M3 Eagle than were initially envisioned in the HLI 2007 Report.

25. Recharge to M3 Eagle's Proposed Well Field

a. A preponderance of scientific evidence, from several separate fields of study, support the conclusion that the sand aquifers underlying the M3 Eagle site are hydraulically connected to, are part of, and are recharged by the greater regional aquifer, and that this regional aquifer is the Pierce Gulch Sand Aquifer. I am unaware of any observed or measured data, or any geological fact, that contradicts these conclusions.
b. The Treasure Valley Hydrologic Project ("TVHP") Report assumed an aquifer boundary at the base of the foothills, essentially beneath the alignment of the Farmers Union Ditch, and did not attempt to characterize the thickness, dip, or geologic origin or extent of the Aquifer. To the extent one would attempt to infer that the Aquifer terminates at the base of the foothills, or is not recharged by the Boise River and associated water sources, the TVHP Report contains no evidence to support such an inference.
c. Separate lines of evidence support the conclusion that the Aquifer receives robust recharge from the Boise River system. These include: 1) ground water monitoring data, 2) ground water geochemistry data and analysis, 3) borehole geophysical logs and interpretation, 4) hydraulic testing, and 5) computer modeling.

26. Discharge of Boise Basin Ground Water to the Payette Basin:

a. A preponderance of scientific evidence, from several separate fields of study, support the conclusion that the ground waters within sand aquifers underlying the M3 Eagle site are hydraulically connected to and discharge to sand aquifers in the Payette Basin.
b. The separate lines of supporting evidence for ground water discharge from the Boise River basin to the Payette River basin include: 1) ground water monitoring data and numerous hydraulic gradient measurements, 2) observable facts pertaining to the depositional environments and physical outcrop geology between the two basins, 3) correlation of borehole geophysical logs from the site with those within the Payette Basin, 4) ground water flow maps of previous workers (USGS), and 5) computer modeling.
c. Although I conclude that substantial amounts of ground water flows from the Boise Basin to the Payette Basin, such an exchange is not required to substantiate the availability of ground water under the M3 Eagle property nor the interconnection to recharge sources in the Boise Valley. In other words, even if the ground water flow from the Boise Valley to the M3 Eagle site were to return to the Boise Basin, it would have no material effect on the recharge source or the conclusions as to the amounts of water available or the effects of producing it.

Other Technical Opinions Relative to the M3 Eagle Water Right Application

27. Borehole Geophysics:

- **a.** Measured borehole geophysical logs clearly show a characteristic geophysical signature of the Pierce Gulch Sand from M3 Eagle to the Boise Valley. In my opinion, this conclusively proves that the sand aquifer is continuous from well into the foothills on the north to the Boise Valley aquifer system extending under Star, Eagle, Meridian, and Boise.
- **b.** I have personally run the geophysical logs used for correlation, or have obtained these from a geophysicist trained by me and running the logs at my direction and using the same equipment. I have full confidence in the accuracy of these calibrated geophysical logs.

28. Water Level Monitoring:

a. HLI's monitoring of 22 wells in the area for approximately two years shows a hydraulic connection from the Pierce Gulch Sand Aquifer under M3 Eagle to the main valley aquifer system under Eagle, Idaho.
b. Pumping events are visible in M3 wells that are also evident in Eagle-area wells.
c. Regional scale drawdown and recovery events evident in valley and M3 Eagle wells show that the M3 Eagle and valley wells are hydraulically interconnected and strongly recharged by the same systems.
d. Measured ground water contours strongly suggest that ground water moves from the Boise Basin to the Payette Basin.
e. The movement of ground water from the Boise Basin to the Payette Basin has been evident for many years by a number of researchers.
f. Significant water level declines are not occurring in the Eagle area.

29. Hydraulic Testing:

- **a.** Based on experience with the design and testing of over 250 large capacity wells in the area, in concert with the data we have compiled about the aquifer system under the M3 Eagle site, I conclude that high-yield wells capable of 2,000-to-3,000 gpm are possible on the M3 Eagle site.
- **b.** The Aquifer is very productive with high transmissivity values.
- **c.** We have tested two small-bore wells on the M3 property that have sustainable yields of approximately 1,000 gpm.

30. Ground Water Geochemistry:

- **a.** The ground water chemistry of the M3 Eagle wells completed into the Aquifer is very nearly identical to the wells in the Valley near Eagle.
- **b.** The ground water geochemistry of the Aquifer is significantly different from that of the Willow Creek Aquifer.
- **c.** I agree with findings by other researchers (SPF Engineering) that the Willow Creek Aquifer, which is in a geologic setting adjacent and similar to that of the Pierce Gulch Sand Aquifer, also has ground water flow toward the Payette basin.

31. Other Professional Opinions:

- **a.** The regional Pierce Gulch Sand Aquifer is continuous from the subsurface under Boise and Eagle to the foothills area underlying M3 Eagle.

b. My understanding of the principles of geologic sedimentation and stratigraphy, in concert with over 20 years of hydrogeologic and geologic observations and testing in the Boise and Eagle foothills, support my conclusion that the Pierce Gulch Sand Aquifer should extend over a large area. Exactly how extensive the aquifer actually is cannot be known without further data and testing.

c. The ground water withdrawals proposed by the M3 Eagle development are reasonable with respect to quantity and I would not expect them to have an adverse effect on existing wells and/or water users.

32B

Mark Utting
Principal Hydrogeologist

Education and Other Qualifications

M.S. Geology (Hydrogeology), 1978, University of British Columbia, Canada
B.S. Geology (Geomorphology, Surficial Hydrology), 1974, University of Washington
Registered Professional Geologist, State of Idaho, No. 1016

Professional Experience

Prior to joining Hydro Logic, Inc., Mr. Utting has over 23 years experience in the field of hydrogeology. He has conducted projects throughout the Northwest US, the Middle East and Mexico. From 1987 to 2000 Mr. Utting was president, co-founder and principal hydrogeologist of Pacific Groundwater Group, a northwest consulting firm specializing in groundwater resource evaluation and management and in groundwater pollution assessment and control. Prior to that, he worked as a Senior Project Hydrogeologist for Hart Crowser Inc. from 1979-1987.

Mr. Utting provides well-rounded expertise in all aspects of hydrogeologic consulting, including groundwater development, aquifer management, contamination assessment, and soil and groundwater cleanup. Mr. Utting has led over 200 successful groundwater-related projects. Among the services he has provided to industrial, governmental and private clients are wellfield and aquifer development studies, regional groundwater evaluations, major industrial site assessments and pollution cleanups (including work in Superfund areas), negotiations with regulatory agencies on behalf of his clients, and expert testimony. Mr. Utting's expertise includes the assessment of the effects of groundwater pumping on river flows (surface water-groundwater interactions) and saltwater intrusion. Another field of expertise is unsaturated flow. As part of his graduate studies at the University of British Columbia, he developed field methods to evaluate hydraulic parameters in the unsaturated zone. Mr. Utting's previous employment includes work with Exxon's coal division, where he performed detailed geologic mapping, air photo interpretation, and resource evaluations.

Representative Project Experience

- Principal hydrogeologist for Hydro Logic, Inc. with respect to aquifer test analyses and hydrologic water budget for the M3 Eagle planned community in the North Eagle foothills
- Conducted a multi-year, multi-million dollar hydrogeologic characterization in support of developing water rights for the City of Auburn, Washington in the context of Endangered Species Act listing for native fish. The relationship between groundwater and two surface water basins was quantified. The project required installing dozens of test and monitoring wells; assessing strategies for wellhead protection; and quantifying the interaction between groundwater and surface water. Production wells with sustainable yields of 2,500 to 5,000 gallons per minute were then installed.
- Implemented various numerical and analytical models for dewatering projects, industrial and municipal projects, and groundwater development projects to evaluate aquifer response and/or contaminant transport under different pumping regimes.

- Designed and conducted a major groundwater resource evaluation for the southern coast of the Mexican state of Nayarit. The project assessed groundwater recharge, saltwater intrusion potential, groundwater capture areas and groundwater pollution potential for the region. The project was presented to top governmental officials including two governors, ministers and technical staff.
- Helped to select the optimal site and then permit Washington's regional landfill in Klickitat County, Washington, after characterizing the hydrogeology various sites; designing, installing, and testing dozens of wells up to 1500 feet deep; conducting geophysical assessments and evaluating multi aspects of the subsurface and surficial hydrology.
- Designed and tested numerous production wells ranging from 1 to 5,000 gpm for various municipalities, counties, state agencies and private water systems in Washington and Alaska, along with review of well designs and testing in Oman, China, Mexico and Thailand.
- Assessed the groundwater resources and development potential of five Washington counties as part of Coordinated Water System and Groundwater Management Plans.
- Assessed the groundwater flow directions, potential impacts of a waste pond on groundwater resources and made recommendations for well and aquifer testing in rural eastern Oregon.
- Evaluated mountain-front recharge and its impacts to coastal aquifers for a USAID project in Oman, Arabian Gulf. The project required extensive field reconnaissance and interaction with groundwater professionals within the country.
- Prepared hydrogeologic characterizations for several gravel mines in western Washington.
- Provided analysis, technical expertise and testimony to the Pollution Control Board of Washington in support of contested water rights for the City of Sequim granted by the Department of Ecology. The water rights were allowed to stand as granted.
- Conducted a Remedial Investigation/Feasibility Study under State "superfund" laws (MTCA) for the cleanup of an industrial site in eastern Washington. The site, which was contaminated with a mixture of heavy and light hydrocarbons, featured a nearby landfill, an automotive wrecking yard, and industrial manufacturing facilities. Groundwater at the site was hydraulically connected to three nearby ponds, complicating the characterization. The site was successfully cleaned up.
- Reviewed agricultural waste monitoring data to assess the impacts of various disposal practices in Western and Eastern Washington.
- Reviewed reports, data and testimony to support a citizen's group in the opposition of a regional landfill that was proposed for a hydrogeologically unsuitable location. After extensive analysis and numerous testimonies including court room, television and EPA Sole Source Aquifer hearings, final permits for the landfill were not issued and the landfill was not constructed.

References available upon request

Bullet Point List for Mark Utting's Testimony at the M3 Water Rights Hearing

I will testify to the following based on my professional analysis of the extensive data collected from the greater M3-Eagle-Star vicinity and beyond:

1. The Pierce Gulch Sand Aquifer is a thick, highly transmissive and extensive regional aquifer that is present beneath the M3 Eagle property and the Boise River Valley area that includes the cities of Eagle, Star and Meridian.

2. The Pierce Gulch Sand Aquifer extends both to the west and north from beneath the North Ada County area to the areas beneath the Payette River Valley where it is either present or merges with and is in hydraulic connection to, other highly transmissive aquifers.

3. Yields from a properly designed and constructed well completed in the Pierce Gulch Sand Aquifer beneath the M3 Eagle property and the greater Eagle-Star vicinity would be in excess of 1,500 gpm and in many cases, 3,000 gpm or more.

4. In general, water levels in the Pierce Gulch Sand Aquifer beneath the greater M3-Eagle-Star vicinity have not declined significantly over the past 30+ years, in spite of the increases in population and in the numbers of supply wells completed in the region.

5. Water within the Pierce Gulch Sand Aquifer beneath the M3 Eagle property originates from a combination of: a) seepage from the Boise River and New York Canal beneath parts of the cities of Boise and Meridian, b) local precipitation, c) applied irrigation water, and probably d) infiltration of surface water from various creeks such as Dry Creek, Willow Creek and other intermittent creeks in the greater M3-Eagle-Star vicinity.

6. The robust recharge to the Pierce Gulch Sand Aquifer would allow the development of 6,535 ac-ft/yr from the Pierce Gulch Sand Aquifer beneath the M3 property, in addition to the water currently being pumping from the greater M3-Eagle-Star vicinity.

7. After 50 years of pumping at the full requested annual average withdrawal of 6,535 ac-ft/yr from the Pierce Gulch Sand Aquifer beneath the M3 property, impacts to existing wells located ½ mile from the M3 property would be on the order of 10 to 15 feet of reduced water level.

8. A water level decline of 10 to 15 feet would not significantly affect the yield of a properly designed and constructed domestic well located ½ mile or more from the M3 property.

9. A portion of the groundwater in the Pierce Gulch Sand Aquifer flows from beneath the Boise River Valley to aquifers beneath the Payette River Valley while a portion remains within aquifers beneath the Boise River Valley.

10. Because the Pierce Gulch Sand Aquifer is continuous and highly transmissive beneath the greater M3-Eagle-Star vicinity, localized water level changes caused by pumping or the onset of major irrigation at valley locations causes small but detectible changes in water

levels in wells completed in portions of the upland area beneath the M3 property. Similarly, pumping or major irrigation in the upland area would cause small but probably detectible changes in water levels in wells completed in the Pierce Gulch Sand Aquifer beneath the Boise River Valley.

32C

Loren Pearson, Hydro Logic, Inc.
Summary of Facts and Opinions
November 26, 2008

- Geophysical logs from test wells at M3 Eagle's property correlate very well based on the similar characteristic shapes and amplitudes of the recorded signals, specifically normal resistivity, natural gamma, and single point resistance.
- A multitude of other wells in the region have nearly identical geophysical signatures to the ones acquired at M3 Eagle, such as United Water Idaho's (UWID) State and Linder Test Wells, UWID State Street Test Well, and many others shown in cross-sections drawn by Hydro Logic, Inc.
- Based on my training and degree in geophysics and more than seven years experience recording and interpreting geophysical logs I have never seen better correlation of signals than the logs from wells shown in our cross-sections.
- I have personally been involved with the on-site drilling, construction, development, and sampling of the M3 Eagle, LLC exploratory test wells and piezometer nests.
- I have personally conducted the borehole geophysical logging for the M3 Eagle, LLC exploratory test wells #1,#2, and #3. I supervised the geophysical logging of M3 Eagle, LLC exploratory test well #4.
- I personally examined the drill-cuttings from the M3 Eagle drilling projects.

32D

CURRICULUM VITAE

University of Idaho

NAME: Osiensky, James L.

DATE: April 8, 2008

RANK OR TITLE: Professor of Hydrogeology

DEPARTMENT: Geological Sciences

OFFICE LOCATION AND CAMPUS ZIP: McClure Hall 301B, 3022 OFFICE PHONE: 208-885-4681
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DATE OF FIRST EMPLOYMENT AT UI: January 1988

DATE OF TENURE: 1996

DATE OF PRESENT RANK OR TITLE: 2002

EDUCATION BEYOND HIGH SCHOOL:

Degrees:

Ph.D., Geology, 1983, University of Idaho, Moscow, Idaho
M.S., Hydrology, 1979, University of Idaho, Moscow, Idaho
B.A., Geology/Chemistry, 1975, Bridgewater State College, Bridgewater, Massachusetts

EXPERIENCE:

Teaching and Research Appointments:

July 2002-present, Professor of Hydrogeology, University of Idaho, Moscow
July 1997-June 2002, Associate Professor of Hydrogeology, University of Idaho, Moscow
January 1988-June 1997, Associate Professor of Hydrogeology, University of Idaho – stationed at Boise State University
June-December 1987, Research Scientist, University of Idaho, Moscow
August 1986-May 1987, Assistant Professor of Hydrogeology, University of Idaho, Moscow
August 1985-May 1986, Assistant Professor of Geology, Washington State University, Pullman, Washington
September 1982-October 1985, Research Scientist, University of Idaho, Moscow
September 1981-September 1982, Research Associate, University of Idaho, Moscow

Non-Academic Employment:

April 1978-August 1979, Hydrogeologist-Reclamation Division of the Montana Department of State Lands
1982-present, Consulting Hydrogeologist

TEACHING ACCOMPLISHMENTS:

Areas of Specialization:

Contaminant Hydrogeology, Hydrogeologic Site Characterization, Hydrogeologic Property Testing, Hydrogeophysical Applications in Hydrogeology, Ground Water Hydraulics

Courses Taught:

Courses offered at the University of Idaho, Moscow from 1997-present:

Applied Hydrogeologic Concepts (HYDR 413/513)
Environmental Hydrogeology (HYDR 412/512)
Ground Water (GEOL 309)
Ground Water (GEOL 409)
Techniques of Ground Water Study (GEOL 410)
Well Hydraulics (HYDR 502)
Ground Water Modeling (HYDR 502)
Contaminant Hydrogeology (HYDR 569)
Computer Applications in Geohydrology (HYDR 577)

Courses offered at Boise State University from 1988-96 [GO xxx = Boise State University; HYDR xxx = University of Idaho]:
Hydrogeology (GO 412), 1988-96
Applied Hydrogeologic Concepts (GO 497), 1990-96
Techniques of Ground Water Study (GO 497) Spring 1988
Ground Water Monitoring (HYDR 502), 1992-94, 1996
Hydrogeology (HYDR 563) Boise to Moscow and Idaho Falls compressed video & tape, 1996
Contaminant Hydrogeology (HYDR 569), Fall 1988, 1989-92, 1994-95
Computer Applications in Geohydrology (HYDR 577), 1989-90, 1993, 1995
Well Hydraulics and Aquifer Testing - Short Courses in Boise and Idaho Falls, Spring 1990
Ground Water Evaluation at a Solid Waste Site - Short courses in Boise, Idaho Falls and Moscow, Spring 1989
Concepts of Contaminant Migration in Saturated Porous Media - Short Courses in Boise and Idaho Falls, Spring 1988

Students Advised:

Undergraduate Students:
Geology/Hydrogeology Option (Senior Theses):
Brad Bennett, 2008 senior thesis
Chad Opatz, 2004 senior thesis
Derek Holom, 2004 senior thesis
Leanne Tumlinson, 2003 senior thesis

Environmental Science (Senior Theses):
Chelsea Sherman, 2007
Jonathon Jacobson, 2007
Jason Sweeney, 2005
John Sugden, 2004
Loy Pehrson, 2004
Nichole Wilson, 2003
Alyssa Douglas, 2002
Justin Nawrocki, 2002
Sarah Scott, 2001
Robin Dunn, 2001
Zachary Garcia, 2001
John Rainey, 2001
Willard Belknap, 2000
Andrea Townley, 1999
Robert Henderson, 1999
Jeremy Cope, 1999
Andrea Dahmen, 1999
Robert Neff, 1999
Lindsay Wichers, 1998

Students Advised (cont.):

Graduate Students, Major Professor, Degree Completed:

Nicole Badon – (UI) MS Hydrology (2007)
Michael McVay – (UI) MS Hydrology (2007)
Hannah Hernandez – (UI) MS Hydrology (2007)
Chad Opatz – (UI) MS Hydrology (2007)
Derek Holom – (UI) MS Hydrology (2006)
Katie Rhode – (UI) MS Hydrology (2006)
Toby Wilson – (UI) MS Hydrology (2006)
Layna Goodman – (UI) MS Hydrology (2006)
Lisa Scott, (UI) MS Hydrology (2005)
Kathryn Dallas – (UI) MS Hydrology (2005)
Terah Douglas – (UI) MS Environmental Science (2005)
Robin Nimmer, (UI) Ph.D. Geology, 2005
Alyssa Douglas, (UI) MS Hydrology, 2004
Dennis Owsley, (UI) MS Hydrology, 2003
Diane Hopster, (UI) MS Hydrology, 2003
Mark Gagnon, (UI) MS Hydrology, 2002
Greg Johnson, (UI) MS Hydrology, 2002
Craig Tesch, (UI) MS Hydrology, 2002
Ryan Molsee, (UI) MS Environmental Science, 2002
Sara West, (UI) MS Hydrology, 2001
James Johnson (UI) MS Hydrology, 2000
Robert Middour (UI) MS Hydrology, 2000
David Baumgarten (BSU) MS Geology 1999
Rick Carlson (BSU) MS Geology, 1999
Scott Urban (UI) MS Hydrology, 1998
Eugene Freeman (UI) MS Hydrology, 1995
Jonathon Hutchings (UI) MS Hydrology, 1995
John Kaminsky (ISU) MS Geology, 1989

Graduate Students, Served on Graduate Committee, Degree Completed:

Lindy Murray, MS Hydrology, 2007
Robert Podgorney, Ph.D. Geology, 2007
Shannon Miller, MS Environmental Science, 2007
Alex Colter, MS Environmental Science, 2007
Scott Struh, MS Hydrology, 2006
Kirandeep Dhami, MS Environmental Science, 2006
Scott Struh, MS Hydrology, 2006
James Heffner, MS Hydrology, 2004
Bethany Nelson, MS Environmental Science, 2003
Edward Teasdale, MS Geology, 2002
Brian Twining, MS Hydrology, 2001
Jungseok Ho, MS Civil Engineering, 2001
Bruce Wakefield, (UI) MS Hydrology 2001
Heidi Bullock, (UI) MS Hydrology, 2000
Scott Miller, (UI) MS Hydrology, 2000
Richard Van Blaricom, (UI) PhD Geology, 1999
Robin Nimmer, (UI) MS Hydrology, 1998
Douglas Bennett, (BSU) MS Geology, 1996
John Smoot, Ph.D (UI) Geology, 1995
Tim Mosko, (UI) MS Hydrology, 1993
Edward Squires (BSU) MS Interdisciplinary Studies, 1992
Fredrick Kirschner, (UI) PhD Geology, 1991
Carlton Parker (BSU) MS Geophysics, 1991

Gary Stevens, (UI) MS Geophysics, 1991
Merion Kendall, (UI) MS Hydrology, 1989

Graduate Students, Major Professor, Current:

Aaren Fiedler, (UI) MS Hydrology in progress

Graduate Students, Serve on Graduate Committee, Current:
Neil Maimer, MS Hydrology in progress
Carolyn T. Moores – MS Hydrology in progress
Joel Hubbell, Ph.D. Geology in progress

Courses Developed:

Hydrogeology (video), Ground Water (video), Contaminant Hydrogeology, Applied Hydrogeologic Concepts, Techniques of Ground Water Study, Computer Applications in Geohydrology, Well Hydraulics, Environmental Hydrogeology, Ground Water Monitoring, plus three, formal short courses.

Continuing Education Credit Classes:

Well Hydraulics and Aquifer Testing. Two-day short courses taught in Boise and Idaho Falls, Idaho, spring semester, 1990.
Ground Water Evaluation at a Solid Waste Site. Two-day short courses taught in Boise, Idaho Falls and Moscow, Idaho, spring semester, 1989.
Concepts of Contaminant Migration in Saturated Porous Media. Two-day short courses taught in Boise and Idaho Falls, Idaho, spring semester, 1988.

SCHOLARSHIP ACCOMPLISHMENTS:

Publications:

Refereed:

Rhode, K. L., J.L. Osiensky and S.M. Miller. 2007. Numerical evaluation of volumetric weighted mean transmissivity estimates in laterally heterogeneous aquifers. Journal of Hydrology, 347, 381-390.

Douglas, A.A., J.L. Osiensky and C.K. Keller. 2007. Carbon-14 dating of ground water in the Palouse Basin of the Columbia river basalts. Journal of Hydrology, 334, 502-512.

Nimmer, R.E., J.L. Osiensky, A.M. Binley, K.F. Sprenke, B.C. Williams. 2007. Electrical resistivity imaging of conductive plume dilution in fractured rock. Hydrogeology Journal, 15, 877-890.

Tumlinson, L.G., J.L. Osiensky, and J.P. Fairley. 2006. Numerical evaluation of pumping well transmissivity estimates in laterally heterogeneous formations. Hydrogeology Journal, 14, 21-30.

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Vadose Zone Science and Technology Alliance (Co-PI with Roy Mink and others) Bechtel, 2000, $396,259.

Moscow, Idaho Area Source Water Assessment Delineations (Principal Investigator) Idaho Department of Environmental Quality, 2000, $23,041.

Graduate Student Support (PI) Idaho State Board of Education through the University of Idaho Environmental Science Program, 2000, $12,000.

Graduate Student Support (Co-PI with Scott Wood) Idaho State Board of Education through the University of Idaho Environmental Science Program, 2000, $12,000.

Technology Incentive Grant (Co-PI with Margrit Von Braun and others) Idaho State Board of Education, 2000, $311,407 (continued from 1999)

Technology Incentive Grant (Co-PI with Margrit Von Braun and others) Idaho State Board of Education, 2000, $97,000 (2-years).

Evaluation of Hydrostratigraphic Conditions in the Palouse Basin (Principal Investigator 50% with Kent Keller) PBAC, 2000, $187,075 (continued from 1999).

Remediation of the Sweet Ave. Ground Water Plume (Principal Investigator) EnviroSafe Services of Idaho, Inc., 1999, $20,000.

Nonpoint Source Control (Co-PI with Roy Mink) USEPA 319 Grant, 1999, $167,699.

Vadose Zone Science and Technology Alliance (Co-PI with Roy Mink and others) Lockheed, 1999, $312,459.

Technology Incentive Grant (Co-PI with Margrit Von Braun and others) Idaho State Board of Education, 1999, $311,407 (3-years)

Evaluation of Hydrostratigraphic Conditions in the Palouse Basin (Principal Investigator 50% with Kent Keller) PBAC, 1999, $187,075 (3-years).

Snake River Plain Water Quality Demonstration Project - Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1998, $78,640.

Snake River Plain Water Quality Demonstration Project - Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1997, $77,750.

Treasure Valley Hydrologic Project (Principal Investigator) – Idaho Department of Water Resources, 1996, $138,746.

Snake River Plain Water Quality Demonstration Project—Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1996, $79,933.

Snake River Plain Water Quality Demonstration Project—Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1995, $68,607.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator- 50% with John Hammel) Idaho Eastern Oregon Onion Committee, 1995, $4,500.

Snake River Plain Water Quality Demonstration Project--Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1994, $73,684.

EnviroSafe Services of Idaho, Inc., 1994, $6,000.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator- 50% with John Hammel) Idaho Eastern Oregon Onion Committee, 1994, $4,500.

Snake River Plain Water Quality Demonstration Project--Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1993, $55,006.

Field Investigation of Landfill Disposal of Cull Onions (Co-principal Investigator- 50% with John Hammel) Idaho Eastern Oregon Onion Committee, 1993, $4,500.

Ground Water Vulnerability Mapping Project Idaho Division of Environmental Quality through the Idaho Water Resources Research Institute, 1993, $9,600.

Snake River Plain Water Quality Demonstration Project -- Ground Water Monitoring (Principal Investigator) USEPA 319 National Monitoring Program, 1992, $102,568.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator) Idaho Eastern Oregon Onion Committee, 1992, $14,300.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator- 50% with John Hammel) Center for Applied Agricultural Research - Oregon Department of Agriculture, 1992, $8,960.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator- 50% with John Hammel) Idaho Water Resources Research Institute, 1992, $10,257.

Comprehensive Groundwater Study of the Boise Municipal Supply -Phase III, Computer Simulation Co-PI with Spencer Wood) Boise Water Corporation, 1992, $19,926.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator) Idaho Eastern Oregon Onion Committee, 1991, $18,230.

Field Investigation of Landfill Disposal of Cull Onions (Principal Investigator- 50% with John Hammel) Center for Applied Agricultural Research - Oregon Department of Agriculture, 1991, $15,970.

Municipal Groundwater Supply for the Boise, Idaho Area: Phase II, Testing to Determine Aquifer Parameters, Vertical Hydraulic Conductivity, Aquifer Conductivity and Leakage (Investigator with Spencer Wood) Idaho Water Resources Research Institute, 1991, $11,605.

Municipal Groundwater Supply for the Boise, Idaho Area: Phase II, Testing to Determine Aquifer Parameters, Vertical Hydraulic Conductivity, Aquifer Conductivity and Leakage (Investigator with Spencer Wood) Boise Water Corporation, 1991, $38,806.

Municipal Groundwater Supply of the Boise, Idaho Area: Phase I, Geologic Framework, Delineation of Aquifers and Production, Preliminary Testing for Aquifer Parameters (Investigator with Spencer Wood) Idaho Water Resources Research Institute, 1990, $11,102.

Municipal Groundwater Supply of the Boise, Idaho Area: Phase I, Geologic Framework, Delineation of Aquifers and Production, Preliminary Testing for Aquifer Parameters (Investigator with Spencer Wood) Boise Water Corporation, 1990, $30,588.

Development of an Improved Method to Evaluate Contaminant Migration in a Fluvial Aquifer (Principal Investigator) Idaho State Board of Education, 1990, $30,800.

Analysis of Contaminant Migration in an Aquifer of Fluvial Origin (Principal Investigator) Idaho State Board of Education Matching Grant, 1989, $39,100.

SERVICE:

Major Committee Assignments:

Geological Sciences Graduate Admissions Committee (Chair), and Graduate Student Coordinator
Geological Sciences Faculty Annual Review Committee
Geological Engineering Program Review Committee
Geological Engineering Curriculum Committee
Geological Sciences Curriculum Committee
COMER computer committee
Geological Sciences Graduate Admissions Committee
Tenure and Promotions Guideline Committee
COMER Hydrology/Hydrogeology Program Development Committee
Environmental Sciences Program Review Committee
Hydrogeology Search Committee
Geological Sciences Tenure and Promotion Committee
Geological Sciences Graduate Admissions Coordinator

Professional and Scholarly Organizations:

American Geophysical Union
National Ground Water Association
International Association of Hydrogeologists

Community Service:

State of Idaho Solid Waste Advisory Committee
State of Idaho Solid Waste Technical Advisory Committee
Treasure Valley Hydrologic Project Technical Advisory Committee
State of Idaho Ground Water Quality Monitoring Technical Committee
Agricultural Ground Water Coordination Committee

PROFESSIONAL DEVELOPMENT:

Scholarship:

Environmental & Subsurface Science Symposium, September 2006, Idaho Falls, ID.
AGU Fall Meeting, December 2006.
Palouse Basin Water Summit, October 2006.
Groundwater Under The Pacific Northwest: Integrating Research, Policy and Education, November 2-3, 2005, Stevenson, WA.
AGU Fall meeting, December 5-9, San Francisco, CA.
Palouse Basin Water Summit, Oct. 6-7, Moscow, ID.
4th Symposium on the Hydrogeology of Washington State, Tacoma, WA, April 8-10, 2003.
Symposium of Applied Geophysics to Environmental and Engineering Problems, Environmental and Engineering Geophysical Society, April 6-9, 2003, San Antonio.
Unsaturated Zone Interest Group Meeting, USGS, USDOE and University of Idaho. July 30-August 2, 2001, Idaho Falls.
Symposium of Applied Geophysics to Environmental and Engineering Problems, Environmental and Engineering Geophysical Society, March 4-7, 2001, Denver.
Eighth National Nonpoint-Source Monitoring Workshop, Sept. 11-14, 2000, Hartford, Connecticut.
Ninth Annual Nonpoint Water Quality Monitoring Results Workshop, January 12-14, 1999, Boise, Idaho,.
National Ground Water Association 50th Anniversary National Convention and Exposition, December 13-16, 1998, Las Vegas, Nevada.
Sixth National Nonpoint-Source Monitoring Workshop, September 21-24, 1998, Cedar Rapids, Iowa.
Seventh Annual Nonpoint Source Water Quality Monitoring Results Workshop, January 7-9, 1997, Boise, Idaho.
National Watershed Water Quality Project Symposium, September 22-26, 1997, Washington, D.C.
Pacific Northwest Section of the American Water Works Association, May 7, 1997, Boise, Idaho.
Connections'97: Ground Water in the Rocky Mountain Region, September, 1997, Boise, Idaho
Fourth National Nonpoint Source Watershed Projects Workshop, September 16-20, Harrisburg, PA.
Symposium of Applied Geophysics to Environmental and Engineering Problems, Environmental and Engineering Geophysical Society, April 23-26, 1995, Orlando, Florida.
Connections: Ground Water in Idaho, Ground Water Technical Workshop, March 9-10, 1995, Boise, Idaho.
Fifth Annual Nonpoint Source Water Quality Monitoring Results Workshop. Jan 3-5, 1995, Boise, Idaho.
Idaho Regional Conference on Hazardous Wastes & Materials, May 3-4, 1994, Boise, Idaho.
Symposium on Engineering Geology and Geotechnical Engineering, March 23-25, 1994, Boise, Idaho,
National Soil Science Society of America Meeting, November, 1993, Cincinnati, Ohio,.
Ground Water Quality Technical Workshop, Feb 11-12, 1993, Boise, Idaho,.
Hazardous Waste: Issues, Problems, and Solutions, Idaho Water Resources Research Institute, May 21-22, 1990, Boise, Idaho.
Third National Symposium on Aquifer Restoration and Ground Water Monitoring, NWWA, May, 1983, Columbus, Ohio.
Second National Symposium on Aquifer Restoration and Ground water Monitoring, NWWA, May, 1982, Columbus, Ohio.

Outreach:

1988-97 University of Idaho Hydrogeologist – on location in the Department of Geosciences at Boise State

University. Two University of Idaho graduate hydrogeology courses (including video) offered per year and two undergraduate Boise State University courses offered per year. Other duties included short courses, visiting lectures, advising graduate students at all three universities, and collaborative research with faculty at Boise State University and Idaho State University in Pocatello, Idaho.

Summary of Comments on Technical Analyses

Dr. James L. Osiensky

University of Idaho Department of Geological Sciences
November 25, 2008

1) This outline summarizes my comments, as of November 25, 2008, regarding certain hydrogeological studies relevant to Water Right Application 63-32573 filed by M3 Eagle LLC.

2) I am familiar with the December 2007 M.S. Hydrology thesis of my former graduate student advisee, Stacey Douglas, entitled "Development of a Numerical Ground Water Flow Model for the M3 Eagle Development Area Near Eagle, Idaho." I was among those advising Ms. Douglas throughout her investigation on this project, and I was her Major Professor. The model development was carried out independently (to the degree possible) from efforts being undertaken in this same area by Hydro Logic, Inc. (HLI) and the Idaho Department of Water Resources (IDWR). However, the modeling product is based primarily on information provided by HLI during the course of the modeling investigation. Ms. Douglas competently evaluated geologic and hydraulic evidence concerning the Pierce Gulch Sand Aquifer beneath the Eagle-Star area in north Ada County, Idaho. Conclusions presented by Ms. Douglas support the conceptual model of the aquifer that HLI described in the May 4, 2007 report entitled "M3 Eagle Regional Hydrogeologic Characterization, North Ada, Canyon, and Gem Counties, Idaho Year-One Progress Report" (HLI, 2007 Report). To my knowledge, IDWR has not developed any data or report conflicting with or questioning either the thesis or the HLI, 2007 Report.

2) I have thoroughly reviewed the first and second drafts of HLI's July 4, 2008 "Re-Analysis of 16 Aquifer Tests in the Greater Eagle-Star Area of North Ada County, Idaho". I provided comments and suggestions to HLI, Inc. on both drafts as a peer reviewer.

3) I am familiar with the academic background and professional work of Ed Squires and believe him to be a competent, experienced, and ethical hydrogeologist.

4) I have read and reviewed the HLI, 2007 Report and I have no reason to disagree with its scientific approach, or its conclusions related to the characterization of the Pierce Gulch Sand Aquifer.

5) I believe the Treasure Valley Hydrologic Project's numerical ground water model and water budget are not adequate with respect to the selection of model layers and boundary conditions to accurately simulate ground water flow conditions in the M3 Eagle development area.

6) Based on my review of the information developed by M3 Eagle's hydrogeologists, sufficient evidence was compiled during the HLI, Inc. investigations to support ground water production estimates for the proposed development.

7) Based on my knowledge of the hydrogeological data developed by HLI, I believe the predicted effects and projected drawdowns presented in their work represent reasonable estimates of the effects that the M3 Development will have on the ground water resource systems in the development area.

8) I have reviewed the November 6, 2008 memorandum from Dr. Dale Ralston to Josephine Beeman in which Dr. Ralston states that the HLI, 2007 Report "does not provide specifics relative to locations and characteristics of recharge [to the aquifer] in the Boise River basin or any information relative to locations and characteristics of ground-water discharge [from the aquifer] within the Payette River basin." I concur with these observations. However, I believe that sufficient evidence exists for substantial underflow to the M3 Eagle Development area primarily from the south and east in the Boise River drainage, and that this ground water flows generally to the northwest toward the Payette River drainage.

9) I have reviewed Dr. Ralston's conclusion that "the characterization of the target aquifer system . . . has not been complete enough to support an analysis of impacts from full project development." In my opinion, HLI has collected sufficient information to support conservative estimates of impacts (i.e., projected drawdowns in the Pierce Gulch Sand Aquifer at various distances from identified production well sites.

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Full Name and Title: Dr. Spencer H Wood

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Nationality: USA
Country of Residence: USA
Institution: Dept. of Geosciences, Boise State University
Contact Details: Boise State University, Boise, ID, 83725 USA
TEL: 1-208-344-9854, **MOBILE:** 1-208-860-9410 1-208-426-1651, **FAX:** 1-208-426-4061.
Email: swood@boisestate.edu

PROFILE

Geomorphologist\geologist with extensive research experience in the US and Asia. Current research interests include: 1) the nature of surficial deposits, soils and vegetation – with emphasis on subtropical rainforest ecosystems; 2)Documenting neotectonics, geomorphic evolution and soil chronosequences of northern Thailand; 3) Geophysics and geophysical log expression of lacustrine sedimentary facies and determining continuity and extent of sand bodies important as aquifers and reservoir rocks in the western Snake River Plain; 4) Geologic mapping of southern Idaho using facies mapping, Ar/Ar dating and tephrochronology. Hydrogeology and geothermal resources of southern Idaho.

EDUCATION

1975 California Institute of Technology - Ph.D., Geology
1970 California Institute of Technology - M.S., Geophysics
1964 Colorado School of Mines - Geophysical Engineer

EXPERIENCE

1978- present: Assist., Assoc. ,Full and Emeritus Professor, Geosciences, Boise State University, Idaho
1994-95 and 2005 Visiting Professor: Geological Sciences, Chiang Mai University, Thailand
1978-83 Project Chief. USGS-Engineering Geology/Tectonics Branch (Alaska & Yukon)
1980 Research Geologist, USGS, Mt. St. Helens Observatory Vancouver, Washington
1976-77 Research Geologist--National Center for Earthquake Research, USGS-Menlo Park, California
1976 Visiting Assistant Professor, Quaternary geology, University of Oregon.
1974-76 Instructor in geophysics and geology, Occidental College, Los Angeles, California
1968-74 NSF traineeship, teaching assistant, Geological & Planetary Sciences, Caltech, California
1965-68 Geophysicist, Mobil Oil of Canada, Ltd./Gelsenberg, A.G. - Tripoli, Libya
1965 Jr. Geophysicist, Mobil Producing Netherlands, The Hague, Netherlands
1964-65 Seismological Engineer, Mobil Oil Geophysical Services, Dallas, Texas

PEER-REVIEWED JOURNALS AND MONOGRAPHS

Wood, S.H. and Ziegler, A.D. 2007. Floodplain sediment from 30-year-recurrence flood in 2005 of the Ping River in northern Thailand. **Hydrology and Earth System Science – Discussions**, v. 4, p. 3839-3868.

Wood, S.H., Ziegler, A.D., and Bundarnsin, T., in press, 2008. Floodplain sedimentation, channel changes and riverbank stratigraphy of the Mekong River area, Chiang Saen, Northern Thailand. submitted to **Geomorphology**. McNamara, J.P., Ziegler, A.D., Wood, S.H., and Vogler, J.B., 2006. Channel head locations with respect to geomorphologic thresholds derived from a digital elevation model: A case from northern Thailand. **Forest Ecology and Management**, 224 (1-2), p. 147-156

Committee on Superfund Site Assessment and Remediation in the Coeur d'Alene River Basin (National Research Council), 2005. **Superfund and Mining Megasites: Lessons from the Coeur d'Alene Basin**. Washington, D.C., National Academies Press, 382 p.

Fenton, C.H., Charusiri, P, and Wood, S.H., 2003, Recent paleoseismic investigations in northern and western Thailand: **Annals of Geophysics**, v. 46, p. 957-981.

Wood, S.H., and Clemens, D.M., 2002. Geologic and tectonic history of the western Snake River Plain, Oregon and Idaho: *in* Bonnichsen, Bill, White, C.M., and McCurry, M. (eds.) , Tectonic and magmatic evolution of the Snake River Plain Volcanic Province. **Idaho Geological Survey Bulletin** 30, 69-103.

Meyer, G.A., Pierce, J.L., Wood, S.H., and Jull, A. J. T., 2001, Fire, storms, and erosional events in the Idaho batholith: **Hydrological Processes**, v. 15, p. 3025-3038.

Wood, S.H., 1994, Seismic expression and significance of a lacustrine delta in Neogene deposits of the western Snake River Plain, Idaho: **American Association of Petroleum Geologists Bulletin**, v. 78, p. 102-121.

Clemens, D.M. and Wood, S.H., 1993, Late Cenozoic volcanic stratigraphy and geochronology of the Mount Bennett Hills, central Snake River Plain, Idaho: **Isochron/ West**, v.60, p. 3-14.

_____, 1993, Timing of volcanism, sedimentation, and tectonics of the Boise foothills, northeastern margin of the western Snake River Plain, Ada County, Idaho:**Isochron/West**, v.59, p. 3-10.

Wood, S.H., Doukas, M.P., Shipley, S., Waitt, R.B., Jr., Sarna-Wojcicki, A.J., Vallance, J.W.,and Eggers, A., (in press), The July 22, 1980 eruption of Mount St. Helens: Characteristics of the eruption and airfall tephra: **USGS Professional Paper 1251**, 20p.

Wood, S.H.,1989, Silicic volcanic rocks and structure of the western Mount Bennett Hills and adjacent Snake River Plain, Idaho: in Ruebelmann, K.L. (ed.), Snake River Plain-Yellowstone volcanic province, **Guidebook T305, International Geological Congress**, American Geophysical Union, Washington D. C., p. 69-77.

Wood, S.H. and Burnham, W.L., 1987, Geologic framework of the Boise Warm Springs geothermal area, Idaho: in Buess, S.S., ed., **Geological Society of America, Centennial Field Guide**, v.2, p.117-122.

Wood, S.H., Wurts, C., Lane, T., Ballenger, N., Shaleen, M., Totorica, D., 1985, The Borah Peak, Idaho earthquake of October 28, 1983 - Hydrologic effects: **Earthquake Spectra**, v.2, p.127-150.

Castle, R.O., Elliott, M.R., Church, J.P., and Wood, S.H., 1984,The evolution of the southern California uplift, 1955 through 1976: **USGS Professional Paper 1342**, 136p., 16 plates.

Sarna-Wojcicki, A.M., Shipley, S., Waitt, R.B., Dzurizin, D., and Wood, S.H., 1981, Areal distribution, thickness, mass, volume, and grain-size of air-fall ash from the six major eruptions of 1980, in Lipman, P.W., and Mullineaux, D.R., eds. The 1980 eruptions of Mount St. Helens, Washington: **USGS Professional Paper 1250**, p.577-600.

Waitt, R.B., Hansen, V.L., Sarna-Wojcikci, A.M., and Wood, S.H., 1981, Proximal air-fall deposits of eruptions between May 18 and August 7, 1980, stratigraphy and field sedimentology: in Lipman, P.W., and Mullineaux, D.R., eds. The 1980 eruptions of Mount St. Helens, Washington: **USGS Professional Paper 1250**, p.617-628.

Wilson, M.E., and Wood, S.H., 1980, Tectonic tilt rates derived from lake level measurements, Salton Sea, California: **Science**, v. 207, p. 183-186.

Wood, S. H., and Elliot, M.R., 1979, Early 20th-Century uplift of the northern Peninsular Ranges province of southern California: **Tectonophysics**, 52, 249-265.

Wood, S.H., 1977, Distribution, correlation, and radiocarbon dating of late Holocene tephra, Mono and Inyo Craters, eastern California: **Geological Society of America Bulletin**, v. 88, p. 89-95.

RECENT ABSTRACTS OF MEETING PRESENTATIONS (last 5 years)

Wood, S.H. and Ziegler, A.D., 2007. Floodplain sediment from a 30-year recurrence flood in 2005 on the Ping River in Northern Thailand: (abs.) American Geophysical Union, Annual Fall Meeting, San Francisco.

Wood, S.H., and Squires, E., 2007. Geology and hydrogeology of Boise, Idaho area (abs). Annual meeting, Pacific Division, American Association for the Advancement of Science.

Wood, S.H., Ziegler, A.D., and Bundarnsin, T., 2005. Riverbank stratigraphy and channel changes, Mekong River, Chiang Saen, Northern Thailand (abs). Abstracts Volume, 6th International Conference on Geomorphology, Zaragoza, Spain, September, 2005. p. 479.

Rothwell, E.L., and Wood, S.H., 2004, Characterization of gravel bars of the Mekong River near the Golden Triangle of northern Thailand: GSA Abstracts with programs,

Forester, C. S., Wood, S.H., and Nash, B.P.,2004, Geologic mapping and tephrochronology of sediments associated with the Miocene Weiser Basalt and Payette Formation in Holland Gulch, northwestern margin of the western Snake River Plain, Idaho. Geological Society of America Abstracts with programs (Cordilleran/Rocky Mountain section).

Sander, K.T., and Wood, S.H., 2004. The Poison Creek Formation: A coarse fan-delta facies in the Miocene Chalk Hills Formation of the western Snake River Plain, Idaho. Geological Society of America Abstracts with programs (Cordilleran/Rocky Mountain section).

Squires, E., Liberty, L.M., and Wood, S.H., 2003, Hydrostratigraphic characterization and Quaternary/Neogene history of Boise and Meridian, Idaho using drill-cuttings analysis, borehole geophysical logs, and high-resolution seismic images: Geological Society of America Abstracts with programs, v. 35, no. 6, p. 571.

Wood, S.H., and Bundarnsin, T., 2003, Mekong River floodplain stratigraphy and radiocarbon dating beneath the 14th Century city of Chiang Saen, Golden Triangle of northern Thailand: Geological Society of America Abstracts with programs, v. 35, no. 6, p. 400.

Udphuay, S., Liberty, L.M., and Wood, S.H., 2003, Outcrop-scale imaging of lacustrine delta sediments using ground-penetrating radar and seismic methods: Annual Meeting, Society of Exploration Geophysicists (Extended Abstracts Volume, Near-surface geophysics, NSG P-1), p. 1468-1471.

Udphuay, S., Liberty, L.M., and Wood, S.H., 2003, Outcrop-scale imaging of lacustrine delta sediments using ground-penetrating radar and seismic methods: Geological Society of America Abstracts with programs, v. 35, no. 6, p. 172

Wood, S.H., McNamara, J.P., and Ziegler, A, 2003, Channel initiation on slopes and roads in a tropical montane watershed in northern Thailand: EOS Trans. of the American Geophysical Union, 84, p. 46.

Wood, S. H., 2003, Quaternary strike-slip faulting and basalt volcanism in northernmost Thailand and adjacent Laos (abs.): Proceedings, International Symposium on Pacific Neogene Stratigraphy, Chiang Mai University, Thailand.

Wood, S.H., 2001, Slip rate estimate from offset streams, valley volumes, and denudation rate: Mae Chan fault, northern Thailand (abs), EOS, Transactions of the American Geophysical Union, v. 82, no. 47, Fall Meeting Supplement, p. F392.

Wood, S.H., 2001, Mae Chan fault, northern Thailand: Offset streams and Quaternary fault activity: International Association of Seismology and Physics of the Earth's Interior. Joint Scientific Assembly, Hanoi, Vietnam.

Liberty, L. M., Wood, S.H., and Barrash, W., 2001. Seismic reflection imaging of hydrostratigraphic facies in Boise: A tale of three scales. 71st Annual International Meeting: Society of Exploration Geophysicists (extended abstracts), *pp. 1393-1396*,

Wood, S.H., Liberty, L., and Squires, E., 2000. Geophysical signatures of lacustrine facies: Experiences from Hydrogeologic Studies of temperate Neogene Lake Idaho sediments and aquifers, U.S. A., Abstract of the General Symposium, 3-1, Lacustrine Sedimentation, 31st International Geological Congress, Rio de Janeiro, Brazil, August 6 - 11, 2000.

Wood, S.H., McNamara, J.P., and Childs, D.M.,2000, Channel Morphology and bed Material of the Riffle-pool Reach of Rio Platano Bioreserve, Northeastern Honduras: a Pristine Central-American mountainous rainforest watershed (poster). American Geophysical Union, 2000 Fall Meeting .

Smith, S. C., Northrup, C.J., and Wood, S.H., 1999, The Rush Peak fault zone, Cuddy Mountains, western Idaho: Evidence for sinistral-oblique late Quaternary movement: : Geological Society of American Abstracts with programs: Annual Meeting, Denver, Oct. 1999.

Wood, S.H., and Meyer, G.A., 1999, Contrasting sediment transport events generated by rain on snow and convective storms on burned basins in the Idaho batholith: Geological Society of American Abstracts with programs: Annual Meeting, Denver, Oct. 1999.

SELECTED PROCEEDINGS, FIELD-TRIP GUIDES, REPORTS

Wood, S.H., Singharajwarapan, F.S., Bundarnsin, T, and Rothwell, E., 2004. Mae Sai Basin and Wiang Nong Lom: Radiocarbon dating and relation to the active strike-slip Mae Chan fault, Northern Thailand. *in* Rieb, S., Wongpornchai, P., and Chantraprasert, S. (eds.), Proceedings of the International Conference on Applied Geophysics, November, 2004, Chiang Mai, Thailand, p. 60-69.

Wood, S.H., Liberty, L.M., Singharajwarapan, F.S., Bundarnsin, T, and Rothwell, E., 2004. Feasibility of gradient magnetometer surveys of buried brick structures at 13th Century (C.E.) Wiang Kum Kam, Chiang Mai Province, Thailand. *in* Rieb, S., Wongpornchai, P., and Chantraprasert, S. (eds.), Proceedings of the International Conference on Applied Geophysics, November, 2004, Chiang Mai, Thailand, p. 22-30.

Wood, S.H., 2004. Geology across and under the western Snake River Plain, Idaho (Chapter 2). *in* Haller, K.M. and Wood, S.H.(eds.), Geological Field trips in southern Idaho, eastern Oregon, and Northern Nevada. U. S. Geological Survey Open-File Report 2004-1222. p. 84-107. Internet http://pubs.usgs.gov/of/2004/1222.

Rothwell, E.L., and Wood, S.H. 2004. Terminal moraine remnants of the Trail Creek glacier northeast of Sun Valley, Idaho (Chapter 6). *in* Haller, K.M. and Wood, S.H. (eds.), Geological Field trips in southern Idaho, eastern Oregon, and Northern Nevada. U. S. Geological Survey Open-File Report 2004-1222. p. 78-83. Internet http://pubs.usgs.gov/of/2004/1222.

Squires, E., and Wood, S.H., 2001, Stratigraphic studies of the Boise (Idaho) aquifer using borehole geophysical logs with an emphasis on facies identification of sand aquifers: Report to the Idaho Department of Water Resources (Treasure Valley Hydrologic Study), 17 p.

Zollweg, J., and Wood, S.H., 1995. Late Cenozoic faulting and maximum credible earthquake assessment: Hells Canyon hydroelectric facilities of Idaho Power Company. Contract report from Boise State University for Idaho Power Company, Boise, Idaho. 71 p.

Wood, S.H. and Stine, S. 1984. Stop 2. Mono Lake County Park at Dechambeau Creek.*in* Bailey, R.A., Harp, E.L., Keefer, D.K., Bennett, M.J., Miller, C.D., Wood, S.H., and Stine, S.: Mono Craters, Long Valley Caldera: Seismicity, volcanism, and engineering geology (Field Trip 11): in Linz, J., Jr. (ed.) Western Geological Excursions, v. 2. ,Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno. p. 37-42.

Wood, S.H., 1984. Obsidian hydration-rind dating of the Mono Craters. *in* Bailey, R.A., Harp, E.L., Keefer, D.K., Bennett, M.J., Miller, C.D., Wood, S.H., and Stine, S.: Mono Craters, Long Valley Caldera: Seismicity, volcanism, and engineering geology (Field Trip 11): in Linz, J., Jr. (ed.) Western Geological Excursions, v. 2. Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno. p. 83-87.

Wood, S.H., and Anderson, J.E., 1981. Chapter 2 – Geology. in Mitchell, J.C. (ed.) Geological, hydrological, geochemical and geophysical investigations of the Nampa-Caldwell and adjacent areas, southwestern Idaho. Geothermal Investigations in Idaho (Part 11). Idaho Department of Water Resources Water Information Bulletin 30. p. 9-31.

RECENT COMMITTEE SERVICE (NON-UNIVERSITY)

National Academy of Sciences, Committee on Superfund Site Assessment and Remediation in the Coeur d'Alene River Basin (National Research Council), 2004-5.

Idaho Department of Water Resources, Technical Committee – Treasure Valley Hydrologic Study 1996-2004.

City of Boise Geothermal Project, Technical Advisory Committee, 1994-96

CURRENT PROJECT PROPOSALS (PENDING)

U.S. Ambassador's Fund for Cultural Preservation: Project title: Artifacts related to the legendary Iron-Age Yonok civilization, Chiang Saen area, northern Thailand: Cataloging, classification, and age-dating of existing collections. (w/ N. Ruangrunsri, proposed project director) Proposal submitted by the Chiang Rai Rajabaht University ($19,890) (submitted February 28, 2006).

Asia-Pacific Network for Global Change Research: Sediment dynamics and down-stream linkages in tropical streams as affected by projected land-cover/land-use and climatic change (Project leader: A. D. Ziegler, University of Hawaii) ($133,425). (pending)

JOURNAL ARTICLE and PROPOSAL REVIEWS

2005 – Forest Ecology and Management
2005 – Geological Society of America Bulletin
2004 – Journal of Paleolimnology
2004 – Geophysical Research Letters
2004 – Proposals – U.S. Civilian Research and Development Foundation

S.H. Wood's Testimony Outline – Nov. 26, 2008
M3 Eagle, LLC Water Right Permit Hearing, week of Jan. 13, 2009

Facts Known

1. We have known for 15 years that a sand-delta system, typically 200 to 600 feet thick, forms a major aquifer in the western Snake River Plain west of Boise, in the Caldwell-Lake Lowell area, and west to the Payette area – published in Wood (1994). At that time it was identified from seismic data near Caldwell and a distinctive funnel-shaped geophysical log using the petroleum-industry standard display of the gamma and the open-hole resistivity logs. This same log pattern is in logs of the Champlin Petroleum well near Lake Lowell, the El Paso Natural Gas well – 7 miles north of Caldwell, and several wells in the Payette area.

2. Correlation of that subsurface delta system to the Pierce Gulch Sand (a coarse-grained sand exposed in the western Boise foothills) is shown in cross-section by Squires and Wood (2001, Figure 10), Wood and Clemens (2002, Figure 16), and Wood (2004, Figure 24).

3. That same geophysical-log character is in a number of United Water Idaho wells and in the M3 Eagle test wells, where the aquifer is at least 200-ft of medium and coarse-grained sand. Farther to east, in the Caldwell area the sand is finer, being farther out in the lake basin.

4. Geophysical logs of the M3-Eagle wells show that Pierce Gulch Sand underlies the southwestern part of the M3-Eagle property. The aquifer dips southwest about 200 feet per mile. The aquifer here is 200-300-ft thick, and composed of medium to coarse permeable sand.

5. Many wells constructed to modern municipal-well standards with 100-ft of screens in the Pierce Gulch Sand Aquifer have high production rates and high specific capacity (up to 3,000 gpm, and 17 gpm/ft). Examples are the UWID Floating Feather well, City of Star Sewer and Water District Supply Well #3, and the Eagle Field Well

6. Surface geology in the M3 Eagle area is poorly exposed, and the sedimentary section lacks any distinctive marker beds. To the north at Freezeout Hill and along Willow Creek are the distinctive oolite beds among sands of the Terteling Springs Formation which underlies the Pierce Gulch Sand. I have examined the exposed sections along the South Side Canal, and believe that the Terteling Springs Formation extends west about 1.5 miles, beyond which is the younger Pierce Gulch Sand, dropped to an elevation below the Terteling Springs Formation, by faulting along a NW-trending fault and by dip. This concept is supported by the occurrence of a thick volcanic ash bed in the sedimentary section exposed in bluffs at 2600-ft elevation between South Slope School and Bramwell, 5 miles west of Freezeout Hill. This same volcanic ash occurs within the younger fluvial

and deltaic sands in the north side bluffs about 22 miles to the northwest, on the bluffs north of New Plymouth.

7. Because geology and faulting are obscure at the surface in the M3 Eagle area, magnetometer profiles were run to identify locations and trends of subsurface faults (Wood, 2007). The technique only detects faulted basalt beneath the sedimentary section, but it should show location of significant shifts in the subsurface strata. The profiles clearly define the location of the north-west trending "West Boise-Eagle fault" originally identified by Wood and Anderson (1981). The profiles also show another down-to-southwest fault near the mouth of Big Gulch that possibly projects NW and is the suspected fault mentioned in item 5 above. It is not know what effect these faults have on the Pierce Gulch Sand Aquifer performance. There may be good continuity across the fault if sand is faulted against sand.

Opinions Held

1. Based on review of available data, the southwestern part of the M3 Eagle property is underlain by a saturated and productive sand aquifer 200-300-ft thick, the top of which is at a depth of 200 to 300 feet. This aquifer is correctly correlated by Hydro Logic, Inc. as the down-faulted and down-dip equivalent of the Pierce Gulch Sand exposed in the western Boise foothills.

2. The geologic framework of the Pierce Gulch Sand Aquifer, and the obvious difference in elevation between the Boise River and the Payette River Valleys indicates that the subsurface groundwater flow should be directed toward the north-northwest beneath the southwestern part of the M3 properties. This flow direction is strongly supported by extensive measurements of the piezometric surface by Hydro Logic, Inc.

3. Available geophysical logs indicate the Pierce Gulch Sand Aquifer dips downward to the southwest beneath the M3 Eagle, City of Eagle, and City of Star area, about 100 ft per mile, thus the aquifer becomes deeper. Therefore productive wells are completed at deeper levels, at sites further southwest into the sedimentary basin. This dip and basin configuration was constructed from sparse data available in 1997 by Wood (1997) for the TVHP, and although the dip was correct, the predicted depths to the base of the aquifer were too shallow. Subsequently, new wells with good geophysical logs by M3 Eagle, City of Eagle, and City of Star have shown the aquifer system is thicker and deeper by about 100 feet over this region.

References

Squires, E., and Wood, S.H., 2001, Stratigraphic studies of the Boise (Idaho) aquifer using borehole geophysical logs with an emphasis on facies identification of sand aquifers: Report to the Idaho Department of Water Resources (**Treasure Valley Hydrologic Study**), 17 p. http://www.idwr.idaho.gov/hydrologic/projects/tvhp-revised/reports.htm

Wood, S.H., and Anderson, J.E., 1981. Chapter 2 – Geology. in Mitchell, J.C. (ed.) Geological, hydrological, geochemical and geophysical investigations of the Nampa-Caldwell and adjacent areas, southwestern Idaho. Geothermal Investigations in Idaho (Part 11). **Idaho Department of**

Water Resources Water Information Bulletin 30. p. 9-31. Internet http://www.idwr.idaho.gov/hydrologic/info/pubs/

Wood, S.H., 1994, Seismic expression and significance of a lacustrine delta in Neogene deposits of the western Snake River Plain, Idaho: **American Association of Petroleum Geologists Bulletin**, v. 78, p. 102-121.

Wood, S.H., 1997. Structure contour map of the top of the mudstone facies, Western Snake River Plain, Idaho. **Contribution to the Treasure Valley Hydrologic Project.** 1:100,000. Internet http://www.idwr.idaho.gov/hydrologic/projects/tvhp-revised/reports.htm

Wood, S.H., and Clemens, D.M., 2002. Geologic and tectonic history of the western Snake River Plain, Oregon and Idaho: *in* Bonnichsen, Bill, White, C.M., and McCurry, M. (eds.) , Tectonic and magmatic evolution of the Snake River Plain Volcanic Province. **Idaho Geological Survey Bulletin** 30, 69-103.

Wood, S.H., 2004. Geology across and under the western Snake River Plain, Idaho (Chapter 2). *in* Haller, K.M. and Wood, S.H.(eds.), Geological Field trips in southern Idaho, eastern Oregon, and Northern Nevada. **U. S. Geological Survey Open-File Report 2004-1222**. p. 84-107. Internet http://pubs.usgs.gov/of/2004/1222.

Wood, S.H., 2007. Qualitative interpretation of magnetic anomalies and progress report on geologic mapping in foothills north of Eagle, Ada and Gem Counties, Idaho. Report prepared for Hydro Logic, Inc., May 20, 2007. 15 p.

EXHIBIT _____32F_____

No Document for this Exhibit

Refer to scanned document:

"Inventory of M3 Eagle Exhibits (as of 8-7-09)"
Document date 10/13/09

32G

Roger Dittus

Outline of Facts and Opinions Pertaining to M3 Eagle Ground Water Studies

November 26, 2008

1. I have attached my CV to this outline.

2. Over the course of approximately the past two years, I have received periodic reports and compiled data from Ed Squires and his staff at Hydro Logic, Inc. (HLI) concerning their ground water investigations relative to the M3 Eagle proposed planned community north of Eagle, Idaho. These reports and data also are available on the North Ada County Project website maintained by the Idaho Department of Water Resources (IDWR).

3. As a professional hydrogeologist employed by United Water Idaho Inc. (United Water), I have been involved for many years in monitoring ground water levels in monitoring and supply wells in the west Boise and foothills areas, for example our dedicated monitoring well at State and Linder and municipal supply wells. We have made data from the State and Linder well available to IDWR and others, including HLI, upon request. Indeed, HLI's principal hydrogeologist, Ed Squires, oversaw the construction of the State and Linder monitoring well, and, when he worked for United Water, was responsible for taking measurements and maintaining the instruments in that well.

4. United Water has operated high capacity wells in the vicinity of Eagle, such as the Floating Feather well and the Redwood Creek well, for several years. These wells have produced significant annual volumes with individual wells pumping at rates up to 3000 gpm. To date, no significant ground water level declines have been observed in these wells, nor is it indicated by other water level data from the general area of which I am aware. The continuing shallow or artesian area water levels in the presence of the many municipal, irrigation, and domestic wells indicates that the Pierce Gulch Sand Aquifer is capable of supplying the water requested in M3 Eagle's application without causing unreasonable drawdown in surrounding wells.

5. I have not seen a water right application that has received as much study or analysis as M3 Eagle has carried out in this case.

6. I have known Mr. Squires for over fifteen years. In my opinion he is a competent and ethical hydrogeologist. His work always has met the highest standards of our profession. His and his colleagues' work for M3 Eagle in this case is highly valuable and extraordinarily thorough.

7. I have reviewed HLI's May 2007 Report characterizing the Pierce Gulch Sand Aquifer, HLI's July 2008 Re-Analysis of 16 Aquifer Tests report, water level contour maps, and several composite cross sections HLI compiled from geophysical data. Based on my review, these materials all properly reach the same correct conclusions: the Pierce Gulch Sand Aquifer covers a large area extending into portions of three counties; it contains a large amount of water, much of which flows into the Payette River drainage; it receives recharge from a large area generally under the Boise River and its stream and canal tributaries. In my opinion, it is unlikely that the proposed development of ground water from the aquifer by M3 Eagle will have a material impact on overall aquifer levels.

ROGER D. DITTUS
2811 Gem Street, Boise Idaho, 83705 (208) 388-4629

Education: BS Geology, Boise State University, 1991

Graduate-Level Course Work (Boise State University):
Exploration Geophysical Well Logging, Contaminant Hydrogeology, Hazardous Waste Management, Applied Hydrogeologic Concepts, Computer Applications in Geohydrology, Environmental Geology, Geophysical Methods

Employment Experience:

1995-Present Hydrogeologist, (P.G. March 2001), United Water Idaho Inc, Boise Idaho
Management of successful Aquifer Storage and Recovery (ASR) projects for mitigating uranium, and hardness
Management of successful aquifer-conditioning project for controlling manganese in groundwater
Managed pilot projects for in situ remediation of ammonia and ASR for arsenic mitigation
Conduct pumping tests and interpret test data for municipal wells
Geophysical logging/ log interpretation and downhole camera operation(1995-1999)
Planning and supervise of well rehabilitation projects
Water rights filings and application support

1992-1995 Geology Technician, Boise State University, Boise ID.
Collected aquifer test data, maintained water-level recorders and database of monitoring wells in Southeast Boise Groundwater Mangaement Area, Sampled and analyzed borehole cuttings for aquifer framework studies
Geology Lab Instructor, Introduction to Geology at BSU

Other Positions:

Internship, BSU, Lithologic analysis of well-cuttings for basin analysis
Jewell Engineering, Boise ID. Draftsman – Commercial electrical plans
Technical Illustrator, Continental Data Graphics, Culver City, CA.
Aircraft assembly drawing, cameraman, incorporation of engineering orders

Additional Information:

- Member of North Ada County Technical Advisory Group (2007-present)
- Member of Groundwater Technical Advisory Committee for Negotiated Rulemaking for revision of Idaho Administrative Well Construction Rules
- American Water Works Association member
- 2008 American Water Works Association PNW Section Conference Presenter: "Converting a Supply well into an ASR well: Case Histories"
- Member of Treasure Valley Hydrologic Project Technical Advisory Committee (2000-2003).
- Member of Southeast Boise Groundwater Management Area Advisory Committee (2000-present)

- 2003 American Water Works Association PNW Section Conference Presenter: "Aquifer Conditioning with ASR in Boise, Idaho"
- 1997 American Water Works Association PNW Section Pre-Conference Seminar Presenter: "Implications of Well-Construction To Aquifer Water-Quality: Some Observations"
- Principle author: "Supporting Data for Groundwater Conditions and Aquifer Testing of the Tenmile Ridge Area of South Boise, Ada County, Idaho" 1998, by R Dittus, J. Allred, and E. Squires.
- Principle author: Hydrogeology, Geochemistry, and Well Construction of the Treasure Valley Hydrologic Project, Monitoring Well #1, Ada County, Idaho", 1999, by R Dittus, J. Allred, and E. Squires.
- Co- author: "Groundwater Conditions and Hydraulic Testing of the Boise-Fan Aquifer, Southeast Boise River Valley, Ada County, Idaho" ,1993 by E. Squires, S. H. Wood, J.L. Osiensky, and R. Dittus

References: Available on request

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PACIFIC GROUNDWATER GROUP

PETER N. SCHWARTZMAN
Associate Hydrogeologist

EDUCATION

M.Sc. Hydrology (Hydrogeology), 1989
University of Arizona

B.A. Geology (Environmental Studies)
1984 Magna Cum Laude
University of Pennsylvania

PROFESSIONAL SOCIETIES

Washington Hydrologic Society
(Co-Founder)

National Society of Ground Water
Scientists and Engineers

PROFESSIONAL EXPERIENCE

Mr. Schwartzman has been involved in local hydrogeologic site assessments, regional groundwater resource evaluations, water-supply development, and contaminant hydrology for over nineteen years. His educational background in geology and hydrology is complimented by project experience in such areas as: characterization and computer modeling of groundwater flow systems; assessment of stream-aquifer interaction and saltwater intrusion; design/installation of water-supply and monitoring wells; aquifer testing; stream gauging; and contaminant delineation. Mr. Schwartzman has developed a variety of regional and local groundwater flow models, and is proficient in many computer applications to hydrogeology. He has modeled groundwater recharge based on climatic, soils and land-use factors; infiltration of recharge through the unsaturated zone; and a wide variety of saturated flow systems. In addition, he has co-instructed groundwater modeling courses and has contributed to the development of groundwater modeling software

REPRESENTATIVE PROJECT EXPERIENCE

Groundwater Modeling

- Developed a groundwater flow model of the Vancouver Lake lowland in Clark County, Washington to evaluate water supply capacity from a high yielding aquifer along the Columbia River. A local groundwater contamination plume may be the limiting factor for groundwater development in this shallow aquifer. Evaluated model scenarios for contemporaneous pumping and containment of the plume, and represented Clark Public Utilities to review an alternative groundwater flow model developed for the Port of Vancouver used for similar predictions. Based on PGG's review of the Port's model and the interest of all parties to develop a mutually acceptable model for evaluating plume containment and water-supply options, PGG is currently working with the Port's consultants to assist in developing a mutually agreeable model.

- Developed and calibrated both local and regional groundwater models to evaluate aquifer capacities to accept groundwater recharge via wastewater infiltration for the LOTT Alliance (a wastewater utility comprised of Lacey, Olympia, Tumwater and Thurston County). PGG subcontracted to Brown & Caldwell to perform this evaluation. Site scale modeling was first used to evaluate aquifer properties based on measured responses to infiltration tests at two sites. A regional model, currently in use by members of the LOTT Alliance, was refined for consistency with local hydrologic conditions, and then used to estimate the movement of infiltrated water and its affect on other hydrologic features. Telescopic mesh refinement, a method used to extract a detailed local-scale model from the regional model, was used to ensure consistency with the regional groundwater flow system *and* obtain reasonable accuracy for local infiltration predictions.

- Designed, constructed and calibrated a groundwater flow model for the Camas-Washougal vicinity along the Columbia River in support of an application for new water rights by the City of Camas. The model was used to estimate impacts of new pumping on baseflows in the Washougal River and to design a mitigation strategy to offset baseflow impacts. The City of Camas will forego diverting water from surface-water sources during critical months

for fish habitat in return for new water rights to pump groundwater. Modeling showed that the surface-water flow returned to the river system (and associated tributaries) will more than offset for the impact of additional groundwater pumping due to seasonal changes to the mode of connection between the Washougal River and the underlying aquifer.

- Updated and calibrated a groundwater flow model of a stratified groundwater flow system on the Olympic Peninsula to evaluate hydraulic continuity between streams and wells in various aquifers and to analyze the effects of reduced groundwater recharge associated with lining leaky irrigation ditches and/or substituting surface-water sources with groundwater sources. The model analysis was performed for Ecology and Sequim-Dungeness irrigators in order to evaluate conservation options recommended for the irrigation system to increase baseflow on the Dungeness River. Worked cooperatively with Montgomery Water Group (irrigation strategies), Clallam County (local data), and the USGS (ongoing hydrogeologic characterization). Model results provided insight into the effects of reduced irrigation recharge on shallow groundwater levels and stream baseflows. This model was further developed by other parties over the past few years. PGG is currently retained by Clallam County (under a grant from Ecology) to refine and improve the existing model in order to use it for evaluating aquifer storage opportunities.

- Developed numerical models for three tributary watersheds of the Yakima River to assist Department of Ecology in evaluating how proposed transfers of irrigation water rights would affect baseflows (low flows) in the tributary streams and mainstem Yakima River. In all cases, irrigation from the streams was predicted to contribute to groundwater recharge via field and ditch seepage loss, and ultimately support stream baseflow both during and after the irrigation season. The water rights (owned by Trendwest) would be transferred to instream flow under the Yakima River Trust program. While the transfers would increase streamflows during most of the irrigation season, periods were predicted (both during and after the season) when the transfers would result in reduced flows due to loss because subsurface return flow would have exceeded diversion quantities. MODFLOW modeling was applied to all three basins to estimate the rates and timing of discontinued return flows under the water rights transfer. Sensitivity analyses were included to evaluate reasonable ranges for hydrologic impacts.

- Developed a groundwater flow model to evaluate how reduced irrigation in the Klamath River Basin (Oregon) would affect stream baseflow both during and after the irrigation season. The model represented a sub-area of the river valley, surrounded by local streams, and depicted the effect of reduced irrigation recharge on a portion of this land area. Stream baseflow was predicted to increase during the irrigation season and reduce over the remainder of the year due to discontinued return flows from irrigation.

- Developed a series of vertical "slice models" across the SeaTac Third Runway embankment to evaluate how the thickness of embankment fill will affect groundwater baseflow ("low flows") in streams located below the embankment slope. Emplacement of a significant thickness of embankment fill was expected to alter the timing of natural recharge to the underlying shallow aquifer by spreading out the seasonal "recharge pulse" over more of the year and causing longer time delays for infiltration to reach the water table. The slice models combined predicted changes in the timing for natural recharge reaching the water table with estimation of lateral flow through the uppermost aquifer towards the receiving streams. Recharge transmission vertically downward through the vadose zone (e.g. various thicknesses of embankment fill) was simulated with Hydrus-2D, a finite-element, variably-saturated flow model. Lateral groundwater flow towards downgradient streams was simulated by developing an in-house, explicit finite-difference model that included multiple layers (a drain layer installed over the existing aquifer) and downward leakage through till at depth. The modeling was peer reviewed, and successfully used to evaluate changes in the streamflow regimes downgradient of the Third Runway embankment.

- Assessed the effects of excavating several hundred feet of unsaturated gravelly materials on groundwater levels and spring flows for a proposed gravel mine on Maury Island. Estimated recharge at the land surface under a variety of geologic and land-cover conditions using an in-house version of the USGS "Deep Percolation Model" (DPM). Performed unsaturated flow modeling with the USDA finite-element code HYDRUS-2D to assess how the thickness of the unsaturated zone affects lagging and dampening of the recharge infiltration from the land surface to the water table. Developed a multi-layer finite difference model of Maury Island with the USGS MODFLOW code

and calibrated to field data. Integrated the results of all three models to make hydrologic impact predictions. Represented client (Dept. of Ecology) in public review process.

- Developed and calibrated a multi-layer finite difference computer model to simulate groundwater flow in a complex glacial/alluvial aquifer system in the vicinity of Renton, Washington. Compiled and interpreted geologic and hydrologic data for model design and calibration. Applied GIS approach to estimate areal recharge from land-use information. Calibrated model to steady state and transient conditions. Used model to delineate three-dimensional capture zones for wellhead protection, predict transport of an existing groundwater contaminant, assess pumping regimes required to exclude contaminant from municipal wells, and evaluate stream-aquifer interactions.

- Developed a series of investigative groundwater flow models to evaluate the subsurface hydraulics supporting a major spring system located at the base of an uplands escarpment near Auburn, Washington. The models were used to better understand how various components of the groundwater flow system support inflow to infiltration galleries completed in more than one hydrostratigraphic unit. Flow conditions were evaluated during transient discharge tests, over seasonal variations, and through occurrence of drought. The models also included aquifer interaction with a nearby stream. The modeling was used to evaluate the sufficiency of existing conceptual models to predict availability of additional springflow (via pumping), as well as resulting impacts on a neighboring stream. The modeling showed that additional subsurface characterization would be needed to adequately explain the physical mechanisms contributing to spring discharge. Empirical approaches were used to estimate spring yields and the hydrologic impacts of increased pumpage at the springs.

- Designed and assisted in development of a three-dimensional groundwater flow model of a highly stratified aquifer system in the vicinity of Auburn, Washington. The layered flow system is truncated by alluvial valley sediments and discharges to two major rivers. GIS approaches were used to estimate the distribution of recharge and define occurrence of hydrostratigraphic units. The model will be used to evaluate coupling between the rivers and groundwater flow system, assess artificial recharge opportunities, delineate wellhead protection capture zones, and evaluate contaminant transport scenarios (if necessary).

- Developed and applied numerous local scale groundwater flow models for prediction of aquifer response to pumping, stream impacts associated with groundwater development, and contaminant transport pathways under both natural and pumping conditions.

- Performed technical review of previously developed groundwater flow models within the Portland Basin. Models developed for the entire basin (USGS), the Portland Wellfield vicinity, and the Blue Lake Aquifer were examined. Approaches to improve existing model configurations (through revised discretization, refined geologic characterization, and additional calibration) were suggested.

Water Rights Assistance and Expert Witness Testimony

- Currently assisting Ecology with water rights analysis, processing and preparation of reports of exam (ROE's) for the City of Northbend's application for new groundwater rights. PGG has been instrumental in developing a technical approach to assess the impacts of proposed pumping, including recommending models used for estimation of baseflow depletion and developing spreadsheets to estimate the capacity of existing mitigation sources based on model results. Technicalities of the project have been reviewed by external parties such as the Tulalip Tribe and the Center for Environmental Law and Policy (CELP).

- Assisted Ecology with water rights analysis, processing and preparation of reports of exam (ROE's) for Trendwest's Mountainstar development near Cle Elum Washington. Managed a team of technical and policy consultants to perform the hydrologic analyses required to evaluate the water right requests. Performed the groundwater and stream-aquifer interaction technical analyses as part of the technical evaluation. The work was performed under Ecology's cost reimbursement program.

- Currently assisting Ecology with processing of the City of North Bend's water right request under the cost reimbursement program. Reviewed technical analyses provided by the applicant's consultant in support of their

water right application. Reviewed water rights policies relevant to the proposed water use. Advised Ecology on policy and technical issues associated with processing the water right application.

- Provided expert witness testimony for a water-rights dispute regarding potential impacts to streamflows in the vicinity of a proposed gold mine in Okanogan County, Washington. Evaluated hydrologic characterization and model predictions prepared by the proponent to assess accuracy of estimated streamflow depletion. Assessed adequacy of proposed mitigation plan to offset streamflow reduction. Assisted attorneys with technical aspects of the water-rights appeal.

- Submitted expert witness testimony in a homeowner–developer dispute regarding potential impacts on groundwater quality associated with land-use activities. Characterized site hydrogeology and evaluated the potential for water-quality impacts within the capture zone of a public water system well.

- Provided technical assistance to support water rights sought and obtained by the City of Sequim. Reviewed historic water-right correspondence to define current status; facilitated certification of water rights based on evaluation of wellfield performance; represented City to Department of Ecology to obtain supplemental rights for a new wellfield with reduced hydraulic continuity to the Dungeness River; performed technical evaluation to set action-levels and conditions on wellfield operation.

- Characterized water-right allocations in four hydrologic basins as part of Initial Watershed Assessments of the Snohomish, Deschutes, Walla Walla, and Kitsap Water Resource Inventory Areas (WRIA's). Defined the spatial distribution of surface-water and groundwater rights, distribution by type of use, and the historic increase in water-rights over time. Compared water-right allocations to estimates of actual consumption to address implications of potential effects of full water right utilization.

- Performed countless assessments of predicted hydraulic impact associated with proposed groundwater withdrawals, as required by Department of Ecology for water right permitting. The assessments typically addressed the potential for impairment to: senior water-right holders (interference drawdown); baseflows in streams and the potential for saltwater intrusion.

Groundwater Resource Evaluation and Development

- Co-authored and edited Initial Waterhed Assessments of the Deschutes, Snohomish and Walla Walla Basins as a part of Ecology's Water Resource Inventory Area (WRIA) studies. Investigated the hydrogeology and reported water-rights allocations and water use for each basin. Coordinated an interdisciplinary team of scientists in order to incorporate evaluations of climate, stream flow, water quality and fisheries into each study.

- Co-authored the Stage 1 Technical Assessment for WRIA 17, a comprehensive hydrologic study covering mst of Jefferson County and portions of Clallam County. The Technical Assessment has been described as one of the most comprehensive prepared in Washington State. Evaluated and described: groundwater hydrology, groundwater/surface-water interaction, groundwater recharge and withdrawals, groundwater quality (including saltwater intrusion), and water rights.

- Provided hydrogeologic assistance to the PUD #1 of Jefferson County for design, installation, and testing of their new (2005) Four Corners Well, located at the Jefferson County Airport. Prepared drilling specifications, oversaw drilling activities, designed and conducted aquifer testing, estimated sustainable yield for the well, characterized the local hydrogeologic framework (thus providing new information to modify the framework delineated by the U.S. Geological Survey), generated a numerical groundwater flow model of the Tri-Area vicinity to evaluate hydrologic impacts associated with pumping.

- Reviewed and provided technical evaluation of a proposal by Fred Hill Materials (FHM) to excavate a new gravel mine ("Wahl Pit") near Thorndyke Creek in Jefferson County. Evaluated hydrogeologic characterization performed by FHM's consultants and estimated hydrologic impacts associated with the proposed excavation. Provided comments to Jefferson County Department of Community Development. PGG's comments resulted in

modifying the County's approval for the Wahl Pit to a phased expansion approach and incorporating a monitoring plan to assess hydrologic impacts during the first phase of excavation.

- Provided hydrogeologic assistance to the Jefferson County Department of Public Works for design, installation and testing of their Quilcene Community Test Well. Managed drilling activities, designed and conducted aquifer testing, estimated sustainable yield for the well, characterized the local hydrogeologic framework, and estimated hydrologic impacts associated with pumping.

- Assumed the lead role in evaluating hydrogeologic conditions within the McAllister Springs Geologically Sensitive Area (Thurston County, WA) to facilitate design of a wellhead protection network. Developed a work plan for test well installation, aquifer testing, and monitoring. Coordinated Wellhead Protection Program (WHPP) field investigations, prepared WHPP characterization report and developed recommendations for ongoing WHPP activities.

- Performed a regional water resource evaluation of a fractured rock flow system in rural Skamania County. Assessed streamflow, recharge, groundwater flow patterns, aquifer properties, potential well yields, and water quality. Performed a regional water budget and evaluated potential impacts of future development. Assisted the client in setting up a monitoring network, field locating wells with GPS, and developing a database of well logs, groundwater levels, and water quality data.

- Provided hydrogeologic assistance to the City of Sequim regarding development and operation of their Silberhorn and Port Williams wellfields. Activities include geologic characterization, well installation and testing, wellfield performance and optimization analysis, evaluation of impacts associated with pumping, development and implementation of monitoring plans, installation of electronic monitoring instrumentation, and representing the City in water rights negotiations with Ecology and other parties.

- Analyzed pumpage, well performance, and aquifer response data for a major water purveyor in Clark County, Washington to formulate wellfield optimization strategies. Recommended strategies to minimize impacts on streamflow. Investigated new water-supply alternatives, developed drilling strategies based on assessment of local and regional geology, and supervised drilling of boreholes. Designed, installed, and tested successful production wells.

- Evaluated hydrologic impacts to rivers and lakes associated with developing a high capacity wellfield as the City of Olympia's primary source of supply. The new wellfield is preferred because it is less susceptible to groundwater contamination than existing sources. Mitigation approaches were developed to prevent lake-level declines and enhance riparian plant communities along lakes. Contributions of a habitat biologist and surface-water hydrologist were integrated into the project.

- Evaluated groundwater conditions and hydraulic consequences of a proposed large-scale wetland creation designed to mitigate wetland loss associated with highway construction. Major issues included: rising groundwater levels on adjacent properties associated with decommissioning of drainage ditches and alteration of the flow regime of a stream which borders the site (e.g. change in flood frequency). Recommended monitoring strategies to evaluate background conditions and the performance of the installed wetland.

- Assessed hydrostratigraphy and saltwater intrusion conditions on the Omani coast for the USAID WASH project in the Middle East. Developed recommendations and technical specifications to further define the hydrogeology and extent of saltwater intrusion. Evaluated and addressed the appropriateness of alternative well technologies as a means of reducing saltwater intrusion.

- Developed a methodology to monitor and evaluate aquifer susceptibility to saltwater intrusion for the Jefferson County Department of Environmental Health. Provided the client with a database to store well, groundwater levels, and water quality information. Designed analytical tools for the client's use in assessing relative degree of susceptibility, as required in the County's critical areas ordinance. Provided ongoing support in assessing saltwater intrusion.

- Evaluated the hydrogeology of a natural embankment of glacial materials directly downstream from the City of Seattle's Chester Morse Lake reservoir. Groundwater conditions in the embankment vary as a function of water level maintained in the lake, and respond quickly to changes in lake-levels. The stability of the embankment is threatened at levels. Historic lake-level, groundwater level, streamflow, and spring discharge data were analyzed to assess hydrogeologic properties of the embankment. Improved understanding of flow-system responses at various lake levels yielded recommendations for system operation and further study.

- Conducted a regional hydrogeologic evaluation of a southeastern Arizona watershed which characterized aquifer parameters, groundwater occurrence and flow patterns, river baseflow, surface water - groundwater interactions; water quality; and projected impacts of groundwater development.

- Developed recharge potential and aquifer vulnerability maps for Clark County, Washington based on digitization of topographic, climatic, and hydrogeologic data.

- Designed and installed numerous water-supply and monitoring wells. Activities included: preparation of technical specifications, geologic logging, well installation and development, aquifer testing, yield assessment for wells and wellfield optimization.

Groundwater Pollution Monitoring and Control

- Developed and applied a groundwater flow model to evaluate contaminant transport near a major wellfield completed in hydraulically connected deltaic and valley-fill (alluvial) deposits. The wellfield was overlain by dense, urban development. Assessed existing concentrations, contaminant pathways, and pumping regimes required to prevent contaminant from entering municipal wells. Evaluated groundwater flow patterns to evaluate possible locations of contaminant release.

- Assessed the distribution of groundwater contamination beneath an eastern Washington landfill site. Applied knowledge of site hydrogeology to discern possible contaminant transport pathways, and assisted in designing and installing a monitoring system to detect further contamination.

- Developed a monitoring plan for a proposed commercial development in eastern Jefferson County in order to detect and respond to potential groundwater quality impacts associated with a stormwater infiltration facility. The plan specified the design and location of monitoring wells, sampling schedules, detection "action" levels, statistical methods for analyzing water-quality data, and an enforcement plan to respond to potential water-quality degradation.

- Evaluated the groundwater flow system beneath a major central Washington landfill site. Logged multiple borehole installations, performed and interpreted aquifer tests, delineated groundwater occurrence and flow patterns, and estimated groundwater fluxes and water-budget components. Installed a system of monitoring wells to evaluate background quality and provide capability to detect potential future contamination. Collected and maintained water quality data for the site.

- Evaluated a dewatering system for cutoff of contaminated groundwater underflow in an alluvial aquifer influenced by complex tidal conditions.

- Implemented RCRA part B monitoring requirements at a major western Washington oil refinery. Managed field monitoring of soils, pore water, and groundwater.

- Evaluated and monitored a vadose zone neutron logging system designed for leak detection in the vicinity of hazardous waste holding ponds at a major Tucson aircraft manufacturing plant.

PUBLICATIONS

"A Hydrogeologic Resource Assessment of the Lower Babocomari Watershed, Southern Arizona", by P. N. Schwartzman, thesis presented to the University of Arizona in partial fulfillment of requirements for the degree of Master of Science in hydrology, September, 1989.

"Hydrology of the Upper San Pedro Basin", by P. N. Schwartzman, University of Arizona Water Resource Research Center, In-house Technical Paper, June, 1987.

COURSE INSTRUCTION

Principals of Groundwater Flow and Transport Modeling. Co-Instructor in a course offered by the University of California Cooperative Extension / Groundwater Hydrology Program over a dozen times between 1997 and 2008.

PRESENTATIONS

"Evaluation of Streamflow Reduction from Cessation of Irrigation Return Flow". AWRA Groundwater/Surface-Water Interaction Conference, Keystone, Colorado, July 2002.

"Evaluation Of Streamflow Impacts from an Upland, Wet Pit Gravel Mine". AWRA Groundwater/Surface-Water Interaction Conference, Keystone, Colorado, July 2002.

"An Initial Watershed Assessment of the Snohomish Water Resource Inventory Area". Washington Hydrologic Society. 1996.

"Hydraulic Continuity Between Groundwater and Surface Water". Law Seminars International. March, 1996.

"Basin Assessments: A Necessary Ingredient for Basin Planning". Law Seminars International. March, 1996.

"Hydrogeology of Jefferson, Clallam and Kitsap Counties - A Local Perspective". Washington State University Extension short course on water resources. Realtors workshop - 1996, 1997, 1998.

"Hydrologic Monitoring: Groundwater Levels, Streamflows, and Seawater Intrusion". Washington State University Extension. Water Watchers Program - 1996, 1997.

"Hydrogeology 101 and Local Conditions". Washington State University Extension. Water Watchers Program – 2008.

Bullet Point List for Peter Schwartzman's Testimony at the M3 Water Rights Hearing
FINAL VERSION: November 25, 2008

1. I was the Pacific Groundwater Group (PGG) project manager and chief modeling expert in developing the 4 PGG reports (titles below). I directly supervised three members of PGG's staff in: developing and calibrating the model, conducting Geographic Information System (GIS) analyses for water budget assessments of recharge, canal leakage and delineation of aquifer positions, and in running the simulations of future pumping and change-in-recharge scenarios for the M3 project. The 4 PGG reports are:
    a. "M3 Groundwater Flow Model and Analysis of Pumping Impacts, First Year Progress Report," June 4, 2008
    b. "Technical Memorandum: Transient Calibration to the SVR #7 Pumping Test (M3 Eagle Groundwater Flow Mode)," July 26, 2008
    c. "Technical Memorandum: 50-Year Drawdown Simulation with Proposed NPW wells (M3 Eagle Groundwater Flow Model)," September 22, 2008
    d. "Technical Memorandum: Model Refinement and Recalibration; Re-simulation of 50-year Drawdown; and Assessment of Affects of Reduced Canal Leakage (M3 Eagle Groundwater Flow Model)," November 14, 2008
2. I have personally designed, developed, calibrated, run simulations and/or managed/overseen at least 22 ground water flow models over the past 19 years as a hydrogeologic consultant. I have also reviewed models developed by outside parties and served as an expert witness presenting the results of my review.
3. I have worked extensively with, and am experienced with, the USGS-developed groundwater flow modeling software "Modflow," and the graphical interface package "Groundwater Vistas" developed by Environmental Simulations, Inc., and have taught groundwater modeling at nationally recognized courses.
4. I played an intimate role in the translation of the hydrogeologic data into the computer input files used in the Modflow model of the greater M3 Eagle vicinity. I worked closely with HLI to ensure that the Modflow model represents the conceptual model of the groundwater flow system developed by HLI, and concur that the model is realistic in its representation of groundwater flow within the Pierce Gulch Sand Aquifer as characterized by HLI, within the model domain presented in the 4 modeling reports.
5. The calibration of the model to existing conditions (i.e. "steady-state" water levels of summer-2007) is within generally accepted, statistically valid level of accuracy. In order to address hydrogeologic uncertainties (that are inherent in characterization of *all* groundwater flow systems), PGG developed two versions of the model which represent a range of possible sub-surface conditions that is jointly consistent with the available hydrogeologic information. Along with the successful steady-state calibration of both versions to summer-2007 conditions, the model(s) were also calibrated in transient mode to several major aquifer tests. Specifically, the "Hmatch" model version showed good calibration to 3 major aquifer tests, and the "Tmatch" model showed good calibration to one major aquifer test and poor calibration to a second aquifer test (Eaglefield #2 aquifer

test). This Eaglefield #2 test may have been influenced by outside conditions not represented by the model, or the calibration may indicate that local conditions (in the immediate vicinity of the test) were not represented in the model, which was designed to represent regional (rather than local) hydrogeologic conditions.

6. The calibrated model groundwater flow contours show that a portion of the groundwater with the Pierce Gulch Sand Aquifer flows to the Payette River Valley and that a portion remains in the Boise River Valley. The calibrated model groundwater flow contours are consistent with the characterization of groundwater flow patterns developed by HLI in the focus area consisting of the M3 property, the cities of Eagle and Star and the nearby environs. Farther away from this focus area, modeled groundwater flow contours are likely to be less accurate.
7. The predictions of drawdowns in the Pierce Gulch Sand Aquifer made by the model, even in its most-conservative version (the Hmatch model calibrated with the higher total pumping rates) are realistic representations of impacts that are likely to occur in the vicinity of the M3 project and the City of Eagle.
8. I have read the *M3 Eagle, LLC Second Amended Application for Water Right Permit* and believe that the model adequately represents the average annual amount of water requested for the project.
9. The model indicates that the Pierce Gulch Sand Aquifer beneath the M3 property can adequately supply the long-term annual average amounts of water requested in the water rights application.

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Richard K Glanzman
President, Glanzman Geochemical LLC
2752 South Braun Way, Lakewood, Colorado, 2005
(303)986-9019 email: dkglanzman@comcast.net

Academic Background

M.S., Geochemistry, Colorado School of Mines
B.S., Geology, University of Utah

Professional Registrations

Professional Geologist, Wyoming PG-1923
Professional Geologist, Wisconsin PG-990

Distinguishing Qualifications

Over 40 years experience in aqueous geochemistry applied to ground water, vadose zone, surface water and their quantitative interactions under both natural and anthropogenically impacted environments on a worldwide basis. Mr. Glanzman interprets physical and chemical data generated by others to solve site-specific water resource problems.

Broad-based experience with chemical and physical relationships between gases, water and solids involving inorganic, organic and microbial populations in most earth surface ecosystems under ambient and geothermal conditions.

Worldwide experience

Applied geochemical specialties:

Geochemical Modeling
Mineralogy, Specializing in Sulfide and Clay Mineralogy
Stable and Radiogenic Isotope Geochemistry
Soil Gas Geochemistry
Sediment Transport and Source Quantification
Field Portable Chemical and Mineralogical Instruments

Agencies and Industry Experience

Federal: EPA, DOD, USGS
Western State Departments of Environmental Quality
Worldwide Municipal Water Purveyors
Worldwide Mining Operations
U.S and Canadian Oil and Gas Operations
Food Processing and Production
Waste Water Treatment
Landfill Operations

Relevant Experience

Mr. Glanzman was a Principal Technologist Geochemist/Geohydrologist in CH2M HILL's Geosciences Discipline. He was responsible for the groundwater work in the western interior states. His responsibilities included planning, developing, interpreting,and reviewing geohydrological and, particularly, geochemical investigations in water supply and hazardous waste. His publications, presentations and reports deal with geohydrology, geochemistry, geomorphology, hydrology, geology, field geochemical techniques, and remote sensing.

Geochemist/Geohydrologist, Worldwide. Aquifer recharge storage and recovery (ASR). Along with David Pyne, he pioneered the applicaton of ASR to municipal wells on a worldwide basis. He extended ASR to include aquifer conditioning to control iron, manganese, arsenic and odor in the subsurface. Mr. Glanzman developed an initial screening analysis that forms a basis for judging geochemical reaction potential between the recharge water and the native groundwater at recharge sites on a worldwide basis. This initial evaluation is a fatal flaw analysis of existing physical, chemical, and biological data for the recharge well, recharge site or area. From this analysis, site-specific tests are designed to address the potential problems. A broad experience in geochemical processes (organic, inorganic, and biological) and clay mineralogy is particularly applicable to the development of a successful recharge project. Over 100 municipal and industrial wells have been successfully recharged using this geochemical technology.

Mr. Glanzman had a key role in the evaluation of geochemical reactions involved in hazardous wastes, water supply systems, and aquifer recharge. Mr. Glanzman uses both field- and computer-based (thermodynamic) models such as PHREEQC and Geochemist's Workbench to evaluate potential inorganic geochemical reactions within the hydrologic system. He has applied these and reviewed other geochemical methods to evaluate hazardous waste fate and transport at sites related to metals (Blackbird Cobalt Mine, Idaho; California Gulch,Colorado; Cherokee County, Kansas; Silver Bow Creek and East Helena sites, Montana), solvents (South Valley site, New Mexico; Des Moines, Iowa),radioactivity (Paducah, Kentucky; Rocky Flats, Colorado), and landfills(OII, California; IWC, Arkansas; Lowry, Colorado). In addition to the Superfund sites, he has worked with many private industry clients involving hazardous wastes in air, water, and many forms of solids.

Mr. Glanzman developed geochemical programs to evaluate the distribution and future concentration of major ions and dissolved metals (specifically arsenic) in a master plan for the groundwater drinking water supply of a major western city. This involved the application of several innovative field methods for both geohydrological and geochemical techniques. Appropriate groundwater sampling and monitoring methodology is critical to an understanding of the groundwater system, particularly estimating the water chemistry of drinking water 10 to 20 years in the future.

Mr. Glanzman has developed and applied several generally considered laboratory analytical techniques for insitu chemical analysis at the field site, generally considered laboratory techniques, to expedite the nature and extent determination of both natural and synthetic chemical elements, compounds, and minerals. X-ray fluorescence (XRF),infrared (IR),and soil gas techniques have been developed for application at field sites. Field portable XRF is used to both screen and analyze the total metals concentration at the field site. IR can determine the presence and amount of organics as well as the types and relative proportion of clay minerals. Soil gas can determine the presence and amount of organic and inorganic gases at a site that can be used to distinguish between natural and anthropogenic sources.

In addition to equilibrium geochemical conditions involving concentration, pH, oxidation-reduction potential, complexing, ion-exchange, and

adsorption, Mr. Glanzman includes volatilization, kinetics, and the role of microbiota in evaluating the nature/extent and fate/transport of geochemical phases involving most media. Both aqueous and vapor phase isotope evaluations have been applied to separate natural and anthropogenic sources.

Quality assurance and control involves the application of both parametric/nonparametric statistical techniques and geostatistical techniques. Basic statistical functions are typically applied. However, other tests that are appropriate for specific applications include cumulative frequency/probability analysis, discriminate function analysis, several types of cluster analysis, principle components analysis, and factor analysis. Geostatistics provides an effective technique to objectively and quantitatively determine the most effective and efficient sample density of physical and chemical parameters in three-dimensional multimedia.

Several levels of remote sensing have been applied by Mr. Glanzman to the physical and geochemical characterization of areas and sites. Relatively inexpensive, rapid, and highly sophisticated computer processing techniques have been developed that can be used to define not only the present surficial conditions but also surficial conditions since the early 1970s through Landsat imagery. Recent improvements in spectroscopy allow fixed-wing imagery that allows the identification, relative quantification, and mapping of such surficial properties as expandable clay and nonexpandable clay, oxidizing sulfide minerals, and geological structures that control groundwater movement on a 10- to 20-foot scale.

Mr. Glanzman, working with the U.S. Bureau of Mines, evaluated techniques for the measurement and removal of radon gas from the mine and industrial environment. His work involved the definition of gas transport, physicochemical interaction between groundwater under unsaturated and saturated conditions, and in both porous media and fracture flow. A position paper on health physics of radon gas was produced and test environments were established for the assessment of removal methods. Groundwater.

Mr. Glanzman authored and was responsible for a series of reports on the geochemistry of arsenic in groundwater for a major city in the southwestern United States. The report on arsenic hydrogeochemistry describes how arsenic moves in the groundwater system, parameters that both increase and decrease its mobility, and case histories of arsenic problems in groundwater. Reports on the analytical methods for the reliable determination of dissolved and total arsenic concentration and speciation in groundwater, water reservoirs, spatial and temporal trends in the groundwater system, identification of problem areas, long-term monitoring program, and the development of methods to treat the water to control and remove arsenic were prepared. He developed an aquifer treatment alternative in which the groundwater is conditioned to immobilize the arsenic in the aquifer matrix.

Geochemist/Geomorphologist, Idaho. Quantified the provenance of sediments deposited by the Snake River into Brownlee Reservoir and in sand bars within Hells Canyon below the Hells Canyon Complex. Chemical and mineralogical signatures of the various sources within the upper and middle Snake River and its tributaries were coupled with the geomorphology to definitively determine the respective amount of sediment from these

sources that has accumulated within both the reservoirs and sand bars of the lower Snake River in Idaho.

Areal groundwater studies were conducted by Mr. Glanzman working with the Water Resources Division of the U.S. Geological Survey. Areal studies in Colorado included the evaluation of groundwater/surface water relationships in the San Luis Valley, sandstone aquifers in Baca and Prowers Counties, groundwater in fractured oil shale of the Piceance Basin, and an evaluation of an extensive soil and stream sediment erosion abatement system near Kiowa. A groundwater sampling grid was established to monitor groundwater chemistry in eastern Colorado. Multiphase fluid flow and the impact of gases on both the chemistry and hydraulic characteristics of groundwater were evaluated in essentially all projects. Work in Utah involved the collection, analysis, and interpretation of the water chemistry of surface and ground-water. Work included stream sediment measurements and both suspended and bedload quantification.

In addition to the application of statistical techniques to quality assurance and control, Mr. Glanzman utilizes statistics to more accurately define and discriminate geochemical anomalies. Basic statistical functions and tests including cumulative frequency/probability analysis, discriminate function analysis, several types of cluster analysis, factor analysis, and kriging. The geostatistical technique, kriging, was successfully applied to analyze and interpret three-dimensional multimedia (soil, vegetation, stream sediment, rock,drill cuttings, and remote sensing) sample data. Kriging is an effective technique to quantitatively determine the most efficient and effective sample density to define physical and chemical parameters.

Mr. Glanzman has extensive experience with the geochemistry of natural decay products of both uranium and thorium. The mobility, fate, and transport of radionuclides was investigated in environments that ranged from ambient to 500 degrees Celsius and included solid, liquid, and gaseous phases of both organic and inorganic types. Mr. Glanzman has 5 years of experience focused on the radioactive gases in subsurface environments. Transport experience includes multiphase fluid flow, interaction with other stable gases and organics, and controls on the release of radioactive gases and their products to the environment.

Mr. Glanzman was Division Geochemist for Chevron Resources. His responsibilities included counseling and advising management and professionals in the use and interpretation of geochemical techniques applied to both domestic and foreign operations. He identified, developed, and applied new technologies for field site geochemistry and mineralogy. He developed and maintained quality assurance and control programs and procedures for analytical data from commercial laboratories.

Mr. Glanzman was project manager of a clay minerals program with the U.S. Geological Survey. The project involved the smectite-type clays and their particular fluid-retaining and permeability-reducing characteristics that make them suitable for use in hydrologic barriers. The work defined chemical and physical paths for the development of clay minerals in sedimentary, igneous, and hydrothermal environments. He has extensive experience with clay mineral response to intense environmental, particularly chemical conditions involving ambient to high pressures, temperatures, and salinity.

Mr. Glanzman has applied stable and radiogenic isotopes for specific purposes in multiple aquifers involving a waste disposal site in Idaho. Stable and radiogenic isotopes were used to distinguish relatively shallow local alluvial groundwater from the regional deep carbonate aquifer and their mixtures across the entire southeastern quarter of the state of Nevada for water rights purposes. Stable and radiogenic isotopes were used to model the geochemistry and age of groundwater in the multiple aquifers of the Boise ID basin. Isotopes provide unique signatures in groundwater chemistry identifying specific sources and document not only the location(s) of their origin(s) but also their mixing with groundwater originating from other sources. As with most aqueous geochemical parameters, interpretation of isotope activities is supported and validated by major, minor and trace constituents in the groundwater.

Stable isotopes and carbon-14 age dating were combined with major, minor and trace element geochemistry to estimate the deep carbonate aquifer groundwater system for central and southern Nevada. A previously unknown groundwater source was identified in the Tule Basin and another large potential source of groundwater was identified by the geochemical evaluation of the regional deep carbonate aquifer groundwater.

Water Rights Expert Witness. Mr. Glanzman was an expert witness for cases involving the Sandy Valley, Kane Springs Valley and Tule Basin water rights hearings before the Nevada State Engineers Office. He authored a geochemical investigation showing the deep regional carbonate groundwater flow paths throughout southestern Nevada from north of Ely, Nevada through Las Vegas to the Ivanpah Playa in California. These hearings involved the U.S. National Park Service, U.S. Bureau of Land Management, U.S. Geological Survey as well as public and municipal advocacies opposed to the development of a new groundwater source. Interpretation of geochemical data was instrumental in the State Engineer awarding the majority of the requested water right.

Membership in Professional Organizations

American Association for the Advancement of Science
Association of Applied Geochemists (two terms as Councilor)
Clay Mineral Society
Colorado Groundwater Association
Colorado Scientific Society
Geochemical Society
Geological Society of America
International Mine Water Association
National Water Well Association
Sigma Xi
Society for Environmental Geochemistry and Health

Richard Glanzman, Geochemist
Glanzman Geochemical, LLC

Pierce Gulch Sand Aquifer

Groundwater chemistry indicates that the Pierce Gulch Sand Aquifer (PGSA) is a discrete aquifer recharged from the Boise River with no apparent hydraulic connection with other aquifers

PGSA groundwater chemistry type is uniquely constrained showing very limited variability over many miles separating individual well locations.

PGSA groundwater chemistry is indicative of a highly permeable aquifer with a consistent minimally soluble aquifer mineralogy.

Similar to water chemistry type, PGSA groundwater total dissolved solids (TDS) show little change throughout the well locations.

Spring Valley Ranch Area

Groundwater chemistry in the Spring Valley Ranch is dominantly recharged from precipitation infiltrating into aquifer sediments with a variable soluble mineralogy resulting in a suite of highly different water chemistry types and TDS.

Spring Valley Ranch (SVR) groundwater generally contains elevated potassium and arsenic concentrations that is not present in groundwater from either the PGSA or other aquifers in this part of the Boise Basin.

SVR groundwater chemistry indicates the most variable aquifer mineralogy of all the aquifers in this part of the Boise Basin.

Willow Creek Aquifer

Groundwater chemistry from the Willow Creek Aquifer (WCA) shows considerable variability suggesting localized recharge and variable hydraulic connection with other aquifers.

WCA groundwater chemistry suggests a variable similarity with groundwater chemistry in the Tertelling Springs Formation.

Tertelling Springs Formation

Groundwater chemistry of the Terteling Spring Formation indicates considerable variability but unlike the SVR and WCA is indicative of increasing dissolution of a discrete aquifer mineralogy.

Groundwater chemistry in the Terteling Springs Formation indicates that the mineralogy is discretely different from that of the PGSA and Spring Valley Ranch aquifer mineralogy.

EXHIBIT 32J

No Document for this Exhibit

Refer to scanned document:

"Inventory of M3 Eagle Exhibits (as of 8-7-09)"

Document date 10/13/09

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SUMMARY OF FACTS AND OPINIONS

SCOTT WONDERS, P.E.
M3 Water Right Application
November 26, 2008

I am prepared to testify concerning the following matters and express the following opinions in this case.

Infrastructure Plans / Costs

1. History of the work done on the project to date.
   -Site Planning
   -Preliminary Engineering
   -Water / Wastewater Systems
2. Timeline and steps necessary in the design process to get to water and wastewater system construction
3. System being designed to be a centralized public water supply system for the development in the M3 Project area. System is not being designed to serve other areas or uses.
4. The M3 Eagle lands (approximately 6,000 acres) provide ample room and suitable sites for all infrastructure contemplated.
5. Stanley is in the process of obtaining the seismic and soil stability analyses, as well as other technical and scientific information necessary to construct and operate infrastructure on the development.
6. Current cost estimates.
7. History of timely payment from M3 Eagle
8. Status and explanation of the DEQ permitting process for wastewater treatment and reuse.

Water Demand Support

1. M3 Eagle's projected residential water usage compared with that in surrounding communities.
2. Comparisons with Stanley's experience in the industry.

3. Opinion that all M3 Eagle's projected water usage amounts are reasonable and consistent with current data and direct experience with water system sizing.

Wastewater Reuse System

1. Description of the proposed M3 Eagle effluent reuse program.
   - Amounts of reuse generation per year at FBO.
   - Proposed Treatment Plant System
   - Class A / Class B reuse requirements from DEQ.
   - Effluent storage over the winter
   - Ability to use effluent on some surface-irrigated lands as necessary.
   - Operational requirements (professional operation)

2. Overall project schematic, including storage tanks, storage lakes and depiction of irrigated areas and commercial and residential use areas. Location for waste water treatment plant (WWTP). How the reuse storage/distribution system will work, including tie-in to non-potable irrigation supply system so that surface-irrigated areas can receive reuse water if necessary.
3. The types and amounts of irrigated acreage. The overall acreages are generally calculated on the high side (such as 120 irrigated acres for a golf course) to ensure the application will cover all irrigation needs.
4. Irrigation efficiencies, xeriscape, drip irrigation, low angle spray nozzles to reduce wind drift/evaporation; rotation scheduling, and metering.

5. The use of potable water vs. reused effluent for irrigation. Show graph from WRA.

32L

Curriculum Vitae
STEVEN E. HOLT, Ph.D., P.E.
Water Resources Engineer
Toothman-Orton Engineering Company

PROFESSIONAL REGISTRATION & AFFILIATION
Professional Engineer, Civil Engineering, License No. 7909, Idaho, 1995
Member, American Water Works Association (AWWA)

EDUCATION
Ph.D. Computational Fluid Dynamics, Minor in Mechanical Engineering, Stanford University, 1990
M.S. Water Resources Engineering, Stanford University, 1985
B.S. Civil Engineering, University of Utah, 1984

BACKGROUND
Mr. Holt started his professional career in 1984 with academic research in water resources engineering followed by consulting engineering since 1991. Mr. Holt has diverse experience in the master planning, design, construction management and project management of water resources engineering projects for municipalities, planned developments, transportation, industry, and private landowners.

Specific areas of experience include domestic water system planning and design, pump station design, water supply, water rights, planning and design of separate pressure irrigation systems, wastewater engineering, surface water hydrology and hydraulics, floodplain and floodway analysis, storm water management, and entitlement and design of land development projects.

PROFESSIONAL EMPLOYMENT HISTORY
February, 1991 - Present
Toothman-Orton Engineering Company, Boise, ID: Water resources engineering and project management.

May, 1985 - September, 1990 – **Stanford University, Stanford, CA**
Environmental Fluid Mechanics Laboratory: Theoretical and numerical investigation of stably stratified and sheared turbulence. Experimental investigation of buoyant fluid mechanics including scale modeling of a reservoir.
Instructor, Department of Civil Engineering: Lead instructor in undergraduate fluid mechanics and laboratory classes.
Recipient: Achievement Reward for College Scientists, ARCS Foundation.

SELECTED PROJECT EXPERIENCE

Community and Municipal Water Systems

Sunrider Ranch, Elmore County, ID - Develop planning, design and construction documents for community water system in 66-lot residential subdivision.

Sterling Sage, Elmore County, ID – Planning and design of community water system including supply and distribution, redundancy requirements and system control for 178-lot residential subdivision.

City of Kuna, Water System Improvements, Kuna, ID - Prepared and calibrated a computer model of the City's municipal water system to evaluate system capacity, pressures and flow performance. Prepared a water system master plan that formed the basis for constructed water system improvements. Assisted with securing water rights for a new supply well. Assisted with the funding, design and construction observation of a new well, booster station and storage tank.

City of McCall, Water System Improvements, McCall, ID - Prepared and calibrated a computer model of the City's municipal water system to evaluate storage capacity, pressures, zoning and flow performance of the existing system and to recommend system improvements for future expansion. Assessed capacity of water rights. Performed field verification of water supply pump station performance. Prepared a comprehensive water system master plan including recommendations for system improvements. Assisted the City with adoption of the water system master plan and funding of improvements. Designed and administered construction of raw water supply pump stations and potable distribution system improvements. Provided design and policy guidance to convert the City system to water meters. Provided hydraulic assessment and technical guidance for additional internal system improvements constructed by the City.

M3 Eagle Planned Community, Eagle, Idaho – Developed comprehensive estimates of water system demands for planned community of approximately 7,000 residential units with approximately 765 acres of common area and recreational public areas. Worked in conjunction with project attorneys, civil site engineer and hydro-geologist in compiling, submitting and processing a municipal groundwater right application for a 20 year build-out horizon. Water system demand estimates included domestic needs, irrigation, generation and reuse of treated sewage effluent, and aesthetic and operational storage ponds.

Water Supply Analyses for Multiple Proposed Developments, City of McCall, ID – Performed analyses of water supply to developments from the City of McCall water system. Analyses included estimating domestic, irrigation and fire flow demands, and potential upgrades to the McCall water system.

Spring Mountain Ranch and Woodlands Subdivisions, McCall, ID – Modeled and designed potable water systems and booster pump stations.

Kings Pines Estates, Adams County, ID - Advisory support for water system master plan and design of water supply, water quality, distribution, pressure zones, storage and pumping stations.

South Loop Waterline Project, City of McCall, ID - Planning and design of transmission line to improve existing system performance and support future expansion at south end of the City's water system.

Idaho Club, Lake and Golf Retreat Subdivision, Lake Pend Orielle, ID - Advisory support for master plan design and construction of community water system.

The Meadows Subdivision, Valley County, ID - Advisory support for master plan and design of regional community water system and multi-phase subdivision.

United Water Idaho, Ada County, ID - Design of pipeline to 6 MGD treatment plant. Hydraulic analysis of existing intake and pump station to increase residual delivery pressure to membrane filtration plant.

Heritage Estates, Canyon County, ID - Master planning of community water system and use of existing irrigation water rights for 100 lot development.

Centerville Public Water System, Centerville, ID - Provide basis of public water system review in contested case.

<u>Pressure Irrigation Systems</u>

Surprise Valley, Boise, ID - Prepared a feasibility study and hydraulic model for a separate pressure irrigation system, designed and managed construction of the irrigation system. Prepared and processed a contested water rights transfer and application for water right in conjunction with project attorneys.

Woodbridge Subdivision, Meridian, ID - Planning, entitlement, modeling and design of a separate pressure irrigation distribution system and pump station. Coordinated with project owner and irrigation district to reconfigure conveyance of existing water rights and combine with supplemental water.

Parks Ranch, Donnelly, ID - Prepared application for use of groundwater to supplement existing surface water rights. Application included analysis of efficacy of existing surface rights, analysis of demand for supplemental water, assessment of aquifer capacity, and preliminary engineering of diversion works. Assisted client and legal counsel with processing of contested water right application.

J.R. Simplot Company, Boise, ID - Planning of separate pressure irrigation system supply for existing and future large-scale development. Designed and assisted client with construction management of main irrigation service including filtering and pressure regulation.

Saddlebrook Development, Star, ID - Master planning and design of pressure irrigation pump system for multi-phase development and future expansion to regional system.

Tuscan Hills Development, Canyon County, ID - Advisory support for master plan of pressure irrigation system with rotation delivery from local irrigation districts.

Multi – Discipline Projects and Land Development

Jug Mountain Ranch, Valley County, ID – Prepared comprehensive master plans for water supply, water distribution, storage allocation, pressure zones, and wastewater collection, pumping and land application system balance.

WestRock Resort, pre-cursor to Tamarack Resort, Valley County, ID – Planning and entitlement for a four-season resort including: stormwater management, detailed hydrologic analysis, storm water quality mitigation, sewage collection and disposal, agency meetings, multi-agency coordination, and regulatory approvals. Prepared a comprehensive master plan for water supply, water distribution, storage allocation, and pressure zones for a domestic water system, public area irrigation and snowmaking. Developed water use and demand estimates, worked in conjunction with legal counsel to formulate municipal water right application, assisted with water right approval process.

J.R. Simplot Company, Micron Technology, Inc., United Water Idaho, Raw Water Supply System, Boise, ID – Managed the design and construction of a pump station and pipeline for delivery of river water to industrial, utility and private entities. Management responsibilities included in-house and sub-consultant design on 10 sub-projects; construction contract administration and inspection involving 5 separate contractors; and coordination of multiple project owners. Assisted the project owners with planning, permitting and hydraulic modeling of overall system. Project consisted of a river intake structure, wet well, pump station and pumping equipment to deliver approximately 20,000 gallons per minute of river water through 16,000 feet of 30-inch and 24-inch steel, ductile and polyethylene piping.

City of McCall, Sewage Lift Station Upgrades, McCall, ID – Assisted with the design and construction management of upgrades to the City's main lift stations.

Hidden Springs Community, Hidden Springs, ID – Assisted with the design and construction management of a central sewage lift station. Provided value engineering review of proposed water supply, booster pump station, and storage allocation.

The Shores Development, Eagle, ID – Project manager for entitlement, design and construction services to develop approximately 100 acres along the South Channel Boise River into 86 luxury residential home sites. Entitlements within the City of Eagle included rezoning, preliminary and final platting, and a comprehensive floodplain development permit that incorporated floodplain storage. Site grading and excavation was configured to accommodate approval of an individual 404 wetlands permit, conservation easements and wetland enhancement. Site utility design included water service with provision for residential fire sprinklers and connection to a deep buried sewer main in a de-watered condition. Water rights were obtained and transferred and used in a separate pressure irrigation system supplemented by amenity water features. A unique split roadway design was developed in conjunction with a non-traditional storm water system that utilized both center and roadside swales for treatment and infiltration of site storm water. Provided survey staking, construction observation and construction coordination services.

Coordination was done with, and approvals obtained from, the City of Eagle, Eagle Sewer District, United Water, Idaho Power Company, Flood Control District #10, Ada County Highway District, the U.S. Army Corps of Engineers, the Idaho Department of Water Resources and Idaho Department of Lands, the Mace-Catlin Ditch Company, and adjacent property owners.

Riverwalk Development, Boise, ID – "No-rise" floodplain encroachment analysis of existing site conditions, proposed development and future bridge effects. Master planned and designed pressure irrigation system with amenity recirculation channels. Advisory support for modification of existing canal drain. Coordinate with legal counsel on water right applications.

Stonebriar Development, Ada County, ID - Master planning and design of low pressure sewage collection system to interface with sequencing batch reactor. Designed combined pressure irrigation pump station and wastewater treatment building.

Stetson Estates, Canyon County, ID - Prepared comprehensive storm water analysis and master plan for hillside development including detention ponds.

Pearson Park, McCall, ID - Grading, drainage and storm water management for storage unit complex.

Rocky Ridge Construction, Multiple Development Sites, ID - Due diligence to assess potential for entitlements, utility service and development cost pro-forma within multiple development sites.

Ridgeline Vistas, Canyon County, ID - Coordination with County, Highway District, power utility provider, District Health Department on 27 estate lot rural foothills development. Develop water rights transfer applications and coordinate with Idaho Department of Water Resources to refine multiple splits and transfers of existing water right.

Homedale and Garnet Road Development, Canyon County, ID - Coordinate with County and referral regulatory agencies to obtain conditional use permit approval for rural subdivision. Coordinate with irrigation and drainage districts to improve and relocate existing facilities.

Market and Homestead Road Development, Owyhee County, ID - Rural subdivision planning and relocation of irrigation canal.

Mace Road Property, Eagle, ID - Due diligence, entitlement analysis and feasibility study for exclusive development under floodplain storage requirements. Assist client in coordinating joint project with adjacent landowner.

Lower Pleasant Ridge Development, Canyon County, ID - Design and layout of rural subdivision. Coordination with irrigation districts, highway district, fire marshal, district health and other referral agencies. Obtain conditional use permit.

Jayker Nursery, Meridian, ID - Grading, drainage and storm water management plan for wholesale landscape and tree nursery.

Majestic View Estates, Canyon County, ID - Master planning of community water system and separate pressure irrigation system for a 110 lot development. Assisted client in obtaining Conditional Use Permit on appeal of prior decision.

Eagle Sewer District, Eagle, ID – On-call continuing services including Qualified Licensed Professional Engineer review of sewer designs by others.

<u>Floodplain and Hydrologic Studies</u>

Monroe, Eagle Gravel, Lakeland Village, WinCo, Eagle River, Boise River Flood Re-Study, Ada County, ID – Managed a flood re-study on an approximately three mile reach of the Boise River for multiple clients. Objective of flood study was to review, analyze then re-model and correct a Federal Emergency Management Agency study. Flood re-

study results include delineation of the floodplain and floodway. Modeling efforts include accounting for topographic changes, cross-section orientation and placement, flow split at the upstream end of Eagle Island, bridge hydraulics, and levees.

Laguna Pointe Subdivision, Ada County, ID - Delineate floodplain and revise FEMA maps.

Hidden Island Subdivision, Ada County, ID - Review FEMA flood study for resolution and optimize floodway.

Blackhawk Development, Valley County, ID - Peer review of flood study on an approximately 1 mile reach of the North Fork Payette River. Obtain FEMA approval in previously contested and rescinded approval.

Riverwoods Development, Cascade, ID - Detailed flood study on approximately 1.5 miles of the North Fork Payette River. Assisted Client with City's proposed changes to floodplain ordinance including no net loss of floodplain storage and no-rise floodplain development limitations.

Payette River Estates, Valley County, ID - Bank stabilization design and hydraulic analysis on the North Fork Payette River to protect existing sewer main serving approximately 200 lot resort subdivision.

Chaparral Road Development, Ada County, ID - Detailed flood study that developed base flood elevations and a floodway using a split flow analysis in conjunction with hydrologic analysis to determine flow rates.

McCauley Property, Eagle, ID - Refinement of FEMA floodway delineation.

Windsor Valley Subdivision, Canyon County, ID - Detailed floodplain, flood elevation and floodway study on an approximately 1-mile reach of Willow Creek including existing under-sized culverts.

Waltman Property, Canyon County, ID - Determination of base flood elevations with split effective flow model.

Mace Family Trusts Property, City of Eagle, ID - Comprehensive flood study to correct and refine FEMA floodplain maps on an approximately 1-mile reach of the North Channel Boise River. Study included cross-section resolution analysis, field survey, determination of base flood elevations and floodway optimization, bridge and irrigation diversion structures.

Osprey Meadows Subdivision, Valley County, ID - Detailed floodplain, base flood elevation and floodway study on approximately 2-miles of the North Fork Payette River.

Silverstone Campus, Meridian, ID - Coordinated with client and City of Meridian to perform joint study effort to assess impacts of existing under-sized culvert crossings of Eight Mile Creek and propose mitigation concepts.

Overland Village, Meridian, ID - Detailed floodplain, flood elevation and split floodway analysis at confluence of Eight Mile Creek and Five Mile Creek. Assess impacts of existing crossing on FEMA flood elevations. Develop grading and drainage plan and floodplain development permit approval.

Sleepy Hollow Subdivision, Garden City, ID - Analysis of multiple potential floodplain results in studies by FEMA and others to facilitate construction of subdivision within context of City of Garden City floodplain ordinance. Obtain LOMR-F for subdivision including revalidation under revised FEMA maps.

McFarland Creek, Ada County, ID - Forensic investigation and peer assistance on hydraulic effects of constructed pond in tributary floodway obtain approvals in contested case.

Riverside Estates, Bellevue, ID - Obtain permits from regulatory agencies including City of Bellevue, U.S. Army Corps of Engineers, and Idaho Department of Water Resources to authorize construction of bank stabilization to protect luxury river front homes on the Big Wood River.

Lonesome Dove Development, Eagle, ID - Analysis and floodplain development permit approval demonstrating interactive hydraulic characteristics of gravel extraction, amenity ponds and floodplain development in the floodway of the North Channel Boise River.

Transportation Hydraulics

7th Avenue North, City of Payette, ID - Coordination with City, ITD and irrigation district to analyze hydraulic performance of existing and proposed bridge over irrigation canal. Analysis included determination of self-limiting extreme flood event and downstream weir.

Pine Bridge, Elmore County, ID - Hydraulic analysis of existing and proposed bridge improvements to mitigate critical levels of pier and abutment scour on bridge over the South Channel Boise River.

Feather River, Elmore County, ID - Hydraulic analysis of existing culverts and proposed replacement bridge. Analysis included hydraulic and roadway skew angles, and channel and riprap design to facilitate fish passage.

Canyon Creek Bridge, Elmore County, ID - Hydraulic analysis of existing bridge and performance of proposed replacement bridge and modified roadway approach. Analysis of scour and design of revetment for channel and embankments.

Industrial Projects

Micron Technology Incorporated, Boise, ID - Planning, entitlement, design, construction and project management for supply of industrial process water.

SSI Food Services, Inc., Wilder, ID – Hydraulic modeling and design of pumping and dual force main facilities for transportation of industrial wastewater to a land application site.

Dairymen's Creamery Association, Boise, ID - Designed a flow equalization facility for collecting and pumping industrial process wastewater to storage and controlling and monitoring tank outflow to the public sewer system.

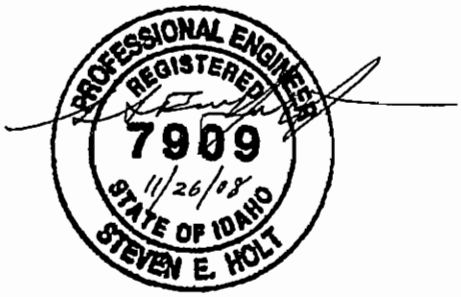
WestFarm Foods, Caldwell, ID - Design and construction assistance for industrial process wastewater including pre-treatment, stabilization, storage equalization and controlled outfall rate to municipal sewer system.

Idaho Power Company, C.J. Strike Projects, Snake River, ID - Coordinate with client to develop proposed improvements for recreational sites and assistance with 404 permitting. Design boat ramps, marina and jetty.

ENGINEERING REPORT
WATER USES

M3 EAGLE PLANNED COMMUNITY

2nd AMENDED WATER RIGHT APPLICATION



Toothman-Orton Engineering Company
Version: November 26, 2008

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Engineering Report
Water Uses

M3 Eagle Planned Community
Second Amended Municipal Water Right Application

Steven Holt, P.E.
Toothman-Orton Engineering Co.
November 26, 2008

M3 Eagle Planned Community – Water Right Application (slide 1)
This report, and the attached PowerPoint slides, outline facts and conclusions concerning the M3 Eagle community ground water diversions and uses at project build-out. This report provides an overview of the groundwater diversion and distribution system to serve those uses, summarizes the diversion and storage quantities requested in the application, and reviews the assumptions, calculations and reference data underlying the requested water right diversion quantities. The calculations are contained in the spreadsheet attached as Exhibit 5.7 to Attachment A of M3 Eagle's Second Amended Application (the "spreadsheet").

The calculations provided in the spreadsheet are intended to be neither too conservative nor too aggressive, meaning they are not the least amounts possible for any given use, and they are not at the high end. However, in a project of this size, it is unavoidable that the actual amounts will vary somewhat as the project is developed through its planning horizon. The intent is that the overall volumes diverted, the acres irrigated, and the indoor uses, will not exceed those calculated in the spreadsheet. Accordingly, the use estimates tend to be on the high side rather than on the potentially achievable low side.

Summary of Water Uses (slide 2)
The indoor potable domestic demand consists of 7153 residential units, schools, hotel rooms and 245 acres of commercial development. Irrigation associated with residential and commercial structures totals approximately 487 acres. Public area irrigation totals 765 acres including common areas, two 18-hole golf courses, several parks and ball fields. Approximately 1828 acre-feet (ac-ft or af) of groundwater and reuse water will be stored in aesthetic, operational and effluent ponds with approximately 100 acres of surface area.

Application Exhibit 5.1 - Well Field Diversion Components - Potable Water (slide 3)
Exhibit 5.1 of the Water Rights Application is a flow-chart schematic illustrating how the well field diversion is distributed into storage and use components. The well field diversion provides for potable (drinking and other indoor) water uses on the left of the exhibit, non-potable uses on the right side of the exhibit and the interconnection of non-potable irrigation with effluent at the bottom center of the exhibit.

The potable uses on the left side of the exhibit illustrate that the well field will supply daily demands up to the maximum day demand. Potable storage will provide fire fighting flows and

supplement diversions from the well field to accommodate peak hour demands for residential irrigation and indoor domestic use.

Preliminary water quality testing by Hydro Logic, Inc. indicates the proposed groundwater source is expected to meet Federal and State drinking water standards without treatment and therefore be potable as diverted from the wells. Supplementary treatment, such as establishing a disinfectant residual in the potable distribution system, may be part of the final water system design.

Application Exhibit 5.1 - Well Field Diversion Components – Non-Potable Water (slide 4)
The non-potable uses on the right side of the exhibit illustrates that the well field will supply daily demands up to the maximum day demand. Storage in non-potable operational ponds will supplement diversions from the well field to accommodate peak hour demands for non-potable irrigation on common areas. Although the groundwater is expected to be potable as diverted from the wells, the non-potable irrigation distribution system will be separate from the potable drinking water system, and would not be expected to receive disinfection as described above. The right side of the exhibit also indicates the well field will supply the aesthetic storage ponds.

Application Exhibit 5.1 - Well Field Diversion Components – Reuse Water (slide 5)
The portion of the potable water not consumptively used indoors would be collected in a conventional sewer system, treated to Class A wastewater standards as defined by the Idaho Department of Environmental Quality (DEQ) and used for irrigation of public areas.

During the relatively high demand months of the irrigation season, diversions from the well field will be used in combination with the treated effluent as produced to meet projected public area irrigation demand. To allow for maximum use of treated effluent for irrigation, from time to time some areas normally irrigated with ditch company or other surface water may be irrigated with effluent instead. The irrigation piping will be designed to accommodate this flexibility.

Until M3 Eagle has produced detailed project layouts of homes, commercial areas, and infrastructure, the areas to be irrigated with existing surface water supplies cannot be determined. It is anticipated that use of surface water on the project, which is made possible primarily by the presence of the Farmer's Union ditch on its southeast portion, may require place of use transfers.

Effluent produced in the non-irrigation season will be stored in ponds and used the following irrigation season. In the calculations, storage and reuse of winter effluent is separated from the reuse of effluent during the irrigation season. The exhibit also illustrates effluent storage ponds, which will be lined to control or eliminate leakage.

Requested Diversion and Storage Quantities (slide 6)
The following discussion summarizes the diversion and storage quantities requested in the water right application.

Application Exhibit 5.4 - Annual Groundwater Diversion Volume (slide 7)
Exhibit 5.4 in the application illustrates the components of the requested 6535 ac-ft of annual diversion volume. Approximately 62% of the indoor potable diversion generates 1818 ac-ft of effluent that could be reused for irrigation. The effluent generation represents 28% of the total annual diversion volume. After overcoming 158 ac-ft of evaporative losses from the effluent storage ponds, an estimated 1616 ac-ft of effluent is reused for 54% of the non-potable irrigation. The benefit of the reuse water in reducing diversions is accounted for in the net municipal well divisions for non-potable irrigation and pond evaporation components of the pie chart. If, due to weather conditions that may include abnormally high precipitation or low temperatures, it is necessary to provide more irrigated acreage on which to use treated effluent, dedicated irrigation water supplies (Farmers Union shares, irrigation wells) will not be used so that those acres within the service area can receive treated effluent instead. This operational flexibility is not calculated in the spreadsheet, but is an example of an option that could be implemented as experience on the site dictates.

Exhibit 5-4 indicates well diversions for evaporative losses in aesthetic and operational ponds but not the evaporation from winter effluent storage ponds because those evaporative losses were originally diverted for indoor use. In other words, the spreadsheet assumes that only effluent will be evaporated in the effluent storage ponds and therefore no additional diversions from the wells are needed to overcome evaporation. The effluent that is evaporated is therefore reuse water used up by evaporation.

Application Exhibit 5.4 - Annual Groundwater Consumptive Use (slide 8)
Exhibit 5.5 of the application illustrates the components of the estimated 5381 ac-ft of annual consumptive use. The estimated 1553 ac-ft of consumptively used reuse water represents 29% of the total CU. The consumptive use of reuse water is included in the pie chart as the evaporation from winter effluent storage ponds (158 ac-ft) and 1395 ac-ft within the public area non-potable irrigation. The reuse water represents 55% of the total consumptive use for non-potable irrigation.

Application Exhibit 5.4 - Maximum Daily Well Diversions (slide 9)
Exhibit 5.6 of the application illustrates the components of the requested maximum daily diversion of 23.18 cfs. The maximum daily diversion coincides with the maximum demand during the irrigation season. The net maximum daily well diversion of 6.27 cfs for non-potable irrigation shown on the pie chart accounts for 2.51 cfs from effluent that is generated and reused during the irrigation season. The net maximum daily well diversion also accounts for using effluent generated during the winter for non-potable irrigation on 120 acres that otherwise would have required 1.67 cfs of maximum day well diversions.

Exhibit 5-6 indicates a maximum day well diversion of 1.10 cfs to overcome evaporation in aesthetic and operational ponds but does not illustrate a well diversion to overcome evaporation from winter effluent storage ponds because those losses were originally diverted for indoor potable uses. As described above, the spreadsheet assumes that effluent will be evaporated in the effluent storage ponds and therefore no additional diversions from the wells are needed to overcome evaporation.

Calculations and Reference Data - Application Exhibit 5.7 – The Spreadsheet (slide 10)
Exhibit 5.7 of the application is a spreadsheet that calculates quantities requested in the water right application. The spreadsheet reflects full build-out of the proposed M3 Eagle Development project at the end of the 30-year planning horizon.

Error Concerning Number of Irrigation Shares
Row 5 of the spreadsheet states that M3 holds 17.93 shares of Farmers Union Ditch Co. water that will be used to irrigate 197 acres in the development. Cells C37 and C38 state that 98 acres of ballfields and parks and 99 acres of common area turf, representing the total of 197 acres irrigated by ditch shares, are excluded from the spreadsheet calculations of well diversions. In other words, the water right application does not provide for well diversions to cover this amount of irrigation.

However, the 17.93 number is incorrect. A certificate for 7.30 shares was inadvertently added twice in totaling 17.93 shares. Attachment D of the Water Rights Application documents that M3 Eagle has 9.97 shares and anticipates acquiring 0.66 additional shares for a total of 10.63 shares. The 0.66 shares have since been acquired. The 10.63 shares represent 117 inches of irrigation water under Farmers Union's standard eleven inches per share, and with historic irrigation of 147 acres, there is a duty of water on these lands for these shares of 0.79 inches per acre.

In addition, M3 Eagle holds a groundwater right No. 63-10669 that provides for irrigation of 111 acres ("Kling right"). The Kling right appears to have been used to supplement uses on those acres served under the Farmers Union ditch shares. However, of the 111 acres in the Kling right's place of use, only 104 acres overlap with the Farmers Union place of use. As a result, the Kling right is the primary water right for at least 7 acres. With the additional 7 acres of irrigation from the Kling right, M3 Eagle has historically irrigated, or is otherwise authorized to irrigate, 154 acres of the 197 acres assumed in the spreadsheet. M3 Eagle has several options to accommodate this discrepancy of 43 acres prior to build-out or licensing.

One option is to remove the 43 acres of irrigated ground from the development plan. Another is to transfer one of its several irrigation ground water rights to use on such parcel(s) as they are proposed for development in the future. Another is to acquire additional surface water, either shares in Farmer's Union Ditch Company or otherwise, to transfer to the project.

Implementation of water conservation measures described in Attachment D, pages 4 and 5, are anticipated to allow for a portion of the 43 acres to be irrigated within the diversion quantities requested in the application.

In addition, each golf course is currently sized for 120 acres of irrigated area and likely is approximately 20 acres more than each course actually will have. This conservatively high estimate alone would account for 40 acres of the discrepancy in ditch shares. In any case, when considering a twenty-year or more build-out period, this error is minor and should not affect water planning for the project.

Irrigation Season – Spreadsheet Page 1 (slide 11)
Cell C8 indicates an irrigation season lasting 244 days from March 15 to November 15. This length of season is consistent with the Idaho Department of Water Resources (IDWR) guidelines for irrigation seasons on the project that range from March 15 to November 15 with 246 days to March 1 to November 15 with 260 days based on average day temperatures above 45 degrees.

Irrigation Efficiencies– Spreadsheet Page 1 (remain on slide 11)
Cells B11 and B12 include estimated turf and drip irrigation efficiencies of 80% and 90%, respectively, based on the references contained in accompanying slide 12.

References for Irrigation Efficiency (slide 12)

Estimated Pond Configuration and Storage Quantities - Spreadsheet Page 1 (slide 13)
Row 14 of the spreadsheet lists the surface area, average depth and storage volume of aesthetic, operational and winter effluent storage ponds. The aesthetic ponds will be maintained at relatively constant levels, the operational pond levels will fluctuate to meet peak hour non-potable irrigation demands, and the winter effluent storage ponds will store effluent produced during the winter for use in the subsequent irrigation season. Taken together, the ponds comprise an estimated 100 acres with approximately 1828 acre-feet of storage. The ponds will be lined or sealed to control exfiltration.

Irrigation Evapotranspiration Demand – Spreadsheet page 1 (remain on slide 13)
Referring to Row 27, the monthly evapotranspiration, or ET demand, for irrigation is based on Allen & Brockway data from their 1983 study titled "Estimating Consumptive Irrigation Requirements for Crops in Idaho." The Allen & Brockway ET data used in the spreadsheet is for alfalfa hay to represent turf grass and other landscape vegetation because the Allen & Brockway data does not provide ET demand for turf grass. Also, the spreadsheet estimates ET in November at 1/3 of the Allen Brockway ET for irrigation in October.

The spreadsheet uses the Allen & Brockway data calculated at the Boise Airport. The 2007 study by Allen & Robison titled "Evapotranspiration and Consumptive Irrigation Water Requirements for Idaho" provides ET data for turf grass at the Boise Airport and at a site named "Boise 7N". The Idaho Department of Water Resources ("IDWR") adopted the Allen & Robison data on February 11, 2008 (Administrator's Memorandum, Miscellaneous Memo No. 16) after the Seconded Amended M3 water right application was filed on February 1, 2008. Locations of these sites and the associated ET data are as set forth in slide 14.

Evapotranspiration Reference Locations (slide 14)

References for Irrigation Evapotranspiration (ET) (slide 15)
The Allen & Robison ET sites have a peak ET demand in July that are within 2% of the Allen & Brockway value used in the spreadsheet. The Allen & Robison ET sites have annual ET demands up to 12% higher than the Allen & Brockway value used in the spreadsheet with modification for the length of irrigation season described previously.

Spreadsheet page 1 (slide 16)
Referring to cell K29, the total ET demand for irrigation is approximately 3.3 feet of water depth per year and is consistent with the IDWR consumptive irrigation requirement of 3.5 ac-ft/ac per year for the project location.

IDWR Consumptive Irrigation and Field Headgate Requirement Map (slide 17)

Non-Potable Irrigation Areas and Demands - Spreadsheet page 1 (slide 18)
Cells E36-E39 list a total of 645 acres to be irrigated with non-potable water using a combination of well diversions and effluent produced during the irrigation season.

Cell E40 indicates 120 acres will be irrigated with stored winter effluent. The 120 acres is calculated in the spreadsheet as a result of winter effluent generation, storage, pond evaporation and irrigation. For simplicity the 120 acre calculation is segregated from the 645 acres in Cells E36-E39.

The bold font in cell H41 represents the maximum day irrigation demand of 8.78 cubic feet per second (cfs) for 645 acres of public areas irrigated by summer effluent and well diversions based on the maximum monthly ET demand in July and the assumed irrigation efficiencies. The maximum day irrigation demand of 8.78 cfs allows for irrigation of common areas over a 24-hour period and, when combined with the 6.78 ac-ft of non-potable storage indicated in cell L41, provides for irrigation of the golf courses, parks, and ball fields in time periods ranging from 9 to 12 hours (cells I36 and I37) to accommodate daytime recreational use. Note that the 8.78 cfs demand is equivalent to 0.014 cfs/acre and is 30% less than the statutory duty of water of 0.02 cfs/acre. The estimated application rate of 0.014 cfs/acre is based on relatively high irrigation efficiencies achieved by sprinkler and drip irrigation, the 24 hour irrigation schedule for the common areas, and use of non-potable storage to allow for the 9 hour and 12 hour irrigation times for the golf courses and ball fields.

Potable Irrigation Areas and Demands - Spreadsheet page 1 (remain on slide 18)
Cells D45 and D46 illustrate the estimated irrigated area for single family detached units consisting of a projected 2000 square feet (s.f.) of turf irrigation area and 1500 s.f. of drip irrigation area where the latter would typically be tree and shrub beds. Taken together, the estimated total of 3500 s.f. of irrigated area per unit represents 45% irrigated area on an average lot size of 7800 s.f.

Cells D52 and D53 indicate estimated 750 s.f. of turf area and 500 s.f. of drip area per dwelling unit for single-family attached and multi-family attached units. Cells B59 and B60 indicate the total 245 gross acres of commercial development with an estimated 5% irrigated area.

The residential and commercial irrigation will be served by the potable water distribution system. Cell H63 indicates a maximum day residential and commercial irrigation demand of 6.45 cfs if applied at a constant rate a 24-hour period. Cells I47-I60 indicate irrigation is estimated to occur over a 12-hour nighttime period and results in the 12.9 cfs total potable irrigation demand shown in cell J63. Because application at 12.9 cfs could require diversions of more than 0.02 cfs/acre,

diversion of 9.74 cfs (cell K63) from the well field at 0.02 cfs/acre is combined with delivery of 1.02 millions gallons of potable water storage (cell M63) to accomplish the irrigation in the estimated 12-hour period.

Indoor Demands –Spreadsheet page 2 (slide 19)
The top half of page 2 of the spreadsheet calculates indoor water demands for the residences, schools, hotels and commercial areas. The residential units represent the majority (82%) of the indoor water demands. Cell D80 indicates an average daily residential demand of 274 gallons per day per unit (gpd/unit) that results from a planning estimate of 100 gallons per capita per day (gpcd) of average daily water use multiplied by 2.74 people/house per the Ada County 2000 census. The 274 gpd/unit estimate is supported by the sources cited below.

References for Residential Use (slide 20)
The references cited illustrate a wide range of data for average daily use per dwelling unit. Factors that contribute to the data range include influence of irrigation, system leakage, unaccounted for water, accuracy of water use and production records, population density and amounts of outdoor use.

Irrigation can have a significant effect on water use in the western United States. The reference data include United Water Idaho data for winter use, which demonstrates approximately 255 gpd/unit, consistent with M3 Eagle's planning estimate of 274 gpd/unit used in the spreadsheet.

Conservation measures and plumbing code restrictions on flow and volume, which are not fully implemented in many existing areas but are expected to be implemented in all phases of the M3 Eagle project, could result in residential demands less than 274 gpd/unit. The actual demand will be metered and adjustments made to the design and construction of the diversion and distribution system where appropriate as the M3 Eagle project develops.

If the average daily indoor potable residential use is lower than 274 gpd/unit, then well diversions for indoor potable water will be lower and effluent production and reuse water likely will decrease. In that case, well diversions for non-potable irrigation will increase to compensate for the reduction in reuse water. The net effect, however, would be a slight reduction in the total requested 23.18 cfs peak daily diversion because of the reduced indoor use.

Maximum Daily Indoor Demands - Spreadsheet page 2 (slide 21)
Diversions from the well field will supply the maximum day indoor demand. For indoor potable use, the maximum day demand is 5.0 cfs as calculated in cell F80. This calculation requires application of a peaking factor to the average daily demand. As indicated in cell B75, the peaking factor was estimated at 1.5.

References for Residential Peaking Factor (slide 22)
Review of data for maximum day peaking factors reveals a range on the order of 1.5 to 3.5. The spreadsheet uses an indoor water use peaking factor of 1.5 because the higher peaking factors appear to be influenced by irrigation. From another perspective, the spreadsheet anticipates up to 50% more indoor water use on the maximum day of demand. Examples including influx of

visitors on holidays, perhaps more showers or ingestion of water during the summer months, and incidental outdoor water uses such as car washing.

Potable Water Storage - Spreadsheet page 2 (slide 23)
Diversions from the wells will supply the maximum daily indoor demand whereas peak hour demands will be supplied by combining the well field diversions with potable water storage. Cell B98 contains an estimate that 2.62 million gallons of potable water storage is needed. The storage components shown in cells B94 to B97 consist of irrigation peaking storage calculated in Cell M63 on page 1 of the spreadsheet, indoor peak hour demand storage calculated in Cell I90, fire flow of 3,000 gallons per minute (gpm) as storage held in reserve, and estimated operational storage for well pump cycling.

Wastewater and Effluent Production - Spreadsheet page 2 (remain on slide 23)
Potable water delivered for average daily indoor water demands is assumed to be either consumptively used or collected as wastewater for treatment and reuse. Cells F106-F108 show that an estimated 60% to 75% of the indoor water demand is generated as wastewater and potentially available for reuse.

References for Residential Wastewater Production Rate (slide 24)
The percent of wastewater generation typically varies from 60% to 130% in reference data. Wastewater production rates greater than 100% indicate the presence of other water sources in the sewer collection system such as infiltration of groundwater into sewer pipes or inflow of stormwater into manholes. The wastewater production rate of roughly 69% in the spreadsheet is at the low end of the data range so as to not over-predict the resulting effluent (and thus under-predict the amount of well pumping needed for non-potable irrigation) and because the design, construction and operation of the M3 sewer system will include measures to control infiltration and inflow.

Effluent Available for Non-Potable Irrigation - Spreadsheet page 2 (slide 25)
Row 124 calculates effluent generated from indoor potable demands. In particular, cell G124 indicates a total of 1818 ac-ft of effluent is produced annually. Cell H124 shows 1215 ac-ft of effluent is generated during the irrigation season and cell I124 shows 603 ac-ft of effluent is produced during the winter.

Cells C128 through C130 calculate the net winter effluent available for reuse. Cell C128 begins with the 603 ac-ft of effluent produced and stored during the winter. Cell C129 deducts an estimated 158 ac-ft of evaporative losses from the effluent storage ponds during the subsequent irrigation season, resulting in a net 445 ac-ft (in cell C130) of winter effluent re-used for irrigation. Cell 131 adds the 1215 ac-ft of effluent produced and re-used during the irrigation season for a total annual 1660 ac-ft (in cell C132) of effluent re-use.

The estimated 158 ac-ft of evaporation from the effluent storage ponds in cell C129 is equivalent to 3.5 ac-ft/acre per year and was derived from the following references. The estimated annual evaporation was also used for the aesthetic and operational ponds.

References for Pond Evaporation (slide 26)

Summary Results - Diversion Rates and Volumes - Spreadsheet Page 3 (slide 27)
Spreadsheet page 3 summarizes calculation results for diversion rates, diversion volumes and consumptive use volumes. A graphic summary of those results is provided in application Exhibits 5.4, 5.5 and 5.6 (pie charts). Spreadsheet pages 3 and 4 also segregate the diversion rates and volumes into the irrigation season and non-irrigation seasons.

Application Attachment A Quantities - Spreadsheet Page 4 (slide 28)
Spreadsheet page 4 provides selected spreadsheet results cited in Attachment A, page 12. Spreadsheet page 4 also calculates the direct well diversion and reuse components of consumptive use for non-potable irrigation and pond evaporation needed for Exhibit 5.5 (pie chart) of the application.

Monthly Potable and Non-Potable Irrigation Demands - Spreadsheet Page 5 (slide 29)
Spreadsheet page 5 calculates monthly diversion volumes and consumptive uses for all irrigation demands. Cell AR58 verifies a total annual irrigation consumptive use of 3.34 ac-ft per acre from the modified Allen Brockway ET input data on spreadsheet page 1. Cell AR59 indicates a total annual irrigation diversion of 4.01 ac-ft/acre resulting from the estimated 80%-90% irrigation efficiencies. The IDWR guidelines for annual irrigation diversions allow for 4.5 ac-ft/acre in the vicinity of the M3 project.

Conclusion
This report summarizes the bases for the groundwater diversion quantities requested in the second amended water right application for the M3 Eagle planned community. Reference data supporting calculation of these quantities are included.

The calculated diversion quantities are reasonable, based on sound engineering judgment, and within the ranges indicated in the literature on water use. They are also within the ranges Toothman-Orton has found or used for other projects.

Calculation of precise usages is impossible at this stage, but the overall proposed annual diversion volume is anticipated to have sufficient flexibility to accommodate changes and actual experience as the project is developed. Overall, the water supply being sought is adequate for this development and provides some cushion to accommodate unforeseen circumstances that may arise during the planning horizon.

M3 Planned Community

Eagle, Idaho

Water Right Application

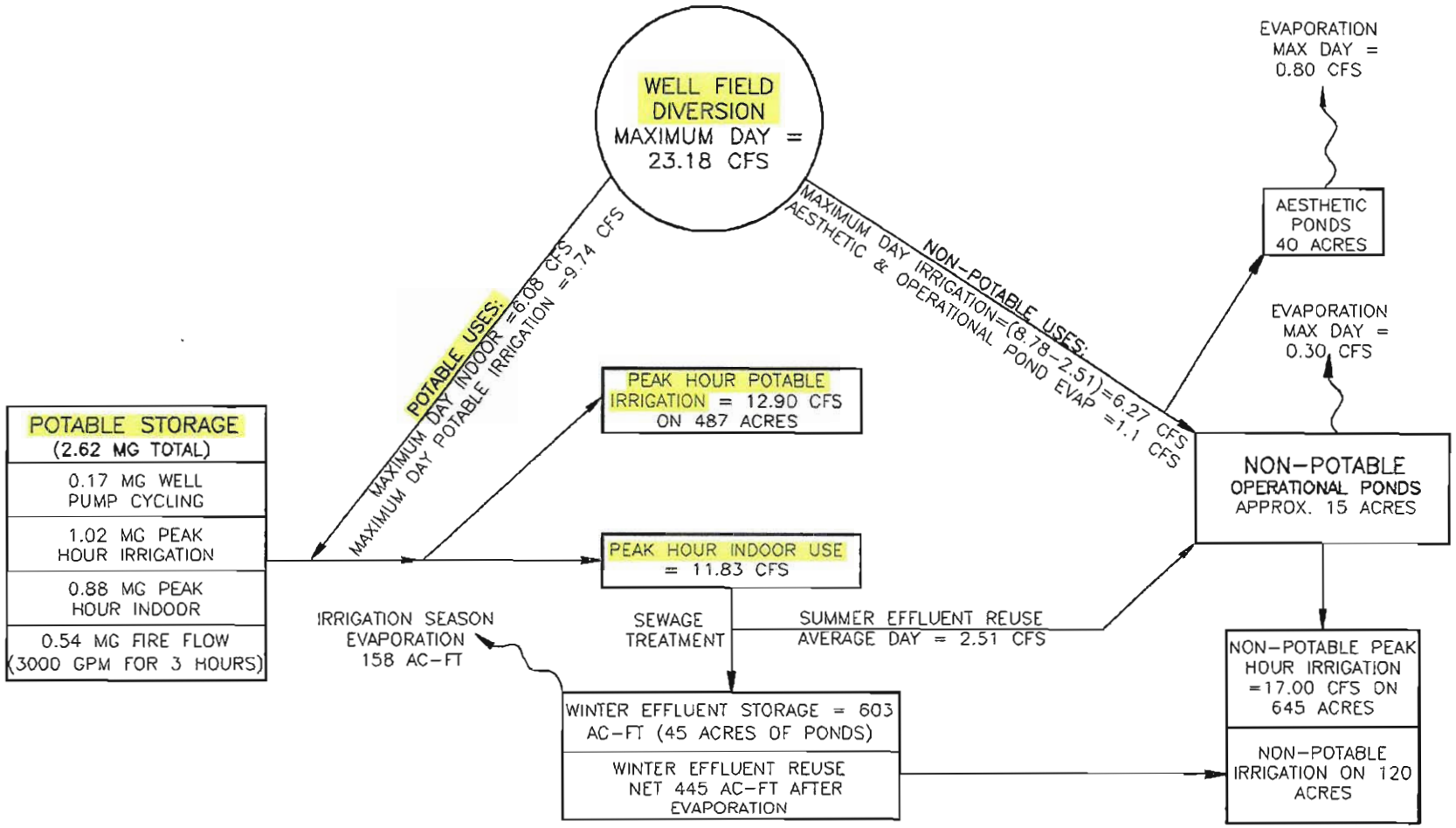
- Water Uses
- Overview of Diversion and Distribution System
- Requested Diversion and Storage Quantities
- Calculations and Reference Data

Summary of Water Uses

- Indoor
  - 7153 residential units (5216 single family and 1937 attached units)
  - Other
    - Schools (5480 students)
    - Hotel rooms (500)
    - Commercial development (245 gross acres)
  - 2.6 million gallons of potable water storage
- Irrigation – 1252 total acres
  - 487 acres residential & commercial
  - 765 acres public area (golf courses, parks, ballfields, common area)
- Aesthetic, Operational and Effluent Ponds
  - 1828 acre-feet (a.f.) of pond volume
  - 100 acres of pond surface area

M3 EAGLE DEVELOPMENT

WELL FIELD DIVERSION COMPONENTS



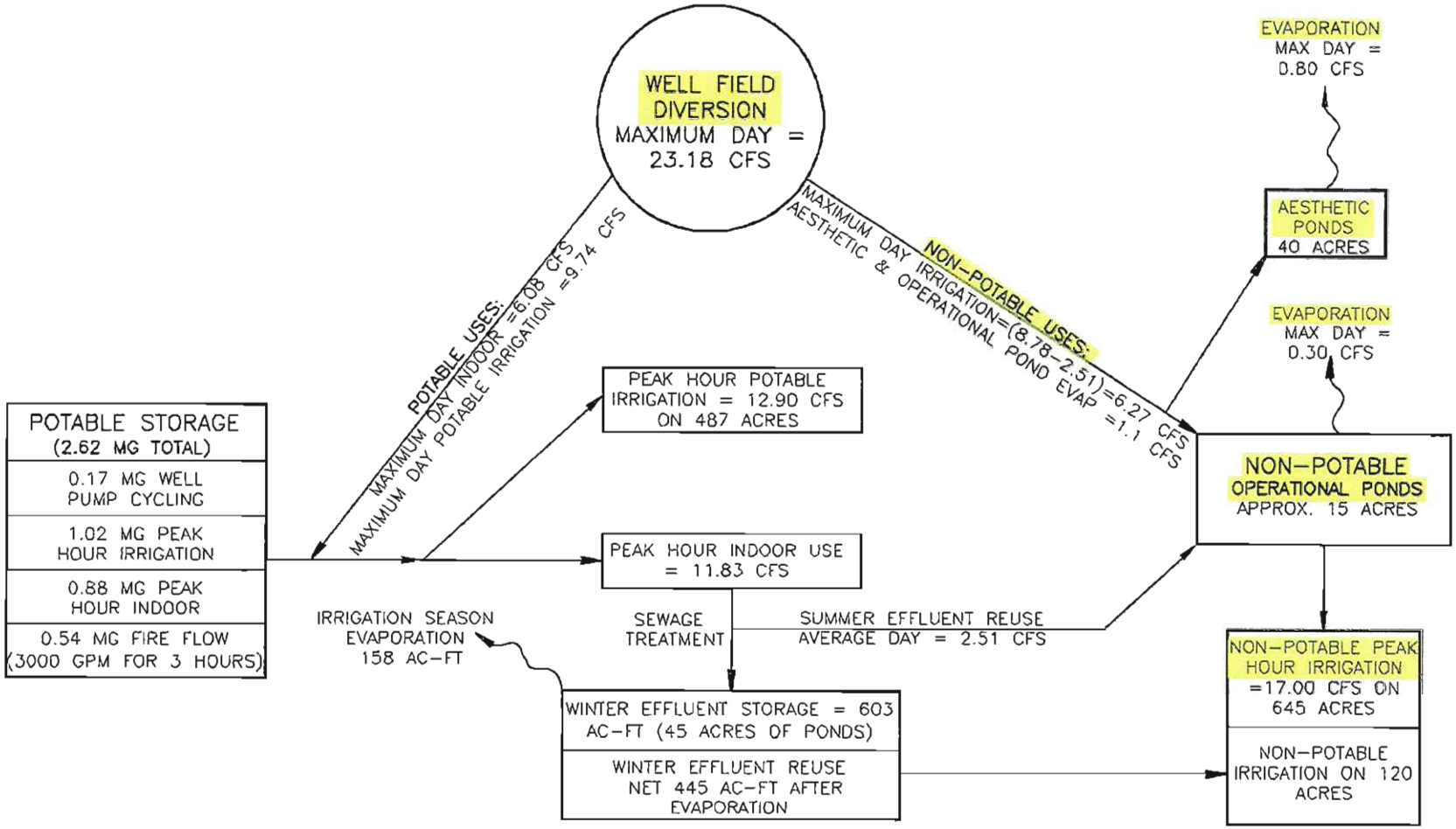
NOTE:

THE CONNECTIONS BETWEEN COMPONENTS DO NOT REPRESENT A SPECIFIC OR PROPOSED CONFIGURATION OF A DIVERSION AND DELIVERY SYSTEM.

ABBREVIATIONS:
CFS = CUBIC FEET PER SECOND
MG = MILLION GALLONS
AC-FT = ACRE-FEET

M3 EAGLE DEVELOPMENT

WELL FIELD DIVERSION COMPONENTS



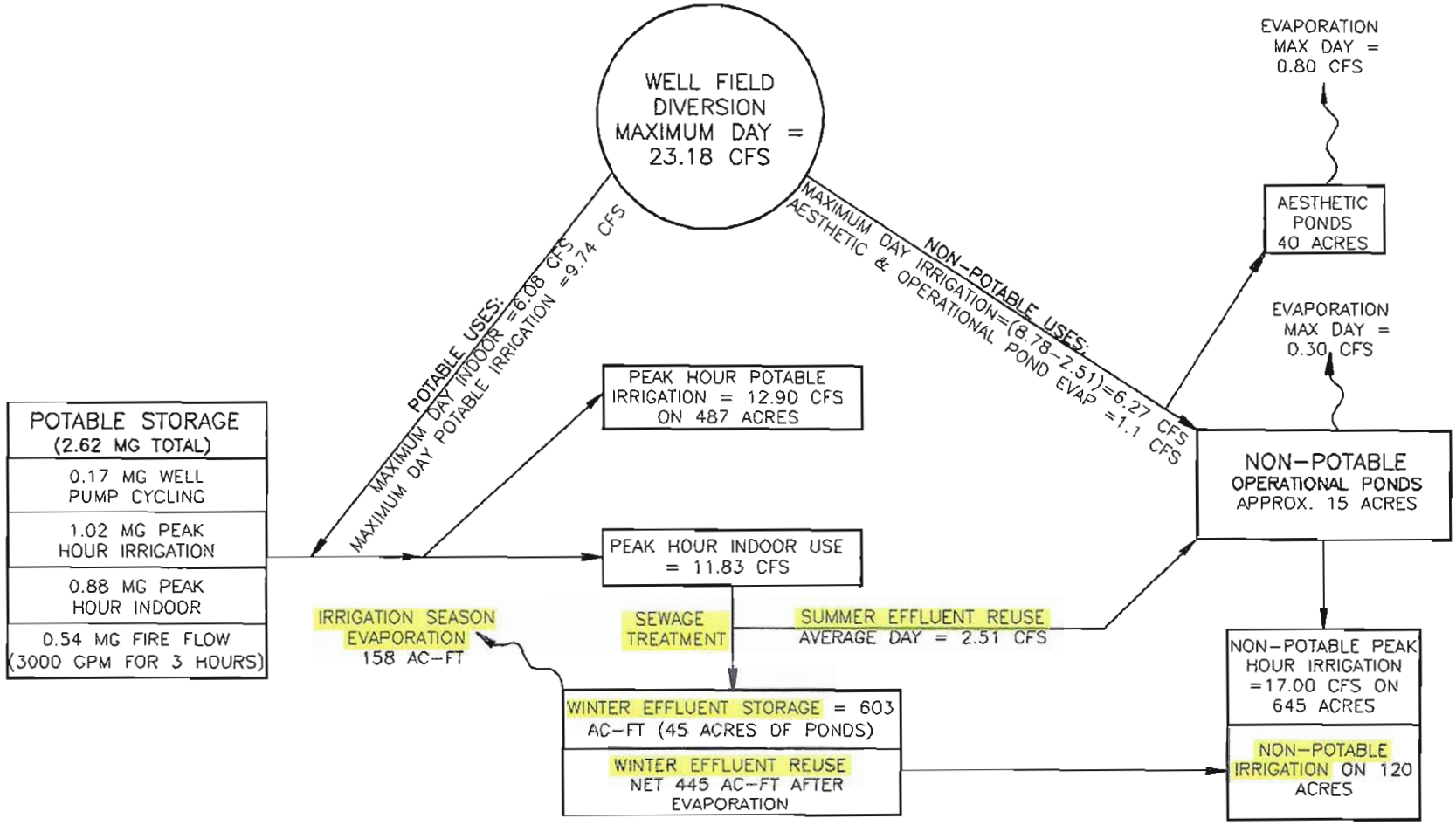
NOTE:

THE CONNECTIONS BETWEEN COMPONENTS DO NOT REPRESENT A SPECIFIC OR PROPOSED CONFIGURATION OF A DIVERSION AND DELIVERY SYSTEM.

ABBREVIATIONS:
CFS = CUBIC FEET PER SECOND
MG = MILLION GALLONS
AC-FT = ACRE-FEET

M3 EAGLE DEVELOPMENT

WELL FIELD DIVERSION COMPONENTS



NOTE:

THE CONNECTIONS BETWEEN COMPONENTS DO NOT REPRESENT A SPECIFIC OR PROPOSED CONFIGURATION OF A DIVERSION AND DELIVERY SYSTEM.

ABBREVIATIONS:
CFS = CUBIC FEET PER SECOND
MG = MILLION GALLONS
AC-FT = ACRE-FEET

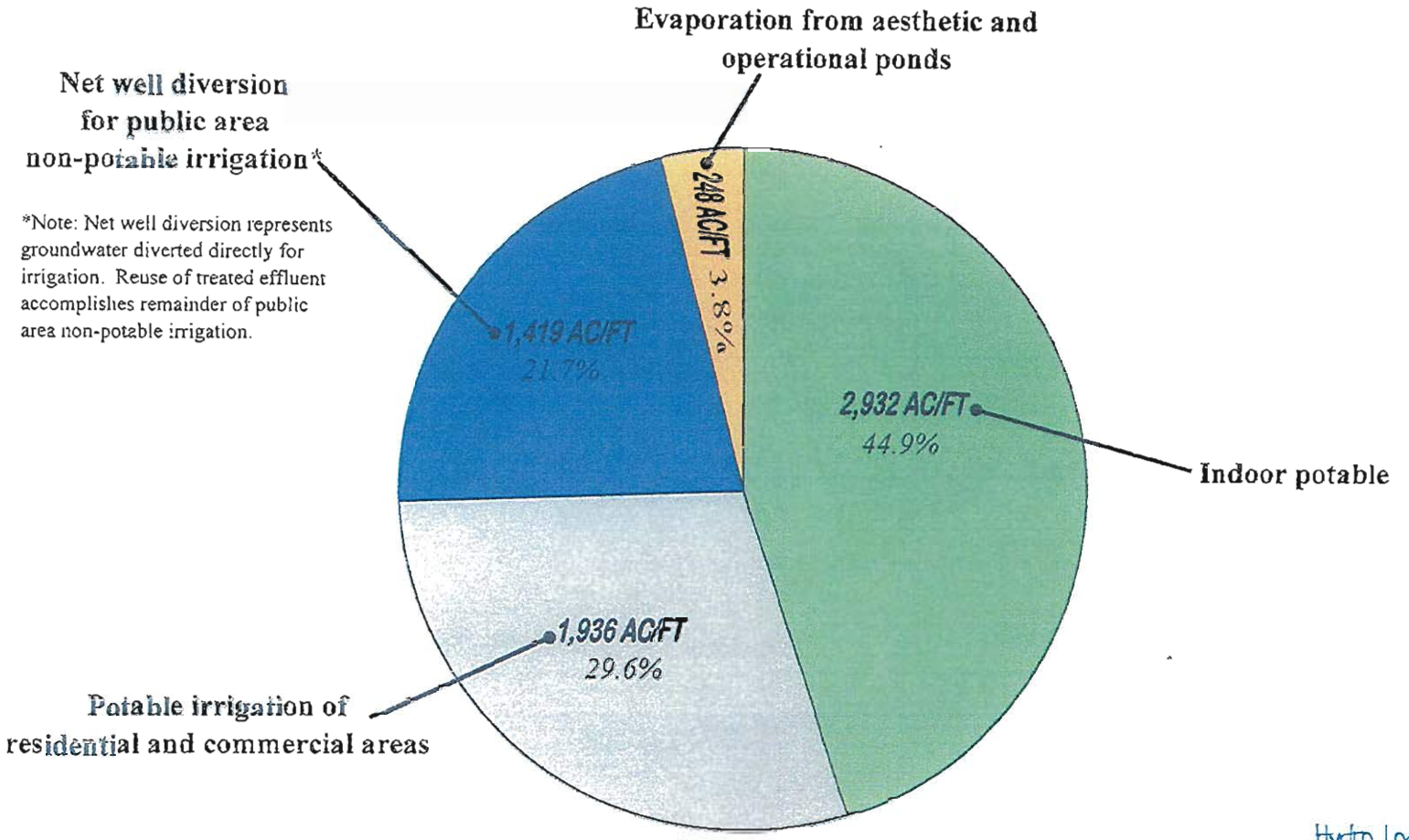
Requested Diversion and Storage Quantities

Exhibit 5.4

M3 Eagle

ANNUAL GROUND WATER DIVERSION VOLUME PERCENTAGES AT FULL BUILD-OUT

(Acre-Feet and Percentage of Total)



Total Annual Ground Water Diversion Volume ≈ 6,535 AC/FT

Note: Components of total well diversion shown herein may not add exactly to total annual diversion volume due to round-off error.

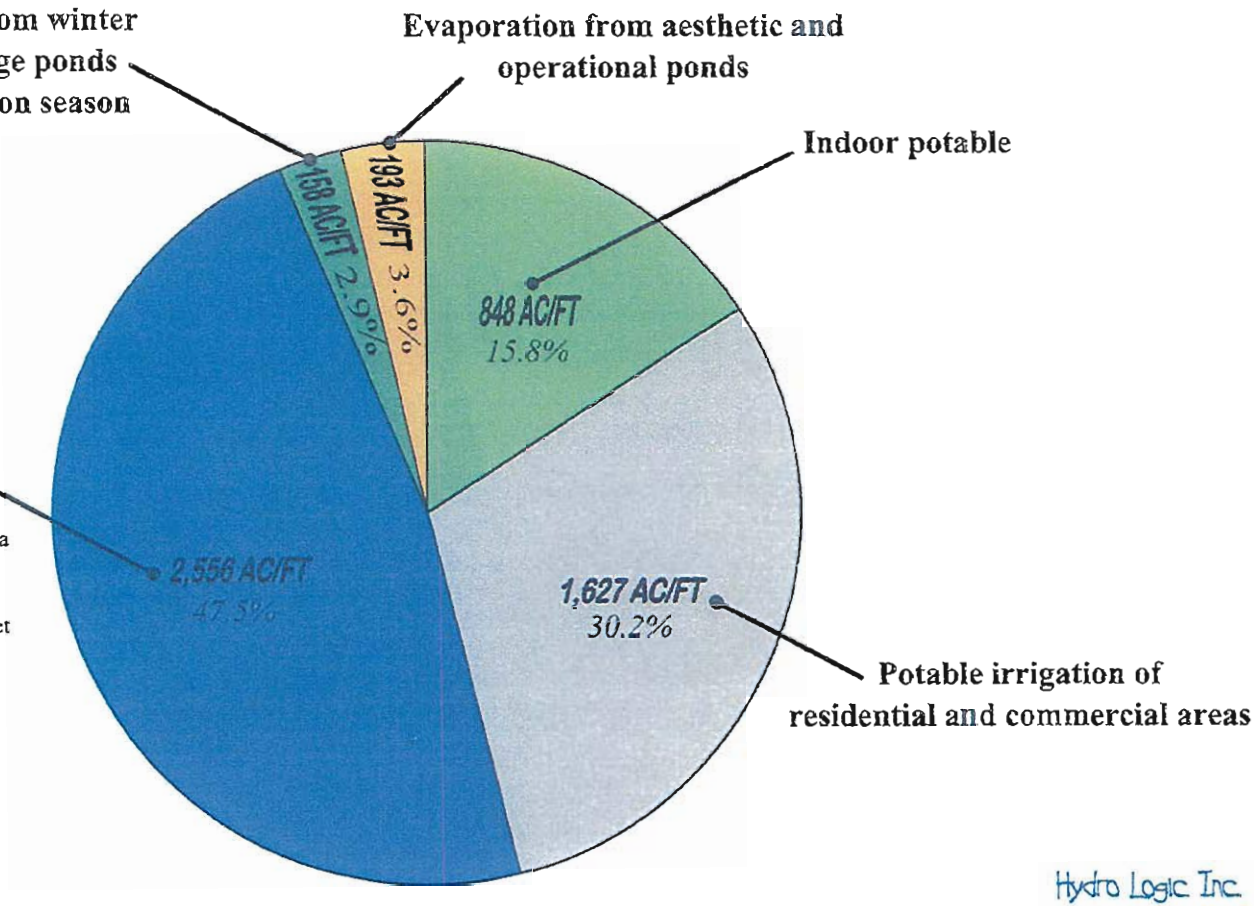
Hydro Logic Inc.
Boise, Idaho

Exhibit 5.5

M3 Eagle

ANNUAL GROUND WATER CONSUMPTIVE USE PERCENTAGES AT FULL BUILD-OUT

(Acre-Feet and Percentage of Total)



*Note: Consumptive use for "public area non-potable irrigation" is comprised of 1,161 acre-feet of groundwater used directly for irrigation and 1,395 acre-feet of "Reuse Water."

Hydro Logic Inc.
Boise, Idaho

Total Annual Consumptive Use ≈ 5,381 AC/FT

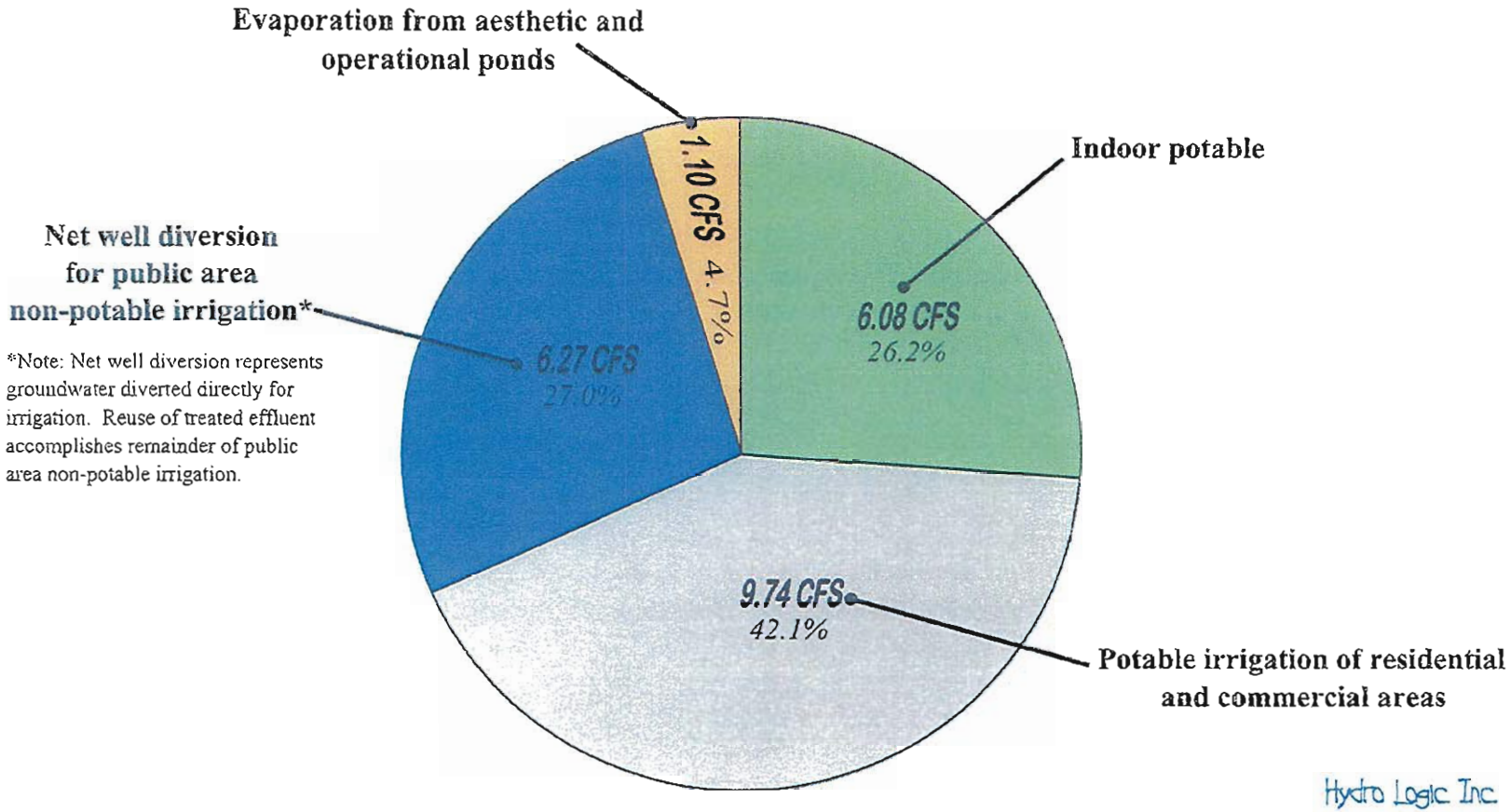
Note: Components of total consumptive use shown herein may not add exactly to total annual consumptive use due to round-off error.

Exhibit 5.6

M3 Eagle

MAXIMUM DAILY WELL DIVERSIONS DURING IRRIGATION SEASON AT FULL BUILD-OUT

(Cubic Feet per Second (CFS) and Percentage of Total)



*Note: Net well diversion represents groundwater diverted directly for irrigation. Reuse of treated effluent accomplishes remainder of public area non-potable irrigation.

Hydro Logic Inc.
Boise, Idaho

Maximum Daily Diversion ≈ 23.18 CFS

Note: Components of daily diversion shown herein may not add exactly to maximum daily diversion due to round-off error.

Calculations and Reference Data

Application Exhibit 5.7
The Spreadsheet

M3 Eagle Water Demand at Build-Out, Based on Projected Uses

Spreadsheet Revision Date: January 31, 2008

IRRIGATION

Irrigation Assumptions: Note: Input data cells in this spreadsheet are shaded.

1) 17.93 shares of Farmers Union Ditch Co. water, at 11 inches per share, and a total of 197 miner's inches (3.94 cfs), will be used to irrigate 197 acres in the development. The shares provide a total of 765 acre-feet at 3.88 ac-ft per acre.
2) Tertiary-treated sewage effluent will be used for non-potable irrigation at sewage production rates during the irrigation season. During non-irrigation season, it will be stored and subsequently used for irrigation.
3) Compressed irrigation times: Golf irrigation assumed to occur only during 9 hours at night; ball fields and residences during 12 hours. Common area can be irrigated anytime. Residences are assumed to migrate to 12 hour overnight irrigation.
4) Number of irrigation days per year: 244 (March 15th - November 15th) Number of non-irrigation days per year: 121 (November 16th - March 14th)
5) It is assumed sufficient standby power is provided to offset the need for standby potable water storage.
6) Turf irrigation efficiency: 80%
7) Drip irrigation efficiency: 90%

8) Acres of aesthetic and operational ponds:	Aesthetic ponds	Operational ponds	Ponds w/winter effluent storage	Totals
Average depth:	40	15	45	100
Acre feet storage:	25	15	13	17.8
Primary water source:	1000	225	603	1,828
	well diversions	well / effluent	effluent	

8a) Operational and effluent ponds will be lined or sealed and will fluctuate with evaporation and irrigation demand. Aesthetic ponds also will be lined or sealed and will fluctuate mainly due to evaporation.
9) Non-potable irrigation storage calculated from maximum day well diversion rate.
10) Potable irrigation storage calculated from .02 cfs/acre well diversion rate.
11) "Max day" refers to highest 24-hour demand. For irrigation, this occurs during July, as shown by the Allen & Brockway numbers. "Peak" refers to peak demand during compressed irrigation periods or on an instantaneous basis.
12) Irrigation diversion rates, as they relate to use of potable water for irrigation, are less than 0.02 cfs/acre except during peak periods, where they may increase to this limit.
13) Monthly evapo-transpiration (ET) is based on Allen & Brockway (1983) for alfalfa, for each month in the irrigation season except November (which Allen & Brockway did not evaluate), which was estimated at one third of October. These values are:

	March 15-31	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*Nov 1-15*	Total Annual		Avg. Daily	
mm/day	*0.760*	*3.670*	*5.410*	*6.610*	*6.730*	*5.110*	*3.680*	*1.450*	*0.483*	*1017.9*	mm/yr	4.17	mm/day
inches/day	*0.030*	*0.144*	*0.213*	*0.260*	*0.265*	*0.201*	*0.145*	*0.057*	*0.019*	*40.1*	in/yr	0.164	in/day
feet/day	*0.002*	*0.012*	*0.018*	*0.022*	*0.022*	*0.017*	*0.012*	*0.005*	*0.002*	*3.34*	ft/yr	0.014	ft/day

			square feet	acres	Average day cfs	Max day acre-feet	Max day cfs	Irr'n Hours	Scheduled peak cfs	cfs when div'ns increased to .02 cfs/a	Acre-feet non-potable storage to meet scheduled peak	Million Gallons potable storage to meet scheduled peak
Public area irrigation (using non-potable water)												
Golf Course (turf):			10,454,400	240	2.07	6.62	**3.34**	9	8.91	4.80	**4.14**	
Parks and Ballfields (turf):		Excluding 98 acres irr'd with ditch shares	8,319,960	191	1.65	5.27	**2.66**	12	5.32	3.82	**2.64**	
Common area (turf):		Excluding 99 acres irr'd with ditch shares	3,659,040	84	0.72	2.32	**1.17**	24	1.17	1.68	**0.00**	
Common area (drip):			5,662,800	130	1.00	3.19	**1.61**	24	1.61	2.60	**0.00**	
Common area drip irrig'd solely with stored effluent:		After effluent evap. from ponds at 3.5 AFA	5,224,612	120								
		Total public area irrigation:	28,096,200	765	5.44	17.40	**8.78**		17.00	12.90	**6.78**	
Residential irrigation (using potable water only)												
Single Family Detached Units:	5,216											
turf area/unit:			2,000	0.05	Note: Single family detached irrigation area based on average lot size of 7,800 sq. ft. with 3900 sq. ft. minimum building footprint plus incidental impervious area.							
drip area/unit:			1,500	0.03								
Total single family turf:			10,432,000	239.49	2.07	6.61	3.33	12.00	6.67	**4.79**		**0.61**
Total single family drip:			7,824,000	179.61	1.38	4.41	2.22	12.00	4.44	**3.59**		**0.28**
		Total single family irrigation (potable):	18,256,000	419.10	3.44	11.02	5.56		11.11	**8.38**		**0.88**
Single Family and Multi-Family Attached units:	1,937											
turf area/unit:			750	0.02	Note: Attached units consist of approximately 80% single family with an assumed irrigation being approximately 1/3 that of single family detached.							
drip area/unit:			500	0.01								
Total multi-family turf:			1,452,750	33.35	0.29	0.92	0.46	12.00	0.93	**0.67**		**0.08**
Total multi-family drip:			968,500	22.23	0.17	0.55	0.28	12.00	0.55	**0.44**		**0.03**
		Total multi-family irrigation (potable):	2,421,250	55.58	0.46	1.47	0.74		1.48	**1.11**		**0.12**
Commercial irrigation (using potable water)												
Acres of Commercial	245	Total commercial turf (25%):	133,403	3.06	0.03	0.08	0.04	12.00	0.09	**0.06**		**0.01**
% of Acres Irrigated	5.0%	Total commercial drip (75%):	400,208	9.19	0.07	0.23	0.11	12.00	0.23	**0.18**		**0.01**
		Total commercial irrigation (potable):	533,610	12.25	0.10	0.31	0.16		0.31	**0.25**		**0.02**
Commercial turf:	25%											
Commercial drip:	75%	**Total irr'n with potable water:**	21,210,860	486.93	4.00	12.79	6.45		12.90	**9.74**		**1.02**
		Total irrigation with both potable and non-potable water:	49,307,060	1251.87	9.44	30.20	15.23		29.90	22.64		

References for Irrigation Efficiency			
No.	Reference	Efficiency (%) based on irrigation type	
		Solid set	Drip
IER1	Rogers, et. al., Efficiencies and Water Losses of Irrigation Systems, Irrigation Management Series, Kansas State University, 1997	70-85	75-95
IER2	Solomon, K. H., Irrigation Systems and Water Application Efficiencies, Center for Irrigation Technology, CSU, Fresno, 1988	70-80	75-90
IER3	AgriMet Irrigation Guide, U.S. Bureau of Reclamation, Pacific Northwest Cooperative Agricultural Weather Network, Internet Website	70-85	75-90
	M3 Spreadsheet Exhibit 5.7 – Cells B11 and B12	80	90

M3 Eagle Water Demand at Build-Out, Based on Projected Uses

Spreadsheet Revision Date: January 31, 2008

IRRIGATION

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4) Number of irrigation days per year: 244 (March 15th - November 15th) Number of non-irrigation days per year: 121 (November 16th - March 14th)
5) It is assumed sufficient standby power is provided to offset the need for standby potable water storage.
6) Turf irrigation efficiency: 80%
7) Drip irrigation efficiency: 90%

8) Acres of aesthetic and operational ponds:	Aesthetic ponds	Operational ponds	Ponds w/winter effluent storage	Totals
Average depth:	25	15	13	17.8
Acre feet storage:	1000	225	603	1,828
Primary water source:	well diversions	well / effluent	effluent	

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feet/day	0.002	0.012	0.018	0.022	0.022	0.017	0.012	0.005	0.002	3.34	ft/yr	0.014	ft/day

		square feet	acres	Average day cfs	Max day acre-feet	Max day cfs	Irr'n Hours	Scheduled peak cfs	cfs when div'ns increased to .02 cfs/a	Acre-feet non-potable storage to meet scheduled peak	Million Gallons potable storage to meet scheduled peak
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Parks and Ballfields (turf):	Excluding 98 acres irr'd with ditch shares	8,319,960	191	1.65	5.27	2.66	12	5.32	3.82	2.64	
Common area (turf):	Excluding 99 acres irr'd with ditch shares	3,659,040	84	0.72	2.32	1.17	24	1.17	1.68	0.00	
Common area (drip):		5,662,800	130	1.00	3.19	1.61	24	1.61	2.60	0.00	
Common area drip irrig'd solely with stored effluent:	After effluent evap. from ponds at 3.5 AFA	5,224,612	120								
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Single Family Detached Units: 5,216											
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Total single family drip:		7,824,000	179.61	1.38	4.41	2.22	12.00	4.44	3.59		0.28
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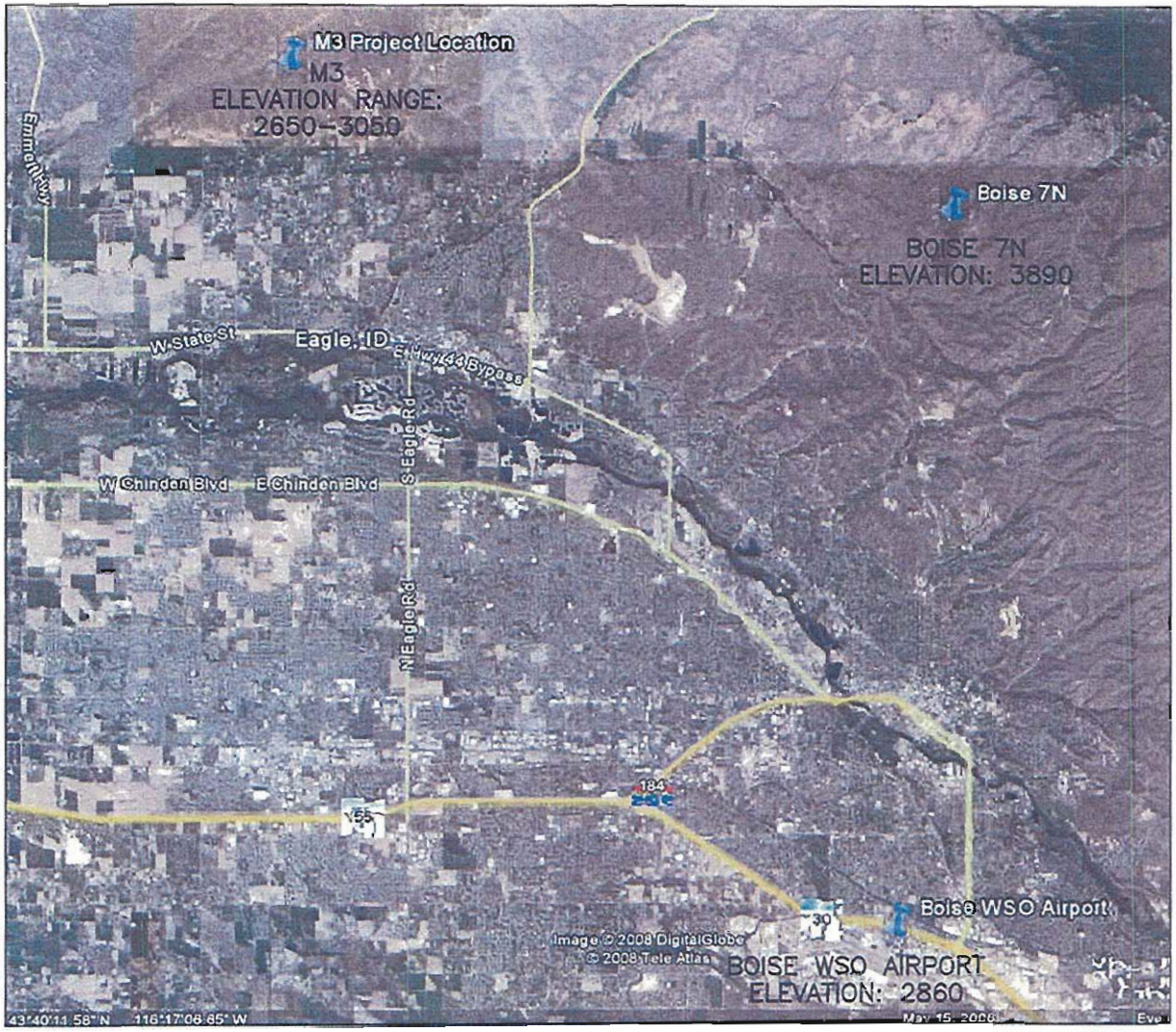
M3 EAGLE DEVELOPMENT

EVAPOTRANSPIRATION REFERENCE LOCATIONS



References for Irrigation Evapotranspiration (ET)					
No.	Crop	Reference	Location	Peak Monthly ET (July) mm/day [1]	Irrigation Season ET mm/season [2]
ETR1	Alfalfa	Allen and Brockway, 1983	Boise Airport	6.73	1021
ETR2	Turf grass	Allen and Robison, 2007	Boise Airport	6.85	1139.7
ETR3	Turf grass	Allen and Robison, 2007	Boise 7N	6.59	1054.2
	Alfalfa	M3 Spreadsheet Exhibit 5.7 – Cells B75 and B74	Boise Airport	6.73	1017.9

[1] Daily ET data for July uses average ET values from Allen and Brockway and mean monthly values from Allen and Robison

[2] Irrigation Season ET data for all references has been adjusted for irrigation in March from 15th-31st and irrigation in November from 1st – 15th.

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Spreadsheet Revision Date: January 31, 2008

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Commercial irrigation (using potable water)											
Acres of Commercial	245	Total commercial turf (25%):	133,403	3.06	0.03	0.08	0.04	12.00	0.09	**0.06**		**0.01**
% of Acres Irrigated	5.0%	Total commercial drip (75%):	400,208	9.19	0.07	0.23	0.11	12.00	0.23	**0.18**		**0.01**
		Total commercial irrigation (potable):	533,610	12.25	0.10	0.31	0.16		0.31	**0.25**		**0.02**
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Commercial drip:	75%	**Total irr'n with potable water:**	21,210,860	486.93	4.00	12.79	**6.45**		12.90	**9.74**		**1.02**
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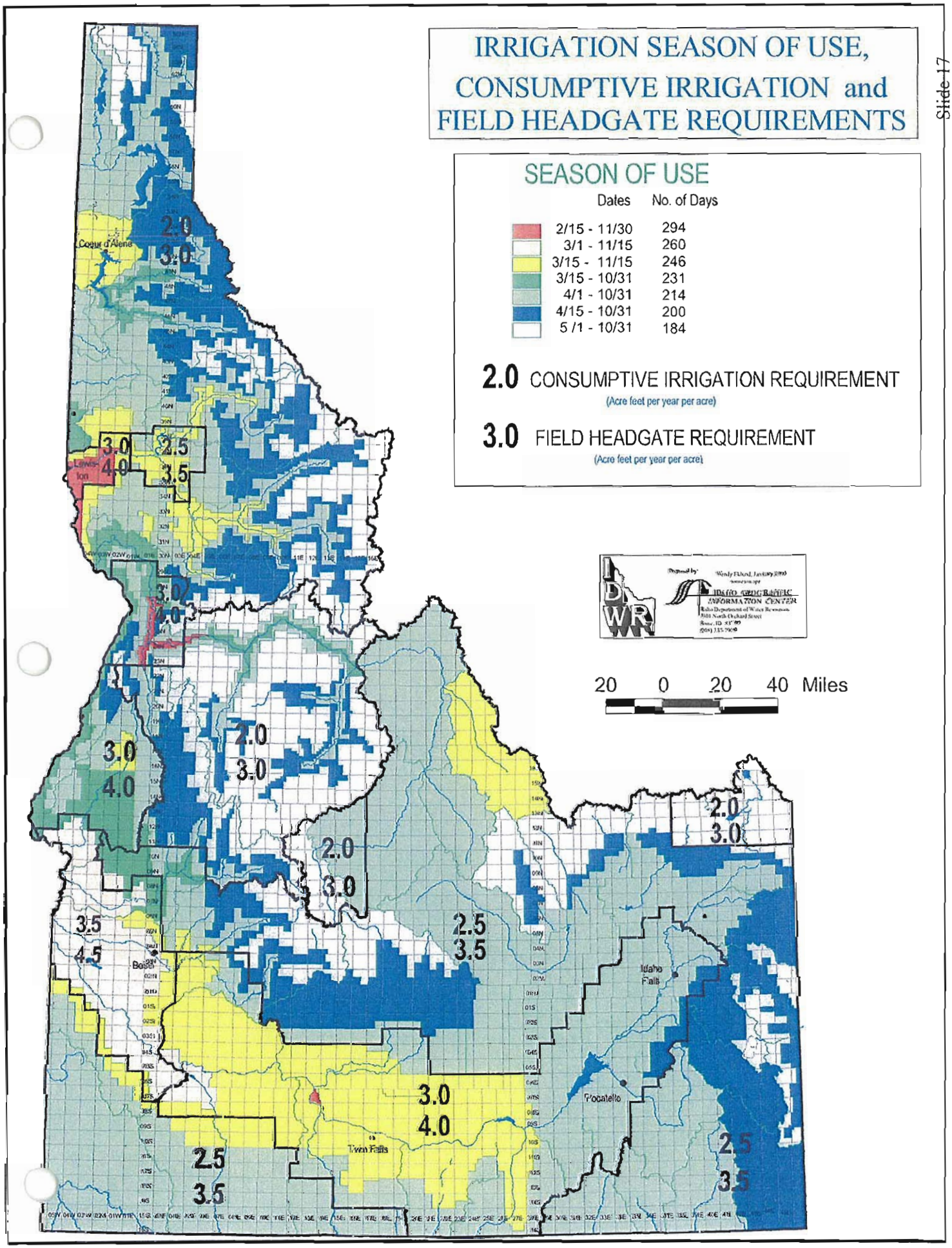
IRRIGATION SEASON OF USE, CONSUMPTIVE IRRIGATION and FIELD HEADGATE REQUIREMENTS



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IRRIGATION

Irrigation Assumptions: Note: Input data cells in this spreadsheet are shaded.

1) 17.93 shares of Farmers Union Ditch Co. water, at 11 inches per share, and a total of 197 miner's inches (3.94 cfs), will be used to irrigate 197 acres in the development. The shares provide a total of 765 acre-feet at 3.88 ac-ft per acre.
2) Tertiary-treated sewage effluent will be used for non-potable irrigation at sewage production rates during the irrigation season. During non-irrigation season, it will be stored and subsequently used for irrigation.
3) Compressed irrigation times: Golf irrigation assumed to occur only during 9 hours at night; ball fields and residences during 12 hours. Common area can be irrigated anytime. Residences are assumed to migrate to 12 hour overnight irrigation.
4) Number of irrigation days per year: 244 (March 15th - November 15th) Number of non-irrigation days per year: 121 (November 16th - March 14th)
5) It is assumed sufficient standby power is provided to offset the need for standby potable water storage.

6) Turf irrigation efficiency: 80%
7) Drip irrigation efficiency: 90%

8) Acres of aesthetic and operational ponds:	Aesthetic ponds	Operational ponds	Ponds w/winter effluent storage	Totals
	40	15	45	100
Average depth:	25	15	13	17.8
Acre feet storage:	1000	225	603	1,828
Primary water source:	well diversions	well / effluent	effluent	

8a) Operational and effluent ponds will be lined or sealed and will fluctuate with evaporation and irrigation demand. Aesthetic ponds also will be lined or sealed and will fluctuate mainly due to evaporation.
9) Non-potable irrigation storage calculated from maximum day well diversion rate.
10) Potable irrigation storage calculated from .02 cfs/acre well diversion rate.
11) "Max day" refers to highest 24-hour demand. For irrigation, this occurs during July, as shown by the Allen & Brockway numbers. "Peak" refers to peak demand during compressed irrigation periods or on an instantaneous basis.
12) Irrigation diversion rates, as they relate to use of potable water for irrigation, are less than 0.02 cfs/acre except during peak periods, where they may increase to this limit.
13) Monthly evapo-transpiration (ET) is based on Allen & Brockway (1983) for alfalfa, for each month in the irrigation season except November (which Allen & Brockway did not evaluate), which was estimated at one third of October. These values are:

	March 15-31	April	May	June	July	August	September	October	Nov 1-15	Total Annual		Avg. Daily	
mm/day	0.760	3.670	5.410	6.610	6.730	5.110	3.680	1.450	0.483	1017.9	mm/yr	4.17	mm/day
inches/day	0.030	0.144	0.213	0.260	0.265	0.201	0.145	0.057	0.019	40.1	in/yr	0.164	in/day
feet/day	0.002	0.012	0.018	0.022	0.022	0.017	0.012	0.005	0.002	3.34	ft/yr	0.014	ft/day

		square feet	acres	Average day cfs	Max day acre-feet	Max day cfs	Irr'n Hours	Scheduled peak cfs	cfs when div'ns increased to .02 cfs/a	Acre-feet non-potable storage to meet scheduled peak	Million Gallons potable storage to meet scheduled peak
Public area irrigation (using non-potable water)											
Golf Course (turf):		10,454,400	240	2.07	6.62	3.34	9	8.91	4.80	4.14	
Parks and Ballfields (turf):	Excluding 98 acres irr'd with ditch shares	8,319,960	191	1.65	5.27	2.66	12	5.32	3.82	2.64	
Common area (turf):	Excluding 99 acres irr'd with ditch shares	3,659,040	84	0.72	2.32	1.17	24	1.17	1.68	0.00	
Common area (drip):		5,662,800	130	1.00	3.19	1.61	24	1.61	2.60	0.00	
Common area drip irrig'd solely with stored effluent:	After effluent evap. from ponds at 3.5 AFA	5,224,612	120								
	Total public area irrigation:	28,096,200	765	5.44	17.40	8.78		17.00	12.90	6.78	
Residential irrigation (using potable water only)											
Single Family Detached Units:	5,216										
turf area/unit:		2,000	0.05	Note: Single family detached irrigation area based on average lot size of 7,800 sq. ft. with 3900 sq. ft. minimum building footprint plus incidental impervious area.							
drip area/unit:		1,500	0.03								
Total single family turf:		10,432,000	239.49	2.07	6.61	3.33	12.00	6.67	4.79		0.61
Total single family drip:		7,824,000	179.61	1.38	4.41	2.22	12.00	4.44	3.59		0.28
	Total single family irrigation (potable):	18,256,000	419.10	3.44	11.02	5.56		11.11	8.38		0.88
Single Family and Multi-Family Attached units:	1,937										
turf area/unit:		750	0.02	Note: Attached units consist of approximately 80% single family with an assumed irrigation being approximately 1/3 that of single family detached.							
drip area/unit:		500	0.01								
Total multi-family turf:		1,452,750	33.35	0.29	0.92	0.46	12.00	0.93	0.67		0.08
Total multi-family drip:		968,500	22.23	0.17	0.55	0.28	12.00	0.55	0.44		0.03
	Total multi-family irrigation (potable):	2,421,250	55.58	0.46	1.47	0.74		1.48	1.11		0.12
Commercial irrigation (using potable water)											
Acres of Commercial	245	Total commercial turf (25%):	133,403	3.06	0.03	0.08	0.04	12.00	0.09	0.06		0.01
% of Acres Irrigated	5.0%	Total commercial drip (75%):	400,208	9.19	0.07	0.23	0.11	12.00	0.23	0.18		0.01
		Total commercial irrigation (potable):	533,610	12.25	0.10	0.31	0.16		0.31	0.25		0.02
Commercial turf:	25%											
Commercial drip:	75%	**Total irr'n with potable water:**	21,210,860	486.93	4.00	12.79	6.45		12.90	9.74		1.02
Total irrigation with both potable and non-potable water:			49,307,060	1251.87	9.44	30.20	15.23		29.90	22.64		

INDOOR WATER DEMANDS

Indoor water demand assumptions:

Commercial water use is based on data published by Larry W. Mays in "Water Distribution Systems Handbook" © 2000, which demonstrates a per commercial acre use of: 1,200 gallons per day per gross acre of commercial development land. (data range is 1100-5100 gpd/acre)

800	gpd/unit is estimated residential peak hour demand in accordance with DEQ minimum system capacity
2.92	Indoor potable water peaking factor (a calculated ratio of peak hour to average day potable water demand)
1.5	Indoor potable water peaking factor (applied to average day to predict maximum day).
10.0%	Distribution system leakage allowance factor

		avg gpd/unit	max day gpm	max day cfs	peak hr gpm	peak hr cfs	Est'd gallons of potable storage for peak hr demand (1)	avg. day cfs	avg. day gpm	Non-Irrigation Season Diversions acre feet	Irrigation Season Diversions acre feet	Total Diversions acre feet
Total Residential Units	7,153	274	2,245.74	5.00	4,371	9.74	727,621	3.34	1,497.06	800.4	1614.0	2414.4
		avg gpd/student (2)										
Schools (Number of Students)	5,480	12	75.35	0.17	147	0.33	24,413	0.11	50.23	26.9	54.2	81.0
		avg gpd/hotel rm (3)										
Commercial (hotel rooms)	500	120	68.75	0.15	134	0.30	22,275	0.10	45.83	24.5	49.4	73.9
	Commercial area acres	gpd/sq. ft.										
Commercial (general office, etc.)	245	0.028	336.88	0.75	656	1.46	109,148	0.50	224.57	120.1	242.1	362.2
Totals			2,726.72	6.08	5,307	11.83	883,457	4.05	1,817.69	971.8	1,959.7	2,931.5

Estimated Potable Water Storage

mg	
1.02	Irrigation peaking
0.88	Indoor potable, max day to peak hour storage
0.54	Fire flow estimated (3,000 gpm for 3 hours)
0.17	Estimated potable well pump cycling
2.62	**Million gallons of potable water storage required**

Notes:
1) Peak hour potable storage calculated as 5.4*max day gals/24 using DEQ design guidelines with well diversions for in-house use at max day rate.
2) Average daily school water demand per student incorporates allowance for approximately 180 school days per year and extra-curricular activities.
3) Average daily hotel room water demand incorporates approximately 60% average seasonal occupancy rate.

WASTEWATER GENERATION AND REUSE

Indoor wastewater production assumptions:

69%	1) Residential wastewater production is assumed to be the following percentage of potable indoor water demand: This percentage excludes leakage allowance in potable water distribution system.
75%	2) School and hotel wastewater production is assumed to be the following percentage of potable indoor water demand: "
60%	3) Commercial unit wastewater production assumed at the percentage of potable indoor water demand: "
	4) Infiltration, inflow, treatment losses & leakage in sewer system are collectively assumed to have no net significant effect.
1.0	Factor indicating that wastewater calculations are based on avg day indoor water demand
67%	Percent of treated effluent produced (and used) during irrigation season (number of irrigation days/365)
33%	Percent of treated effluent stored during (and used) later during the next irrigation season (number of non-irrigation days/365)

Treated Effluent Generation

	# of units	gpd/unit (gpd/student for schools or gpd/sq ft for comm'l)	gpm	cfs	effluent acre-feet/yr	effluent af/irr'n season	effluent af/non-irr'n season	Indoor CU acre-feet/yr	Indoor CU af/irr'n season	Indoor CU af/non-irr'n season
Residences	7,153	189.06	939.13	2.09	1,514.46	1,012.41	502.06	680.6	455.0	225.6
Schools (number of students)	5,480	9.00	34.25	0.08	55.23	36.92	18.31	18.4	12.3	6.1
Commercial (hotel rooms)	500	90.00	31.25	0.07	50.39	33.69	16.71	16.8	11.2	5.6
Commercial (unit area in acres)	245	0.02	122.50	0.27	197.55	132.06	65.49	131.7	88.1	43.7
Total Effluent and Indoor Consumptive Use			1,127.13	2.51	1,817.64	1,215.08	602.56	847.6	566.6	281.0

Effluent Storage and Reuse	Acre-feet/year	
Stored winter effluent	603	
Evaporation from winter effluent storage ponds	158	Evaporation at 3.5 AFA, not 4.5 AFA, as evaporation water originally diverted for indoor use
Net winter effluent for non-potable irrigation	445	
Effluent available for use during irrigation season	1215	
Total annual effluent available for non-potable irrigatio	1660	

References for Residential Use			
No.	Reference	Average Water Use Per Home gallons per day (gpd)	Average Water Use Per Person gallons per capita per day gpcpd)
IRU1	Mays - Editor, Water Distribution Systems Handbook, AWWA, Chapter 3 System Design and Overview (Ysusi), 2000, Table 3.1, Pages 3.3 & 3.4	590.64* (Idaho) 288 (U.S. average) 236 (U.S. median)	186 (Idaho) 105 (US average) 86*(median)
IRU2	Dewberry & Davis, Land Development Handbook, Chapter 13 Table 13.1, Page 461	274*	100
IRU3	Survey of Residential Water Usage by Stanley Consultants - United Water Idaho for SW Boise; canal water for irrigation	330	120*
IRU4	Lindeburg, Civil Engineering Reference Manual, 2001, Table 26.4, Page 26-18	206-356*	75-130
IRU5	Fair, et al., Elements of Water Supply and Wastewater Disposal, 1971, Table 2.8, Page 33	400 (national average) 460 (west)	145* (national average) 168 (west)
IRU6	McGhee, Water Supply and Sewerage, 1991, Page 11	96 - 1452*	35 - 530
IRU7	Marchus, M., DEQ Design File Note – Design Flows - Public Water Systems, July1999	274	100*
IRU8	United Water Idaho Website – Winter Demand 20 MGD for 215,000 people	255*	93
IRU9	Cook, et.al., Domestic, Commercial, Municipal and Industrial Water Demand Assessment and Forecast in Ada and Canyon Counties, Idaho, 2001, Page 2	532*	194
IRU10	Urban, S., Water Budget for the Treasure Valley Aquifer System For the Years 1996 and 2000, for Caldwell, Nampa & Kuna reported to be exclusive of domestic irrigation for 2000, Table 3, Page 3-2	318-614*	116-224
	M3 Spreadsheet Exhibit 5.7 – Cell D80	274	100*

*Calculated based on 2000 Ada County Census Data average of approximately 2.74 persons/house

INDOOR WATER DEMANDS

Indoor water demand assumptions:

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800	gpd/unit is estimated residential peak hour demand in accordance with DEQ minimum system capacity
2.92	Indoor potable water peaking factor (a calculated ratio of peak hour to average day potable water demand)
1.5	Indoor potable water peaking factor (applied to average day to predict maximum day).
10.0%	Distribution system leakage allowance factor

		avg gpd/unit	max day gpm	max day cfs	peak hr gpm	peak hr cfs	Est'd gallons of potable storage for peak hr demand [1]	avg. day cfs	avg. day gpm	Non-Irrigation Season Diversions acre feet	Irrigation Season Diversions acre feet	Total Diversions acre feet
Total Residential Units	7,153	274	2,245.74	5.00	4,371	9.74	727,621	3.34	1,497.06	800.4	1614.0	2414.4
		avg gpd/student [2]										
Schools (Number of Students)	5,480	12	75.35	0.17	147	0.33	24,413	0.11	50.23	26.9	54.2	81.0
		avg gpd/hotel rm [3]										
Commercial (hotel rooms)	500	120	68.75	0.15	134	0.30	22,275	0.10	45.83	24.5	49.4	73.9
	Commercial area acres	gpd/sq. ft.										
Commercial (general office, etc.)	245	0.028	336.88	0.75	656	1.46	109,148	0.50	224.57	120.1	242.1	362.2
Totals			2,726.72	6.08	5,307	11.83	883,457	4.05	1,817.69	971.8	1,959.7	2,931.5

Estimated Potable Water Storage

mg	
1.02	Irrigation peaking
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0.54	Fire flow estimated (3,000 gpm for 3 hours)
0.17	Estimated potable well pump cycling
2.62	**Million gallons of potable water storage required**

Notes:
1) Peak hour potable storage calculated as 5.4*max day gals/24 using DEQ design guidelines with well diversions for in-house use at max day rate.
2) Average daily school water demand per student incorporates allowance for approximately 180 school days per year and extra-curricular activities.
3) Average daily hotel room water demand incorporates approximately 60% average seasonal occupancy rate.

WASTEWATER GENERATION AND REUSE

Indoor wastewater production assumptions:

1) Residential wastewater production is assumed to be the following percentage of potable indoor water demand: 69% This percentage excludes leakage allowance in potable water distribution system.
2) School and hotel wastewater production is assumed to be the following percentage of potable indoor water demand: 75% "
3) Commercial unit wastewater production assumed at the percentage of potable indoor water demand: 60% "
4) Infiltration, inflow, treatment losses & leakage in sewer system are collectively assumed to have no net significant effect.

1.0	Factor indicating that wastewater calculations are based on avg day indoor water demand
67%	Percent of treated effluent produced (and used) during irrigation season (number of irrigation days/365)
33%	Percent of treated effluent stored during (and used) later during the next irrigation season (number of non-irrigation days/365)

Treated Effluent Generation

	# of units	gpd/unit (gpd/student for schools or gpd/sq ft for comm'l)	gpm	cfs	effluent acre-feet/yr	effluent af/irr'n season	effluent af/non-irr'n season	Indoor CU acre-feet/yr	Indoor CU af/irr'n season	Indoor CU af/non-irr'n season
Residences	7,153	189.06	939.13	2.09	1,514.46	1,012.41	502.06	680.6	455.0	225.6
Schools (number of students)	5,480	9.00	34.25	0.08	55.23	36.92	18.31	18.4	12.3	6.1
Commercial (hotel rooms)	500	90.00	31.25	0.07	50.39	33.69	16.71	16.8	11.2	5.6
Commercial (unit area in acres)	245	0.02	122.50	0.27	197.55	132.06	65.49	131.7	88.1	43.7
Total Effluent and Indoor Consumptive Use			1,127.13	2.51	1,817.64	1,215.08	602.56	847.6	566.6	281.0

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Stored winter effluent	603	
Evaporation from winter effluent storage ponds	158	Evaporation at 3.5 AFA, not 4.5 AFA, as evaporation water originally diverted for indoor use
Net winter effluent for non-potable irrigation	445	
Effluent available for use during irrigation season	1215	
Total annual effluent available for non-potable irrigatio	1660	

References for Residential Peaking Factor			
No.	Reference	Maximum Day: Average Day	Peak Hour: Average Day
IRP1	Larry Mays, Water Distribution Systems Handbook, AWWA, Chapter 3 System Design and Overview (Ysusi), 2000, Table 3.6, Page 3.9	1.5 – 3.5 : 1	2.0 – 7.0 : 1
IRP2	Harberg, Planning and Managing Reliable Urban Water Systems, 1995, Table 5-1, Page 95	1.4 – 1.7 : 1 (estimated)	2.0 – 4.0 : 1
IRP3	Fair, et al., Elements of Water Supply and Wastewater Disposal, 1971, Table 2-8, Page 33	1.5 – 3.5 : 1	1.5 – 3.5 : 1
IRP4	Dewberry & Davis, Land Development Handbook, 1996, Page 462	1.5 – 3 : 1	2 –5 : 1
	M3 Spreadsheet Exhibit 5.7 – Cells B75 and B74	1.5	2.92 (calculated)

INDOOR WATER DEMANDS

Indoor water demand assumptions:

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1.5	Indoor potable water peaking factor (applied to average day to predict maximum day).
10.0%	Distribution system leakage allowance factor

			max day gpm	max day cfs	peak hr gpm	peak hr cfs	Est'd gallons of potable storage for peak hr demand [1]	avg. day cfs	avg. day gpm	Non-Irrigation Season Diversions acre feet	Irrigation Season Diversions acre feet	Total Diversions acre feet
		avg gpd/unit										
Total Residential Units	7,153	274	2,245.74	5.00	4,371	9.74	727,621	3.34	1,497.06	800.4	1614.0	2414.4
		avg gpd/student [2]										
Schools (Number of Students)	5,480	12	75.35	0.17	147	0.33	24,413	0.11	50.23	26.9	54.2	81.0
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Commercial (hotel rooms)	500	120	68.75	0.15	134	0.30	22,275	0.10	45.83	24.5	49.4	73.9
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Totals			2,726.72	6.08	5,307	11.83	883,457	4.05	1,817.69	971.8	1,959.7	2,931.5

Estimated Potable Water Storage

mg	
1.02	Irrigation peaking
0.88	Indoor potable, max day to peak hour storage
0.54	Fire flow estimated (3,000 gpm for 3 hours)
0.17	Estimated potable well pump cycling
2.62	**Million gallons of potable water storage required**

Notes:
1) Peak hour potable storage calculated as 5.4*max day gals/24 using DEQ design guidelines with well diversions for in-house use at max day rate.
2) Average daily school water demand per student incorporates allowance for approximately 180 school days per year and extra-curricular activities.
3) Average daily hotel room water demand incorporates approximately 60% average seasonal occupancy rate.

WASTEWATER GENERATION AND REUSE

Indoor wastewater production assumptions:

1) Residential wastewater production is assumed to be the following percentage of potable indoor water demand: 69% This percentage excludes leakage allowance in potable water distribution system.
2) School and hotel wastewater production is assumed to be the following percentage of potable indoor water demand: 75% "
3) Commercial unit wastewater production assumed at the percentage of potable indoor water demand: 60% "
4) Infiltration, inflow, treatment losses & leakage in sewer system are collectively assumed to have no net significant effect.

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67%	Percent of treated effluent produced (and used) during irrigation season (number of irrigation days/365)
33%	Percent of treated effluent stored during (and used) later during the next irrigation season (number of non-irrigation days/365)

Treated Effluent Generation

	# of units	gpd/unit (gpd/student for schools or gpd/sq ft for comm'l)	gpm	cfs	effluent acre-feet/yr	effluent af/irr'n season	effluent af/non-irr'n season	Indoor CU acre-feet/yr	Indoor CU af/irr'n season	Indoor CU af/non-irr'n season
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Net winter effluent for non-potable irrigation	445	
Effluent available for use during irrigation season	1215	
Total annual effluent available for non-potable irrigatio	1660	

References for Residential Wastewater Production			
No.	Reference	Wastewater production as % of water demand	Gallons of wasterwater per day per residential unit
WWP1	Fair, et al., Elements of Water Supply and Wastewater Disposal, 1971, Page 37	60-70%	n/a
WWP2	Survey of Residential Water Usage and Wastewater Generation completed by Stanley Consultants	69 – 127%	n/a
WWP3	Merritt, Standard Handbook for Civil Engineers, 1983, Page 22-5	70-130%	n/a
WWP4	McGhee, Water Supply and Sewerage, 1991, Page 18	70-130%	n/a
WWP5	Bench Sewer District	n/a	184-214
WWP6	Northwest Boise Sewer District	n/a	300
WWP7	Eagle Sewer District	n/a	266
	M3 Spreadsheet Exhibit 5.7 – Cell F106	69%	189

INDOOR WATER DEMANDS

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Totals				2,726.72	6.08	5,307	11.83	883,457	4.05	1,817.69	971.8	1,959.7	2,931.5

Estimated Potable Water Storage

mg	
1.02	Irrigation peaking
0.88	Indoor potable, max day to peak hour storage
0.54	Fire flow estimated (3,000 gpm for 3 hours)
0.17	Estimated potable well pump cycling
2.62	**Million gallons of potable water storage required**

Notes:
1) Peak hour potable storage calculated as 5.4*max day gals/24 using DEQ design guidelines with well diversions for in-house use at max day rate.
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WASTEWATER GENERATION AND REUSE

Indoor wastewater production assumptions:

1) Residential wastewater production is assumed to be the following percentage of potable indoor water demand:	69% This percentage excludes leakage allowance in potable water distribution system.
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4) Infiltration, inflow, treatment losses & leakage in sewer system are collectively assumed to have no net significant effect.	
1.0	Factor indicating that wastewater calculations are based on avg day indoor water demand
67%	Percent of treated effluent produced (and used) during irrigation season (number of irrigation days/365)
33%	Percent of treated effluent stored during (and used) later during the next irrigation season (number of non-irrigation days/365)

Treated Effluent Generation

	# of units	gpd/unit (gpd/student for schools or gpd/sq ft for comm'l)	gpm	cfs	effluent acre-feet/yr	effluent af/irr'n season	effluent af/non-irr'n season	Indoor CU acre-feet/yr	Indoor CU af/irr'n season	Indoor CU af/non-irr'n season
Residences	7,153	189.06	939.13	2.09	1,514.46	1,012.41	502.06	680.6	455.0	225.6
Schools (number of students)	5,480	9.00	34.25	0.08	55.23	36.92	18.31	18.4	12.3	6.1
Commercial (hotel rooms)	500	90.00	31.25	0.07	50.39	33.69	16.71	16.8	11.2	5.6
Commercial (unit area in acres)	245	0.02	122.50	0.27	197.55	132.06	65.49	131.7	88.1	43.7
Total Effluent and Indoor Consumptive Use			1,127.13	2.51	1,817.64	1,215.08	602.56	847.6	566.6	281.0

Effluent Storage and Reuse

	Acre-feet/year
Stored winter effluent	603
Evaporation from winter effluent storage ponds	158
Net winter effluent for non-potable irrigation	445
Effluent available for use during irrigation season	1215
Total annual effluent available for non-potable irrigatio	1660

Evaporation at 3.5 AFA, not 4.5 AFA, as evaporation water originally diverted for indoor use

	References for Pond Evaporation	
No.	Reference	Evaporation in acre-feet/acre (AFA)
PER1	Idaho Department of Water Resources (IDWR) Pond Evaporation Map	3.5 (42 inches)
PER2	Allen and Brockway, 1983 Alfalfa – Boise WSO Airport (Equivalent Crop)	3.34
PER3	Allen and Robison, 2007, Open Water – Shallow at Boise 7N	2.92 (878 mm)
PER4	Allen and Robison, 2007, Open Water – Shallow at Boise Airport	3.08 (952 mm)
PER5	Climatalogical Handbook for Columbia Basin States Precipitation Volume 2 Page A-87 - Average Lake Evaporation, 1969	2.83 (34 inches)
PER6	Idaho Department of Water Resources (IDWR) Consumptive Use Map (Equivalent Crop)	3.0 - 3.5
PER7	M3 Spreadsheet Exhibit 5.7	3.5

SUMMARY

Average daily well diversions

	cfs	gpm	af/day	mgd
Indoor potable average day (constant annual rate)	4.05	1,818	8.0	2.6
Residential and commercial potable irrigation average day (during irrigation season only)	4.00	1,795	7.9	2.6
Public area non-potable irrigation average day demand (during irrigation season only)	5.44	2,442	10.8	3.5
Less water reuse / treated effluent produced (during irrigation season)	-2.51	-1,127	-5.0	-1.6
Net average day well diversion for public area non-potable irrigation	**2.93**	**1,315**	**5.8**	1.9
Evaporation from aesthetic & operational ponds	0.68	306	1.4	0.4
Average daily diversion from wells during irrigation season:	**11.66**	**5,233**	**23.1**	**7.5**
Average daily diversion from wells during non-irrigation season:	**4.05**	**1,818**	**8.0**	**2.6**

Maximum daily well diversions

	cfs	gpm	af/day	mgd	
Indoor potable max day	6.08	2,727	12.0	3.9	(Well field produces max day potable in house demand; potable storage with well field produces peak hour demand.)
Residential and commercial potable irrigation max day (during irrigation season only)	9.74	4,371	19.3	6.3	Well field produces max day outdoor potable irrigation demand at 0.02 cfs/acre; potable storage with well field produces scheduled peak demand
Public area non-potable irrigation max day demand during irrigation season	8.78	3,939	17.4	5.7	Well field produces max day non-potable irrigation demand; non-potable pond storage with well field produces scheduled peak demand
Less: water reuse / treated effluent produced during irrigation season	-2.51	-1,127	-5.0	-1.6	Effluent is used for non-potable irrigation at sewage production rate
Net max day well diversion for public area non-potable irrigation	**6.27**	**2,812**	**12.4**	4.0	
Evaporation from aesthetic & operational ponds	1.10	494	2.2	0.7	Evaporation from ponds at 0.02 cfs/acre
Maximum daily diversion from wells during irrigation season:	**23.18**	**10,403**	**46.0**	**15.0**	
Maximum daily diversion from wells during non-irrigation season:	**6.08**	**2,727**	**12.0**	**3.9**	(Evaporation from ponds is assumed to be neglible during non-irrigation season)

Annual ground water diversion volume

	acre feet	million gallons	
Indoor potable	2,932	956	(Annual ground water diversions for potable indoor uses based on average annual demand, including leakage allowance.)
Potable irrigation of residential and commerical areas	1,936	631	(Annual potable irrigation diversions from ground water based on total annual Allen Brockway ET, and factoring in irrigation efficiency.)
Public area non-potable irrigation demand	3,079	1003	
Less: water reuse / treated effluent originally diverted from well for indoor demand	-1,660	-541	(Reuse water is the total annual effluent production including stored winter effluent less evaporation from effluent ponds.)
Net annual well diversion for public area non-potable irrigation	**1,419**	**462**	(Annual non-potable irrigation diversions from ground water based on total annual Allen Brockway ET, and factoring in irrigation efficiency.)
Evaporation from aesthetic & operational ponds	248	81	(Annual well diversions at 4.5 AFA to overcome evaporation. The non-potable peaking storage is considered part of operational storage for this calculation.)
Irrigation season evaporation from winter effluent storage ponds	158	51	
Less: water reuse / treated effluent originally diverted from well for indoor demand	-158	-51	
Net annual well diversion for pond evaporation	**248**	**81**	
Well Diversion Volume During Non-Irrigation Season	**972**	**317**	
Well Diversion Volume During Irrigation Season	**5,563**	**1,813**	
Total annual well diversion volume:	**6,535**	**2,130**	

Annual consumptive use of ground water

	acre feet	million gallons	
Indoor potable	848	276	(Indoor consumptive use is the difference between average annual water demand and sewage production rate and excludes distribution system leakage allowance that returns to groundwater.)
Potable irrigation of residential and commerical areas	1,627	530	(Potable and non-potable irrigation CU is the total annual Allen Brockway ET.)
Public area non-potable irrigation	2,556	833	"
Evaporation from winter effluent storage ponds during irrigation season	158	51	(Annual pond consumptive use--i.e., evaporation--is based on an estimated 3.5 acre feet per acre.)
Evaporation from aesthetic & operational ponds	193	63	(Annual pond consumptive use--i.e., evaporation--is based on an estimated 3.5 acre feet per acre. The non-potable peaking storage is considered part of operational storage for this calculation.)
Subtotal pond evaporation	**350**	**114**	
Consumptive Use During Non-Irrigation Season	**281**	**92**	(Consumptive use due to pond evaporation is accounted for in the irrigation season)
Consumptive Use During Irrigation Season	**5,100**	**1,662**	
Annual consumptive use of ground water:	**5,381**	**1,753**	
Annual CU as % of diversions:	82%		(Overall efficiency of use of well diversions)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
208														
209	**Source numbers for Attachment A, Page 11 of Water Rights Application Narrative**													
210														
211							**Consumptive use expressed as direct well and reuse components**							
212							**Direct Well**	**Reuse Water**						
213	**Type of Use**	**Peak Diversion**		**Annual Diversion**	**Annual C.U.**		**Annual C.U.**	**Annual C.U.**						
214		**Rate**	**Average Diversion Rate**	**Volume**	**Volume**		**Volume**	**Volume**						
215		**(cfs)**	**(cfs)**	**(acre feet)**	**(acre feet)**		**(acre feet)**	**(acre feet)**						
216														
217	Indoor Potable	6.08	4.05	2,932	848		848	0						
218														
219	Residential and Commercial Potable Irrigation	9.74	4.00	1,936	1,627		1627	0						
220														
221	Public Area Non-Potable Irrigation	6.27	2.93	1,419	2,556		1161	1395						
222														
223	Pond Evaporation	1.10	0.68	248	350		193	158						
224														
225	Irrigation Season Total	23.18	11.66	5,563	5,100		3,548	1552						
226														
227	Non-Irrigation Season Total	6.08	4.05	972	281		281	0						
228														
229	Total Annual	23.18	9.03	6,535	5,381		3829	1552						
230		(peak day)	(annual average)											

Irrigation Demands by Month (Note: Maximum Monthly Demand and Maximum Daily Demand Occurs in July)

Non-Potable Irrigation Demand (excluding 197 acres irrigated by Farmer's Union ditch shares):

		January	Feb	March 15-31			April			May			June			July			August			September			October			November 1-15			December	Totals
				avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	af/day	af/mo	cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs		af/yr
	Golf	0.00	0.00	0.75	12.72	**0.38**	3.61	108.37	**1.82**	5.32	165.07	**2.69**	6.51	195.18	**3.29**	6.62	205.34	**3.35**	5.03	155.92	**2.54**	3.62	108.66	**1.83**	1.43	44.24	**0.72**	0.48	7.14	**0.24**	0	1,003
	Ballfields	0.00	0.00	0.60	10.12	**0.30**	2.87	86.24	**1.45**	4.24	131.37	**2.14**	5.18	155.33	**2.61**	5.27	163.42	**2.66**	4.00	124.08	**2.02**	2.88	86.48	**1.46**	1.14	35.21	**0.57**	0.38	5.68	**0.19**	0	798
	Common turf	0.00	0.00	0.26	4.45	**0.13**	1.26	37.93	**0.64**	1.86	57.77	**0.94**	2.28	68.31	**1.15**	2.32	71.87	**1.17**	1.76	54.57	**0.89**	1.27	38.03	**0.64**	0.50	15.48	**0.25**	0.17	2.50	**0.08**	0	351
	Common drip	0.00	0.00	0.36	6.12	**0.18**	1.74	52.18	**0.88**	2.56	79.48	**1.29**	3.13	93.97	**1.58**	3.19	98.87	**1.61**	2.42	75.07	**1.22**	1.74	52.32	**0.88**	0.69	21.30	**0.35**	0.23	3.44	**0.12**	0	483
Common drip with stored effluent:		0.00	0.00	0.33	5.65	**0.17**	1.60	48.14	**0.81**	2.37	73.33	**1.19**	2.89	86.70	**1.46**	2.94	91.22	**1.49**	2.23	69.26	**1.13**	1.61	48.27	**0.81**	0.63	19.65	**0.32**	0.21	3.17	**0.11**	0	445
	Totals:	0.00	0.00	2.30	39.06	**1.16**	11.10	332.85	**5.60**	16.36	507.02	**8.26**	19.98	599.49	**10.09**	20.35	630.72	**10.28**	15.45	478.90	**7.80**	11.13	333.76	**5.62**	4.38	135.89	**2.21**	1.46	21.92	**0.74**	0.00	**3,080**

Non-potable irrigation demand by application type:

	Non-potable Irr'n demand (acre feet)	Non-potable CU (acre feet)
Turf irr'd w/well and effluent as produced	2,151	1,721
Drip irr'd w/well and effluent as produced	483	434
Drip irr'd w/winter stored effluent (after evap. from effluent ponds)	445	401
Totals:	3,079	2,556

Potable Irrigation Demand

		January	Feb	March 15-31			April			May			June			July			August			September			October			November 1-15			December	Totals
				avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	af/day	af/mo	cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs	avg af/day	af/mo	avg cfs		af/yr
	Detached, Turf	0	0	0.75	12.69	**0.38**	3.60	108.13	**1.82**	5.31	164.72	**2.68**	6.49	194.76	**3.28**	6.61	204.90	**3.34**	5.02	155.58	**2.53**	3.61	108.43	**1.83**	1.42	44.15	**0.72**	0.47	7.12	**0.24**	0	1,000
	Detached, Drip	0	0	0.50	8.46	**0.25**	2.40	72.09	**1.21**	3.54	109.81	**1.79**	4.33	129.84	**2.19**	4.41	136.60	**2.23**	3.35	103.72	**1.69**	2.41	72.29	**1.22**	0.95	29.43	**0.48**	0.32	4.75	**0.16**	0	667
	Attached, Turf	0	0	0.10	1.77	**0.05**	0.50	15.06	**0.25**	0.74	22.94	**0.37**	0.90	27.12	**0.46**	0.92	28.53	**0.46**	0.70	21.67	**0.35**	0.50	15.10	**0.25**	0.20	6.15	**0.10**	0.07	0.99	**0.03**	0	139
	Attached, Drip	0	0	0.06	1.05	**0.03**	0.30	8.92	**0.15**	0.44	13.59	**0.22**	0.54	16.07	**0.27**	0.55	16.91	**0.28**	0.41	12.84	**0.21**	0.30	8.95	**0.15**	0.12	3.64	**0.06**	0.04	0.59	**0.02**	0	83
	Commercial, Turf	0	0	0.01	0.16	**0.00**	0.05	1.38	**0.02**	0.07	2.11	**0.03**	0.08	2.49	**0.04**	0.08	2.62	**0.04**	0.06	1.99	**0.03**	0.05	1.39	**0.02**	0.02	0.56	**0.01**	0.01	0.09	**0.00**	0	13
	Commercial, Drip	0	0	0.03	0.43	**0.01**	0.12	3.69	**0.06**	0.18	5.62	**0.09**	0.22	6.64	**0.11**	0.23	6.99	**0.11**	0.17	5.31	**0.09**	0.12	3.70	**0.06**	0.05	1.51	**0.02**	0.02	0.24	**0.01**	0	34
	Total			1.44	24.56	**0.73**	6.98	209.28	**3.52**	10.28	318.78	**5.19**	12.56	376.92	**6.35**	12.79	396.56	**6.46**	9.71	301.10	**4.91**	6.99	209.85	**3.53**	2.76	85.44	**1.39**	0.92	13.78	**0.46**	0	**1,936**

Potable irrigation demand by application type:

	Acre-feet Potable Demand	**Acre-feet Potable CU**
Turf	1,153	922
Drip	784	705
Annual Potable Irrigation Water demand (acre feet)	1,936	1,627

Summary of Irrigation Demands:

Total Irrigated Acreage	1,252	acres
Total CU	4,184	ac-ft/yr
Total Demand	5,016	ac-ft/yr
Total CU/ Total Irrigated Acres	3.34	ac-ft/ac
Total Demand / Total Irrigated Acres	4.01	ac-ft/ac

Note: This summary is for acres irrigated by well diversions or reuse water and excludes the 197 acres irrigated with Farmer's Union ditch shares.

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John S. Church

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Summary of Qualifications

Visiting Assistant Professor, Boise State University

Corporate Economist, Idaho Power Company, Boise, Idaho. 1980 - 1997

Author of detailed Regional Economic and Demographic Forecasts

Member of the Western Blue Chip Economic Forecast Panel

Professional Experience

Corporate Economist, Idaho Power Company, Boise, Idaho. 1980 - 1997

Mr. Church has nearly 20 years of experience in the energy industry. For the past fifteen years, Mr. Church has annually prepared regional economic forecasts as an integral part of long-term utility resource and financial planning. These forecasts included the preparation of economic and demographic forecasts for the state of Idaho and the Idaho Power Company service area. In this role, Mr. Church developed a Regional Econometric Model of the state of Idaho. The model, a simultaneous equation Economic-Demographic model, provides projections of output and employment for the major industries in Idaho, and population (by age cohort and sex), households (by age of head of household and household size), industry average wages and salaries (for major industries in the state) and personal income (by income component) for the state of Idaho and the Idaho Power Company service territory.

These forecasts have proven to be quite accurate, earning Mr. Church the honor of being the most accurate economic forecaster in the Western Blue Chip Economic Forecast Panel in two of the past ten years.

Mr. Church developed a further enhancement to the State of Idaho Economic Forecast with a forecast of economic activity for each of Idaho's forty-four counties. Initially the forecasts of economic activity in each of Idaho's counties was developed as a tool to aid in the spatial evaluation of Idaho Power Company's future human and equipment resource needs in preparation for customer growth. However, these forecasts of economic activity and population and household growth have been widely accepted by the State's business and government communities. Today, these forecasts are used by many private firms and government entities as an integral part of their planning process.

Mr. Church also had past responsibilities for the preparation and analysis of annual electricity sales and load forecasts, as well as forecasts of system peak electricity loads over a 25 year forecast horizon. These economic projections were the basis for forecasts of future revenue, forecasts of power plant operation and future fuel procurement needs, as well as forecasts of the needs for future electricity supply.

Mr. Church has also developed methodologies for the weather normalization of sales that has been used by electric and water utilities for internal financial analysis and use in utility regulatory proceedings.

In other areas of economic forecasting and analysis Mr. Church has developed methodologies for forecasting future coal prices for existing long-term fuel supply contracts. These forecasts have provided clients with a higher degree of accuracy in the budgeting of future operating expenses. In a similar fashion, Mr. Church has prepared, for industrial

clients, forecasts of the monthly and annual utilization of some commonly used inputs materials allowing the client to recalibrate and minimize its inventory expenses.

Mr. Church played an integral role in the evaluation, negotiation, and litigation of long-term fuel supply contracts. He has made recommendations and prepared strategies to overcome particular sticking points in the negotiation process that allowed both parties to capture the economic benefits desired. In addition, the coal price forecasting capability allowed for a timely and detailed economic cost-benefit analysis of negotiating positions and proposals.

Other projects that Mr. Church has participated in include:

The evaluation of the financial and operational impacts of office consolidation and downsizing initiatives.

The evaluation of national and international markets for various types of renewable energy supplies.

The preparation of a scenario analysis of corporate restructuring and downsizing initiatives.

The preparation of studies on the impact of differing energy tax proposals on electric utility operating costs plus, an analysis of the potential effects on operating costs of competing electric utilities in the Northwest.

Development of an extensive country screening methodology for the evaluation of foreign business climates for a client's potential foreign investments. This screening methodology utilized a first phase macroeconomic evaluation to eliminate some countries from further evaluation thereby minimizing the expenses of additional market research or ongoing sales activities in areas that may have poor potential for future market growth.

The preparation of population and demographic forecasts for a client's site location evaluation process. These forecasts provided detailed annual estimates of future population by county, ZIP Code area, age cohort, sex over a twenty year time horizon. Projections of the annual number of births, by age of mother, and deaths by age cohort were also provided for the requested geographic areas.

The preparation of an economic and local government fiscal impact analysis for a large residential planned community in Southwest Idaho.

The preparation of forecasted economic and demographic impacts on the local county and city governments and upon the local school districts in a sparsely populated Idaho County due to the development, construction, and ongoing operation of a $1.1 billion year-round resort complex.

Prepared an evaluation of the potential economic impacts on four South Central Idaho Counties due to the potential short-term closure of a large food processing plant.

Examined the potential fiscal impacts that could result from a proposal to modify teacher certification standards for Idaho's elementary and secondary public school teachers.

Prepared forecasts of the number of customers by geographic area, customer water usage by class of customer, water losses, utility company internal use, and water used for hydrant flows by month for a major water utility.

Prepared a economic and fiscal impact analysis for a $1.4 billion coal-fired electric generating plant proposed for South Central Idaho.

Prepared an economic and fiscal impact analysis of a phosphate fertilizer plant and phosphate mine located in Southeast Idaho on the Idaho and western Wyoming economies.

Mr. Church has also prepared and presented testimony to utility regulatory agencies and in state and federal courts.

As a well-known economist, Mr. Church has made numerous speeches and presentations to private, government, and civic organizations throughout Idaho and the Northwest. Over the last five years, the total annual audience, at speeches and presentations by Mr. Church has averaged nearly three thousand per year. Often asked by the news media for comments and opinions on the current economic environment, Mr. Church is frequently quoted in the local Idaho print and television media and has also been cited in national publications such USA Today, Newsweek, Time, The Kiplinger Washington Letter, and The Wall Street Journal.

Education

University of Idaho 1979 - 1981
Moscow, ID
Major: Economics, MS degree.

Boise State University 1976 - 1979
Boise, ID
Major: Business Administration, Minor: Economics, BBA degree

University of Washington 1967 - 1971
Seattle, WA
Major: Civil Engineering, Minor: Mathematics

Selected Publications and Presentations:

Annual economic outlook presentations for the state of Idaho to the Joint Select Committee on Revenue Projections of the Idaho State Legislature, January of the years 1983 - 1986 and 1988 - 2005.

Member of the Boise Visions Project Planning Committee. (City of Boise's Comprehensive Planning Project), and Liaison to the Boise Visions Executive Committee for the Utility and Water Planning Subcommittees, 1992

Member of the Ada Planning Association Demographic Advisory Committee: 1991, 1995, and 1997.

Economic Outlook Presentation to Boise Chamber of Commerce Executive Retreat, Sun Valley, Idaho, Sept. 1994

Kick-Off speaker, Idaho Manufactured Housing Association Annual Convention, Boise, ID, Annually 1991 - 2004.

Panelist, Boise Chamber of Commerce's Annual Economic Outlook Breakfast, Annually 1991 - 2003.

Keynote speaker, Idaho Building Operators Association Annual Meeting, Sun Valley, Idaho, April 1998.

Keynote speaker, Idaho Hispanic Business Association Annual Meeting, Boise, Idaho, April 1998.

Panelist, Caldwell, Idaho Chamber of Commerce's Economic Outlook Breakfast, November 1998.

Keynote speaker, Franklin Building Supply's Contractor's Economic Outlook Forum, Boise, January 2001, 2002

Keynote speaker, D.L. Evans Bank Economic Outlook Forum, Boise, February 2001, 2002, 2003, & 2004.

Keynote speaker, Idaho Building Operators Association Annual Meeting, Boise, March 2001.

Keynote speaker, Nampa, Idaho Chamber of Commerce's Economic Outlook Breakfast, January 2002.

Keynote speaker, Idaho Mortgage Banker's Association, Boise, April 2002, April 2003, March 2004

Speaker, Idaho Department of Transportation's, Transportation 2020 Conference, Boise, March 2000.

Columnist, Quarterly Reviews of Idaho's Economy for the Idaho Statesman, Boise, Idaho

Economic Consulting and Forecast Clients:

Agrium U.S.A.
City of Boise, Idaho
Farmers and Merchant's State Bank
Idaho Department of Water Resources
Idaho Small Business Development Center – Pocatello
Intermountain Gas Company
Northwest Research Group
St. Lukes Regional Medical Center
SunCor Idaho, LLC
Holland and Hart, LLC
Browning Ferris Industries (BFI)
Tammarack Resort
INEEL
Community Planning Association of Southwest Idaho (COMPASS)
Boise Metro Chamber of Commerce
CH2M Hill
Goldman Sachs
Idaho State Attorney General's Office
Idaho Power Company
Magic Valley Regional Medical Center
Power Engineers
United Water Idaho
Idaho Department of Education
ISBDC - Pocatello
Idaho Hospital Association
Sun Valley Development L.L.C.
-Warm Springs Ranch Development
JR Simplot Company
SunCor – Idaho, LLC

Additional Professional Activities:

Instructor, Department of Continuing Education, Boise State University: 1986 – 2000
Visiting Assistant Professor, Department of Economics, Boise State University: 2000 – Present

Past Users of State and County Economic Forecasts Prepared by John Church:

Idaho Chambers of Commerce:

Blackfoot Chamber of Commerce
Boise Area Chamber of Commerce
Bonner County Economic Development
Caldwell Chamber of Commerce
Coeur d'Alene Chamber of Commerce
Eagle Chamber of Commerce
Grangeville Chamber of Commerce
Homedale Chamber of Commerce
Idaho Falls Chamber of Commerce
Jerome Chamber of Commerce
Lewiston Chamber of Commerce
Meridian Chamber of Commerce
Moscow Chamber of Commerce
Mountain Home Chamber of Commerce
Nampa Chamber of Commerce
Ontario Chamber of Commerce
Payette Chamber of Commerce
Pocatello Chamber of Commerce
Rexburg Chamber of Commerce
Soda Springs Chamber of Commerce
St. Anthony Chamber of Commerce
Twin Falls Chamber of Commerce
Washington County Economic Dev.

Past Users of State and County Economic Forecasts Prepared by John Church:

State & Local Government:

Ada County, Ada County Sheriff
Ada Planning Association
Boise City Economic Development, Planning & Zoning, Police Department, & Public Works
Blaine County Planning & Zoning Commission
Boise County Planning & Zoning
Boise Neighborhood Housing Services
Boise State University
Caldwell, City of
Canyon County Planning and Zoning
College of Southern Idaho
Custer County Planning & Zoning
Elmore County Planning & Zoning
Emmett, City of
Filer, City of
Idaho State Government: Departments of:
Agriculture, Corrections, Commerce, Education, Financial Management, Law Enforcement Transportation, Tax Commission, & Water Resources
Idaho Falls, City of
Idaho Housing Agency
Idaho State University
Idaho Supreme Court
Malheur County Planning and Zoning
Mountain Home, City of
Nampa City Hall
State of Nevada, State Demographer's Office - UNR
Nez Perce County Planning
Nyssa, City of
Ontario, City of
Payette County Planning and Zoning
Pocatello, City of
Port of Lewiston
Twin Falls, City of
University of Idaho
Washington County Planning and Zoning
Valley County Planning & Zoning

Private Sector:

Albertsons Inc.
Associated Food Stores
Bank of America - Boise, Los Angeles, San Francisco
Bannock Regional Medical Center
BMC West
Caldwell Economic Development Project
CHQSA Architects
Consolidated Supply
Cornerstone Research
Davis, Wright, Tremaine
DBSI Realty
Dow Jones Co., New York
Dun & Bradstreet, New Jersey
Foodmaker, Inc
Global Travel
Group Health Northwest
Henkle-Buchanan Group
Holland & Hart
IDA-ORE Economic Development
Idaho State Journal
Intermountain Gas Company
Intermountain Health Care
International Strategies
JUB Engineers
Kootenai Electric - Coop.
Kootenai Regional Medical Center
KTVB
Lockheed Martin Idaho Technologies
Magic Valley Regional Medical Center
Marples Business Newsletter
Medical Center Physicians
Medical Service Bureau
Moodys Investor Service
Mountain States Appraisal
O'Neill Enterprises Inc.
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Post Register - Post Falls
St. Alphonsus Regional Medical Center
St. Lukes Regional Medical Center
U.S. BanCorp
United Water - Idaho
US West
Valley Medical Center
Washington Federal Savings
Washington Water Power
Wausau Insurance Co.
Wm. Clark Planning & Development

Outline of Facts and Opinions

John Church

M3 Eagle Water Right Application No. 63-32575

November 25, 2008

Background and experience as an economist.

I am president of Idaho Economics, an economic consulting firm located in Boise, Idaho. The firm's mailing address P.O. 45694, Boise, Idaho 83711. I am an independent economic consultant and a visiting assistant professor in the Economics Department at Boise State University. I have a Bachelor of Science degree in civil engineering from the University of Washington, a Bachelor of Business Administration degree from Boise State University, and Master of Science degree in economics from the University of Idaho. Prior to becoming an economic consultant I was corporate economist for Idaho Power Company in Boise, Idaho.

I have 17 years of professional experience at Idaho Power Company as corporate economist and 8 years experience as an independent economic consultant. I have experience in building economic models and performing economic impact analysis studies. I have constructed and maintain a long-term economic forecasting model for the purpose of forecasting economic activity and demographic characteristics of the state and each of Idaho's forty-four counties. The output of this economic forecasting model is regularly used various clients around the state of Idaho for their long-term business and resource planning needs. In addition, I have experience in the economic valuation of long-term resource purchase contracts, the economic evaluation of decision alternatives, economic modeling of local area impacts resulting from transportation improvement projects, and the economic modeling and forecasting of long-term demand and supply for elementary and secondary education teachers.

I have prepared economic impact studies for the Idaho National Engineering and Environmental Laboratory (now the Idaho National Laboratory), resorts, planned communities, location decisions by manufacturing, utility, and service industry firms, expansion decisions by manufacturing firms. For many economic impact studies I have also prepared fiscal impact studies for site or regulatory approval. I have prepared and presented sworn testimony before state regulatory authorities, legislative committees, and to state and federal courts.

Some of my recent economic consulting clients include: Idaho Power Company, Intermountain Gas Company, St Lukes Regional Medical Center, Hecla Mining Company, Agrium USA, the Idaho Mining Association, Developers Diversified Realty, and M3-Eagle LLC.

I have attached a copy of my resume.

The analysis for M3-Eagle entitled "M3-Eagle Development: Demographic Forecast and Economic and Fiscal Impact Analysis"

This is an analysis I prepared for the M3-Eagle development.

The primary objective of the analysis was to estimate the fiscal impact that the M3-Eagle development would have upon those public service providers that would be affected by the development.

Specifically, those public service providers were deemed to be: Ada County, the City of Eagle, the Meridian Joint School District #2, the Eagle Fire District, the Ada County Highway District, Ada County Emergency Medical Services, Ada County Weed and Pest Control as well as the Mosquito Abatement District.

Because most of the additional costs that the M3-Eagle development would impose on these public service providers is a function of the additional population that the development would have it was necessary to forecast the population and its demographic characteristics.

However, an examination of the additional costs that the M3-Eagle development would impose upon these public service providers is an incomplete picture without also examining the additional revenues that would be forthcoming from taxes and fees paid by the residents of M3-Eagle.

Annual estimates of the additional costs that each public service provider would experience were made. In addition, annual estimates of the additional revenue that the M3-Eagle development would generate for those affected public service providers were made. These annual estimates of additional costs and the estimates of additional revenues were compared for each year of the projected twenty year time horizon to full build out of M3-Eagle to determine if the development would impose a burden upon the existing tax paying population.

The method used to make the projections of the M3-Eagle population and its demographic characteristics.

The population and household demographic projections performed for M3-Eagle Development were prepared so as to accurately reflect the anticipated future composition of the development.

The analysis used population, household, and demographic parameters from the 2000 Census of the local population in order to capture the demographic composition of the population that may be likely to reside with the M3-Eagle Development.

However, in order to realistically reflect the potential future population one should match the characteristics that the proposed community will possess with communities or neighborhoods with similar attributes in the local area. Some of the important characteristics that are envisioned for M3-Eagle Development and that are important for drawing comparisons to the demographics of other areas locally are the types of homes in the community and the number of homes of each type, and the projected selling price of each type of new home in the development, and the number of multi-family homes in the development.

While it is known that marketing efforts directed to target a certain demographic may change the future composition of the population in the development they may not capture that market segment. The fundamental truth may be that the underlying characteristics of the population from which the community's new residents are to be drawn will be the determining factor which represents the basis of its future demographic composition.

The homes proposed within M3-Eagle vary in size, amenities, and price. The M3–Eagle development envisions that there would be, at full build-out of the project, nearly 5,316 residences that would typically be classified as "single family detached" homes. These are the traditional one-residential-building-is-equal-to-one-household home and would account for 65.1 percent of the nearly 7,153 residences that are anticipated to be built over the twenty year build-out of the project.

Housing statistics from the 2000 U.S. Census reveal that, on average, "single-family detached" homes represented 67.5 percent of the total housing stock in Ada County. The proposed housing mix for the M–3 Eagle development is similar. Multi-family housing units within M–3 Eagle Development are slated to account for the remaining 34.9 percent of the development's residential housing stock.

While census figures show that nearly 74.4 percent of the City of Eagle's housing is "single-family detached," the lower number for M3 Eagle is reasonable given its size and the fact that it is a planned community that is intended to provide for a variety of ages and lifestyles.

Another factor that was considered in constructing the projections of the future population and demographics of the M3-Eagle development was the price of the residential homes that are proposed to be built in the project. Home prices can act as a filter of the population such that future residents of the M3–Eagle community may not have a different demographic composition from that found in the City of Eagle or that found in Ada County as a whole.

Because of these factors it was decided that utilizing 2000 Census demographic averages drawn from the City of Eagle or from Ada County as a whole would not accurately reflect or predict the future population and its demographic characteristics within the M3–Eagle development. In order to more accurately predict the future population and its composition within the M3–Eagle development a search was made for smaller areas of Ada County where the composition of the housing stock (single-family versus multi-

family) and the value (price) of that housing stock more accurately reflected the future conditions envisioned for the M3–Eagle Development.

Smaller geographic areas of the County were screened and eight areas were selected. For these eight areas population and demographic statistics from the 2000 Census were assembled for an area one-half mile in diameter centered on a judgmentally determined central point within this smaller "surrogate area". Again, these "surrogate areas" are small residential areas of the County that appear to have characteristics that are similar to the residential housing proposed for the M3–Eagle development.

The choice of these "surrogate" residential areas was based upon them having a similar proportion of multi-family housing, having single family residential housing of newer vintage, housing with the characteristics of similar size and value, and housing within residential developments with a degree of amenities that may be comparable to those that will be found in M3–Eagle. The selected "surrogate" residential areas were then examined using data from the 2000 US Census to develop a profile of the population and households therein. These profiles were then utilized to construct a composite profile of the future population and household characteristics of the M3–Eagle project.

The demographic profiles of these eight "surrogate areas" in Ada County chosen to represent the future composition of the M3–Eagle Development, as well as a comparison of the population and demographic characteristics of the United States, the State of Idaho, the Boise MSA, Ada County, the City of Boise, and the City of Eagle, can be found in Appendix A of the M3-Eagle Development: Demographic Forecast and Economic and Fiscal Impact Analysis report.

The M3-Eagle development can be absorbed by the projected housing market in the Boise MSA.

The M3-Eagle development, consisting of 7,153 housing units, is envisioned to take twenty to thirty years to complete.

While the size of the M3-Eagle development is not something seen before in the Boise MSA housing market, the long-term planning horizon to completion also is a new phenomenon here. But planning such developments as a whole, rather than proceeding toward the same overall numbers in a piecemeal fashion, is a prudent approach to managing growth. This is because projections, including economic projections, can be made at the outset and decisions can be made early on to accommodate specific amounts and locations of development.

In order to put the proposed 7,153 housing units in the M3-Eagle development in perspective realize that would be, on average, the addition of 358 housing units per year over a projected twenty year build-out. Alternatively, that is a pace of about 29 homes a month.

Over the period 1970 – 2000, and here I have deliberately left off the recent (2004- 2006) strong surge in housing additions, Ada and Canyon counties added 108,331 housing units (81,371 in Ada County and 26,960 in Canyon County). The proposed housing additions of the M3-Eagle development would only represent 6.6 percent of that historic experience.

The proposed average annual M3-Eagle housing unit additions, an annual average pace of 358 units per year, would have represented less than one month of housing additions in the City of Meridian in 2004, 2005, or 2006.

I believe the M3-Eagle development is not too big for the market, and the 30-year planning horizon appears appropriate.

The implications to the M3-Eagle proposed planning horizon due the current economic downturn in the residential housing market.

Again, the M3-Eagle development is envisioned to take twenty to thirty years to complete. Housing markets have their ups and downs. However, I know of no evidence to support the conclusion that this slowdown today is the starting point for a long-run decline in the overall population of the Boise MSA. And even if it were, and even if that resulted in the M3 Eagle project failing to realize its full development, this then would mean that the end of the planning horizon was reached with the project needing a license for less ground water than it originally was projected to need.

In my opinion, the current slowdown in housing demand will abate and another upswing will be forthcoming. As a matter of fact, the Ada and Canyon County housing unit additions over the period 1970 – 2000 that I previously mentioned had arguably the largest economic recession that the State of Idaho has ever experienced and one of the largest housing market slowdowns during the 1980 – 1982 national recession.

That is a very positive point about taking the long view as M3 has with this development. Even if twenty years were projected to full build-out of the M3-Eagle development, this time period in itself makes clear that M3 expects there will be ups and downs in the housing market as the project goes forward.

The future needs water rights application seeks a 30 year planning horizon sought in the water right application compared to M3-Eagle's best case of 20 years to full build-out.

A thirty year horizon for the water rights application appears to me to be the prudent course of action, even though a case can be made that build-out will occur in 20 years.

This water rights application seeks a planning horizon of thirty years. It is not the longest time-horizon for a water rights application. Economic and population projections that I made for United Water in their IMAP application were made with an anticipated 50 year horizon. Of course, the 50-year horizon is for a company obligated to serve new users

within a continually expanding service area, whereas M3 Eagle proposes a planned community within specified boundaries. Therefore, its planning horizon is much more appropriately set within a somewhat smaller timeframe.

I believe that M3-Eagle's 30 year planning horizon to fully develop the water rights it seeks under the application is reasonable and prudent for three reasons: first, the M3-eagle development is anticipated to take at least twenty years until full build-out; second, at least substantial portions of the infrastructure necessary for the project (including the water supply system) will have to be put in place prior to any residential housing units are sold or occupied; and third, the housing market has its ups and downs, and it is prudent to provide some flexibility for those potential fluctuations.

The M3 Eagle future needs/planning horizon application is one of only three such applications I have seen, the other two being that mentioned previously for United Water Idaho and the future needs application approved several years ago for Tamarack. As an economist, I find such an approach to land and water supply planning to be prudent and in furtherance of good decision-making by both the public and the private proponent.

Projections of future residential water demand in M3-Eagle.

I have reviewed the applicant's projections of future residential water demands as they are shown in the application at Exhibit 5.7 and found them to be reasonable. On page 3 of Exhibit 5.7 of the application it is projected that the annual indoor potable water needed for the 7,153 residences planned for M3-Eagle will be 956 million gallons, an annual average of 133.23 thousand gallons per residential customer. In 2005, I co-authored a water demand analysis for United Water Idaho, and am familiar with long-term forecasting methods for utilities. I also have reviewed United Water's annual reports of water use on file with the Idaho Public Utilities Commission. The projected annual average water use per residential customer for the M3 Eagle project is not dissimilar from United Water's average annual water use per residential customer for the years 2005-2007 of 135.17 thousand gallons, or an average of 370 gallons per day per residence on a year-round basis. In United Water's system, many of these customers would be using water for irrigation as well as in-house uses, and M3 Eagle's figures exclude irrigation.

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B. Simulation of Ground Water Flow in the Lower Boise River Basin by Christian R. Petrich (Feb. 2004)

C. Simulation of Increased Ground Water Withdrawals in the Lower Boise River Basin by Christian R. Petrich (Feb. 2004)

D. Characterization of Ground Water Flow in the Lower Boise River Basin by Christian R. Petrich and Scott M. Urban (Feb. 2004

E. Appendix C: Monitoring Well Diagrams for the Report, Characterization of Ground Water Flow in the Lower Boise River Basin (Mar. 2004)

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H. Influence of Canal Seepage on Aquifer Recharge Near the New York Canal by Jon Hutchings and Christian R. Petrich (Dec. 2002)

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P. Structure Contour Map of the Base of Quaternary Basalt, Murphy and west part of Mountain Home Map Sheets, Idaho by Spencer H. Wood (Aug. 1997)

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TREASURE VALLEY HYDROLOGIC PROJECT EXECUTIVE SUMMARY

Prepared by

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Idaho Water Resources Research Institute
Research Report IWRRI-2004-04

February 2004

ACKNOWLEDGEMENTS

The work described in this report was conducted as part of the Treasure Valley Hydrologic Project (TVHP). Participants in the TVHP include the Idaho Department of Water Resources (IDWR), the Idaho Water Resources Research Institute (IWRRI), University of Idaho (UI), United Water Idaho, Inc. (UWI), Boise State University (BSU), U.S. Geological Survey (USGS), U.S. Bureau of Reclamation (USBR), Idaho Water Resource Board, Ada and Canyon Counties, and the cities of Boise, Nampa, Caldwell, Meridian, Kuna, and Eagle. The project was funded by the U.S. Environmental Protection Agency, the Idaho State Legislature, UWI, and the Idaho Water Resource Board. In addition, in-kind services were provided by UWI, USGS, and the USBR.

A Policy Advisory Committee (PAC) helped define general water resource issues and planning questions to be addressed through this project. The PAC consisted of representatives from UWI, IDWR, USGS, Ada and Canyon County governments, and elected officials from Ada and Canyon County communities. A Technical Advisory Committee (TAC), consisting of Treasure Valley geological and hydrological experts, provided technical guidance and review.

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1. INTRODUCTION

1.1. Project Background

The Treasure Valley of southwestern Idaho has experienced significant population growth, local ground water declines, and periodic drought conditions in the last two decades. This led to public concern about the status and future of water resources in the valley. The following questions typify those that were asked about Treasure Valley water supplies:

1. Does the Treasure Valley have a ground water shortage?
2. How has and does land development impact Treasure Valley water supplies?
3. Where and to what degree are ground water levels declining?
4. What is the carrying capacity of the hydrologic system in the Treasure Valley?
5. How big is our aquifer system? Where are the aquifer boundaries?
6. How are shallow and deep aquifers connected?
7. How are Treasure Valley aquifer systems recharged and where does the recharge occur?
8. How susceptible is the Treasure Valley aquifer system to contamination?
9. What is the degree of hydraulic connection between Treasure Valley surface and ground water?
10. Is water conservation necessary to meet future water demands?
11. Can additional tools and/or data be developed to assist local, state, and federal governments with decisions on issues that impact water resources, such as land use planning, zoning, water rights, septic tank permitting, waste treatment, etc.?

The Treasure Valley Hydrologic Project (TVHP) was formed to provide technical information needed to address most of these issues and to provide a framework for future water management. The project included characterization of ground water flow in the Treasure Valley aquifer system, evaluation of flow system geochemistry, estimation of ground water residence times, and construction of a numerical model of ground water flow. The ground water flow model was used to evaluate potential changes in recharge and predict possible effects of increased ground water withdrawals.

1.2. Purpose and Objectives

The purpose of the TVHP was to develop a better understanding of ground water resources in the Treasure Valley and to evaluate the effects of potential change on ground water supplies. Specific objectives for the project included:

1. Developing a water budget of inflows and outflows to the Treasure Valley aquifer system.
2. Improving the understanding of the Treasure Valley hydrologic system.
3. Developing a spatially-oriented database of hydrologic data.
4. Developing a numerical model to simulate ground water flow in the regional hydrologic system.
5. Using the numerical model to simulate potential impacts to Treasure Valley ground water levels from changes in regional ground water withdrawals and/or recharge patterns.
6. Conveying project results to those making land and water resource planning decisions and to the general public.

1.3. Report Scope

This report presents a summary of the TVHP. It includes an overview of the project, summarizes results from primary project reports, and addresses the questions listed in Section 1.1. More detailed information is presented in the project reports, which are listed in Section 2.10. Brief answers to the questions posed in Section 1.1 are provided in Section 5.

2. PROJECT DESCRIPTION

The Treasure Valley of southwestern Idaho consists of the lower Boise River sub-basin and the area between the lower Boise River sub-basin and the Snake River (Figure 2-1). The lower Boise River sub-basin begins where the Boise River exits the mountains near Lucky Peak Reservoir. From Lucky Peak Dam, the lower Boise River flows about 64 (river) miles northwestward through the Treasure Valley to its confluence with the Snake River. The project area extends south to the Snake River because ground water flows from some portions of the lower Boise River basin south toward the Snake River.

The Treasure Valley includes the cities of Boise, Nampa, Caldwell, Meridian, Eagle, Kuna, and a number of smaller communities. The central portion of the valley is drained by the Boise River; the southern portion of the valley is drained by the Snake River.

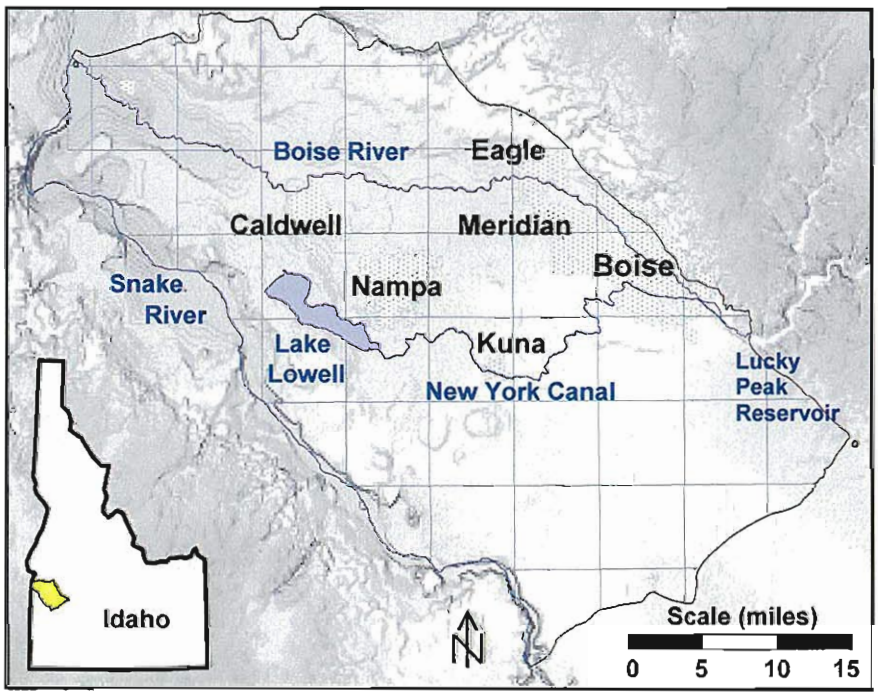

Figure 2-1: Treasure Valley and surrounding areas.

The TVHP consisted of numerous tasks designed to help define, evaluate, and quantify Treasure Valley aquifer and ground water flow characteristics and to simulate potential effects of hydrologic changes on the ground water flow system. The project included the following tasks:

1. Mass ground water level measurements
2. Monthly ground water level measurements
3. Construction of dedicated, multi-level ground water monitoring wells
4. Geologic interpretation
5. Seismic surveys
6. Seepage measurements
7. Geochemical analyses
8. Water quality analyses
9. Data development
10. Water budget development
11. Numerical modeling
12. Scenario development and simulation
13. Reporting
14. Public outreach

These tasks are summarized in the following sections.

2.1. Mass Ground Water Level Measurements

Mass ground water level measurements were conducted as part of the TVHP in the spring and fall of 1996, 1998, and 2000, and fall 2001. A mass measurement consists of collecting ground water level measurements in multiple wells over a short period of time (in this case, one to two weeks). The purpose of a mass ground water level measurement is to define a potentiometric surface at a point in time. A potentiometric surface represents the hydraulic head over an area. Potentiometric surfaces can be used to describe local and regional hydraulic gradients and can provide a baseline for large-scale water level changes over time.

Each measurement, conducted either by the U.S. Geologic Survey (USGS) or Kleinfelder, Inc., included over 245 wells throughout the Treasure Valley area (Table 2-1). Data collected by the USGS were included in the GWSI database; all data were included in the Idaho Department of Water Resources (IDWR) Well_Log database.

2.2. Monthly Ground Water Level Measurements

The TVHP monitoring well network consisted of approximately 70 wells[1] in which water levels were measured monthly from 1996 through 2001 and quarterly after 2001. The purpose of the periodic measurements was to provide a basis for evaluating seasonal fluctuations in water levels and establishing long-term water level trends.

Mass Measurement	Number of Wells	Measuring Entity
Spring 1996	339	USGS
Fall 1996	331	USGS
Spring 1998	381	USGS
Fall 1998	361	USGS
Spring 2000	305	USGS
Fall 2000	245	Kleinfelder, Inc.
Fall 2001	281	Kleinfelder, Inc.

Table 2-1: Numbers of wells measured in the mass water level measurements.

The monitoring was conducted in existing water wells, which were selected (in aggregate and individually) based on the following general criteria:

1. Spatial distribution throughout project area
2. Available drillers' reports
3. Reasonably detailed lithologic log
4. Discrete open interval, preferably corresponding with specific aquifer depths
5. Access to well by USGS, IDWR, or other personnel for conducting measurements

Results from these measurements are reported in Petrich and Urban (2004).

2.3. Dedicated TVHP Monitoring Wells

Four dedicated monitoring wells were constructed as part of this project (see Figure 2-2). Each monitoring well has multiple piezometers, each of which was completed (i.e., screened) at multiple discrete intervals, allowing the measurement of hydraulic head at various aquifer depths. Descriptions of these measurement wells are included in Petrich and Urban (2004).

[1] These wells are also included in the mass measurements described in Section 4.2.

2.4. Geological Cross-Sections

Numerous geologic cross-sections were prepared for this project (Beukelman, 1997a; Beukelman, 1997b; Beukelman, 1997c; Beukelman, 1997d; Squires and Wood, 2001; Wood, 1996a). These cross-sections and other data were used to interpret several geologic surfaces, including the base of the sedimentary section (Wood, 1996b), a structural contour map of the top of the Miocene basalt (Wood, 1997b), and the top of the mudstone facies (Wood, 1997c).

2.5. Seismic Surveys

Several seismic surveys were conducted as part of the project by Boise State University Center for the Geophysical Investigation of the Shallow Subsurface (CGISS). These surveys (Liberty, 1996; Liberty and Wood, 2001) and interpretations based on the stratigraphic data (Liberty, 1996; Liberty, 1998; Liberty and Wood, 2001; Squires and Wood, 2001; Wood, 1997a; Wood and Clemens, in press) contributed to an improved understanding of subsurface stratigraphy in the Treasure Valley.

In addition, CGISS digitized geophysical logs from a number of existing Treasure Valley wells. These logs are available at http://cgiss.boisestate.edu/TVHP/TVHP.html.

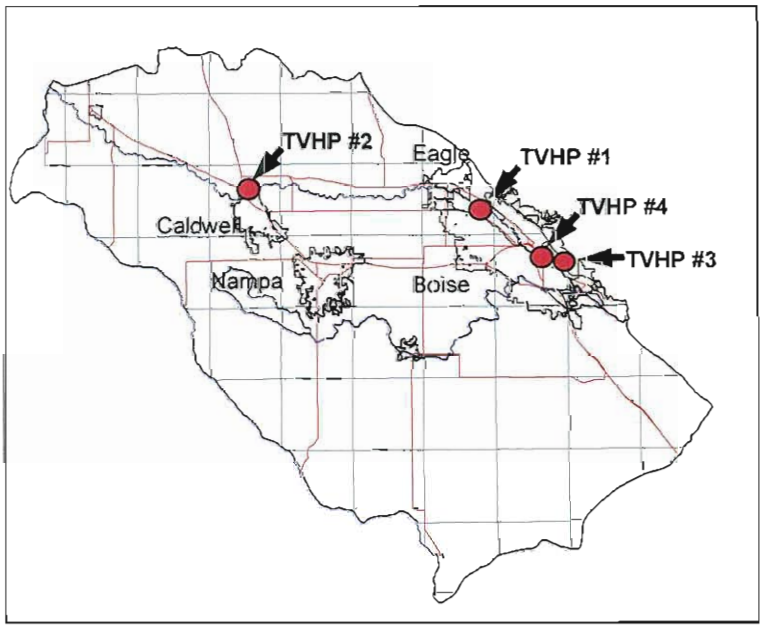

Figure 2-2: TVHP monitoring well locations (Petrich and Urban, 2004).

2.6. Seepage Measurements

Seepage measurements were conducted by the USGS in 39 irrigation and canal reaches in the lower Boise River basin, three reaches of the Boise River, and the New York Canal (Berenbrock, 1999; Carlson and Petrich, 1998). Results from these

measurements contributed to an understanding of ground and surface water interaction along the New York Canal and throughout some of the valley's irrigated areas.

2.7. Water Chemistry Analyses

Water chemistry analyses consisted of the following:

1. Analyzing general water quality trends (this was done through the Statewide Ambient Ground Water Quality Monitoring Program - Neely and Crockett, 1998).
2. Describing hydrochemical characteristics of principal aquifers in the regional Treasure Valley ground water flow system (Hutchings and Petrich, 2002a). Information from these analyses was used to help describe regional ground water flow patterns.
3. Estimating residence times in the regional ground water flow system (Hutchings and Petrich, 2002a). Ground water residence time data gave insight into the effective rate of flow in the regional ground water flow system.
4. Evaluating the influence of canal seepage on deep aquifer recharge near the New York Canal based on chemistry and hydrologic data (Hutchings and Petrich, 2002b). Chemistry data were used to describe the depth of penetration of surface water and evaluate alternative sources of recharge to deep aquifers.

2.8. Water Budgets

Two water budgets for the Treasure Valley aquifer system were developed based on 1996 and 2000 calendar-year inflow and outflow estimates (Petrich and Urban, 2004; Urban, 2004). Inflows estimated in the water budgets included canal seepage, recharge from rivers and streams, recharge from Lake Lowell, subsurface inflow, recharge from precipitation, and surface water irrigation recharge from rural domestic septic systems. Discharge estimates included withdrawals for municipal, self-supplied industrial, irrigation, rural domestic, and livestock needs; discharge to rivers and drains; and underflow into the valley.

2.9. Spatial Data development

A variety of spatial data were collected, developed, and/or compiled as part of, or in conjunction with, the TVHP. Spatial data were used to augment the hydrologic data collected in the tasks outlined above. These data included the following:

1. Topographic data (USGS digital raster graphics [DRGs] at 1:24,000, 1:100,000, and 1:250,000 scales)
2. Land Use Data–Color Infrared Images (CIR) were analyzed using standard photo interpretation techniques. The CIR images were produced from scanned, geocorrected, and mosaicked 1:24,000-scale CIR aerial photographs

taken in 1998 and 2000. A suite of ARC/INFO AMLs were developed and used to conduct the image interpretation. The land use and land cover data was plotted at 1:24,000-scale, and the maps were verified in the field.

3. Shaded relief images were created from the National Elevation Dataset (NED).
4. Digital Line Graphs (DLGs) (for highways, etc) were obtained from the USGS and/or the US Census Bureau at a 1:100,000-scale.
5. Political boundaries were taken from the 2000 census (1:100,000-scale).
6. Hydrography data (e.g., canals, streams, rivers, drains) were taken from Pacific Northwest Ada and Canyon County hydrography data (USGS and Idaho Department of Lands; varied scales between 1:24,000 and 1:100,000). Data were enhanced by IDWR.
7. Irrigation district boundaries were created for the Snake River Basin Adjudication. The boundaries were generated from the (1) Bureau of Land Management's (BLM) Geographic Coordinate Data Base (GCDB)[2], (2) digitized from the 1987-88 National Aerial Photography Program (NAPP)[3], or (3) provided by irrigation districts or companies. Scales varied between 1:24,000 and 1:100,000.
8. Well information, including well location, lithology, depth, well construction details, yield, completion date, etc., was obtained from the drillers' reports and the IDWR Well_Log database.
9. Urban water purveyor boundaries were created from a number of different sources throughout the state of Idaho. The boundaries represent the municipal service areas of municipal delivery entities within the state (scale: 1:100,000). The boundaries were (1) generated for the 2000 Census, (2) digitized from the 1987-88 NAPP Photography, or (3) provided by individual cities. In the Treasure Valley, some of the initial municipal boundaries were obtained from the Southwest Community Planning Association (COMPASS) and from United Water Idaho, Inc. (UWI).
10. Surface Energy Balance Algorithm for Land (SEBAL) evapotranspiration (ET) data (Kramber, 2002) were provided by IDWR.

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[2] From http://www.blm.gov/gcdb/. This is a collection of geographic information representing the Public Land Survey System (PLSS) of the U.S. The GCDB grid is computed from BLM survey records (official plats and field notes), local survey records, and geodetic control information.

[3] The NAPP provides a standardized set of cloud-free aerial photographs covering the conterminous U.S. over 5- to 7-year cycles. The program began in 1987 and continues to be our most recent and consistent source of high-quality aerial photography. The photographs were acquired from an altitude of 20,000 feet and are available in black and white (B/W) or color infrared (CIR), depending on location and date. Each photo is centered on one-quarter section of a 7.5-minute USGS quadrangle, and covers approximately a 5.5 x 5.5 mile area.

2.10. Project Reports, Data, and Information

Reports prepared as a part of, or in conjunction with, the TVHP include the following:

- Characterization of Ground Water Flow in the Lower Boise River Basin (Petrich and Urban, 2004)
- Simulation of Ground Water Flow in the Lower Boise River Basin (Petrich, 2004a)
- Simulation of Potential Increased Treasure Valley Ground Water Withdrawals Associated with Unprocessed Well Applications (Petrich, 2004b)
- Water Budget for the Treasure Valley Aquifer System for the years 1996 and 2000 (Urban, 2004)
- Geologic and Tectonic History of the Western Snake River Plain, Idaho and Oregon (Wood and Clemens, in press)
- Hydrogeologic Conditions in the Boise Front Geothermal Aquifer (Petrich, 2003a)
- Investigation of Hydrogeologic Conditions and Ground Water Flow in the Boise Front Geothermal Aquifer–Executive Summary (Petrich, 2003b)
- Simulation of Increased Ground Water Withdrawals in the Treasure Valley Associated with Unprocessed Well Applications (Petrich, 2004b)
- Treasure Valley's Water Future–Summary of the Treasure Valley Water Summit (COMPASS et al., 2002)
- Ground Water Recharge and Flow in the Regional Treasure Valley Aquifer System (Hutchings and Petrich, 2002a)
- Influence of canal seepage on aquifer recharge near the New York Canal (Hutchings and Petrich, 2002b)
- Developing evapotranspiration data for Idaho's Treasure Valley using Surface Energy Balance Algorithm for Land (SEBAL) Treasure Valley (Kramber, 2002)
- Stratigraphic Studies of the Boise (Idaho) Aquifer System using Borehole Geophysical logs with Emphasis on Facies Identification of Sand Aquifers (Squires and Wood, 2001)
- Domestic, Commercial, Municipal, and Industrial Water Demand Assessment and Forecast in Ada and Canyon Counties, Idaho (Cook et al., 2001)
- Seismic Reflection Project - UPRR 2000 Profile (Liberty and Wood, 2001)
- Hydrogeology, Geochemistry, and Well Construction of the Treasure Valley hydrologic Project Monitoring Well #1 (Dittus et al., 1999)
- 1996 Water Budget for the Treasure Valley Aquifer System (Urban and Petrich, 1998)

- New York Canal Geologic Cross-Section, Seepage Gain/Loss Data, and Ground Water Hydrographs: Compilation and Findings (Carlson and Petrich, 1998)
- Seismic Reflection Imaging of a Geothermal Aquifer in an Urban Setting (Liberty, 1998)
- Structure Contour Map of the Top of the Mudstone Facies, Western Snake Supporting Data for Groundwater Conditions and Aquifer Testing of the Tenmile Ridge Area of South Boise, Ada County, Idaho (Dittus et al., 1998)
- Ground water quality characterization and initial trend analysis for the Treasure Valley shallow and deep hydrologic subareas (Neely and Crockett, 1998)
- Structure Contour map of the Top of the Mudstone Facies, Western Snake River Plain, Idaho (Wood, 1997c)
- Cross Section of the Treasure Valley in the Boise Area: Notes on the Geology of the Boise, Ontario, Parma, and Notus areas (Beukelman, 1997a; Beukelman, 1997b; Beukelman, 1997c; Beukelman, 1997d)
- Preliminary Map of the Base of the Sedimentary Section of the Western Snake River Plain (Wood, 1996b)

2.11. Outreach

Outreach for the TVHP included project workshops, preparation of project brochures and newspaper inserts, public presentations, and the first-ever Treasure Valley Water Summit.

2.11.1. Treasure Valley Water Summit

The Treasure Valley Water Summit was a primary outreach effort of the TVHP. On January 14 and 15, 2002, more than 300 people participated in the Treasure Valley Water Summit, a community-wide discussion about Treasure Valley water issues. Topics focused on the current state of water resources, the potential effects of population growth on water resources, and strategies for planning a water future. Participants included citizens, elected officials, federal, state, and local government, scientists, planners, and engineers, representatives of agriculture and industry, private developers, and legal professionals. In April 2002, the Summit results were summarized for valley decision-makers. A summary report (COMPASS et al., 2002) and accompanying appendices give agendas, discussion group summaries, and summaries of selected presentations.

2.11.2. Presentations

The following is a partial list of presentations given as part of the TVHP:

- *Treasure Valley Hydrology* (2003)
  Association of Idaho Cities and the Community Planning Association of Southwest Idaho (Petrich)
- *Simulation of Increased Withdrawals* (2003)
  United Water Idaho, Inc. (Petrich)
- *Treasure Valley Hydrologic Project Overview* (2003)
  U.S. Bureau of Reclamation (Petrich)
- *An Update: Ground and Surface Water Hydrology in the Proposed Conjunctive Administration Area, Treasure Valley* (2003)
  Idaho Department of Water Resources (Petrich).
- *Treasure Valley Hydrology – an Overview* (2003)
  BSU Civil Engineering class (Petrich)
- *Simulation of Increased Ground Water Withdrawals in the Lower Boise River Basin, Idaho* (2003)
  MODFLOW2003, Golden, CO (Petrich)
- *Treasure Valley Hydrology* (2002)
  Treasure Valley Water Summit (Petrich)
- *Treasure Valley Hydrology* (2002)
  Treasure Valley Water Summit Follow-Up (Petrich)
- *Treasure Valley Hydrology* (2002)
  Canyon County Planning Commission (Petrich)
- *Treasure Valley Hydrologic Project Progress Report* (2002)
  U.S. Environmental Protection Agency (Castelin and Petrich)
- *Ground and Surface Water Hydrology in the Proposed Conjunctive Administration Area, Treasure Valley* (2002)
  Idaho Department of Water Resources (Petrich).
- *Treasure Valley Ground Water Data* (2000)
  DEQ Source Water Assessment team (Petrich)
- *Treasure Valley Hydrologic Project Progress Summary* (2001)
  City of Eagle (Petrich).
- *Introduction to Ground Water Flow Modeling* (2001)
  Idaho Water Users Association (Petrich)
- *Treasure Valley Hydrology* (2001)
  BSU geology class (Petrich)
- *Treasure Valley Hydrology* (2001)
  BSU geology class (Petrich)
- *Treasure Valley Aquifer Description* (2000)
  Board of Realtors (Petrich and Castelin

- *Well Logs and Ground Water Studies* (2000)
  Idaho Ground Water Association (Petrich)
- *Project Update* (2000)
  United Water Idaho, Inc. (Petrich and Castelin).
- *Project Update* (1999)
  United Water Idaho, Inc. (Petrich).
- *Project Overview and Flow Model Development* (1999)
  Agricultural Research Service (Petrich and Hutchings).
- *Calibration of the Treasure Valley Ground Water Model using Parameter estimation* (1999)
  Idaho Ground Water Connections Conference (Petrich)
- *Characterization of the Treasure Valley Ground Water Flow System* (1999)
  Boise River 2000 (Petrich and Castelin)
- *Surface and Ground Water Interaction near the New York Canal* (1999)
  Idaho Ground Water Connections Conference (Carlson)
- *Development and Calibration of a Regional Ground Water Flow Model of the Lower Boise River Basin, Southwestern Idaho* (1999)
  Annual Meeting of the Geological Society of America (Petrich)
- *Treasure Valley Model Development* (1998)
  American Society of Civil Engineers (Petrich)
- *Treasure Valley Hydrology* (1998)
  Ground Water Resource Conference, Changchun, China (Petrich)
- *Treasure Valley Hydrologic Project: an Overview* (1997)
  Idaho Ground Water Connections Conference (Petrich)
- *Treasure Valley Ground Water Flow Model – an Overview* (1997)
  Idaho Association of Professional Geologists (Petrich)
- *Treasure Valley Hydrologic Project – an Overview* (1997)
  Idaho Water Users Association (Petrich)
- *Development of a Hydrologic Data Platform for Conjunctive Management in Southwest Idaho* (1999)
  Pacific Northwest Focus Ground Water Conference (Petrich)

2.11.3. Web Site

IDWR is developing a comprehensive web site (http://www.idwr.state.id.us) that describes Treasure Valley hydrology, a project description, and project results. All project reports are being posted to this web site.

3. DESCRIPTION OF GROUND WATER FLOW

This section presents a summary of Treasure Valley ground water flow characteristics, water level measurements, and aquifer inflows and outflows (from Petrich and Urban, 2004). The summary represents the "conceptual model" of ground water flow that was used as the basis for aquifer simulations.

The Treasure Valley aquifer system is comprised of a complex series of interbedded, tilted, faulted, and eroded sediments, extending to depths of over 6,000 feet in the deepest parts of the basin (Wood and Clemens, in press). The valley contains shallow, local flow systems (with ground water residence times ranging from years to hundreds of years) and a deeper, regional flow system (with residence times ranging from thousands to tens of thousands of years). Few water wells extend beyond a depth of 1,200 feet.

The Treasure Valley sedimentary section reflects a history of lacustrine, deltaic, fluvial, and alluvial deposition (Wood and Clemens, in press). In general, basin sedimentary deposits grade from coarser, more permeable sediments near the Boise Front[4] to finer, less permeable sediments at the distal end of the basin. At the basin scale, sediments also grade finer with depth. Highly permeable deposits associated with deltaic and/or fluvial deposition are often sandwiched between lacustrine deposits of lower permeability.

Ground water flow in the Treasure Valley is controlled by aquifer characteristics and hydraulic gradient. Aquifer characteristics influencing ground water flow include grain size, sorting, stratigraphic layering, sedimentary layer dip, sediment grain cementation, and the degree of fracturing (e.g., rock aquifers). Additional controls on the movement of ground water are attributed to structural processes, including faulting throughout the basin and along the basin margin.

Ground water chemistry data (Hutchings and Petrich, 2002a) indicate different ground water chemistry north of the fault zone compared to the area south of the fault zone, suggesting restricted flow across the fault zone. Basin downwarping and an associated downslope trend in sediment deposition contribute to steeply dipping sedimentary deposits that may cause deeper aquifer units to pinch out at depth (Wood, 1997). Based on seismic imaging and outcrop mapping, aquifer sediments of various fault blocks dip at angles ranging from zero to approximately 12 degrees (Wood, 1997).

Fractures within shallow Pleistocene basalts, or along upper and lower surfaces of individual basalt flows, can contribute to ground water movement. For instance, basalt fractures and course-grained sediments underlying the basalt may contribute greatly to

[4] Boise Front describes the portion of the Idaho Batholith that forms the northeastern boundary of the lower Boise River basin.

transmitting leakage from the New York Canal (and other surface water channels) into shallow aquifers.

An erosional unconformity associated with changing lake levels in Pliocene Lake Idaho truncates down-dipping units near the basin margin near Boise (Squires and Wood, 2001; Squires et al., 1992; Wood, 1997a). The unconformity separates lacustrine and deltaic sediments (tilted in the Boise area) from overlying lacustrine/deltaic sediments. Coarse-grained sediments associated with the erosional unconformity (Wood, 1997; Squires et al., 1992) appear to serve as a manifold for deeper, regional ground water migrating horizontally into the basin from alluvial fan sediments in the eastern portion of the basin (corroborated by E. Squires, pers. comm., 2002).

Potentiometric surface contours indicate ground water movement in a northwesterly to southwesterly direction, depending on depth and location (Figure 3-1 through Figure 3-4). Potentiometric surface contours in shallow aquifer zones reflect surface hydrologic conditions, such as mounding under the New York and Mora Canals, or discharge to the Boise River. Mounding in the vicinity of the New York Canal represents a local ground water divide, with shallow ground water north of the canal flowing toward the Boise River, and shallow ground water south of the canal flowing toward the Snake River. Potentiometric surface contours from shallow aquifers show ground water flow toward and discharge to the Boise River in mid- to lower reaches. Potentiometric surface contours in deeper zones indicate a more uniform westerly flow direction (e.g., Figure 3-3). Downward hydraulic gradients are indicated along the Boise Foothills, the eastern part of the study area (e.g., TVHP#4, Figure 3-5), and in the vicinity of the New York and Mora Canals. Upward gradients are evident in the central and western portions of the valley (e.g., TVHP#2, Figure 3-5), especially in the vicinity of the lower Boise River.

Individual hydrographs indicate relatively stable water levels in many areas, although water level declines have occurred in a number of wells (Petrich and Urban, 2004). Wells in two areas, southeast Boise and south of Lake Lowell, have experienced declines of approximately 30 feet and 65 feet, respectively. Water levels in these areas appear to have stabilized in recent years. Additional ground water level declines were observed in the areas between northwest Boise and Eagle and southwest Boise, Meridian, and Kuna). Most of the long-term declines in these wells have been less than 10 feet. Reasons for the declines may include increased withdrawals from the measured wells (very few of the monitoring wells are dedicated to monitoring alone), increased nearby withdrawals, and/or changes in local infiltration rates. Further investigation of these apparent declines is warranted to determine if they reflect regional or local conditions. Additional monitoring wells would also be warranted in these areas of apparent declines.

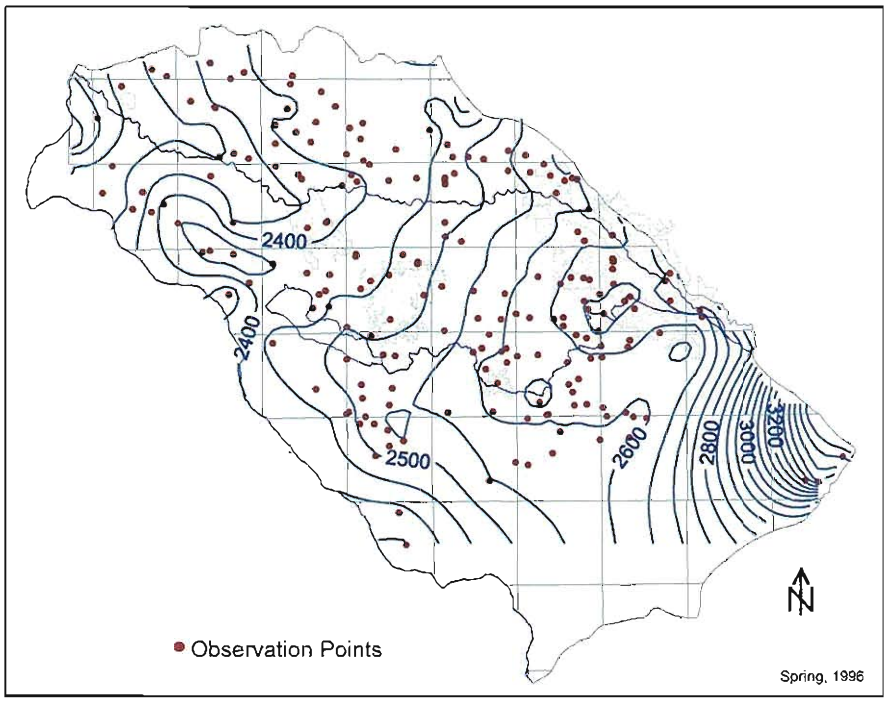


Figure 3-1: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 1.

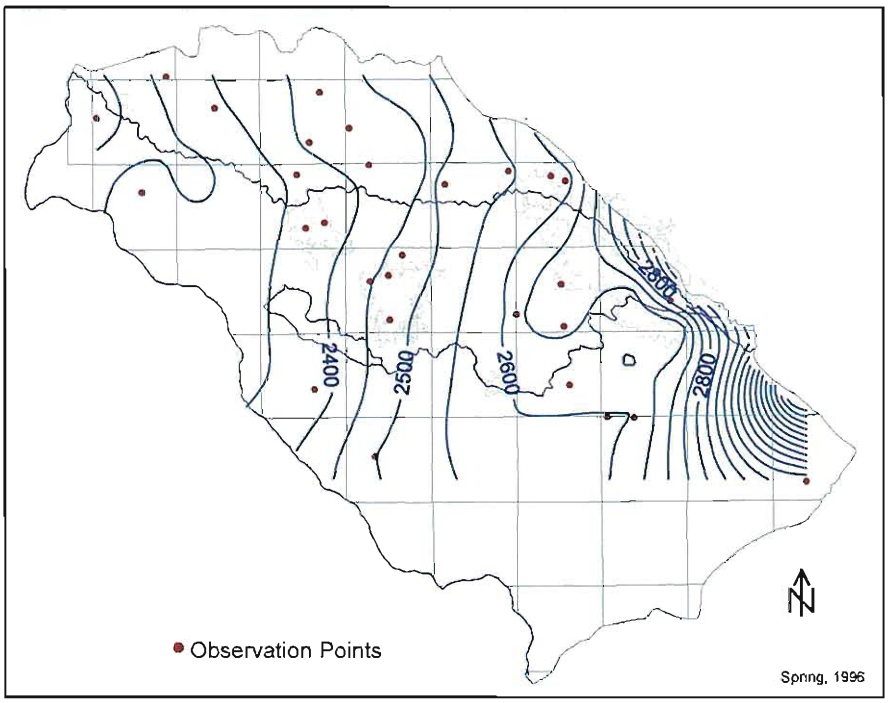


Figure 3-2: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 2.

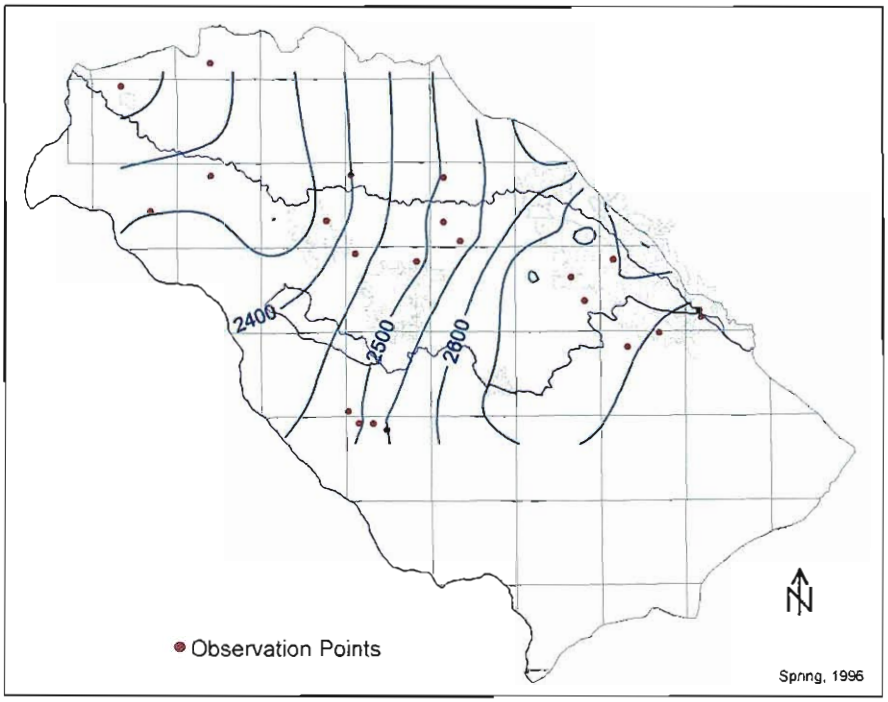


Figure 3-3: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 3.

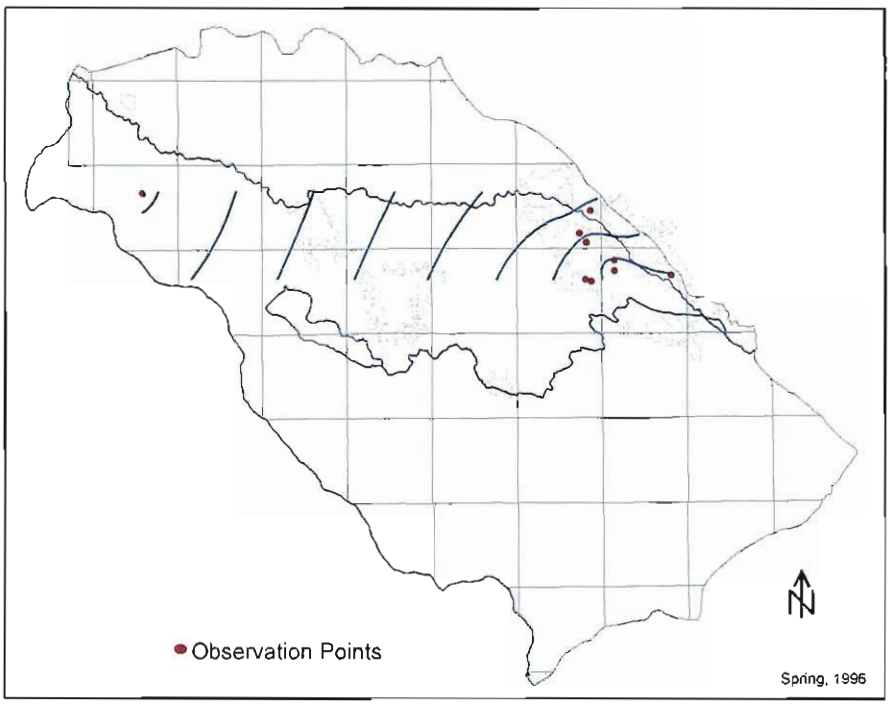
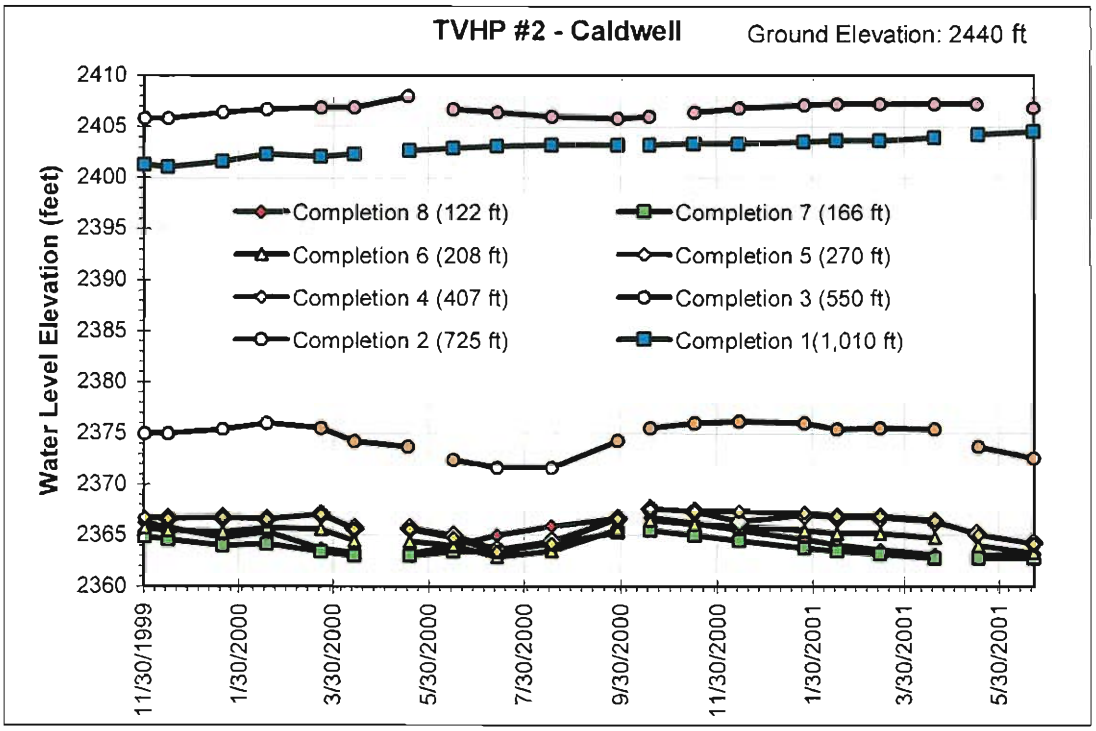
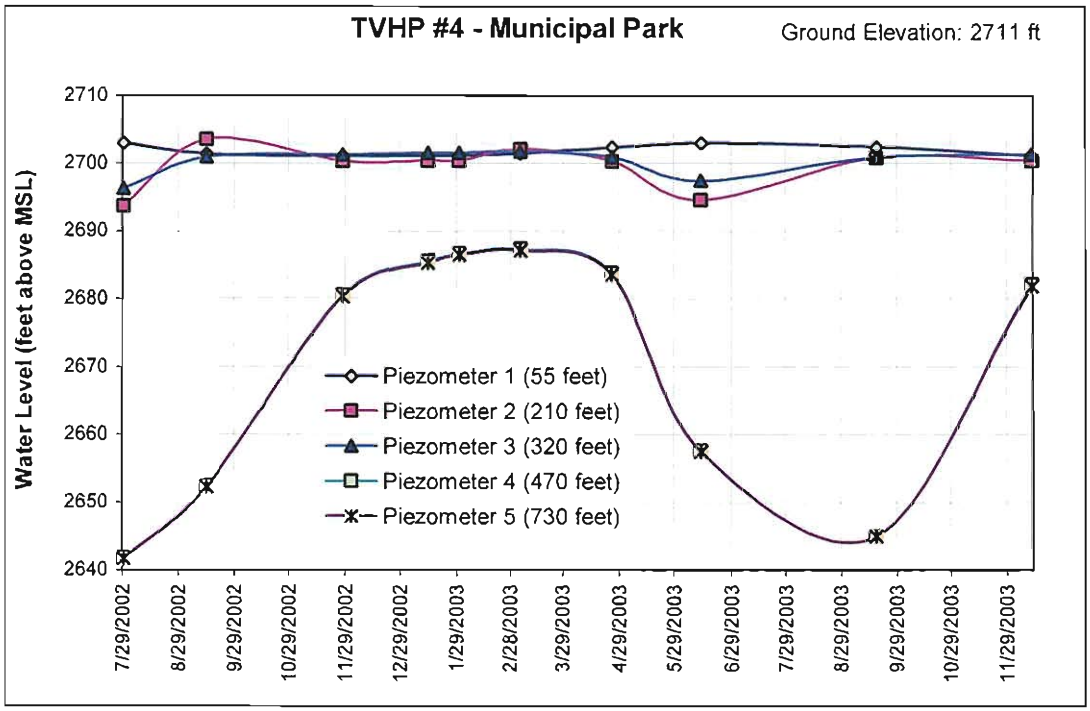


Figure 3-4: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 4.



From Petrich and Urban (2004)



From Petrich and Urban (2004)

Figure 3-5: Water level data from the Caldwell and Boise Municipal Park wells.

A number of shallow monitoring wells indicated water level decreases. Shallow wells may be especially sensitive to changes in local surface water irrigation patterns in areas where the water table is not in direct hydraulic connection with surface channels. Ground water level changes are less likely in shallow wells in areas where the water table is controlled by topography (by virtue of drains and canals).

Seasonal water level fluctuations are evident in many Treasure Valley wells. The fluctuations are generally a response to seasonal increases in withdrawals (e.g., summer irrigation withdrawals) or increases in recharge associated with surface water irrigation.

The largest component of recharge to shallow aquifers is seepage from the canal system and infiltration associated with irrigated agriculture (Urban and Petrich, 1998). Water enters shallow aquifers as infiltration from canals, irrigated areas, and other water bodies (e.g., Lake Lowell), and possibly from upper reaches of the Boise River (e.g., Barber Dam to Capitol Street Bridge) during high flows. Infiltration from surface channels occurs if and when (1) water is available and (2) hydraulic heads in the channel (or lake) are higher than the surrounding aquifer heads. Additional recharge sources include mountain front recharge, underflow from the granitic Idaho Batholith and tributary sedimentary aquifers, and direct precipitation.

Shallow aquifer levels increased by as much as 100 feet in some areas in response to the initiation of large-scale flood irrigation in the late 1800s and early 1900s. Shallow ground water levels rose to and have remained at (or near) ground surface in many areas (at least seasonally), discharging to drains and other surface channels.

Shallow and intermediate aquifers are separated from deeper zones by interbedded silt and clay layers in many parts of the valley. While individual clay layers are not necessarily areally extensive, multiple clay layers in aggregate form effective barriers to vertical ground water movement.

Recharge to the deeper aquifers begins as downward flow through coarse-grained alluvial fan sediments in the eastern portion of the basin and as underflow at basin margins. Ground water is then thought to flow horizontally into the basin via more permeable sediments (e.g., coarse-grained sediments of the geological unconformity overlying Chalk Hills sediments) intersecting the alluvial fan sediments.

This is illustrated in water chemistry data collected from shallow aquifers near the New York Canal. Water in the canal, as in upper portions of the Boise River, has relatively low specific conductance (and by inference, total dissolved solids). In shallow aquifers underlying the canal, specific conductance was found to increase with depth, corresponding with canal water that has infiltrated through soil horizons. In contrast, water in deeper sand units separated from upper zones by multiple clay layers, has lower specific conductance than water in overlying horizons (Hutchings and Petrich, 2002a; Hutchings and Petrich, 2002b). This finding indicates that water in at least

some deeper aquifers originates at the basin margins and does not enter the ground water regime through the carbon-rich sediments found in Treasure Valley soils.

Residence times of Treasure Valley ground water were generally found to increase with depth and with distance along a regional east-to-west-trending flow path (Hutchings and Petrich, 2002a). Residence time estimates in the regional aquifer system ranged from thousands to tens of thousands of years. The youngest waters entered the subsurface a few thousand years ago and were found along the northeastern boundary of the basin, adjacent to the Boise Foothills. The oldest waters entered the subsurface between 20,000 and 40,000 years ago and were found in the western reaches of the basin near the Snake River. Ground water in the deep deltaic aquifers beneath Boise entered the subsurface between 10,000 and 20,000 years ago.

Comparisons between measured water chemistry constituents and established models of geochemical processes (Hutchings and Petrich, 2002a) show that (1) ground water near the northeastern basin margin has experienced little interaction with aquifer minerals, and (2) ground water beyond the northeastern basin margin has experienced substantial interaction with aquifer minerals. Geochemical evolution of Treasure Valley ground water appears to be influenced by a solution of both carbonate and silicate minerals.

Ground water discharge to rivers, drains, and canals represents the dominant form of discharge from the Treasure Valley aquifer system (Urban and Petrich, 1998). The primary form of natural discharge from the deeper aquifers is thought to be regional upwelling in the southern and western portions of the basin, with ultimate discharge to the Boise River and/or Snake River. Rates of discharge from the deeper aquifers in the western portions of the valley are unknown but are probably low because of the thick accumulation of lacustrine clays separating these aquifers from ground surface.

Relatively long residence times in the regional flow system (over 20,000 years) implies that (1) regional aquifers are not very transmissive, (2) recharge rates to the deeper regional aquifers are limited, and/or (3) regional aquifers are discharge-limited. Although there are abundant silt and clay layers with low hydraulic conductivity, productive sand layers are present throughout central portions of the valley. These sand zones are tapped by many irrigation and municipal wells. Recharge to the deeper, regional system is limited, but generally has been sufficient for current rates of withdrawal. Thick lacustrine clays at the distal end of the valley likely inhibit upward (discharge) flow, limiting the amount of water that can flow through the system.

In summary, the Treasure Valley aquifer system consists of shallow aquifers containing local ground water flow systems and a deeper, regional ground water flow system. Recharge to the shallow system consists largely of infiltration from irrigated fields and canals. Primary discharge is to the Boise and Snake Rivers and other streams and to drains discharging into these channels. The deeper, regional flow system consists of (1) recharge in alluvial sediments in southeast Boise and at the base

of the mountain front north of Boise, (2) movement of ground water from the recharge areas into the deeper Boise area fluvio-lacustrine aquifers, and (3) movement of ground water from the Boise area aquifers into regional lacustrine/deltaic aquifers in the central and western portions of the valley.

4. MODEL RESULTS

A numerical model of regional ground water flow in the Treasure Valley aquifer system was developed to evaluate (1) the effects of large-scale increases in ground water withdrawals on regional ground water levels and (2) the potential effects of altered recharge rates (associated with conversion of agricultural to urban land use) on regional ground water levels. The model was constructed using the three-dimensional, finite difference MODFLOW code (Harbaugh et al., 2000; McDonald and Harbaugh, 1988; McDonald and Harbaugh, 1996). The model was calibrated under steady-state hydraulic conditions using the automated parameter estimation code PEST (Doherty, 1998; Doherty, 2000). Horizontal and vertical hydraulic conductivity parameters were calibrated to 200 averaged water level observations and six actual and estimated vertical head differences. This section summarizes model results[5].

The model calibrated with higher horizontal hydraulic conductivity (K_h) values in the uppermost shallow aquifer zones, corresponding with known areas of coarser-grained sediments. PEST-calibrated parameter values also indicate relatively higher K_h and vertical hydraulic conductivity (K_v) values in areas of the eastern and central portion of the valley associated with fluvial/deltaic deposition. Simulated fluxes between model layers in the base calibration indicated that a relatively small amount of water moves vertically between model layers, especially in the lower layers. Based on simulation results, most recharge occurring in shallow aquifer zones does not reach lower zones.

A recalibration with a 10% increase or decrease in recharge led to minimal changes in water levels or parameter value estimates because shallow ground water levels in central portions of the basin are controlled, in part, by elevations of surface water channels. Increased or decreased recharge resulted in changes in the rates of water discharging to model drain, general head boundary (Lake Lowell), constant head (Snake River), and river (Boise River) cells. Changes in land use that lead to decreases in shallow-aquifer recharge may not have a substantial effect on shallow ground water levels until the water table elevations remain below those of nearby surface channels.

Simulations indicated that some ground water level declines might occur with a 20% withdrawal increase over 1996 levels. Simulated modest declines were observed in the Boise area in upper model layers (which roughly encompass the upper 400 feet of aquifer depth). Greater simulated declines were observed in the central portion of the valley (especially in the Lake Lowell area) in lower model layers (which roughly encompass aquifers zones extending from 400 to 1,200 feet in depth). The sources of water for the simulated 20% increase in withdrawals included increased leakage from

[5] These results are based on a variety of assumptions and limitations, which are described in Petrich (2003d).

the Boise River, decreased discharge to agricultural drains, and decreased discharge to the Snake River.

These predicted changes were based on differences in water levels or mass balances between the base simulation and predictive simulations. The comparisons between the two represent changes in both the calibration and hydraulic stress (Petrich, 2004a). Additional comparisons should be done between minimized heads in both the base and predictive simulations.

Currently, there are over 450 unprocessed new water right applications in the lower Boise River basin, an area of southwestern Idaho home to approximately 35% of Idaho's population. The additional water has been requested for irrigation, municipal, commercial, and aesthetic uses. The water requested for non-supplemental uses[6] could represent an approximate 20% increase over 1996 levels of ground water withdrawals. The potential impact on regional ground water levels from processing these new well applications was evaluated using the ground water flow model.

Aquifer level declines might occur if all of these currently unprocessed, non-supplemental, ground water rights were granted. Average water level declines could range from 10 feet to over 40 feet, depending on location within the valley, the actual amount of withdrawals, and the depth of extraction. These predicted changes were based on differences in water levels or mass balances between the base simulation and predictive simulations (additional comparisons should be done between minimized heads in both the base and predictive simulations). Local areas of simulated declines were noted south of Lake Lowell, in an area in the northwestern portion of the model, and in portions of the area between Boise, Meridian, and Kuna. These may be associated with unrealistically high simulated stresses or excessively low simulated aquifer parameter values. The simulated declines may also indicate potential problems in supplying the increasing ground water demands in these areas. The least declines were predicted in the uppermost model layer, which corresponds roughly with the uppermost 200 feet of aquifer. Most of the estimated new withdrawals in the uppermost layer represented water that would otherwise have discharged to drains.

What do these predictions mean for water managers? First, predicted water level declines based on the comparisons between base and predictive simulations reflect both calibration and stress changes. Additional simulations should be conducted to compare minimized base water levels with predicted water levels. These simulations may reduce the area and magnitude of predicted declines. Second, some additional withdrawal increases might be considered in areas of stable water levels, even if predictions suggest possible water level decreases. Any increases in withdrawals should be accompanied by monitoring of water levels and extraction rates. Third,

[6] "Supplemental" ground water is used for irrigating areas that are irrigated with surface water when surface water is available. "Non-supplemental" uses include all other ground water uses.

managers might use caution in approving additional withdrawals in areas of currently decreasing water levels and predicted water level declines. Finally, model predictions for some areas (some shallow aquifers, for instance) indicate that additional withdrawals are probably possible without affecting ground water levels. However, additional extractions in these areas may increase losses from, or decrease discharge to, surface water channels.

5. ANSWERS TO PROJECT QUESTIONS

A number of questions regarding ground water resources were raised at the beginning of the TVHP. Typical questions asked at the beginning of the project were listed in Section 1.1. This section provides answers for those questions based on project results.

1. *Does the Treasure Valley have a ground water shortage?*

The Treasure Valley does not currently have a water shortage. In total, there is a sufficient amount of water in the basin. In fact, approximately one million acre-feet of water flows out of the basin every year. However, water is not always available where and when it is needed. Currently-unprocessed well applications indicate an unfulfilled demand for water. In dry years, there may be an insufficient amount of water available for irrigation or other uses. The challenge facing IDWR and Treasure Valley water users will be to manage water so that it is available where and when it is needed.

2. *How big is our aquifer system? Where are the aquifer boundaries?*

In general, the aquifer system extends from the Boise Foothills on the north and northeast to the Snake River (Figure 2-1) on the south and west. Little is known about aquifer boundaries in the far eastern portion of the basin because of the lack of wells in this area.

Aquifer sediments extend to depths of approximately 6,000 feet (Wood and Clemens, in press). However, much of the lower portion of these sediments consists of fine-grained clay and silt, from which it is difficult to extract water. Also, elevated temperatures (e.g., greater than 85°F) in some of the deeper aquifers prevent development for cold-water uses. Most wells in the valley are less than 1,200 feet in depth; many of these draw water from the upper 250 feet of aquifer depth.

3. *Where and to what degree are ground water levels declining?*

Plots of water levels in wells (*hydrographs*) indicate relatively stable water levels in many areas, although water level declines have occurred in a number of wells. Wells in two areas, southeast Boise and south of Lake Lowell, have experienced declines of approximately 30 feet and 65 feet, respectively. Water levels in these areas appear to have stabilized in recent years. Additional ground water level declines were observed in individual wells in other areas, including the area between Eagle, west Boise, Meridian, and Kuna. Most of the long-term declines in these wells have been less than 10 feet. Reasons for the declines may include increased withdrawals from the measured wells (very few of the monitoring wells are dedicated to monitoring alone), increased nearby withdrawals, and/or changes in local infiltration rates. Further investigation of these apparent declines is warranted to determine if they reflect local

(near-well) or regional conditions. Additional monitoring is also warranted in these areas of apparent declines.

A number of shallow monitoring wells indicated water level increases or decreases. Shallow wells may be especially sensitive to changes in local surface water irrigation patterns in areas where the water table is not in direct hydraulic connection with surface channels. Ground water level changes are less likely in shallow wells in areas where the water table is controlled by topography (by virtue of drains and canals).

Seasonal water level fluctuations are evident in many Treasure Valley wells. The fluctuations are generally a response to seasonal increases in withdrawals (e.g., summer irrigation withdrawals) or increases in recharge associated with surface water irrigation.

4. *What is the carrying capacity of the hydrologic system in the Treasure Valley?*

The carrying capacity of the hydrologic system is difficult to determine. The ultimate carrying capacity will be influenced by the valley's population, demand for water, spatial and seasonal distribution of water demand, cost of water, and other factors. Currently more than one million acre-feet of water are discharged from the valley to the Snake River every year. Some of this water may be available for further development.

There currently appears to be more capacity for ground water withdrawals in some areas (e.g., the western portion of the valley) and less in other areas (e.g., southeast Boise). Current ground water withdrawals represent a small portion of the total amount of water used in the valley. Some of the water leaving the basin may be available for additional use. The key to using existing supplies for a growing population will include the successful negotiation of transfers of water between different water uses and users.

5. *What is the degree of hydraulic connection between Treasure Valley surface and ground water?*

There is a high degree of connection between surface water and shallow aquifers in the Treasure Valley. Water readily seeps into or out of surface channels, depending on the difference in hydraulic head between the aquifer and surface water body.

Currently, canals drain much of the central portion of the valley. As long as aquifers are in direct hydraulic connection with surface channels, increases in withdrawals from shallow aquifers, or decreases in recharge, will lead to decreases in drain discharge in these areas or increases in losses from surface channels. If aquifer levels are below surface channels, increases in withdrawals and/or decreases in shallow recharge may lead to shallow ground water level declines.

6. *How are shallow and deep aquifers connected?*

Deep aquifers in the Treasure Valley are generally separated from shallow zones by layers of fine-grained sediments, such as clay and silt. This leads to confined or partially-confined conditions in deeper aquifers, indicated by water levels in wells rising above those of the deeper aquifers themselves.

There are relatively few data describing the degree of vertical hydraulic connection within the deeper, regional aquifer system. Substantial clay zones would be expected to limit vertical flow. Model simulations indicated little vertical movement in central and westerns portions of the valley because of relatively low simulated vertical hydraulic conductivity values.

7. *How are Treasure Valley aquifer systems recharged and where does the recharge occur?*

The primary source of ground water recharge to Treasure Valley aquifers comes from seepage and infiltration from canals and flood-irrigated fields. However, much of this recharge ultimately discharges to surface channels such as streams, rivers, and drains. Recharge to the deeper aquifers occurs primarily in the eastern portion of the basin and along the Boise Front. Only a very small portion of the total infiltration entering shallow aquifers recharges deeper aquifers.

Thick clay zones in most of the valley prevent a larger amount of water from moving downward from shallow aquifers into deeper, regional aquifers. The clay zones are generally absent in the easternmost portions of the basin, which allows downward movement of water in the eastern portion of the basin.

Similarly, there is a relatively small amount of upward ground water movement from the deep aquifers into shallow zones in the western portion of the basin. Again, thick clay zones inhibit upward flow. One of the reasons that ground water residence times in the deeper aquifers are so long is that ground water from the deep aquifer cannot return easily to ground surface.

8. *How has and does land development impact Treasure Valley water supplies?*

Land use in the Treasure Valley has changed substantially during the last 150 years. First, extensive construction of canals and surface irrigation in the late 1800s and early 1900s led to increases in shallow ground water levels, as much as 80 to 100 feet in some places. Water levels rose so much that shallow ground in some areas in the central portion of the valley became saturated, requiring the construction of drainage channels.

During the last several decades, the valley has experienced rapid urbanization. Community wells provide water for much of the population growth, especially in

growing cities like Boise, Nampa, Caldwell, Meridian, and Eagle. In general, water for these communities comes from deeper aquifers.

Similarly, population growth in the urban-rural interface has led to the construction of many new domestic wells. These wells draw water mostly from shallow aquifers, but also from intermediate and deep aquifers, depending on location.

The extent to which urbanization of agricultural lands leads to changes in shallow aquifer recharge is not clear. Newly developed residential and commercial areas may have less irrigated area, but water may be applied at higher rates and for longer seasons than the previously agricultural area. This is an area that merits further investigation.

Some urban developments are using pressurized irrigation systems with surface water that was used previously for agricultural irrigation. Pressurized irrigation system water stemming from surface water sources may contribute to shallow aquifer recharge. Such irrigation systems reduce the need for irrigation with treated municipal water (which generally comes from deeper aquifers).

Simulations show that modest decreases in shallow aquifer recharge (e.g., 10%) on a regional basis will generally result in increased seepage from canals and/or decreased flow to drains. Increased withdrawals from shallow aquifers would have similar effects.

9. *How susceptible is the Treasure Valley aquifer system to contamination?*

The Treasure Valley aquifer system is susceptible to contamination in a number of ways. Land use activities can lead to direct contamination of shallow aquifers. Wells completed with poor surface seals can allow contaminants to move into the aquifer from ground surface. Wells completed in multiple aquifers, or wells with inadequate seals between aquifers, can allow contaminants in upper aquifers to migrate to deeper zones. Similarly, in areas with upward hydraulic gradients, these can lead to unnecessary flow from deeper zones to shallower zones.

10. *Is water conservation necessary to meet future water demands?*

Efficient use of a resource is always a worthwhile goal. There are clearly opportunities for water conservation, especially if the source of water is the deeper, regional aquifer system. However, surface water irrigation, through canal leakage or infiltration from irrigated fields, is the source of a large portion of recharge to shallow aquifers. Increasing efficiency in these areas could lead to decreased discharge to drains. If ground water levels decline below that of drains, the increased efficiency may lead to exacerbated declines in shallow aquifer levels. This may impact some shallow wells. Some form of managed aquifer recharge may be required if increases in agricultural irrigation efficiency lead to declining water levels.

11. *Can tools and/or data be developed to assist local, state, and federal governments with decisions on issues that impact water resources, such as land use planning, zoning, water rights, septic tank permitting, waste treatment, etc.?*

The tools and data developed as part of the TVHP have helped and will continue to help water managers make better decisions about water resource issues. Numerical modeling will assist in the evaluation of regional water management strategies. The model will also provide a basis for developing possible conjunctive administration options. Data from the numerical model have and will continue to be used to evaluate source water areas for public water supply wells. Spatial and hydrologic data are available for a variety of resource evaluations.

The study focused on regional-scale ground water flow. The study did not provide answers to site-specific land use planning, zoning, septic tank permitting, or waste treatment questions. Results of this study, however, provide a framework for addressing water resource questions on a local scale.

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Appendix A: Conversion Factors

Volume

1 cubic foot of water = 7.4805 gallons = 62.37 pounds of water
1 acre-foot (af) = enough water to cover 1 acre of land 1 foot deep
1 acre-foot (af) = 43,560 cubic feet
1 acre-foot (af) = 325,850 gallons
1 million gallons = 3.0689 acre-feet

Flow Rates

1 cubic foot per second (cfs) = 448.83 gallons per minute (gpm) = 26,930 gallons per hour
1 cubic foot per second (cfs) = 646,635 gallons per day = 1.935 acre-feet per day
1 cubic foot per second (cfs) for 30 days = 59.502 acre-feet
1 cubic foot per second (cfs) for 1 year = 723.94 acre-feet
1 cubic meter per second (cms) = 25.31 cubic feet per second
1 cubic meter per second (cms) = 15,850 gallons per minute
1 million gallons per day (mgd) = 1,120.147 acre-feet per year
1 miner's inch = 9 gallons per minute
1 miner's inch = 0.02 cubic feet per second

Hydraulic Conductivity

1 gallon per day per foot^2 (gal/day/ft^2) = 0.134 foot/day = 0.0408 meters/day

Economic

$0.10 per 1,000 gallons = $32.59 per acre-foot

APPENDIX B: SOURCES OF REPORTS AND INFORMATION

Data and information generated from this project are available from the following source:

Idaho Department of Water Resources
1301 North Orchard Street
Boise, ID 83706-2237
Contact: Scott Urban, (208) 327-5441
(208) 327-7866 (fax)
E-mail: surban@idwr.state.id.us
Website: http://www.idwr.state.id.us
(*project reports, data, maps, GIS coverages, and other information*)

Costs associated with this publication are available from the Idaho Department of Water Resources in accordance with Section 60-202, *Idaho Code*. IDWR-21000-20-03/2004.

33B

SIMULATION OF GROUND WATER FLOW IN THE LOWER BOISE RIVER BASIN

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Idaho Department of Water Resources
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- Dr. John Doherty (Watermark Computing, Brisbane, Australia) helped develop and apply PEST (parameter estimation code) for the model calibration and predictive analysis.
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- Garth Newton (IDWR)
- R. D. Schmidt (USBR)
- Scott Urban (IDWR)

Abstract

The lower Boise River basin (Treasure Valley) aquifer system consists of a series of shallow, relatively high-permeability aquifers and a deeper, regional flow system. A numerical model of regional ground water flow was developed to evaluate (1) the effects of large-scale increases in ground water withdrawals on regional ground water levels and (2) the potential effects of altered recharge rates (associated with conversion of agricultural to urban land use) on regional ground water levels.

The model was constructed using the three-dimensional, finite difference MODFLOW code (Harbaugh et al., 2000; McDonald and Harbaugh, 1988; McDonald and Harbaugh, 1996). The model was calibrated under steady-state hydraulic conditions using the automated parameter estimation code PEST (Doherty, 1998; Doherty, 2000). Horizontal and vertical hydraulic conductivity parameters were calibrated to 200 averaged water level observations and 6 actual and estimated vertical head differences.

The model calibrated with higher hydraulic conductivity values in the uppermost aquifer zones, corresponding with known areas of coarser-grained sediments. PEST-calibrated parameter values also indicated relatively high hydraulic conductivity values in areas of the eastern and central portion of the valley associated with fluvial/deltaic deposition. Simulated fluxes between model layers in the base calibration indicated a relatively small amount of water moves vertically between model layers, especially in the lower layers. Based on simulation results, most recharge that occurred in shallow aquifer zones did not reach deeper zones.

A 10% increase or decrease in recharge led to minimal changes in water levels or parameter value estimates because shallow ground water levels in central portions of the basin are controlled, in part, by elevations of surface water channels. Decreased or increased recharge resulted in changes in the rates of water discharging to model drain, general head boundary (Lake Lowell), constant head (Snake River), and river (Boise River) cells. Changes in land use that lead to decreases in shallow-aquifer recharge may not have a substantial effect on shallow ground water levels until the water table elevations remain below those of nearby surface channels.

Simulations indicated that some ground water level declines might occur with a 20% increase in ground water withdrawals over 1996 levels. Modest simulated declines were observed in the Boise area in layers 1 and 2. Greater simulated declines were observed in the central portion of the valley (especially in the Lake Lowell area) in layers 3 and 4. The simulated 20% increase in ground water withdrawals resulted in increased losses from the Boise River (23%), decreased discharge to agricultural drains (62%), and decreased discharge to the Snake River (9%). Simulated water level declines and/or changes in mass balance components reflected a combination of parameter uncertainty and response to a changed hydraulic stress.

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Simulation Files (CD-ROM)

Simulation *SS2bc* (Base Calibration) .....CD-ROM
Simulation *SS7a* (Sensitivity Simulation) .....CD-ROM
Simulation *SS7b* (Sensitivity Simulation) .....CD-ROM
Simulation *SS7c* (Sensitivity Simulation) .....CD-ROM
Simulation *SS5e-min* (Scenario Files) .....CD-ROM
Simulation *SS5e-max* (Scenario Files) .....CD-ROM

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1. INTRODUCTION

1.1. Project Background

The lower Boise River basin (Figure 1-1) of southwestern Idaho (commonly referred to as the "Treasure Valley") has experienced significant population growth, local ground water declines, and periodic drought conditions in the last two decades. This led to public concern about the status and future of water resources in the valley. The Treasure Valley Hydrologic Project (TVHP) was formed to address some of these issues and to provide a framework for future water management.

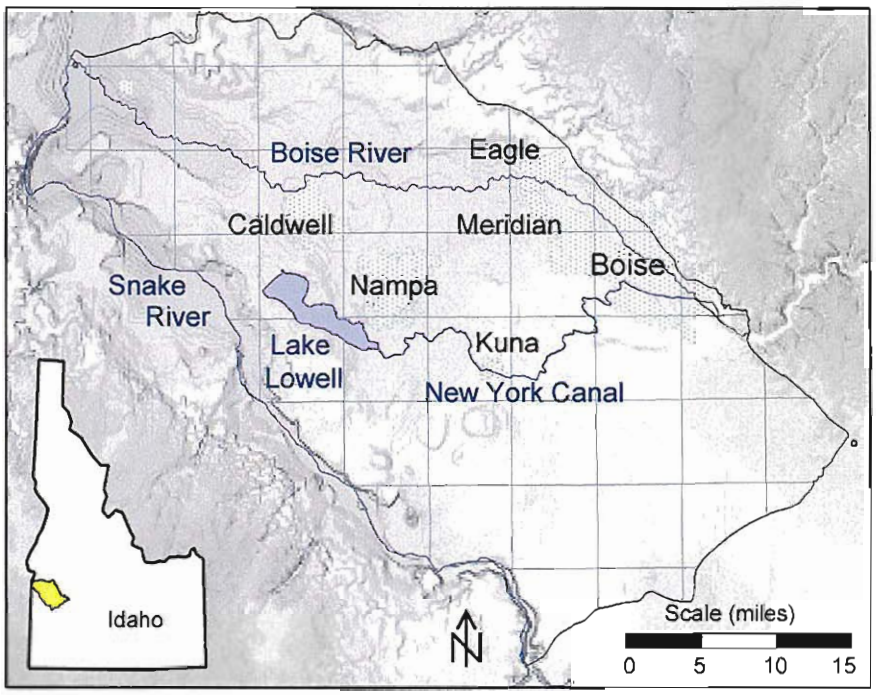


Figure 1-1: Treasure Valley area.

A numerical model of ground water flow was constructed as part of the TVHP. The purpose of the model was to develop an improved understanding of regional ground water flow in the Treasure Valley. General objectives of the model simulations were to evaluate (1) the effects of large-scale increases in ground water withdrawals on regional ground water levels and (2) the potential effects of altered recharge rates (associated with conversion of agricultural to urban land use) on regional ground water levels. Specific objectives included the following:

1. Construct a ground water flow model capable of simulating steady-state hydraulic conditions.

2. Use the modeling process as a framework for assembling hydrologic data.
3. Use the model to better define recharge processes and recharge rates to the regional aquifer system.
4. Evaluate potential changes in regional recharge rates associated with changes in land use.
5. Simulate the potential changes in ground water levels from increased ground water withdrawals associated with continued population growth.
6. Simulate the potential changes in ground water levels associated with processing currently unprocessed water right applications.

1.2. Report Scope

This report presents a summary of methods, data, and results of the ground water flow simulations, including a detailed description of the modeling approach, model construction, model calibration, and simulation results. The conceptual basis for model construction is described in "Characterization of Ground Water Flow in the Lower Boise River Basin" (Petrich and Urban, 2004), which also includes detailed descriptions of the geologic setting, aquifer characteristics, water levels, and aquifer inflows and outflows. A companion report describes simulations to evaluate the potential hydrologic effects associated with currently pending water right applications in the Treasure Valley (Petrich, 2004a). The results from these reports and from other research conducted as part of the TVHP are summarized in a project summary (Petrich, 2004b).

1.3. Previous Investigations

Several ground water flow models have been constructed to simulate regional ground water flow in all or parts of the Treasure Valley. Lindgren (1982) developed a model to evaluate the overall impact of federal irrigation and flood control projects on the economy and hydrology of the lower Boise River valley. This model was a two-dimensional (one-layer) model built using a finite difference code (de Sonneville, 1972) that was also used for the first Eastern Snake River Plain simulations.

Lindgren (1982) modeled the northern boundary of the lower Boise River system (along the northern highlands bounding the Boise River) as an impermeable, no-flow boundary. A southeast no-flow boundary extended from the Snake River south of Melba to a point 6 miles east of Kuna and from a point 11 miles east of Kuna to Diversion Dam on the Boise River. A constant head boundary was used between the latter no-flow segments because ground water contours and other information indicated ground water flow across the boundary in this area. Head-dependent boundaries were assigned to the remaining Snake River reaches, the Boise River from Diversion Dam to its confluence with the Snake River, and Lake Lowell. Aquifer thicknesses in the Lindgren model were determined from well logs; a 1,000-foot thickness was assumed in areas where no well logs were available.

Aquifer recharge from irrigation was determined on the basis of mapped irrigation areas (Lindgren, 1982). Canal seepage from major irrigation canals was distributed on a reach-by-reach basis. Infiltration from areal precipitation was assumed to be 5% of 12.4 inches (average annual precipitation) in non-irrigated areas and 100% in irrigated areas. Underflow from areas north of the Boise River (Willow Creek, Dry Creek, and Parma Gulch) was simulated based on estimated hydraulic conductivity and hydraulic gradient values.

The Lindgren model was calibrated to 1972 steady-state conditions. A transient calibration was performed for the period of April 1, 1970, to March 31, 1971, using two-week time steps. Calibration difficulty was encountered in the area south of Lake Lowell and in some areas northwest of Lake Lowell, which was attributed to infiltration lags and leakage phenomena.

A second regional model, constructed by the USGS (1991), simulated ground water flow under the 144-mile-long, 50-mile-wide area of the Western Snake River Plain. The model was constructed as part of the USGS's Regional Aquifer System Analysis (RASA) study that began in 1979. The three-layer, finite difference model was constructed using the USGS MODFLOW code (McDonald and Harbaugh, 1984). The model boundary approximated the boundary of the Snake River plain from the junction of Salmon Falls Creek and the Snake River on the east to the confluence of the Payette and Snake Rivers on the west.

The model grid consisted of 25 rows, 72 columns, and 3 layers, with each cell representing an area of 2 miles per side. The model domain was divided into 11 subareas based on geologic and hydrologic characteristics. The uppermost model layer represented an unconfined aquifer in sedimentary (sands and gravels) and volcanic rocks. The top of the upper layer was defined based on 1980 water levels; the bottom of the top layer was assumed to be 500 feet below the 1980 water level contours. The middle layer represented a confined aquifer in about 4,000 feet of mostly fine-grained sedimentary rocks and volcanic rocks. The bottom model layer represented water under high pressure in about 7,000 feet of volcanic rocks.

Model boundaries on the north, south, and west sides of the USGS model were simulated as constant flux boundaries. The flux was derived from water budget estimates because of the lack of actual underflow data. The eastern Snake River boundary was simulated as head dependent in the upper layer and no flow in the middle and bottom layers. The Snake River, Payette River, Salmon Falls Creek, and Lake Lowell were simulated as head dependent cells (i.e., MODFLOW river cells). The average river width was assumed to be 1,300 feet, with an average length per cell of 2 miles. The hydraulic conductivity of river cells was assumed to be 1×10^{-5} ft/s.

Transmissivity values estimated based on specific capacity data were assigned (by model subarea) to the uppermost layer. A uniform transmissivity of 8,600 ft^2/day was assumed for layers 2 and 3. The vertical hydraulic conductivity was assumed to be

9 ft/day between the upper two layers and 22 ft/day between the lower two layers based on published data for similar rock types.

Portions of the Snake, Boise, and Payette River valleys were simulated as drains. The bottom drain elevation was specified as the approximate land surface elevation in the cell. Cells containing both drains and the Boise River were assigned as drain cells. Canals were treated similar to rivers. The average length of major canals in a cell was estimated to be about 9 miles, and the average canal width was assumed to be 20 feet. These dimensions represented about 1.3% of the irrigated area in a cell, or about 33.3 acres per cell. A canal bed thickness of one foot and a vertical hydraulic conductivity of 1×10^{-6} ft/sec (8.6×10^{-2} ft/day) were assumed. Estimated values for effective vertical conductance values between layers were used because of the lack of information describing individual confining zones.

The model was first calibrated under steady-state conditions using 1980 hydrologic data. Calibration parameters included transmissivity, river and drain conductance, and vertical hydraulic conductivity. The model was then calibrated to transient hydraulic conditions based on 1880 (pre-irrigation) through 1980 water level data by adjusting aquifer storage coefficients. Successful calibration was only achieved for the upper layer, where simulated hydraulic heads approximated the measured heads. Insufficient hydrogeologic data for the middle and lower aquifer units prevented an acceptable calibration of the middle and lower model layers. The model was thus deemed useful for understanding the western Snake River aquifer system but not for detailed management analyses. Model calibration indicated that a more refined knowledge of subsurface hydrology was needed, with more data describing the vertical hydraulic head distribution in the upper and middle aquifer units, hydraulic properties of aquifers and confining beds, and underflow.

Brockway et al. (1999) simulated ground water flow in the southeast Boise area as part of an aquifer recharge and recovery evaluation. Built with the USGS MODFLOW code, the model was used for simulations of recharge and recovery scenarios based on injection and withdrawal in a 1,100-foot-deep well at the Micron Technology, Inc., facility. The model area extended from Lucky Peak Reservoir on the east to Cole Road on the west and from the base of the Boise Foothills to Kuna-Mora Road. The model was used to simulate various recharge scenarios (with up to 3,000 gallons per minute of recharge) and recovery scenarios (based on combinations of recovery in 4 wells). The authors concluded that recharge (injection) fully mitigated impacts from increased production.

2. CONCEPTUAL MODEL DESCRIPTION

This section presents a summary of Treasure Valley ground water flow characteristics, water level measurements, and aquifer inflows and outflows (Petrich and Urban, 2004). The summary represents the "conceptual model" of ground water flow that was used as the basis for aquifer simulations.

The Treasure Valley aquifer system is comprised of a complex series of interbedded, tilted, faulted, and eroded sediments extending to depths of over 6,000 feet in the deepest parts of the basin (Wood and Clemens, in press). The valley contains shallow, local flow systems (with ground water residence times ranging from years to hundreds of years) and a deep, regional flow system (with residence times ranging from thousands to tens of thousands of years). Few water wells extend beyond a depth of 1,200 feet.

The Treasure Valley sedimentary section reflects a history of lacustrine, deltaic, fluvial, and alluvial deposition (Wood and Clemens, in press). In general, basin sedimentary deposits grade from coarser, more permeable sediments near the Boise Front[1] to finer, less permeable sediments at the distal end of the basin. At the basin scale, sediments also grade finer with depth. Highly permeable deposits associated with deltaic and/or fluvial deposition are often sandwiched between lacustrine deposits of lower permeability.

Ground water flow in the Treasure Valley is controlled by aquifer characteristics and hydraulic gradient. Aquifer characteristics influencing ground water flow include grain size, sorting, stratigraphic layering, sedimentary layer dip, sediment grain cementation, and the degree of fracturing (e.g., rock aquifers). Additional controls on the movement of ground water are attributed to structural processes, including faulting throughout the basin and along the basin margin.

Ground water chemistry data (Hutchings and Petrich, 2002a) indicate different ground water chemistry north of the fault zone compared to the area south of the fault zone, suggesting restricted flow across the fault zone. Basin downwarping and a downslope trend in sediment deposition contribute to steeply dipping sedimentary deposits that may cause deeper aquifer units to pinch out at depth (Wood, 1997). Based on seismic imaging and outcrop mapping, aquifer sediments of various fault blocks dip at angles ranging from zero to approximately 12 degrees (Wood, 1997).

Fractures within shallow Pleistocene basalts, or along upper and lower surfaces of individual basalt flows, can contribute to ground water movement. For instance, basalt fractures and course-grained sediments underlying the basalt may greatly contribute to

[1] Boise Front describes the portion of the Idaho Batholith that forms the northeastern boundary of the lower Boise River basin.

transmitting leakage from the New York Canal (and other surface water channels) into shallow aquifers.

An erosional unconformity associated with changing lake levels in Pliocene Lake Idaho truncates down-dipping units near the basin margin near Boise (Squires and Wood, 2001; Squires et al., 1992; Wood, 1997). The unconformity separates lacustrine and deltaic sediments (tilted in the Boise area) from overlying lacustrine/deltaic sediments. Coarse-grained sediments associated with the erosional unconformity (Wood, 1997; Squires et al., 1992) appear to serve as a manifold for deeper, regional ground water migrating horizontally into the basin from alluvial fan sediments in the eastern portion of the basin (corroborated by E. Squires, pers. comm., 2002).

Potentiometric surface contours indicate ground water movement in a northwesterly to southwesterly direction, depending on depth and location (Figure 2-1 through Figure 2-4). Potentiometric surface contours in shallow aquifer zones reflect surface hydrologic conditions, such as mounding under the New York and Mora Canals, or discharge to the Boise River. Mounding in the vicinity of the New York Canal represents a local ground water divide, with shallow ground water north of the canal flowing toward the Boise River, and shallow ground water south of the canal flowing toward the Snake River. Potentiometric surface contours from shallow aquifers show ground water flow toward and discharge to the Boise River in mid- to lower reaches. Potentiometric surface contours in deeper zones indicate a more uniform westerly flow direction (e.g., Figure 2-3). Downward hydraulic gradients are indicated along the Boise Foothills, the eastern part of the study area (e.g., TVHP#4, Figure 2-5), and in the vicinity of the New York and Mora Canals. Upward gradients are evident in the central and western portions of the valley (e.g., TVHP#2, Figure 2-5), especially in the vicinity of the lower Boise River.

Individual hydrographs indicate relatively stable water levels in many areas, although water level declines have occurred in a number of wells (Petrich and Urban, 2004). Wells in two areas – southeast Boise and south of Lake Lowell – have experienced declines of approximately 30 feet and 65 feet, respectively. Water levels in these areas appear to have stabilized in recent years. Additional ground water level declines were observed in the areas between northwest Boise and Eagle and southwest Boise, Meridian, and Kuna. Most of the long-term declines in these wells have been less than 10 feet. Reasons for the declines may include increased withdrawals from the measured wells (very few of the monitoring wells are dedicated to monitoring alone), increased nearby withdrawals, and/or changes in local infiltration rates. Further investigation of these apparent declines is warranted to determine if they reflect regional or local conditions. Additional monitoring wells would also be warranted in these areas of apparent declines.

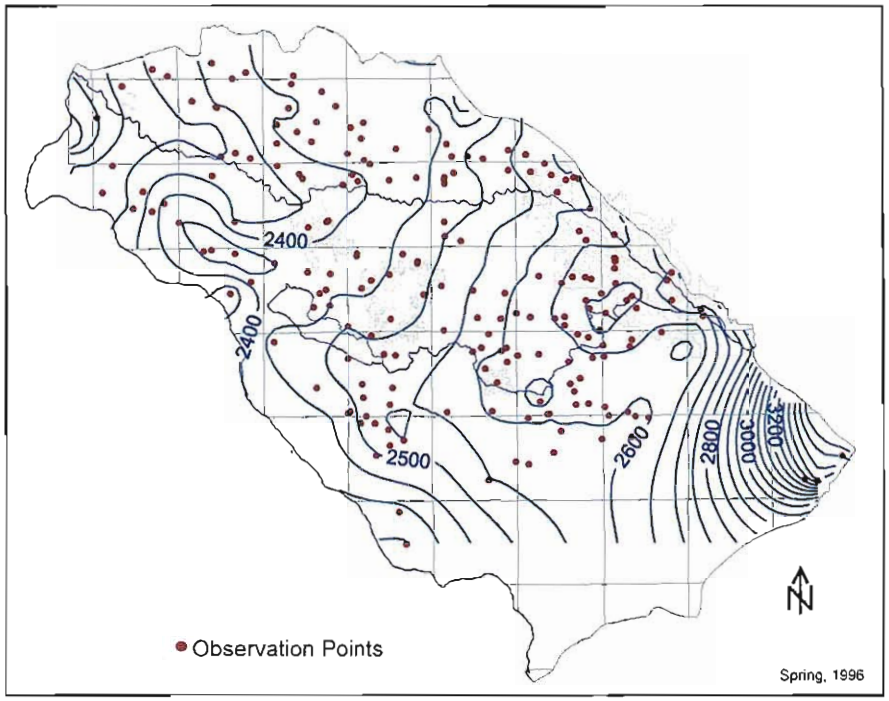


Figure 2-1: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 1.

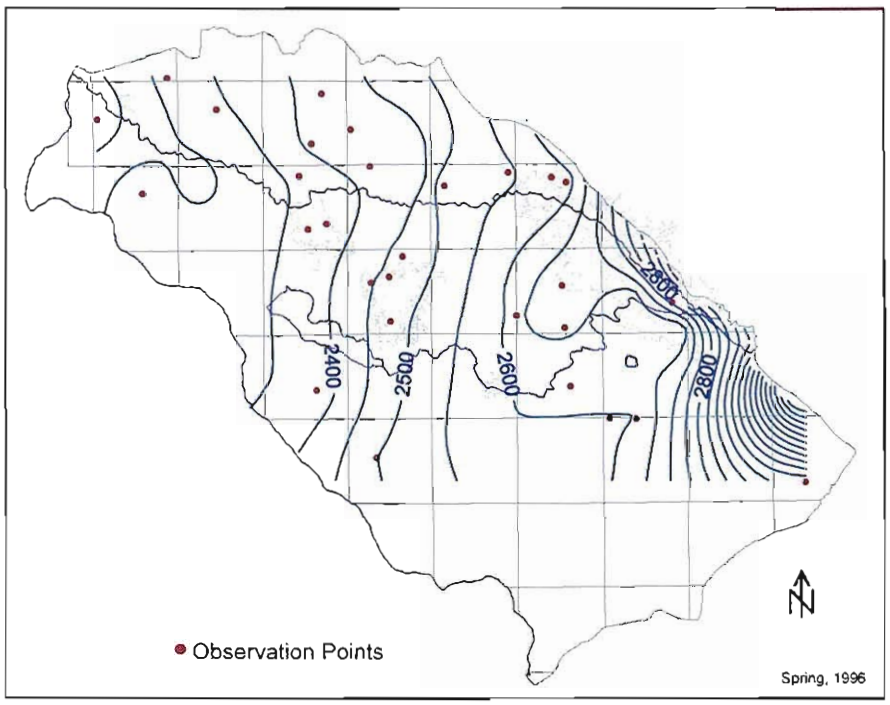


Figure 2-2: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 2.

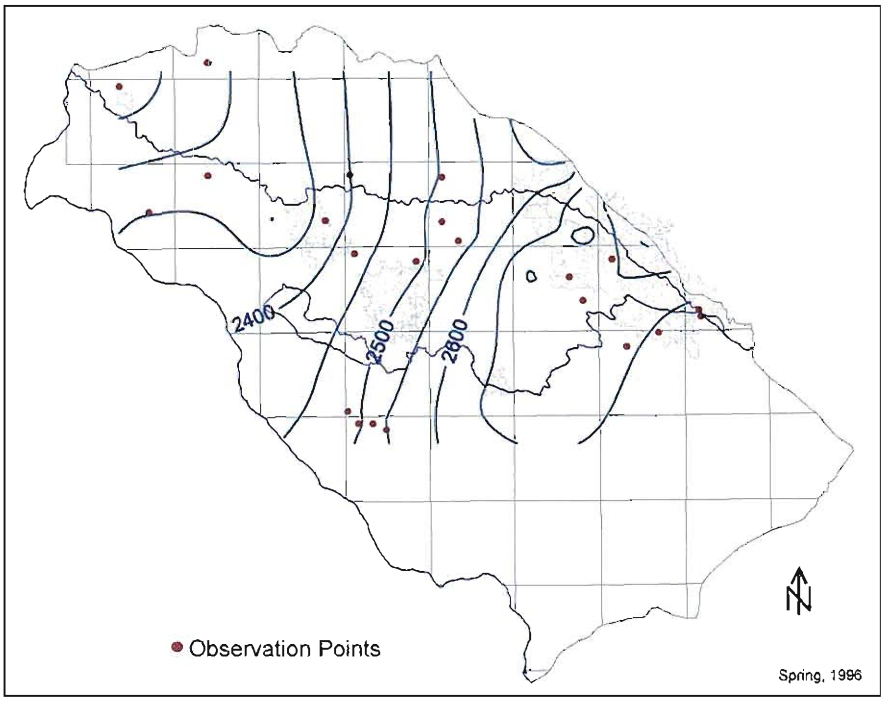


Figure 2-3: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 3.

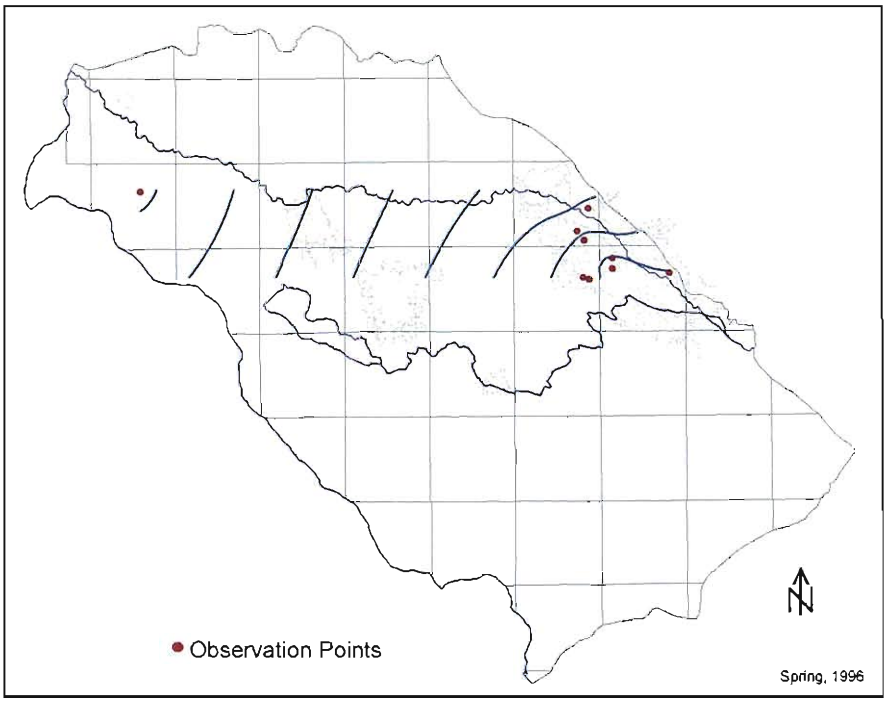
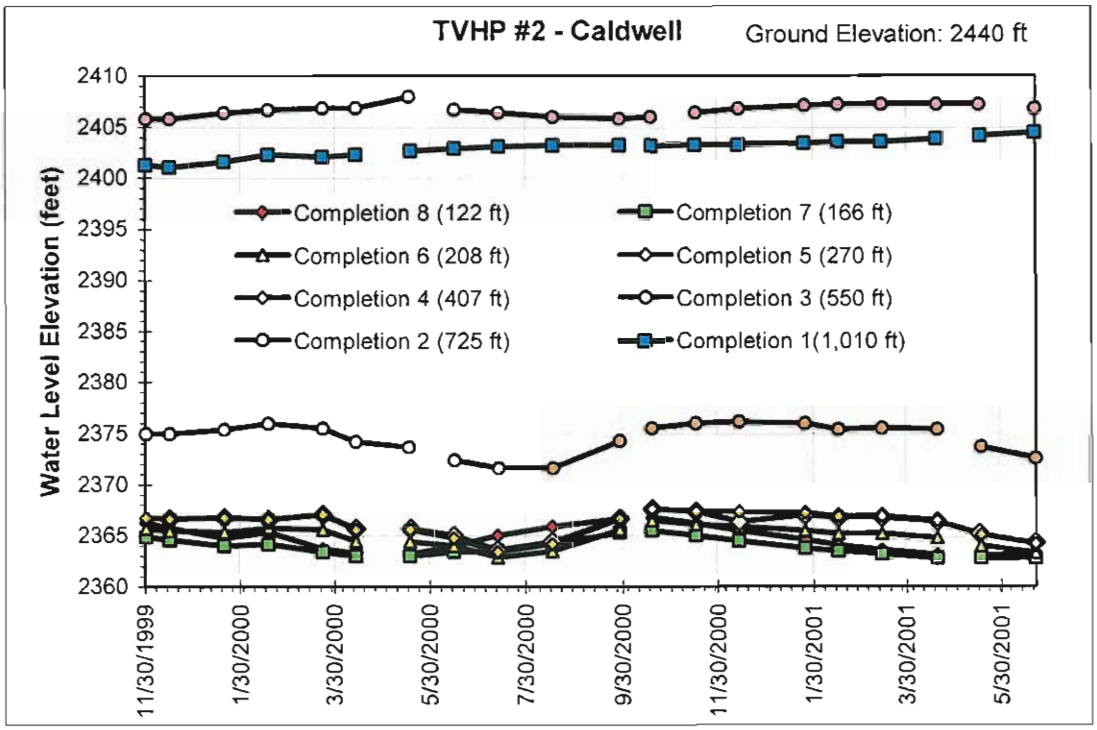
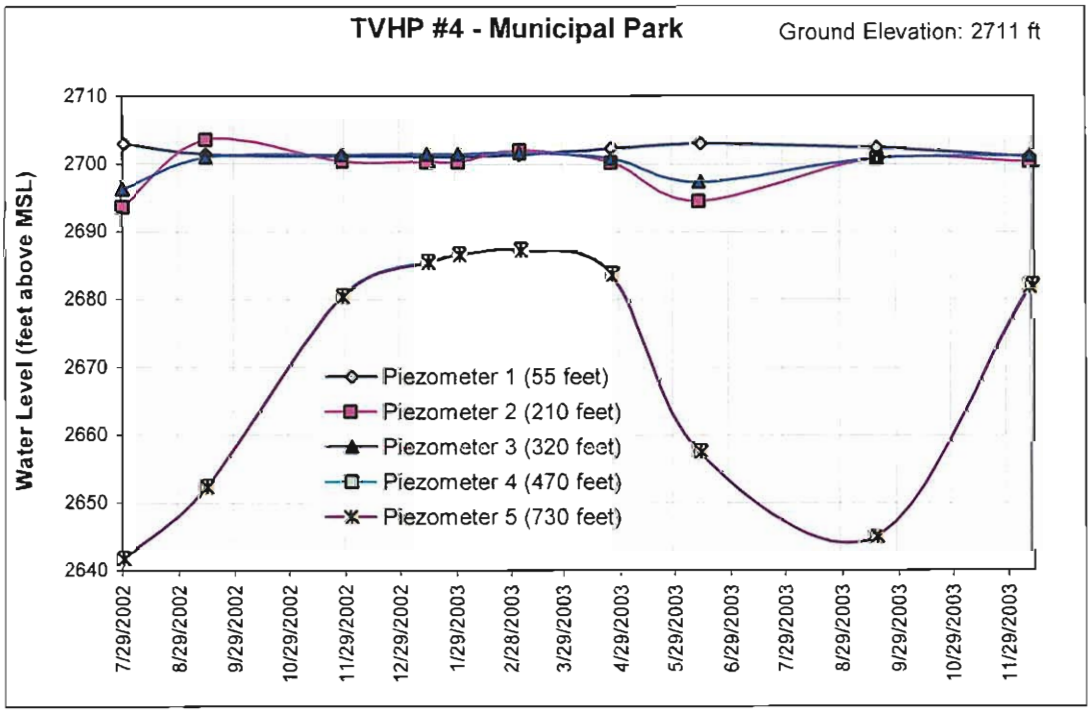


Figure 2-4: Potentiometric surface based on 1996 water level measurements from wells completed in model layer 4.



From Petrich and Urban (2004)



From Petrich and Urban (2004)

Figure 2-5: Water level data from the Caldwell and Boise Municipal Park wells.

A number of shallow monitoring wells indicated water level decreases. Shallow wells may be especially sensitive to changes in local surface water irrigation patterns in areas where the water table is not in direct hydraulic connection with surface channels. Ground water level changes are less likely in shallow wells in areas where the water table is controlled by topography (by virtue of drains and canals).

Seasonal water level fluctuations are evident in many Treasure Valley wells. The fluctuations are generally a response to seasonal increases in withdrawals (e.g., summer irrigation withdrawals) or increases in recharge associated with surface water irrigation.

The largest component of recharge to shallow aquifers is seepage from the canal system and infiltration associated with irrigated agriculture (Urban and Petrich, 1998). Water enters shallow aquifers as infiltration from canals, irrigated areas, and other water bodies (e.g., Lake Lowell), and possibly from upper reaches of the Boise River (e.g., Barber Dm to Capitol Street Bridge) during high flows. Infiltration from surface channels occurs if and when (1) water is available and (2) hydraulic heads in the channel (or lake) are higher than the surrounding aquifer heads. Additional recharge sources include mountain front recharge, underflow from the granitic Idaho Batholith and tributary sedimentary aquifers, and direct precipitation.

Shallow aquifer levels increased by as much as 100 feet in some areas in response to the initiation of large-scale flood irrigation in the late 1800s and early 1900s. Shallow ground water levels rose to and have remained at (or near) ground surface in many areas (at least seasonally), discharging to drains and other surface channels.

Shallow and intermediate aquifers are separated from deeper zones by interbedded silt and clay layers in many parts of the valley. While individual clay layers are not necessarily areally extensive, multiple clay layers in aggregate form effective barriers to vertical ground water movement.

Recharge to the deeper aquifers begins as downward flow through coarse-grained alluvial fan sediments in the eastern portion of the basin and as underflow at basin margins. Ground water is then thought to flow horizontally into the basin via more permeable sediments (e.g., coarse-grained sediments of the geological unconformity overlying Chalk Hills sediments) intersecting the alluvial fan sediments.

This is illustrated in water chemistry data collected from shallow aquifers near the New York Canal. Water in the canal, as in upper portions of the Boise River, has relatively low specific conductance (and by inference, total dissolved solids). In shallow aquifers underlying the canal, specific conductance was found to increase with depth, corresponding with canal water that has infiltrated through soil horizons. In contrast, water in deeper sand units, separated from upper zones by multiple clay layers, has lower specific conductance than water in overlying horizons (Hutchings and Petrich, 2002a; Hutchings and Petrich, 2002b). This finding indicates that water in at least

some deeper aquifers originates at the basin margins and does not enter the ground water regime through the carbon-rich sediments found in Treasure Valley soils.

Residence times of Treasure Valley ground water were generally found to increase with depth and with distance along a regional east-to-west-trending flow path (Hutchings and Petrich, 2002a). Residence time estimates in the regional aquifer system ranged from thousands to tens of thousands of years. The youngest waters entered the subsurface a few thousand years ago and were found along the northeastern boundary of the basin, adjacent to the Boise Foothills. The oldest waters entered the subsurface between 20,000 and 40,000 years ago and were found in the western reaches of the basin near the Snake River. Ground water in the deep deltaic aquifers beneath Boise entered the subsurface between 10,000 and 20,000 years ago.

Comparisons between measured water chemistry constituents and established models of geochemical processes (Hutchings and Petrich, 2002a) show that (1) ground water near the northeastern basin margin has experienced little interaction with aquifer minerals, and (2) ground water beyond the northeastern basin margin has experienced substantial interaction with aquifer minerals. Geochemical evolution of Treasure Valley ground water appears to be influenced by solution of both carbonate and silicate minerals.

Ground water discharge to rivers, drains, and canals represents the dominant form of discharge from the Treasure Valley aquifer system (Urban and Petrich, 1998). The primary form of natural discharge from the deeper aquifers is thought to be regional upwelling in the southern and western portions of the basin, with ultimate discharge to the Boise River and/or Snake River. Rates of discharge from the deeper aquifers in the western portions of the valley are unknown but are probably low because of the thick accumulation of lacustrine clays separating these aquifers from ground surface.

Relatively long residence times in the regional flow system (over 20,000 years) implies that (1) regional aquifers are not very transmissive, (2) recharge rates to the deeper regional aquifers are limited, and/or (3) regional aquifers are discharge-limited. Although there are abundant silt and clay layers with low hydraulic conductivity, productive sand layers are present throughout central portions of the valley; these sand zones are tapped by many irrigation and municipal wells. Recharge to the deeper, regional system is limited but has generally been sufficient for current rates of withdrawal. Thick lacustrine clays at the distal end of the valley likely inhibit upward (discharge) flow, limiting the amount of water that can flow through the system.

In summary, the Treasure Valley aquifer system consists of shallow aquifers containing local ground water flow systems, and a deeper, regional ground water flow system. Recharge to the shallow system consists largely of infiltration from irrigated fields and canals. Primary discharge is to the Boise and Snake Rivers and other streams and to drains discharging into these channels. The deeper, regional flow system consists of (1) recharge in alluvial sediments in southeast Boise and at the base

of the mountain front north of Boise, (2) movement of ground water from the recharge areas into the deeper Boise area fluvio-lacustrine aquifers, and (3) movement of ground water from the Boise area aquifers into regional lacustrine/deltaic aquifers in the central and western portions of the valley.

3. MODEL CONSTRUCTION

This section describes the basic construction of the Treasure Valley ground water flow model. A description of model inputs in provided in Section 4.

3.1. Model Code

The three-dimensional, finite difference MODFLOW code (Harbaugh et al., 2000; McDonald and Harbaugh, 1988; McDonald and Harbaugh, 1996) was selected for this model because it has been thoroughly validated, continues to evolve and is in common use by Idaho agencies and consultants. Several Graphical User Interfaces (GUIs) were used, including the Ground Water Modeling System (GMS - Brigham Young University, 2002) and PMWIN (Chiang and Kinzelbach, 2001).

The parameter estimation code PEST (Doherty, 1998; Doherty, 2000) was used for model calibration. PEST is a model-independent parameter estimator that is used in the calibration of environmental models, particularly ground water flow models. PEST has the ability to analyze the range of model prediction values, under the constraint that model parameters satisfy constraints imposed by the calibration process. Utility software supplied with PEST allows the use of "pilot points" in conjunction with geostatistically-based regularization criteria in characterizing a three-dimensional model domain.

3.2. Model Domain

The model domain includes the area between the Boise Foothills and the Snake River, which includes the lower Boise River sub-basin (Figure 1-1). The lower Boise River sub-basin begins where the Boise River exits the mountains near Lucky Peak Reservoir. From Lucky Peak Dam, the lower Boise River flows about 64 miles northwestward through the Treasure Valley to its confluence with the Snake River.

The northeastern model boundary follows the base of the Boise Foothills (Figure 1-1). Alternative boundaries for this part of the model include (1) the northern topographic divide for the lower Boise River basin (watershed boundary) or (2) a sediment-granite contact in the foothills. The base of the Boise Foothills was selected because of (1) the lack of well data within the foothills for model calibration and (2) the difficulty in simulating steep hydraulic gradients with grid cells sized for a regional-scale model. The eastern boundary of the lower Boise River basin follows a watershed divide. The southern and southwestern boundary was defined as the Snake River.

3.3. Model Scale

The flow model was designed to simulate ground water flow on a regional (Treasure Valley) scale. A model simulating flow on this scale is suitable for evaluating regional changes in water levels resulting from regional changes in land use or increases in withdrawals. The direct use of the model for evaluating small-scale (e.g., individual wells) issues is limited. However, the regional model provides a basis for constructing submodels that focus on smaller-scale ground water flow questions.

3.4. Model Units

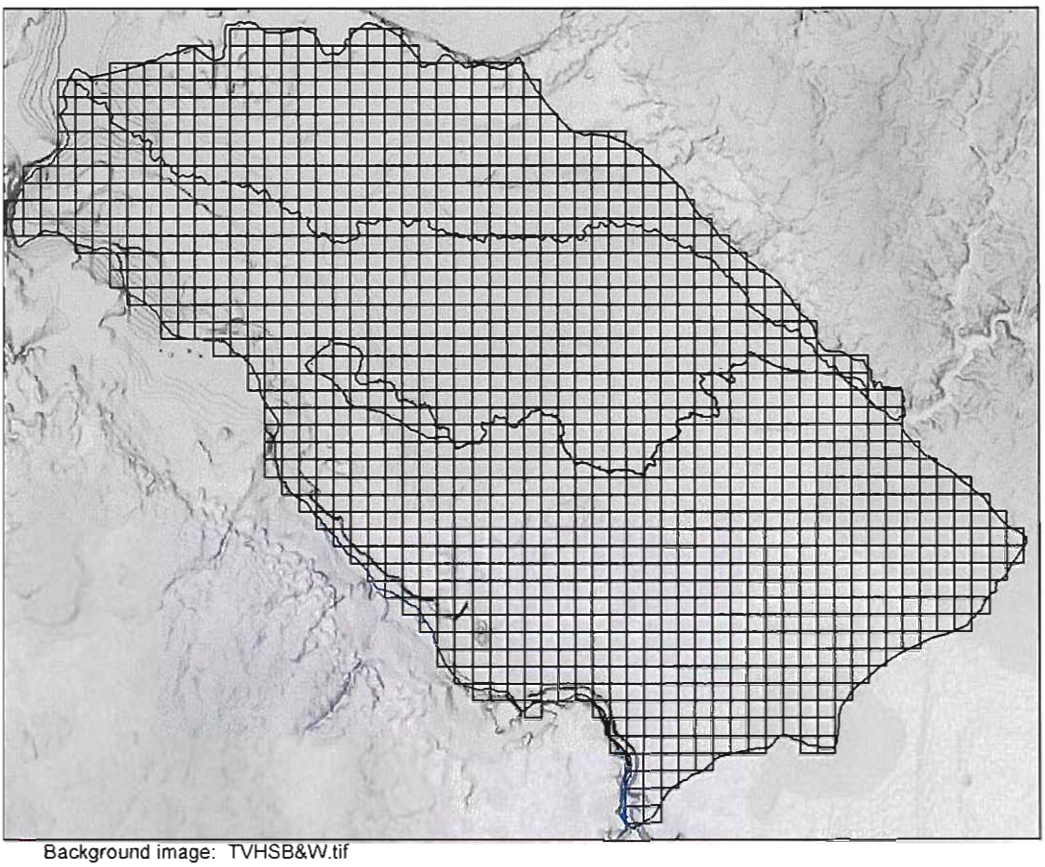
MODFLOW allows the use of any consistent units (e.g., SI [metric] or traditional [English] units). Spatial data covering the Treasure Valley are maintained by IDWR in the Universal Transverse Mercator (UTM) Zone 11 and/or the Idaho Transverse Mercator (IDTM) coordinate systems, which are based on metric units. Most ground water data collected in the study area (e.g., water level data, flow rates, recharge rates, stream fluxes, etc.) are recorded in English units. Errors associated with converting spatial data from metric to English are readily apparent when the spatial data are plotted. However, errors associated with conversion of other data from English to metric units may not be readily apparent when the data are used. For this reason, the model was constructed in English units (feet) with spatial data in UTM Zone 11 (feet). Time units are in days.

3.5. Model Discretization

The Treasure Valley flow model domain was discretized into a four-layer, 61×49 uniform grid (Figure 3-1 and Table 3-1) with each square cell representing an area of one square mile. The model grid contains 11,956 cells, 5,448 of which are active. One-mile cells were deemed adequate for the regional nature of the simulations.

Grid Corner	Easting (ft)	Northing (ft)	Comment
Northwestern corner	1,610,421	15,941,680	MODFLOW grid origin
Southwestern corner	1,610,421	15,682,960	Standard grid origin
Northeastern corner	1,932,501	15,941,680	
Southeastern corner	1,932,501	15,682,960	

Table 3-1: Grid coordinates (UTM Zone 11).



Background image: TVHSB&W.tif

Figure 3-1: Model domain showing uniform, one-mile grid cells.

The model grid was aligned in an east-west direction for two reasons. First, ground water in the deeper, regional flow system in central portions of the Treasure Valley (e.g., the Meridian–Caldwell area) flows in a general westerly direction (Figure 2-2 through Figure 2-4). Second, the east-west orientation simplifies model construction (many data are linked to the east-west land survey system).

Several alternatives for layer definition were considered, including (1) geologic strata, (2) sediment color transitions, (3) ground surface, (4) water table surface, and (5) elevation surface based on Boise and Snake River elevations. Ideally, model layers would be defined based on geological strata or aquifer material characteristics. Several geologic strata were considered for defining layers: (1) the base of the Snake River Formation sediments, (2) the unconformity (where present) separating Chalk Hills sediments from overlying sediments, and (3) the top of the predominantly mudstone section within the Idaho Group sediments. However, the transitions between these strata are neither apparent nor consistent over the entire model domain, or in some cases, even large areas within the domain. When visible (such as the Snake River Formation sediments and basalt), the formation may be above the saturated zone, and the transition may vary substantially in elevation.

Another visible identifier in many wells is the transition from brown to blue-gray sediments. This color change, sometimes referred to as the "blue clay" surface, ranges in depth below ground surface from approximately 30 feet to more than 200 feet in some areas. The surface varies in elevation, with differences of up to 200 feet over relatively short distances. The blue-gray color is most frequently associated with clay sediments in drillers' logs, but bluish coarse-grained sediments have also been noted. The color transition may be the result of a combination of depositional and post-depositional geochemical changes. Post-depositional erosion is not associated with a unique lithologic layer and does not necessarily reflect unique transitions in hydraulic properties.

Model layers are sometimes defined as uniform distances from ground surface. However in this case, the depth of the uppermost saturated zone varies substantially. A uniform layer encompassing the first 200 feet of saturated zone below the Boise River would be completely unsaturated in some areas between the Boise and Snake Rivers.

A water table surface was also considered as a surface for defining layers, such as the uppermost water level surface based on an average of spring and fall 1996 measurements (Figure 3-2). Use of a water level surface would ensure that upper model cells remain saturated, at least prior to an applied stress. However, hydrologic conditions, such as recharge and extraction, influence this surface; it does not necessarily reflect hydrogeologic conditions at depth.

The final alternative for layer definition, an elevation surface based on Boise and Snake River elevations (Figure 3-3), was chosen for the following reasons. First, it represents a relatively uniform surface throughout the model domain. Second, because ground water is in direct hydraulic connection with the Boise and Snake Rivers, a surface connecting these two rivers ensures that the upper model layers remain saturated under initial non-stressed conditions. Third, the surface is dipping basinward, not unlike some of the dipping strata existing in the basin. Finally, this surface offered a basis for defining relatively uniform layer surfaces at depth.

The elevation surface based on the Boise and Snake River elevations was considered to represent a layer "datum" (Figure 3-3 and Figure 3-4). The first model layer was defined as extending 200 feet below the datum (Table 3-2). This zone, at least in the Boise River area, included most of the coarser-grained Snake River sediments. The uppermost model layer is assumed to represent a continuous, unconfined aquifer throughout the model domain. This assumption is valid throughout most of the model area, although some perched aquifers are known to exist. The top of the uppermost model layer is considered to be ground surface. The ground surface in most parts of the model domain is higher than the layer datum (Figure 3-4).

The base of the second layer was defined as extending 200 feet below the base of the first layer (Table 3-2). The bottom of the second layer, 400 feet below the layer datum, roughly corresponds with the geologic unconformity separating Chalk Hills and

overlying sediments (see Section 2). Layers 3 and 4, each extending 400 feet below layer 2, represent the deeper Idaho Group sediments from which the valley's deeper wells draw water. Virtually all water-producing wells in the Treasure Valley are completed at depths above the base of model layer 4.

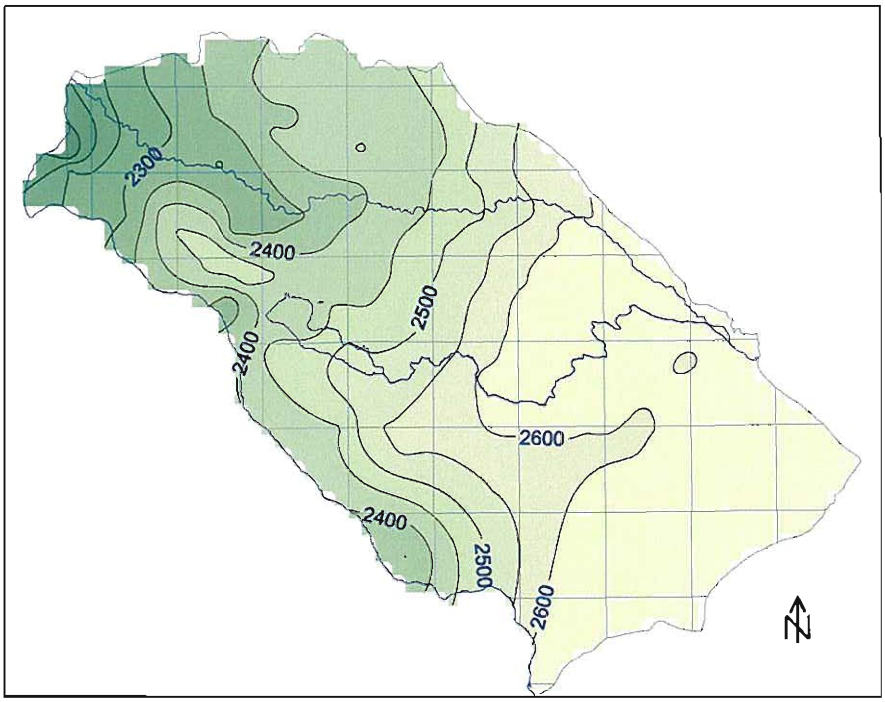


Figure 3-2: Average 1996 potentiometric surface of the uppermost aquifer (ft).

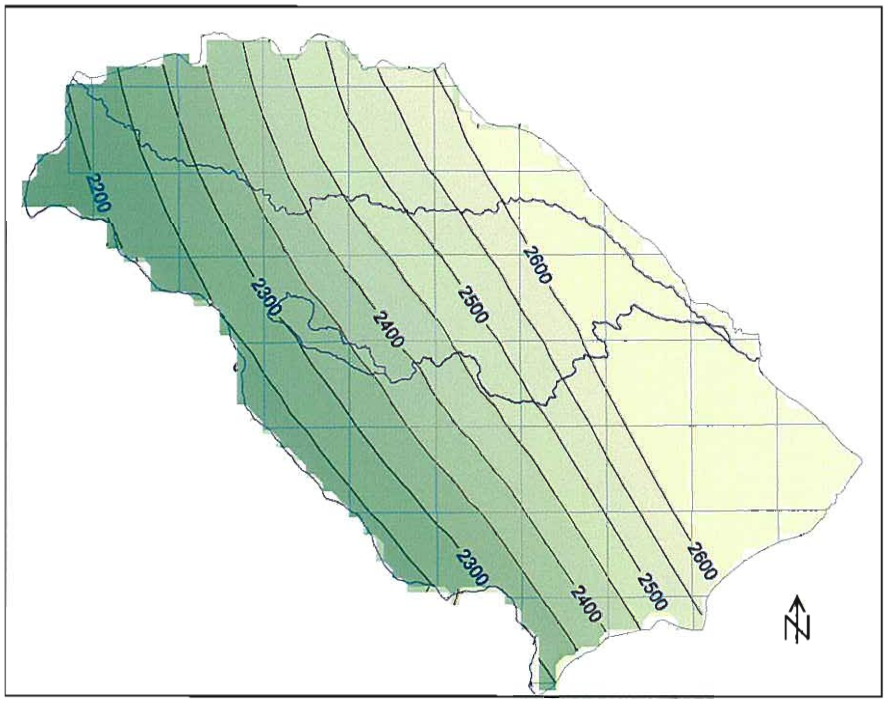


Figure 3-3: Elevation (ft) of uniform layer surface (i.e., layer "datum").

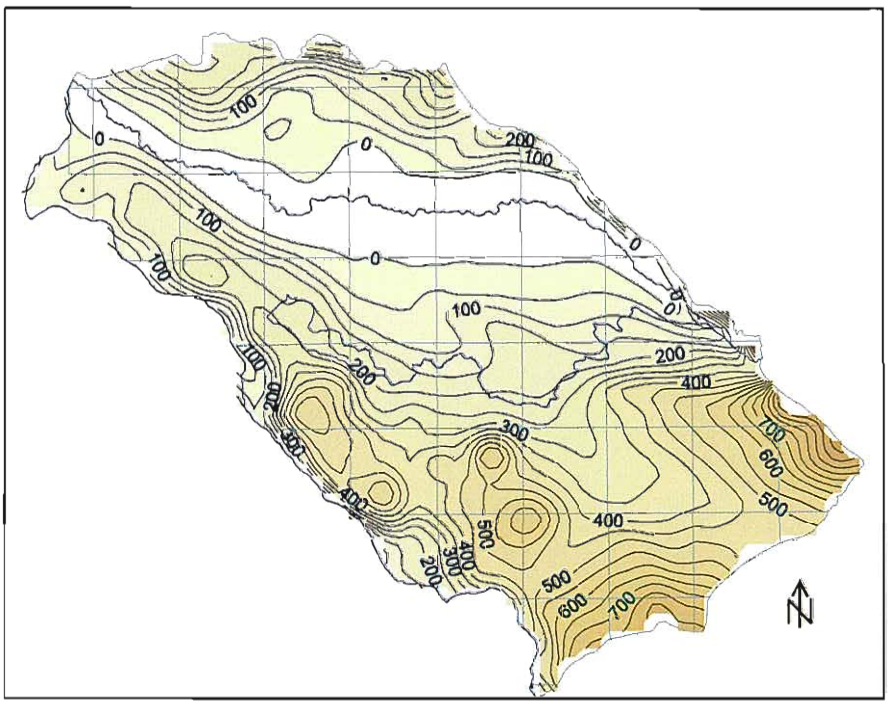


Figure 3-4: Depth from ground surface to layer "datum" (ft).

Layer	Thickness (ft)	Depth from Layer "Datum" to Top of Layer (ft)	Depth from Layer "Datum" to Bottom of Layer (ft)
1	200	0	200
2	200	200	400
3	400	400	800
4	400	800	1,200

Table 3-2: Definition of model layers.

3.6. Boundary Conditions

Boundary conditions were simulated as no-flow, specified flux, head-dependent flux, or free surface (Figure 3-5). No-flow conditions were described for the northern and southeastern sides of the model. The northern edge of the model was assumed to be a ground water flow divide separating the Payette and Boise River drainages. The southeastern boundary (following a hydrologic divide) is relatively parallel to the regional ground water flow lines as presented in Newton (1991) and was therefore assumed to represent a no-flow boundary[2].

No-flow conditions were also defined for the model base. There is evidence that there may be some vertical mixing between geothermal and overlying cold ground water aquifers based on fluoride concentrations, sodium/calcium ratios, and water temperatures (Hutchings and Petrich, 2002a). Nonetheless, it was assumed that on a regional scale, fine-grained sediments at the base of the cold-water system form an effective barrier to substantial upward movement of geothermal ground water into upper cold-water aquifers.

Specified flux boundary conditions were used to simulate recharge (Section 4.6), withdrawals from wells (Section 4.2), and underflow (Section 4.2). Recharge components (Section 4.6) included (1) seepage from canals, (2) seepage from rivers and streams, (3) seepage from Lake Lowell, (4) underflow, (5) infiltration from precipitation and irrigation, and (6) seepage from septic systems.

Ground water withdrawals consist of water that is pumped or flows under artesian pressure from municipal, industrial, agricultural, and rural domestic water supply wells (Urban and Petrich, 1998). This includes water withdrawn from a variety of depths and aquifers. Simulated withdrawal rates are summarized in Section 4.2.

Underflow was assumed along the northeastern edge of the model (simulated a specified flux with injection wells as shown in Figure 3-5). Underflow was included in the model as positive flow to wells (as opposed to negative flow, or withdrawals).

2 There are few wells available along the southeastern model boundary to confirm this assumption.

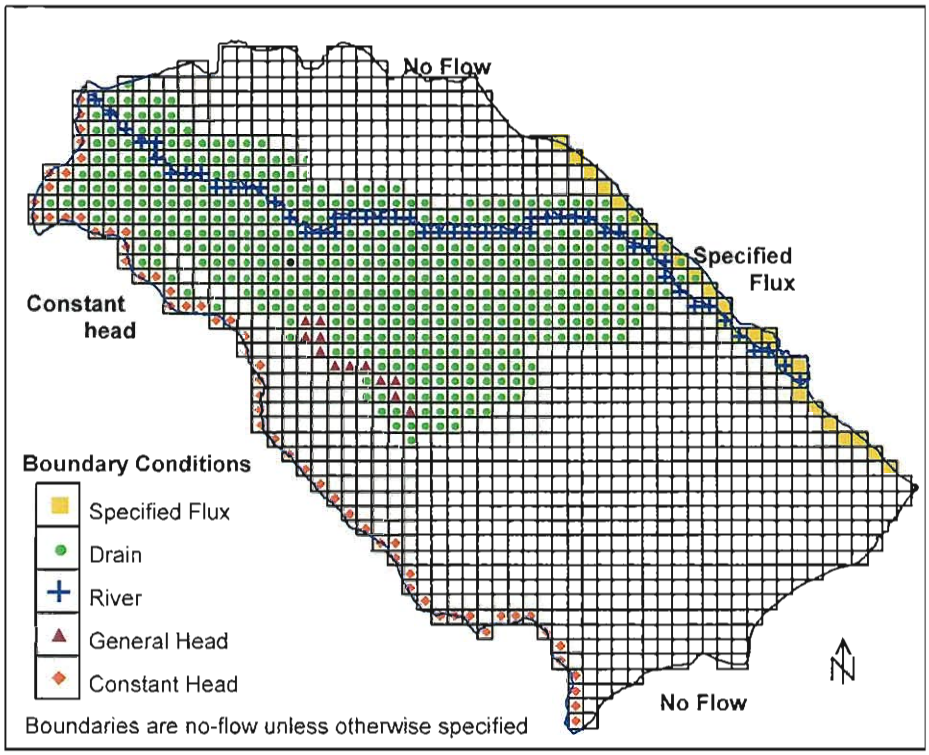


Figure 3-5: Model grid and boundary conditions.

Head-dependent flux boundaries were used to simulate losses to and gains from streams and lakes and flow to drains. Fluxes into and out of the Boise River were simulated using the MODFLOW River Package (Section 4.3). Discharge to drains was simulated using the MODFLOW Drain Package (Section 4.4). Fluxes into and out of Lake Lowell were simulated using the MODFLOW General Boundary package (Section 4.5).

A free-surface boundary represents the water table in model layer 1. The position of the free-surface boundary was calculated by the model in response to surrounding hydraulic heads, other boundary conditions, and aquifer properties.

4. DEVELOPMENT OF MODEL INPUT FILES

4.1. Overview

Multiple files are needed for constructing and calibrating a model. Some of the files are required by the MODFLOW code, some stem from the graphical user interface. This section describes (1) the files that were used for model construction, (2) the data included in the files, and (3) how the files were created. Model files required for the MODFLOW simulations are listed in Appendix B. Files required for model calibration are described in Section 5.10.

Estimated withdrawal, recharge, and underflow rates for 1996 (Urban and Petrich, 1998) were used for model inputs for these simulations. A revised water budget for the year 2000 is being prepared but was not available at the time of model development or calibration.

4.2. Well Package

The MODFLOW well package was used to list (1) ground water withdrawals from cells within the model domain and (2) underflow into the model along model boundaries. Ground water withdrawals consisted of water that was pumped or flowed under artesian pressure from municipal, industrial, agricultural, and rural domestic water supply wells[3].

Withdrawal amounts (Table 4-1) were those estimated in the 1996 water budget (Urban and Petrich, 1998). Withdrawal amounts were estimated[4] on an areal basis (unless withdrawals were associated with known screened intervals in specific wells). The withdrawals were then distributed vertically throughout the model domain based on a distribution of well depths by model layer. The distribution of well depths was drawn from wells listed in IDWR's Well_Log database. The resulting withdrawal distribution by model layer is shown in Figure 4-1. Each cell in the model domain was identified in the well package, although cells without any ground water extraction had values of zero. The spatial distribution of estimated withdrawal rates per model cell is shown in Figure 4-2 through Figure 4-5. In general, ground water withdrawals are greatest in urban areas and in areas of substantial irrigation with ground water.

Estimates of underflow along the northeastern model boundary were made in the Treasure Valley Water Budget (Urban and Petrich, 1998). The magnitude of underflow across the northeast boundary was estimated by assuming all precipitation

[3] The withdrawal estimates for rural domestic wells included all withdrawals. Septic seepage was included in the recharge file (Section 4.6).

[4] The well data were prepared by Scott Urban (IDWR) using the spreadsheet "1996pump-revised-4-21-03.xls".

within the Boise Foothills, less evapotranspiration and stream discharge, enters the model domain as underflow (Urban and Petrich, 1998). This resulted in a total underflow estimate of 8,000 af/yr (8,840 ft^3/day/cell). However, this estimate is uncertain, as is the horizontal and vertical distribution of the underflow along the Boise Foothills. Results from early calibration runs suggested that underflow values might be lower than estimated. Therefore, a lower value of 1,000 ft^3/day/cell was used for the base simulation[5]. Cells in which underflow was specified are indicated (in yellow) in Figure 3-5.

Category	Estimated 1996 Withdrawals		
	Acre-feet (af)	ft^3/day	Percent of total
Domestic and Industrial Withdrawal	66,100	7.89×10^6	34
Municipal Irrigation	9,700	1.16×10^6	5
Self-Supplied Industrial	20,800	2.48×10^6	11
Agricultural Irrigation	71,900	8.58×10^6	37
Rural Domestic Withdrawal	26,600	3.17×10^6	12
Stock Watering	2,600	3.10×10^5	1
TOTAL:	197,700	2.36×10^7	100

(from Urban and Petrich, 1998)

Table 4-1: Estimated ground water withdrawals in 1996.

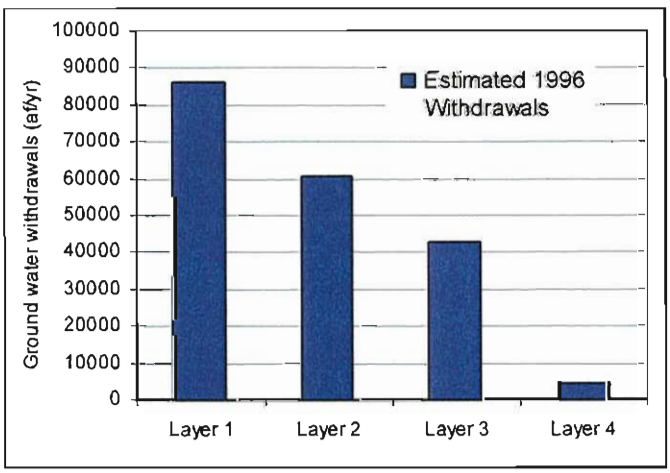


Figure 4-1: Estimated 1996 withdrawals, by model layer.

[5] A higher underflow rate of 8,000 ft^3/day/cell per cell was tested in a sensitivity simulation (see Section 8.3).

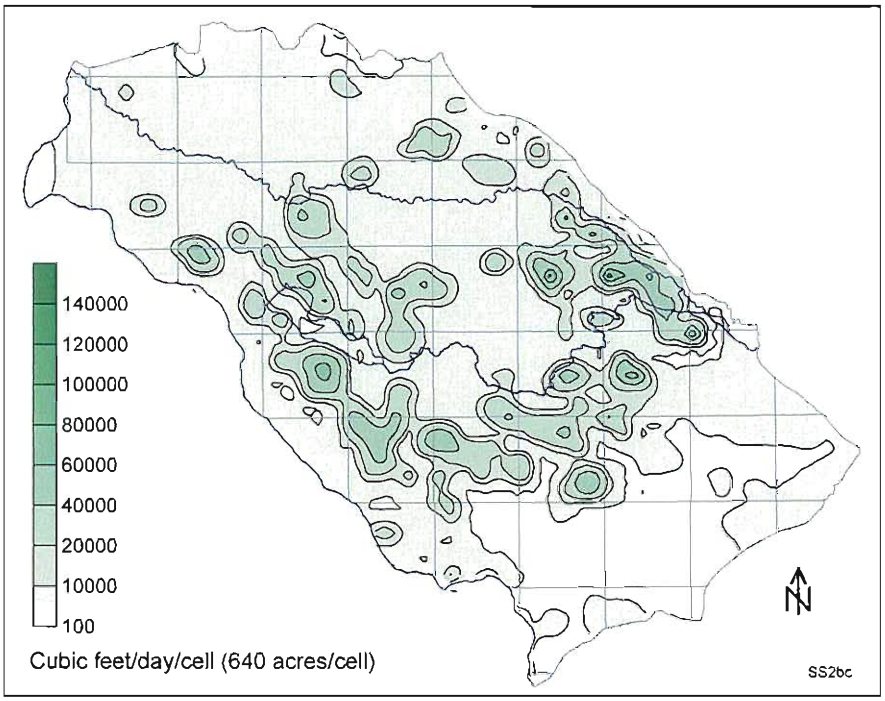


Figure 4-2: Estimated 1996 withdrawals, layer 1.

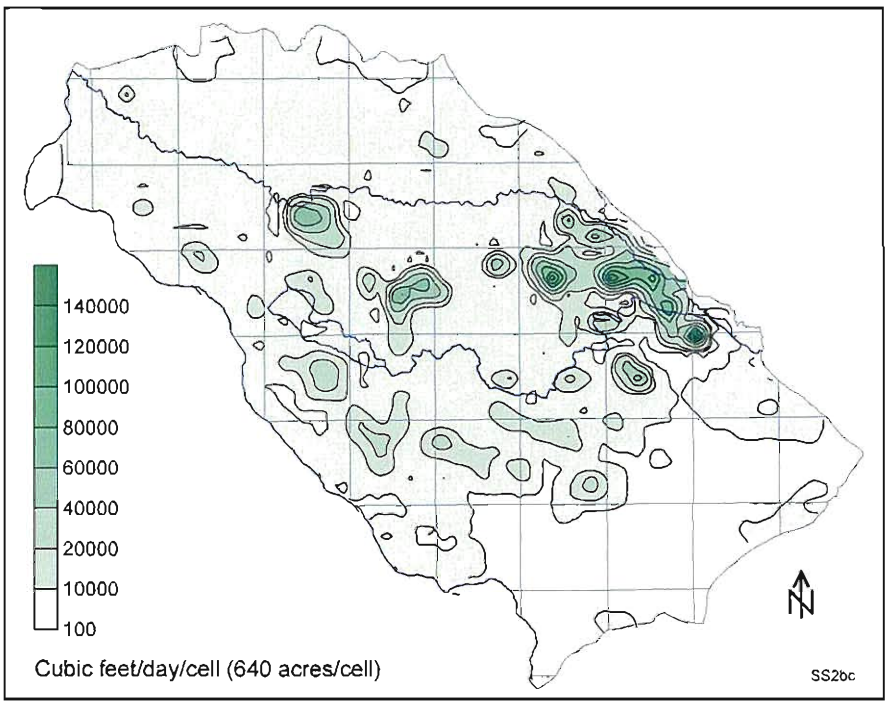


Figure 4-3: Estimated 1996 withdrawals, layer 2.

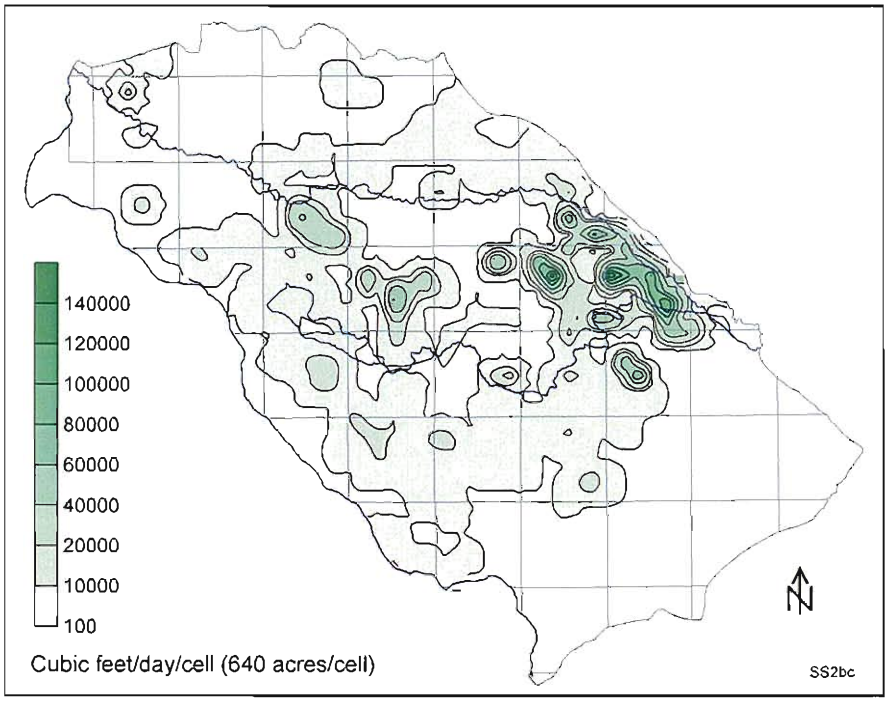


Figure 4-4: Estimated 1996 withdrawals, layer 3.

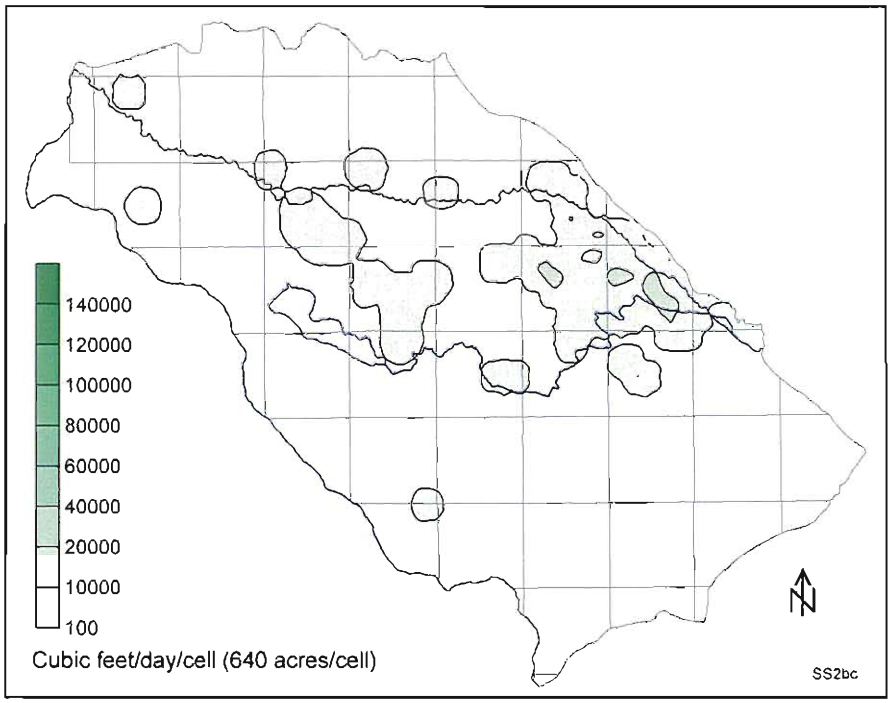


Figure 4-5: Estimated 1996 withdrawals, layer 4.

4.3. River Package

The river package allows simulation of the effects of flow between surface and ground water systems. The rate of flow between a surface channel and an underlying aquifer is calculated in each simulation based on river stage, surrounding ground water levels, channel dimensions, and streambed conductance characteristics. Ground water moves into the surface channel if surrounding ground water levels are higher than the river stage and vice versa if the ground water levels are lower than the river stage.

The river package was used to simulate ground water hydrologic conditions associated with the Boise River to allow for both gaining and losing reaches (the lower Boise River is predominantly a gaining reach). The Snake River was simulated as a constant head boundary because it is predominantly a gaining reach throughout the model domain. Major canals (e.g., New York Canal) were not simulated as river features because seepage from these channels was included in the recharge estimates.

The river stage elevations were based on topographic contour elevations. It was assumed that the river has an average depth of 10 feet. The river bottom elevations were therefore assumed to be 10 feet less than the river stage. River stage varies throughout the year, thus approximate average elevations were assumed. The river stage elevation was assumed to be 2,742 feet[6] where it enters the model domain; the river stage at the confluence with the Snake River was assumed to be 2,170 feet.

The riverbed hydraulic conductance is defined as

$$COND = \frac{K_R L_R W_R}{M}$$

where K_R is the hydraulic conductivity of the riverbed material, L_R is the reach length, W_R is the channel width, and M is the riverbed thickness (McDonald and Harbaugh, 1988). K_R, L_R, W_R, and M vary substantially throughout the model domain, and there is a high degree of uncertainty associated with any estimates of K_R. The riverbed conductance was assumed to be the same for all river cells[7]. The initial conductance value for base calibration simulations was 2.0×10^5 ft^2/day based on the assumptions listed in Table 4-2.

4.4. Drain Package

The drain package is used to simulate the effects of features such as agricultural drains, which enable discharge from an aquifer at a rate proportional to the difference between the aquifer head and the drain elevation (McDonald and Harbaugh, 1988). Simulated

[6] Taken from a USGS 7.5-minute quadrangle map.

[7] A constant river bed conductance (*COND*) was assumed to simplify the model. In actuality, the riverbed conductance would be expected to vary within river cells and among different river cells because of differences in riverbed materials, reach lengths, and river widths.

water enters the drain if the cell head values are greater than the drain elevation; the drains have no effect if the aquifer head levels fall below that of the drains.

Parameter	Value
Aggregate reach length per cell (*L*)	5,280 ft (1 mile)
Aggregate reach width per cell (*W*)	50 ft
Hydraulic conductivity of riverbed material (*K*)	3.8 ft/day
Riverbed thickness (*M*)	5 ft
Streambed conductance (*COND*)	2.0×10^5 ft^2/day

Table 4-2: Streambed conductance values.

Surface topography limits the upper range of shallow ground water levels in the central portion of the basin (i.e., aquifer discharge occurs if ground water levels rise to near ground surface elevations). Drain cells were used to simulate this process – to help the model "remove" this aquifer discharge. Model cells were identified as drain cells if typical shallow aquifer head values, based on fall 1996 water levels, fell within approximately 10 feet of the ground surface elevation. Some additional drain cells were identified if known drains were present in the cells. Factors influencing discharge to a drain include the difference between local aquifer heads and drain heads, drain dimensions, and drain-bottom sediment characteristics.

The drain conductance is a lumped parameter that describes head loss between a drain and underlying aquifer. The conductance was defined similar to river conductance (see Section 4.3). Drain conductances were kept has high as possible (to drain as much water as necessary) without creating model instability. Assumed parameter value assumptions for drain cells are given in Table 4-3.

Parameter	Value
Aggregate reach length per cell (*L*)	26,400ft (5 miles)
Aggregate reach width per cell (*W*)	5 ft
Hydraulic conductivity of lake sediment material (*K*)	3.79×10^{-1} ft/day
Lakebed thickness (*M*)	1 ft
Drain cell conductance (*COND*)	5.0×10^4 ft^2/day

Table 4-3: Initial drain conductance values.

4.5. General Head Boundary

The general head boundary package was used to simulate the effects of flow between Lake Lowell and underlying shallow aquifers (Figure 3-5). The mathematical basis for this package is similar to that of the river (Section 4.3) and drain (Section 4.4) packages, in that flow from an external source (in this case, Lake Lowell) is proportional to the difference in head between the external source and the aquifer. The

conductance of the external source (Lake Lowell bottom sediments) was assumed to be 4,000 ft^2/day/cell (Table 4-4).

Parameter	Value
Aggregate reach length per cell (*L*)	5,280 ft
Aggregate reach width per cell (*W*)	5,280 ft
Hydraulic conductivity of lake sediment material (*K*)	1.15×10^{-3} ft/day
Lakebed thickness (*M*)	8 ft
General head boundary conductance (*COND*)	4.0×10^{3} ft^2/day

Table 4-4: Initial general head boundary conductance values.

4.6. Recharge Package

The recharge package was used to simulate areally distributed recharge over the uppermost Treasure Valley aquifers. The primary sources of recharge consisted of (1) seepage from canals, (2) seepage from rivers and streams, (3) seepage from Lake Lowell, (4) infiltration from precipitation and irrigation, and (5) seepage from septic systems (Urban and Petrich, 1998). A summary of estimated annual recharge rates is shown in Table 4-5.

The MODFLOW recharge file[8] was created based on estimated Treasure Valley ground water recharge rates (Urban and Petrich, 1998) for the 1996 calendar year. Average daily recharge rates in the MODFLOW recharge file were calculated based on annual recharge estimates. The recharge file does not include seepage from the Boise River (which is simulated as a head-dependent boundary based on river package parameters, see Section 4.3). It also does not include seepage from Lake Lowell, (which is simulated as a head-dependent boundary based on general head boundary package parameters, see Section 4.5).

The MODFLOW recharge file represents a smaller recharge volume (973,711 af/yr) than that listed in Urban and Petrich (1998), for two reasons. First, the model domain represents a slightly smaller area than that used to estimate total recharge for the Treasure Valley. Second, the model also simulates recharge via river, underflow, and head-dependent boundary cells. Total simulated recharge is reconciled with estimated water budget inflows in Table 7-2.

The areal distribution of recharge (as applied on a cell-by-cell basis in the model) is shown in Figure 4-6. The greatest simulated recharge rates were along the New York Canal and areas of flood irrigation in central portions of the valley. Losses from (or gains to) the Boise River are not specified in the recharge package but were simulated as a head-dependent boundary in the MODFLOW river package (Section 4.3).

[8] MODFLOW recharge files were created by Scott Urban, IDWR (*1996rechnew.xls*).

Sources of Recharge	Estimated Recharge for 1996		
	Acre-feet (af)	ft^3/day	Percent of Total
Canal Seepage	637,000	7.60×10^7	61
Seepage from Rivers and Streams	16,000	1.91×10^6	1
Seepage from Lake Lowell	19,000	2.27×10^6	2
Underflow	8,000	9.55×10^5	1
Flood Irrigation and Precipitation	302,000	3.60×10^7	30
Recharge by Other Land Uses	48,000	5.73×10^6	4
Rural Domestic Septic Systems	5,000	5.97×10^5	<1
Total	1,035,000	1.24×10^8	99

(from Urban and Petrich, 1998)

Table 4-5: Estimated recharge to shallow Treasure Valley aquifers in 1996.

4.7. Solver Package

MODFLOW comes with several solver options: Slice-Successive Over-Relaxation (SSOR), Strongly Implicit Procedure (SIP), and the Preconditioned Conjugate-Gradient Method (PCG2). Different solvers may work better for different problems. The PCG2 solver was successful in solving the Treasure Valley model simulations; other solvers were not required.

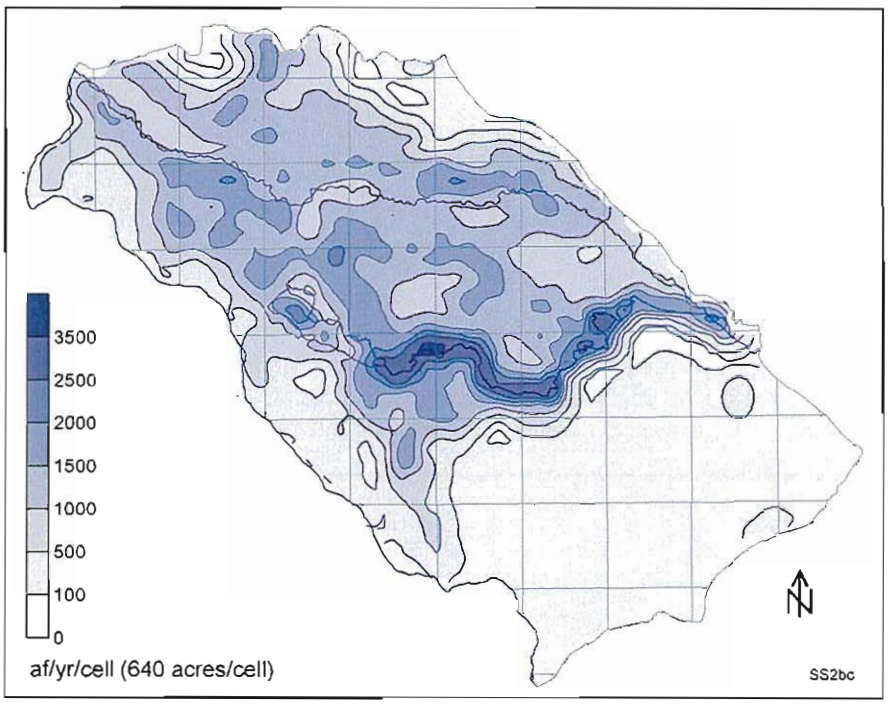


Figure 4-6: Areal distribution of estimated recharge.

5. MODEL CALIBRATION

5.1. Introduction

Model calibration is the process of adjusting model parameters so simulated observations match measured or estimated observations as closely as possible. This chapter describes the calibration of the Treasure Valley ground water flow model under steady-state hydraulic conditions.

5.2. Automated Parameter Estimation

Initial model calibration was conducted using "trial-and-error" manipulation of individual cells or zones of cells. Trial-and-error calibration involves manually manipulating parameter values (e.g., hydraulic conductivity, vertical conductance, etc.) such that simulated head values are as close as possible to observed head values.

Automated parameter estimation involves the use of codes that automatically manipulate parameter values to minimize an objective function (e.g., sum of squares of the residuals between simulated and observed heads). Automated calibration methods generally yield descriptive statistics[9] that quantify the uncertainty of the calibration.

Several parameter estimation codes existed at the time of calibration (Doherty, 1998; Doherty, 2000; Harbaugh, 2000; Hill, 1992; Hill et al., 2000; Poeter and Hill, 1998). PEST (Doherty, 2000) was initially selected because of it's ability to limit parameter value ranges, availability of utilities designed to ease the use of MODFLOW input of files created in GMS[10] (a graphical user interface), and parallel processing utilities. Subsequent improvements in PEST that were used in this model calibration included regularization with pilot points and predictive analysis tools (Doherty, 2000).

PEST's regularization scheme allows estimation of a larger number of parameters than would otherwise be possible without incurring parameter instability and non-uniqueness. Preferred values for parameters, or relationships between parameters, were used as supplementary information to help constrain model calibration. Regularization and pilot points (see Section 5.6) allowed an increased number of calibration parameters.

PEST operates independently of the MODFLOW code or the graphical user interface. Using the Gauss-Marquardt-Levenberg method, PEST adjusts specified model parameters and/or stresses (excitation) values on an iterative basis until an objective function is minimized.

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[9] Some of PEST's descriptive statistics may not apply with the use of regularization (see Section 5.6).

[10] http://www.ems-i.com

The parameter estimates from any model calibration may have a degree of non-uniqueness, whereby additional adjustments of any given parameter have no material impact on the overall calibration (i.e., the objective function will not be lowered further with additional parameter adjustments). The degree of non-uniqueness depends on the general strength of the calibration, the nature of the individual parameters, and the number and quality of observation data. PEST's predictive analysis tools help estimate maximum and minimum outcomes within the context of a set of "calibrated" parameters.

5.3. Steady-State versus Transient Calibration

Model calibration can be performed under steady-state and/or transient hydraulic conditions. Steady-state conditions require the assumption that hydraulic conditions, fluxes and water levels, are at equilibrium. Fluxes and water levels change over time under transient conditions. Steady-state calibration parameters generally include hydraulic conductivity; transient calibrations require the calibration of aquifer storativity as well. Ground water flow models generally are calibrated to steady-state conditions first and to transient conditions[11] if data allow.

A steady-state calibration is appropriate if the model questions focus on equilibrium aquifer conditions, or long-term aquifer sustainability. Similarly, model predictions under steady-state simulations are appropriate to evaluate questions of long-term (i.e., equilibrium) water levels, or aquifer sustainability. Simulated equilibrium water levels are determined by hydraulic conductivity values, which are estimated in a steady-state calibration. Transient flux and water level data will not help estimate hydraulic conductivity parameters; they would only help in estimating the time required to reach equilibrium.

Basing a steady-state calibration on water levels that are experiencing long-term rises or declines may yield inaccurate results. In general, water levels in the Treasure Valley have been relatively constant over time (years). However, two areas have experienced substantial declines, an area south of Lake Lowell and the southeast Boise area, although water levels in these areas appear to have stabilized in recent years.

Many areas experience seasonal variations in ground water levels. To reduce errors introduced into the steady-state simulations from seasonal variations, the flux rate inputs (underflow, recharge, extraction rates, etc.) were converted to daily average rates based on 1996 totals. For example, daily rates for summer irrigation-dominated recharge were divided into uniform daily rates based on total recharge for the 1996 calendar year (see Section 4.6). Similarly, water level observations used for model

11 Hydraulic conductivity and/or transmissivity values often are correlated with storativity values, and thus, a transient calibration might focus first on adjusting storativities while using hydraulic conductivity and/or transmissivity values from a steady-state calibration.

calibration represent an average between spring and fall 1996 observations. Thus, simulated recharge and withdrawal rates, and river, general head, constant head, and drain flux rates, represent daily rates averaged over an entire year.

A transient model was not constructed, for two reasons. First, detailed temporal flux data are required to help calibrate aquifer storativity in a transient simulation[12]. Detailed flux data were not yet available during model construction and simulation. The USBR and IDWR are currently compiling more detailed irrigation diversion and return data for the valley, which would be essential for transient simulations (especially those focusing on shallow aquifer conditions). Second, successful transient simulations depend on well-defined temporal water level changes. Temporal water level change information enables calibration of aquifer storativity. Without these data, simulated storativity parameters may be excessively correlated with hydraulic conductivity[13] parameters.

Transient simulations with temporal water level change data can be conducted over short or long time periods, depending on data availability. With some exceptions, long-term Treasure Valley water levels have remained relatively steady over the last several decades, and therefore, may not provide adequate long-term changes that could be used to calibrate a transient model. Exceptions include the areas south of Lake Lowell and southeast Boise, but these two areas are probably not extensive enough to provide a sufficient basis for a regional transient model calibration.

The Treasure Valley also experiences seasonal water level changes (see hydrographs in Petrich and Urban, 2004). Seasonal fluctuations are dominated with two general patterns. Water levels in wells are influenced either by water level rises corresponding with irrigation applications or by summer irrigation withdrawals, or both. Variations in local withdrawals and/or shallow recharge, even if well defined, may reduce the reliability of simulated regional storativity estimates. Thus, these seasonal water level fluctuations may be insufficient for a solid seasonal transient calibration for a model covering the entire Treasure Valley area.

However, transient calibrations are probably feasible for local ground water flow models within the Treasure Valley or submodels of the regional model. These calibrations would be possible (depending on the specific type of question to be answered by the model) if detailed local water level and surface recharge/discharge data were available.

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[12] Aquifer storativity was assumed to be zero during a steady-state simulation because the steady-state simulation does not account for water level changes over time.

[13] Aquifer hydraulic conductivity and storativity represent independent physical characteristics of an aquifer. However, the effect of these parameters in a model calibration may, if not adequately constrained, appear correlated.

5.4. Calibration Parameters

Primary calibration parameters for the steady-state calibration were horizontal hydraulic conductivity (K_h) and vertical hydraulic conductivity (K_v). Underflow was also varied between several runs, but generally held constant within runs because of correlation with hydraulic conductivity parameters.

Areal recharge was also a potential calibration parameter. However, recharge is often correlated with K_h and K_v (a change in recharge values and a corresponding change in K_h or K_v may lead to the same calibration result). The range of recharge values might be constrained if detailed system discharge data (e.g., ground water discharge to discrete reaches of the Snake and Boise Rivers) were available at the time of calibration.

Layers 3 and 4 were considered to be one layer for model calibration for two reasons[14]. First, there were relatively few observation wells in these layers (Section 5.5), many of which are concentrated in the Boise area. Some of the wells that extend to depths encompassed by these layers were completed in multiple model layers, excluding their use as layer-specific observation wells. Second, the nature of aquifer materials represented in these layers probably is more consistent (interbedded sand, silt, and clay, with increasing finer-grained sediments with depth) than overlying layers. Thus, K_h and K_v parameters for model layers 3 and 4 were tied together because of the relatively small number of water level data points in these lower model layers.

5.5. Calibration Observations

Calibration observations included (1) ground water levels based on mass ground water level measurements (Petrich and Urban, 2004) and (2) estimated or observed vertical differences in potentiometric surface. The steady-state calibration was conducted based on 1996 water levels, which coincides with water budget estimates for this same year.

5.5.1. Ground Water Levels

The 1996 spring and fall mass measurements (Petrich and Urban, 2004) included 339 and 331 wells, respectively. Candidate wells for the mass measurement were selected by the USGS from the USGS Ground Water Site Inventory (GWSI) database. Criteria for observation well selection included (1) available drillers' reports, (2) completion depths falling within the layer intervals, and (3) horizontal and vertical distribution (where possible) throughout the model domain. Several wells with screen openings spanning both layers 3 and 4 were used as observation wells because they were located in areas with few observation alternatives.

[14] Two layers were used in the lower portion of the model to allow future parameter and/or flux variations.

Not all observations taken during the mass measurement were used for calibration for several reasons. First, several of the measurements were made in areas that were later removed from the model domain (e.g., Boise Foothills). Second, wells that were located in the half of a cell adjacent to an exterior boundary were excluded (or moved to the interior half of a cell) because of errors incurred by GMS's spatial interpolation function by which cell heads were calculated based on surrounding grid nodes. Third, a number of observations appeared to represent suspect data caused by active pumping or other reasons.

Finally, a number of shallow wells were located in areas where drains are present (see Section 4.4). Measurements from these wells were given a calibration weight of zero because the water levels in these wells were at or above drain elevations. Water level data in areas where topography was actively controlling the water table are not appropriate for estimating hydraulic conductivity because the water level (i.e. hydraulic gradient) reflects the topography (or drain elevations), not aquifer characteristics[15]. Furthermore, water levels from shallow wells near drains can confound model calibration because PEST attempts to force the model to match these water level elevations but cannot match them because the simulated drains siphon away water that is above the drain elevations. Non-zero calibration weights for these wells would have caused a contribution to the objective function that would have been impossible for PEST to reduce. In the end, 200 observations with weights greater than zero were used for model calibration (Figure 5-1 through Figure 5-3, and Appendix C). These are shown in Figure 5-1 through Figure 5-4.

Water levels vary throughout the year in response to well withdrawals, nearby pumping, and/or seepage from surface water and irrigation. Of 284 project observations (not all of which were used for calibration), 154 wells experienced a water level rise between the spring and fall mass measurement, 106 wells experienced a water level decline, and the remaining wells experienced no change (Table 5-1). With five exceptions, average water levels between spring and fall measurements were taken for each well for the simulation under steady-state hydraulic conditions. The spring measurements for 5 wells in layer 4 were used instead of an average because (1) these wells were not measured in the fall, and (2) elimination of these wells would have meant a substantial reduction in observations in layer 4.

[15] Darcy's law implies describes the relationship between flow, hydraulic conductivity, and hydraulic gradient: $q = K\frac{\partial h}{\partial L}$, where q is unit flow, K is hydraulic conductivity, and $\frac{\partial h}{\partial L}$ is the hydraulic gradient. The purpose of the calibration is to estimate K on the basis of the hydraulic gradient. If the hydraulic gradient is controlled by ground surface (i.e., drain elevation), then the observation is not necessarily appropriate for use in model calibration.

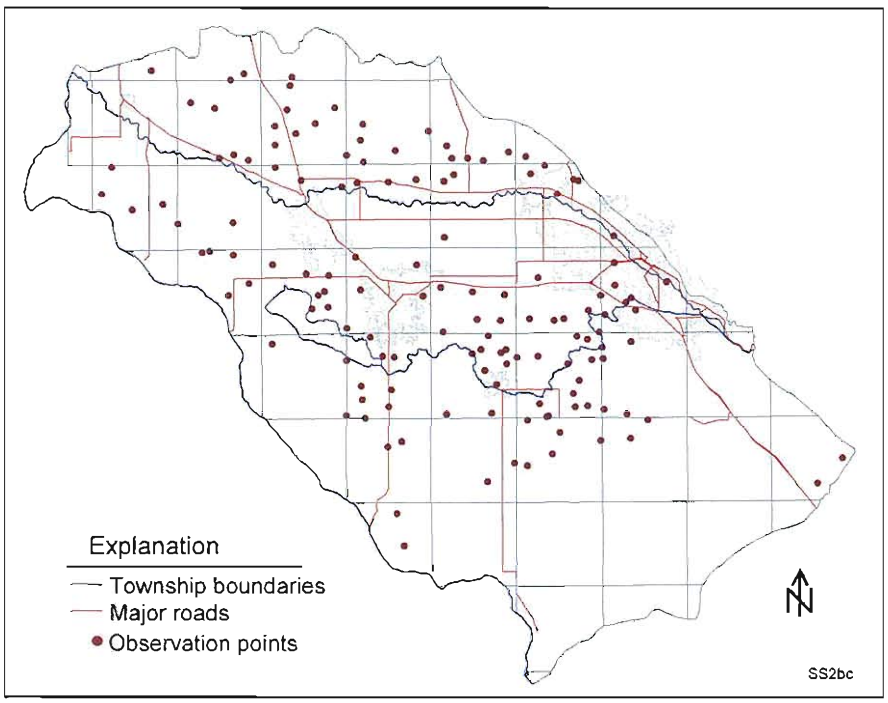

Figure 5-1: Locations of water level observations, layer 1.

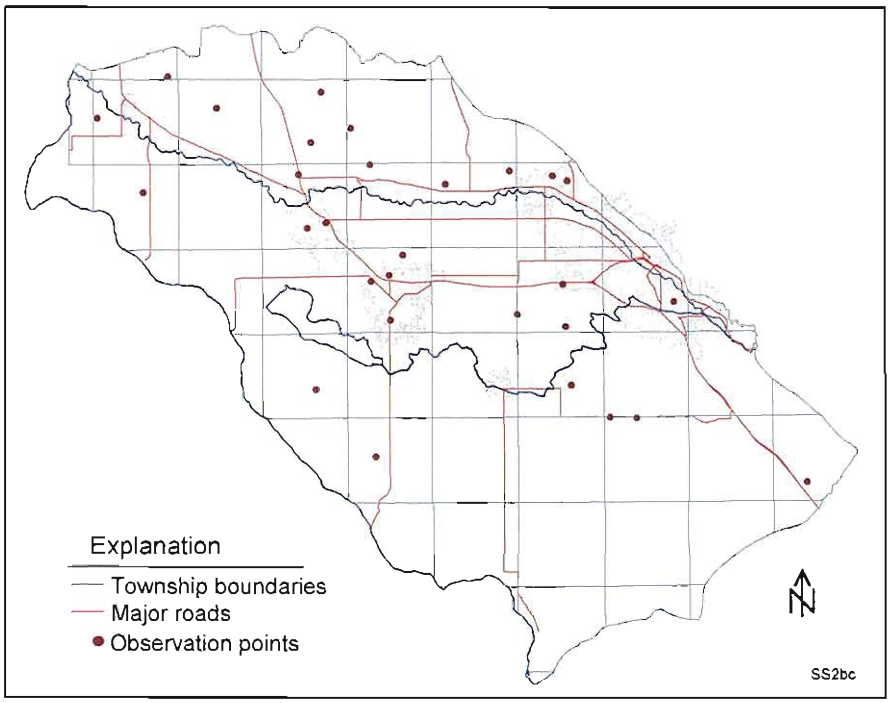

Figure 5-2: Locations of water level observations, layer 2.

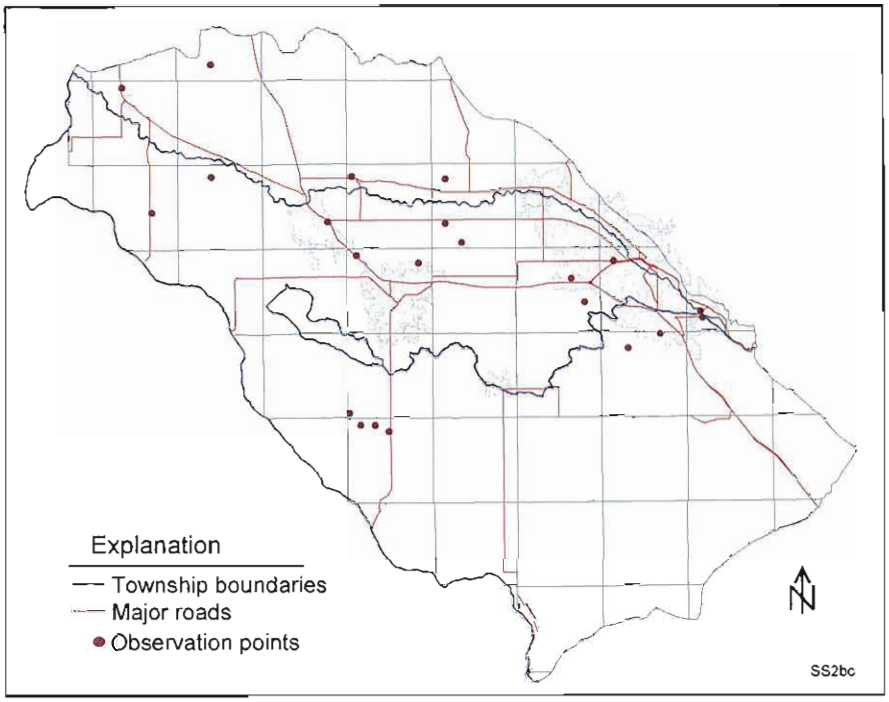

Figure 5-3: Locations of water level observations, layer 3.

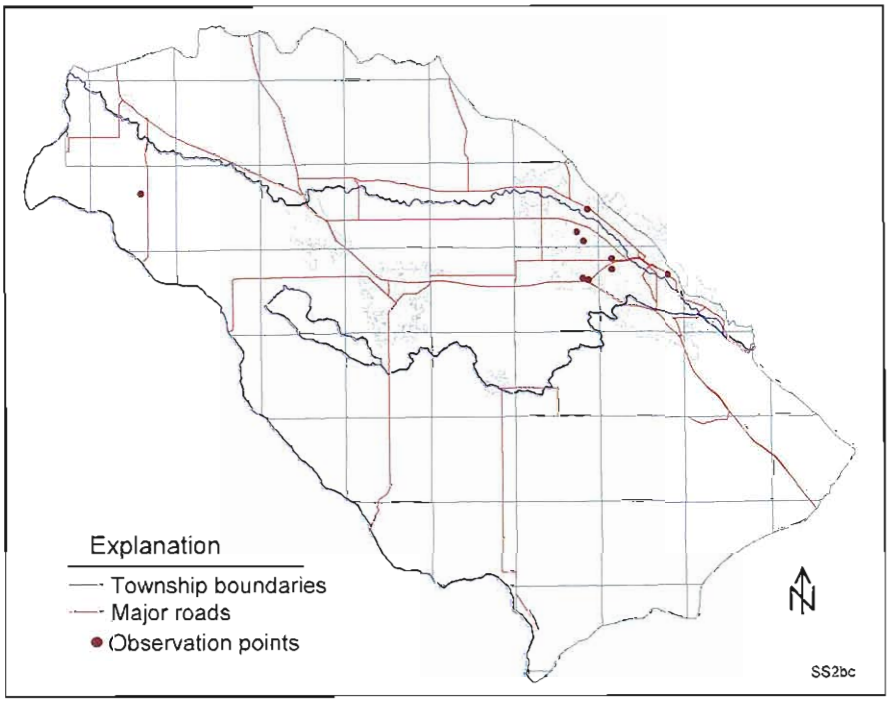

Figure 5-4: Locations of water level observations, layer 4.

Parameter	Value
Total number of wells	284
Observations with weight > 0	200
Number of wells increasing in water level (weight > 0)	93
Maximum water level increase from spring to fall	48 ft
Median water level increase	3 ft
Percentage of wells with less than 10 ft increase	82.8 %
Number of wells decreasing in water level	91
Maximum water level decrease from spring to fall	-45 ft
Median water level decrease	-3 ft
Percentage of wells with less than 10 ft decrease	81.3 %

From "Final 1996 obs Data.xls"

Table 5-1: Statistics for water level changes in observation wells between the spring and fall mass measurements, 1996.

The quality of model calibration depends, in part, on potential errors associated with the calibration data. Water level measurements taken by the USGS generally have an accuracy of ±0.01 foot. However, other potential errors may influence model calibration. Potential sources of error associated with the water level observations include the following:

1. Ground surface elevations used for calculating water level elevations were taken either from 7.5-minute topographic maps or resource-grade global positioning system (GPS) device. This may have contributed to elevation errors at least as great as 10 feet.
2. Errors may have occurred during water level measurement, although USGS protocols are intended to minimize measurement error.
3. Errors may have occurred in identifying the spatial location of a well.
4. Recent pumping may have influenced water levels in some wells. The USGS reduces the risk of inadvertently measuring water levels immediately after a pump shuts off by taking two measurements in succession. The measurement is recorded if the measurements are within 0.01 foot of one another. Despite precautionary measures, water levels may reflect long-term drawdown or influence from nearby wells.
5. An inaccurate water level reading may result in artesian wells if the measured well is currently flowing or has recently flowed or if a nearby well is flowing or has recently flowed.
6. An inaccurate drillers' report may result in water level measurements from a well being attributed to an incorrect model layer.
7. Interpolating observation point measurements to node locations (locations at which heads are simulated) may introduce some interpolation error, particularly near the model boundary where head gradients are high, and near sources of significant recharge/discharge (e.g., near pumped wells and leaking channels) where there may be curvature of the potentiometric surface.

8. Error may be introduced because water levels in some wells represent a composite value of hydraulic head over a vertical distance (depending on the screened interval of the well), while the model simulates a single head value that represents an average over the thickness of a model cell.
9. Finally, calibration data quality is influenced by grid design. Water level measurements represent hydraulic head at a point – the well – and simulated heads represent an interpolated average over an entire grid cell. The larger a cell, the greater the potential for differences between a measured water level and the simulated head for the same location. Again, the potential error is greatest for areas in which the water levels vary spatially (i.e., steeper horizontal hydraulic gradients), such as along the Snake River.

Flux data, such as aquifer discharge measurements, may be useful for model calibration. Some reach-gain estimates are available for the Boise and Snake Rivers (Table 5-2). However, the individual contributions from ground water discharge to river and streams, irrigation returns, or the contributions of ground water discharge to drains have not yet been determined (the USBR is compiling these data as part of the TVHP, but the data were not available at the time of model calibration).

Component	Estimated flux (af/yr, 1996)
Discharge to Boise River *Includes direct ground water discharge to the Boise River and flows from drains. The flows from drains includes both irrigation return flows and ground water discharge to drains.*	523,200
Discharge to Snake River *Includes direct ground water discharge to the Snake River and flows from drains. The flows from drains includes both irrigation return flows and ground water discharge to drains. Estimated discharges entering the south side of the Snake River have been excluded.*	290,800
Total discharge to rivers and drains	814,000

From Urban and Petrich (1998)

Table 5-2: Summary of discharge to the Boise and Snake Rivers.

5.5.2. Vertical Gradient Measurements and Observations

Vertical differences in water levels can be used in a model to help calibrate vertical hydraulic conductivity estimates. There is abundant anecdotal information regarding vertical head differences in the Treasure Valley based on observations while drilling wells. Substantial, areally-extensive, subsurface, fine-grained sediments associated with lacustrine depositional environments contribute to confined-aquifer conditions.

However, relatively few reliable vertical gradient data are available. Exceptions include the multiple-completion monitoring wells installed as part of the TVHP. The

two deepest project wells with multiple vertical gradient data (Petrich and Urban, 2004) are in Caldwell and Boise's Municipal Park (Figure 2-5). The vertical head difference in the Caldwell well ranged from 35 to 41 feet (upward gradient) with an average of 37 feet between November 30, 1999, and June 20, 2001. Water levels in the Boise Municipal Park monitoring well ranged from 15 to 61 feet (downward gradient) with an average of 28 feet between July 29, 2002, and April 24, 2003. The lower summer water levels in the deeper Boise Municipal Park well piezometers probably reflect impacts from summer irrigation withdrawals in nearby wells.

Six vertical gradient "observations" were established to help calibrate vertical hydraulic conductivity. These "observations" (Figure 5-5) included (1) real data collected in the Caldwell monitoring well and (2) synthetic values based on anecdotal water level information. Downward water level differences of 35 feet are not uncommon in the eastern portion of the valley; 40-foot upward differences are not uncommon in the central and western portions of the valley (E. Squires, pers. comm., 2000). Thus, six vertical gradient observation points were specified: (1) three observations with a difference in 40 feet (upward gradient) between model layers 1 and 4; (2) two observations with 30 feet (upward gradient); and (3) one observation with a downward gradient of 30 feet. All but those shown at location "Grad 6" represented synthetic points[16].

[16] These "observation" estimates were made prior to the construction of the Boise Municipal Park monitoring well. The Municipal Park well indicated vertical water level differences consistent with the assumed 30-foot downward gradient represented by "Grad 6" (Figure 5-5).

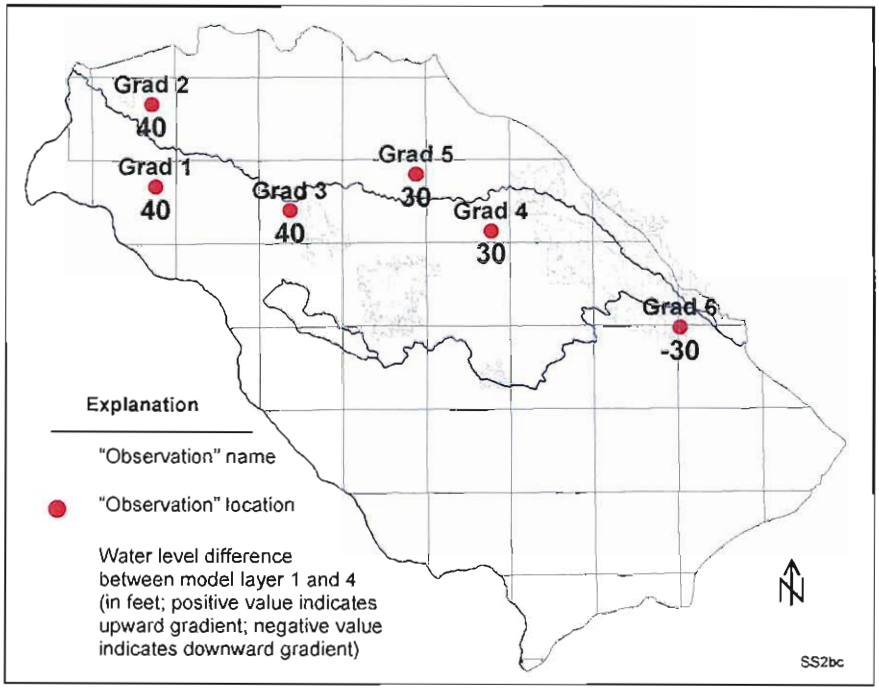

Figure 5-5: Vertical gradient "observation" locations.

5.5.3. Observation Weights

Calibration data were assigned weights in the PEST control file. Theoretically, the weights are inversely proportional to the standard deviations of the field measurements to which they pertain (Doherty, 2000). In this case, all weights for head observations were made equal (with a value of 0.196). All hydraulic head differences were given a weight of 25.0.

The weights for the vertical head differences were a somewhat subjective choice. The vertical head differences were given a substantially greater weight than water levels for the following reasons (Doherty, 2003):

1. There were fewer head differences used in the observation dataset than direct head measurements. A weight of 25.0 allowed the total contribution of vertical head differences to roughly equal the total measurement head differences in the objective function. This allowed better estimation of parameters to which these head differences are most sensitive (e.g., vertical conductivities), as the objective function was not "dominated" by general water level residuals to which these parameters were very insensitive.
2. It is likely that the errors associated with head measurements in different layers are correlated. This is an outcome of both the measurement procedure (including the fact that well reference elevation errors affect both of these heads equally when heads are measured for different layers in the same well)

and "model structural error" (i.e., the inability of the model to represent every detail of system behavior), which tends to affect model-generated heads in overlying layers in the same way. This results in correlation between measured heads in neighboring layers. The variance of a head difference is thus represented by the formula:

$$\sigma^2_{h1\text{-}h2} = \sigma^2_{h1} + \sigma^2_{h2} - 2\sigma_{h1,h2}$$

where the last term is the correlation between the two individual measurements. This can be as large as the variance of the measurements themselves, resulting in a relatively small value for $\sigma^2_{h1\text{-}h2}$, hence requiring that it be assigned a higher weight in the inversion process.

3. The head differences assigned to a particular location within the model domain were intended to represent average head differences over broader area, and thus, can accommodate the use of a higher weight.

5.6. Parameterization using a Pilot Points Regularization Scheme

The use of too many model parameters may lead to numerical instability or non-uniqueness of parameter estimates. To reduce the number of parameters, a model is sometimes divided into a number of zones with assumed parameter homogeneity in each zone. Individual zones might be designated based on common geological or hydrological characteristics. This was attempted in early simulations with the Treasure Valley model. However, there is little basis for areal zone boundaries in the Treasure Valley because of the nature of lacustrine deposition over much of the area. Faulting might represent a basis of zonation, but many fault locations have not yet been identified, and many of the known or suspected faults may not extend throughout the entire stratigraphic sequence. Furthermore, use of zones may result in abrupt parameter transitions for which there is no physical justification.

A related problem with highly parameterized systems (i.e., a large number of parameters) is that individual parameter estimates may show a large degree of spatial variability. Calibration by trial-and-error or with a parameter estimation code may result in individual simulated parameter value variations to accommodate nuances in an observation data set, even though the nuances may merely represent "observation noise."

PEST includes an option for regularization that imposes a smoothing constraint on parameter values (Doherty, 2000). The regularization consists of defining preferred relationships ("prior information") between pairs of parameter values and then attempting to minimize variations from these preferred relationships. In particular, PEST seeks to minimize the (1) measurement component of the objective function (e.g., sum of the squared differences between simulated and observed values) and (2) variation between the preferred relationships necessary to minimize the measurement component of the objective function.

The extent to which parameter smoothing is enforced at the cost of reducing the amount of model-to-measurement misfit is dictated by a "regularization weight factor". The regularization weight factor is calculated by PEST as part of the regularized inversion process. This weight factor can be considered as the Lagrange multiplier in a constrained optimization problem (Doherty, 2003). In this problem, PEST was asked to minimize the "regularization objective function" (i.e., maximize the extent of parameter smoothing) subject to the constraint that the measurement objective function (which is inversely proportional to the degree of model-to-measurement misfit) falls no lower than a certain user-specified value. This value was set high enough to prevent PEST from estimating parameters that reflect observation noise rather than data. Thus, when used in "regularization mode," PEST gave priority in choosing parameter values to those which maximized model-to-measurement fit but did not obtain a better fit than was deemed appropriate.

In general, if a preferred level of fit cannot be obtained because the level of observation noise (or model structural error) is greater than anticipated, PEST will still allow estimation of many parameters. It does so by using the regularization process to obtain the best fit achievable, with as smooth a parameter set as can be calculated to achieve it under numerically stable conditions.

The prior information used in the regularization process has a role in the model calibration similar to that of measured observations, and consequently increases the number of parameters that might otherwise be calibrated because of the higher information content available for use by the calibration process. Regularization can make insensitive parameters (e.g., parameters distant from field measurements) more sensitive because of relationships between parameters that are enforced as part of the calibration process.

Regularization should include a substantial number of relationships between most or all of the parameters involved in the parameterization process and should encapsulate some "preferred state" of the system. Deviations from this preferred state, (e.g., non-zero differences between parameter pairs) are tolerated only to the extent that they allow the model to provide an acceptable fit to field measurements (Doherty, 2000). Homogeneity conditions were the most common preferred state for Treasure Valley model parameters. Prior information was used to keep values for similar parameters (e.g., K_h) within a layer the same unless individual parameter variation was necessary to reduce local measurement residuals.

Regularization can be applied to individual parameters, parameter zones, or pilot points. Calibration using individual parameters, especially if based on individual MODFLOW cells, would generally exceed even the most robust data sets available for most ground water simulations. Calibration using parameter zones, if not based on specific geologic or hydrogeologic characteristics, may result in abrupt parameter value transitions at zone boundaries. Also, the use of a limited number of parameters prevents the parameter estimation process from extracting maximum information from

the dataset used in the calibration process. Calibration with pilot points is a parameterization scheme in which parameter values are estimated for a series of points within the model domain. Values from these points are then spatially interpolated before each model run to individual model cells using kriging or some other spatial interpolation method (Doherty, 2000). Regularization using prior information can then be used to limit the degree of spatial parameter variation between pilot points; this was the approach taken in the Treasure Valley model.

Locations for pilot points used in the calibration of the Treasure Valley model (Figure 5-6) were established using three general criteria. First, pilot points were placed throughout the areas of greatest interest. Second, pilot points were placed in the vicinity of observation points so observation information could guide parameter estimation.

Finally, a number of pilot points were placed near model boundaries to help estimate parameter values near the boundaries. Although lack of observation data in these areas prevented robust estimation of these parameters, values were estimated through the regularized inversion process undertaken by PEST. Parameters represented by these pilot points were estimated on the basis of smoothing relationships between them and parameters closer to the center of the model domain, where more data were available for estimation of parameters.

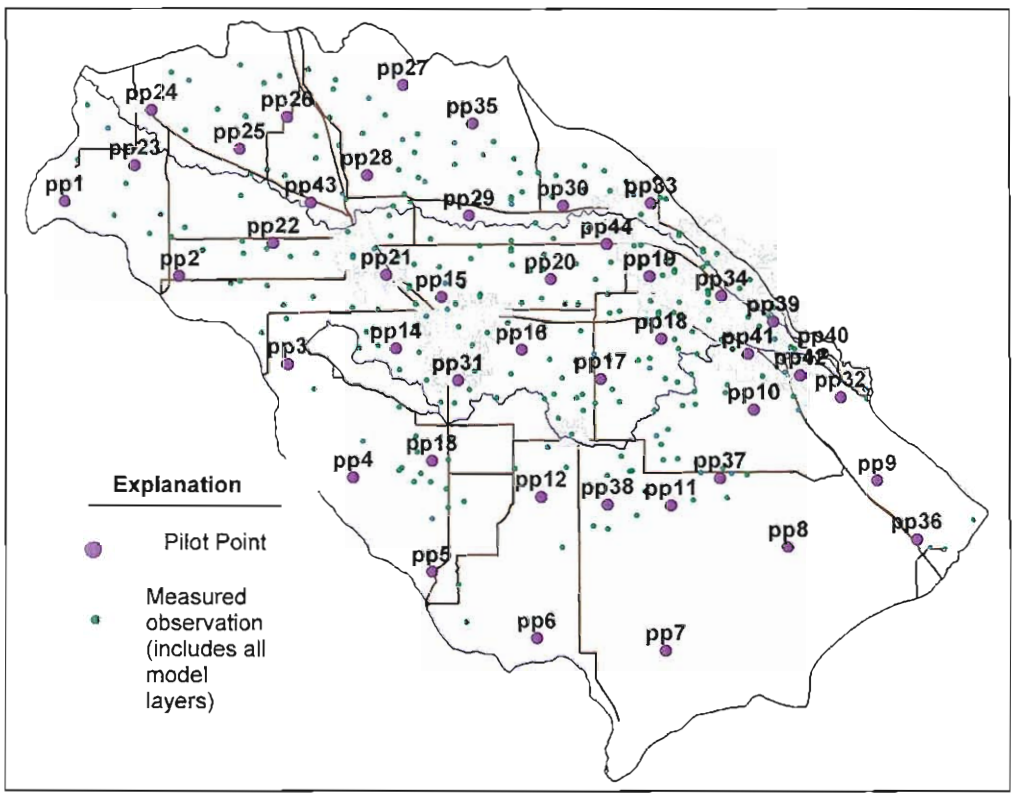

Figure 5-6: Distribution of pilot points.

The use of pilot points and regularization led to the estimation of 270 model parameters (Table 5-3), consisting of K_h and K_v, at each pilot point for model layers 1 through 4. Of these, some parameters were tied together and were calibrated in groups to further reduce the number of parameters requiring estimation. Tied parameters, if all in one area, form *de facto* parameter zones. However, the boundaries are not as discrete as those of the parameter zones normally employed in the calibration process because of the pilot point spatial interpolation. Areas with tied K_v values are shown in Figure 5-7and Figure 5-8. Data describing spatial variations in K_v, especially in deep layers, were unavailable. Geologically, it seemed reasonable to assume that K_v values of fine-grained materials associated with large-scale lacustrine deposition would not vary greatly over some subareas. This reduced the number of parameters requiring estimation to 149 (Table 5-3). This number of parameters is insufficient to define all heterogeneities within the flow system (such as heterogeneities caused by faulting, basalt intrusions, and basalt flows). However, the number of parameters was thought reasonable given the amount and resolution of subsurface data describing large-scale aquifer heterogeneities and the amount of observations available for model calibration.

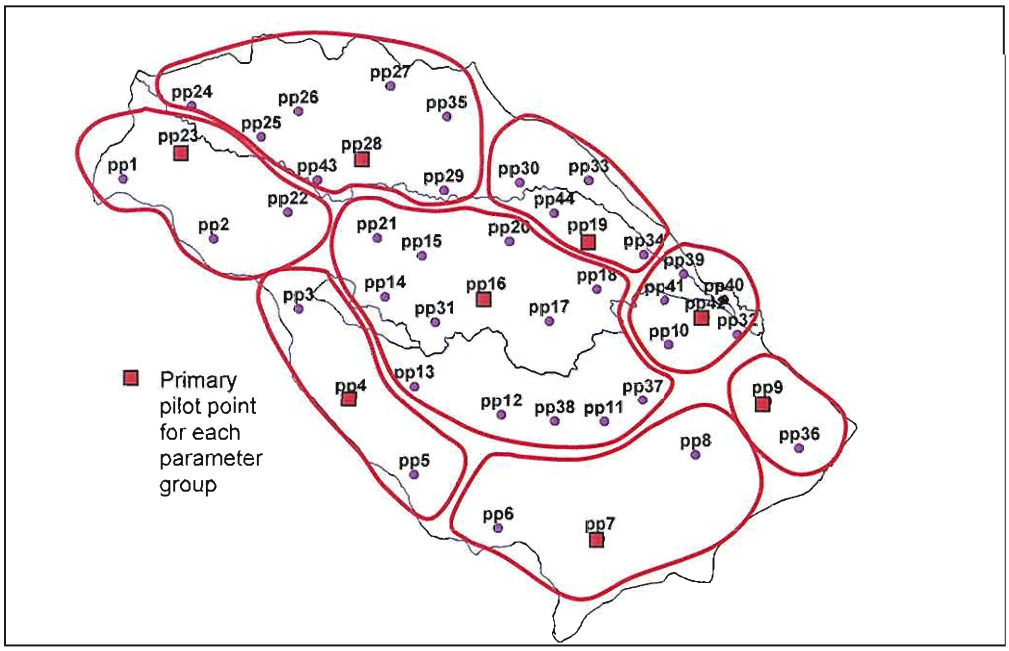

Figure 5-7: Tied K_v parameters in layer 1.

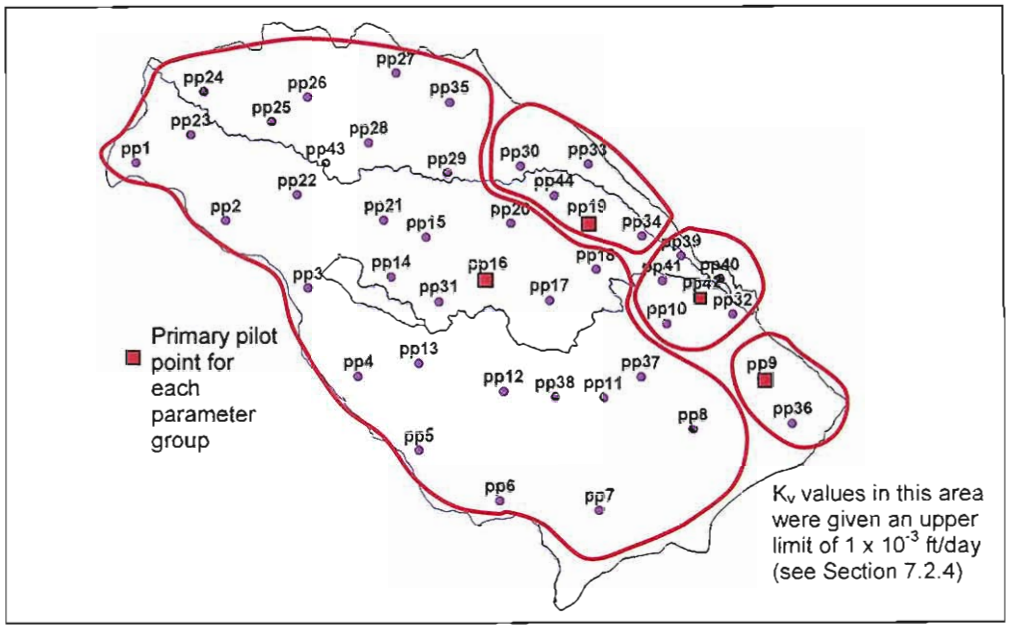

Figure 5-8: Tied K_v parameters in layers 2 and 3.

Parameter	Total Number of Parameters	Number of Tied Parameters	Comments
Layer 1 K_h	44	1	
Layer 2 K_h	44	2	
Layer 3 K_h	44	2	
Layer 1 K_v	44	36	Individual pilot point parameters tied to one of the following: PP4, PP7, PP9, PP16, PP19, PP23, PP28, and PP42
Layer 2 K_v	44	40	Individual pilot point parameters tied to one of the following: PP9, PP16, PP19, and PP42
Layer 3 K_v	44	40	Individual pilot point parameters tied to one of the following: PP9, PP16, PP19, and PP42
Underflow	6		Fixed values
Total Parameters	270	121	

See Sections 4.2 and 8.3.

Table 5-3: Parameter distribution (Simulation *SS2bc*).

There are several spatial interpolation options available with PEST (as separate utilities) for interpolating pilot point parameter values to model cells. Kriging was used for the Treasure Valley model calibration. The kriging parameters (variogram model, range, sill, search radius, transform, etc.) are specified in a control file. Some of these parameters can be estimated through the calibration process if desired, or they can be specified in the calibration. In this case, the variogram was fit using an

exponential model with a nugget of zero. The search radius was estimated through the calibration process but was found to be relatively insensitive. Thus, in most PEST runs the search radius was assigned a fixed value of 150,000 feet. The variogram sill has no effect on the spatial interpolation process.

5.7. Objective Function

PEST adjusted specified model parameters (Section 5.4) on an iterative basis until the primary objective function was minimized to a specified value or until a specified number of iterations were exceeded (generally 50 iterations). The primary objective function (Φ) consisted of two components: (1) the regularization objective function and (2) the measurement objective function. The regularization component consisted of the sum of squared differences between parameter differences and preferred values (Section 5.9) for these differences (zero in all cases). The measurement objective function consisted of two sub-components. The first sub-component consisted of the sum of the squared differences between measured and simulated water level observations. The second sub-component (the vertical gradient component) consisted of the sum of the squared differences between measured and simulated vertical head differences.

Targets set for the objective function in regularization mode (variable *PHIMLIM*) influenced the base calibration. Setting the target too low forced PEST to manipulate parameter values at pilot points by creating heterogeneities into the model domain that may or may not exist. This would be done at the expense of reducing the regularization constraints (increasing the regularization component of the objective function). There are two ways to limit the amount of unrealistic parameter distortion required to calibrate the model. The first is to set an objective function target that is not too low (a judgment call based on initial simulations). The second is to limit the number of iterations that PEST can use to meet the objective function target.

5.8. Initial Values

Initial parameter values are shown in Table 5-4. The initial values for K_v and K_h are not particularly relevant because the simulations are conducted under steady-state hydraulic conditions. The upper and lower parameter value limits were used to constrain the calibrated parameter values to "reasonable" values based on an anticipated mix of aquifer sediments within a given layer thickness. The upper limits on parameter values are consistent with gravel sediments (Freeze and Cherry, 1979). The lower limits are consistent with silt sediments; the lower limit value for K_v is consistent with marine clay.

5.9. Prior Information

Prior information consists of preferred relationships between pairs of parameter values (Section 5.6). The basis for these relationships is information that is not necessarily represented in other calibration observations. For instance, differences between individual K_v values may be minimal over large areas of lacustrine sediments. Prior information indicating that K_v values may be the same throughout a given area adds information to the model calibration that is not added in other ways. PEST (Doherty, 2000) attempts to minimize the deviation from the preferred relationships, deviating only if necessary to reduce the primary measurement component of the objective function.

Parameter	Units	Initial Value	Lower Limit	Upper Limit	Comment
Horizontal hydraulic conductivity (K_h)	ft/day	10	0.001	1,000	Fixed, tied, or log value[(a)]
Vertical hydraulic conductivity (K_v)	ft/day	0.1	1×10^{-8}	1,000	Fixed, tied, or log value[(a)]
Range[(b)]	ft	150,000	50,000	2×10^6	Fixed
Underflow[(c)]	ft^3/day	5,000	100	50,000	Fixed
Notes:					
(a) See Table 5-3.					
(b) Refers to the search radius used in calculating variograms for spatial interpolation of pilot point parameter values (Doherty, 2000).					
(c) See Figure 3-5 for locations of underflow cells.					

Table 5-4: Initial parameter values.

The primary objective function contains measurement and regularization components (Section 5.7). At the beginning of a calibration, the regularization objective function began with a value of zero and increased as prior information relationships were altered to reduce the measurement objective function. Prior information components (Table 5-5) are listed in the PEST control file (**.pst,* Section 5.10). The objective function values were printed for each PEST iteration in its run record file (**.rec*).

Prior Information (preferred-state homogeneity relationships)	Prior Information Variable Names	Number of Prior Information Relationships
Attempt to keep K_h values in layer 1 the same	ppreg1 – ppreg946	903
Attempt to keep K_h values in layer 2 the same	ppreg947 – ppreg1892	861
Attempt to keep K_h values in layer 3 the same	ppreg1893 – ppreg2838	861
Attempt to keep K_h values in layer 1 the same as those in layer 2	pvh1 – pvh44	42
Attempt to keep K_h values in layer 2 the same as those in layer 3	pvhb1 – pvhb44	42
Attempt to keep keep K_v values in layer 2 the same as those in layer 3	pvvb16, pvvb42 – pvvb44	5
Attempt to keep K_v values in layer 1 the same	Pvlat13 – pvlat39	27
Attempt to keep K_v values in layer 2 the same	Pvlat4 – pvlat6	3
Attempt to keep K_v values in layer 3 the same	Pvlat10 – pvlat12	3
	Total	2,747

Table 5-5: Prior information in steady-state simulations.

5.10. Calibration Input Files

PEST requires three types of input files: template files, instruction files, and the PEST control file. PEST uses one template file (**.tpl*) for every model input file that contains parameter values to be adjusted through the parameter estimation process. Instruction files (**.ins*) guide PEST to locations in model output files for reading specific output data. The PEST control file (**.pst*) supplies the names of all template and instruction files and corresponding model input/output files. The control file also gives PEST the model name (or a batch file that runs one or more models or utilities), initial parameter estimates, observations, prior parameter information, and PEST variables that control the calibration.

PEST can be used to calibrate any model using ASCII input and output data. Consequently, files used by the calibration process include those that are specific to the model and specific to the particular calibration exercises that are being undertaken. A calibration includes files that are unique to the particular simulation being calibrated. Files used for this Treasure Valley steady-state model calibration are listed in Appendix D. Some of the files are required by the PEST code, some are MODFLOW or GMS files, and some are utility files. More detailed file descriptions of the PEST files are available in the PEST manual (Doherty, 2000). Files produced in a Treasure Valley model calibration are listed in Appendix E.

5.11. Processing Calibration Results

The calibration process results in a number of PEST and model files (Appendix E). The steps taken in processing a typical calibration run are outlined in Table 5-6.

	Process	File
1.	Check for "dry" model cells.	MODFLOW output file (**.out*)
2.	Check percentage discrepancy in the volumetric budget .	
3.	Load head values into GMS, view in map and cross-section views.	MODFLOW head file (**.hed*)
4.	Review optimization record; check objective function ($\phi_{measurement}$ and ϕ_{regul}) values, check "optimization results".	PEST run record (**.rec*)
5.	Review highest and lowest eigenvalues *As a rule of thumb, the highest and lowest values should be within 7 orders of magnitude (Doherty, pers. comm., 2001).*	
6.	Review high eigenvalues and identify correlated parameters. *Eigproc.exe is a utility that provides eigenvector values for high eigenvalues.*	PEST run record (**.rec*); eigproc.exe
7.	Review parameter sensitivity values. *The larger the sensitivity value, the more sensitive the calibration is to the parameter, and hence, the better the estimate of that parameter is likely to be. Conversely, the smaller the number, the less sensitive the calibration is to this parameter, and hence, more uncertainty will normally be associated with estimates of that parameter.*	PEST parameter sensitivity file (**.sen*)
8.	Plot head values. *This can be done in a variety of ways. The head values illustrated in this report were loaded into GMS, exported as ASCII data files, loaded into "HeadProcessor.xls" in which values are distributed to separate worksheets by layer, and then graphed in Surfer™ (eliminating all values of z = -999).*	**.hed* HeadProcessor.xls Runname Heads.xls Sim Head.lvl
9.	Plot residual values. *1. Copy the residual data from run record file into SS residuals.xls, process the residual data, and create Surfer™ grid files. Review "print page" data.* *2. In Surfer™, open Grid, Data, select file, set columns, open Grid Blanking, select Active.bln, save as grid file (e.g., run_name L# res.grd).* *3. Map contours in Map menu; use "ResCont.lvl" for contour fills.*	PEST run record (**.rec*) SS Residuals.xls
10.	Plot K_h and K_v distributions. *The batch file "real2surf.bat" runs "real2srf.exe, which uses the *.ref files created during a MODFLOW run to create .grd files for Surfer™. Contour maps can then be created with Surfer™ using the "K Distribution.lvl" file to color-fill the contours.*	real2surf.bat runs real2srf.exe, requiring the following files: kh1.in; kv1.in; kh2.in; kv2.in; kh3.in; kv3.in tvm.spc kh1.ref; kv1.ref; kh2.ref; kv2.ref; kh3.ref; kv3.ref

Table 5-6: Simplified outline for simulation/calibration review.

6. MODEL ASSUMPTIONS AND LIMITATIONS

There are many assumptions, limitations, and potential errors associated with the numerical simulation of ground water flow (Table 6-1). These assumptions and limitations should be kept in mind when reviewing model results.

There are several specific potential sources of error in this Treasure Valley model. First, there is a high degree of geologic uncertainty throughout the system. Many strata, although substantial, are not spatially continuous over the model domain. While it is clear that there are shallow and deep aquifers, with markedly different flow characteristics, residence times, and recharge rates, there are not clearly identifiable strata that separate these aquifers over the entire model domain. There are some areas within the model domain with little or no hydrogeologic data (e.g., southern Ada County) because few or no wells have been drilled in these areas. Horizontal and vertical aquifer heterogeneity is seen in lithologic, chemical, and aquifer test data. In addition, faulting can and does influence ground water flow. The locations of some faults are known or have been inferred. Offsets of some of the faults appear to be greater than 800 feet, but the hydraulic influences of most faults are unknown.

Second, flux rates at boundaries are unknown. There is substantial uncertainty in the estimates of underflow into the model domain. Streambed and drain conductances are unknown, as are lakebed conductance values.

Third, parameter uncertainty is high in some portions of the model domain because of the lack of observation data (again, because there are few wells in some portions of the model domain). In general, there are fewer deep wells than shallow wells, and the distribution of deep wells is limited primarily to more highly populated areas. This limits the number of observation points for deeper aquifers in some portions of the model domain.

Observation data were collected from a variety of wells. Some are clearly influenced by ground water pumping, either from within the observation well or from nearby wells. The elevations of some of the wells are known only within general limits (e.g., ±10 feet). Spatial discretization of areas with substantial variations in potentiometric surfaces (e.g., drawdown) can lead to model errors. Some water level measurements from shallow wells, if influenced by surface drainage, may lead to model calibration errors (these were removed where surface influences were recognized).

The water table elevation in some parts of the model domain is controlled by the elevation of land surface. The water table elevations in these areas do not contain information for estimating hydraulic conductivities in these areas, leading to high uncertainty in local K_h estimates.

Category	Potential Limitations, Assumptions, and Errors
Potential conceptualization errors	Incorrect flow system conceptualization
	Incorrect application of numerical approach
	Incorrect layer and/or grid definitions
	Errors in assumed boundary conditions
	Errors in parameter regularization assumptions
Basic ground water flow assumptions required for using MODFLOW	Ground water flow does not meet Darcian flow assumptions, which include the following: flow is laminar, fluid is incompressible, fluid density is constant, gravitational acceleration is constant, and water movement is caused mechanical (e.g., hydraulic) gradients.
	Borehole storage is negligible.
	There is no change in hydraulic characteristics with respect to degree of saturation.
Limitations and assumptions associated with the discretization of space and time	Grid resolution is inappropriate for model objectives.
	Simulated head values are based on heads in surrounding nodes; steeply sloping and/or non-linear heads (or other dependent variable) and may not be accurately represented by finite difference grid.
	Aquifer characteristics, inflows and outlows, and other properties are assumed to be constant within a grid cell.
	Flux characteristics are assumed to be constant within time steps.
	Hydraulic properties are assumed to be constant in time.
	Wells are assumed to be fully penetrating in assigned layers.
	Simulated observations are averaged over too large an area (this may be a concern if water level observations are based on wells experiencing substantial drawdown). Model grid is not fine enough to reproduce head curvature in the vicinity of lines and points of groundwater extraction and inflow.
Potential causes for numerical errors	Model cells go dry
	Incorrect solution closure criteria
	Truncation error, roundoff error
Potential model input errors	Errors in recharge package inputs (e.g., data errors, interpolation errors, etc.)
	Errors in well package inputs (e.g., data errors, interpolation errors, etc.)
	Errors in drain package inputs (e.g., data errors, interpolation errors, etc.)
	Errors in river package inputs (e.g., data errors, interpolation errors, etc.)
	Errors in general head boundary package inputs (e.g., data errors, interpolation errors, etc.)
Potential observation measurement errors	Physical measurement errors
	Water levels influenced by pumping in observation well
	Water levels influenced by nearby pumping
	Water levels observation based on approximated or incorrect well elevation

Table 6-1: Sources of possible error leading to parameter uncertainty.

The nature of the steady-state simulations also contributes to parameter uncertainty. Flux data (e.g., recharge, withdrawals, etc.) are averaged over an entire year, even though the stress may occur only during one season (e.g., irrigation season). Observation data for the steady-state simulations also consisted of averaged water levels based on 1996 spring and fall measurements.

Calibration errors can result from incorrect parameterization, assignments of pilot point locations, and parameter regularization relationships. Parameter non-uniqueness and/or correlation can also lead to calibration errors. Some indication of parameter uncertainty is given during the calibration process. PEST output includes parameter sensitivity values, which are strongly influenced by parameter correlation. However, it is important to remember that some parameter values may be highly uncertain but not relevant to a particular model prediction. Predictive analysis (Doherty, 2000) is probably a more useful approach (Section 9) for evaluating a scenario in the context of various parameter uncertainties.

It is also important to note that no ground water model can be calibrated without some form of implicit or explicit regularization. Regularization is the process by which model parameterization is simplified to the extent that parameter estimation can take place. Where zones are used, regularization is implicit. Where PEST's regularization functionality is used, regularization is explicit, with regularization constraints enforced to the extent necessary (through calculation of an appropriate regularization weight factor). In either case, the complexity of the parameter estimation problem is reduced to a level that is compatible with the information content of the data used for calibration. The less observation data, the greater the role of regularization in the calibration process.

The parameter field that results from the calibration process cannot be considered the "true" hydraulic property field prevailing within the model domain – even if the fit between model outputs and field data is perfect. It is one of many possible parameter fields that could fit the data. Where PEST's regularization functionality is used, it is the smoothest of all these fields; where zones are used, it is the "blockiest" field. In either case, the calibrated field cannot reflect small- or even medium-scale heterogeneity of true aquifer hydraulic properties; these are simply beyond the ability of the calibration process to capture.

In general, where model predictions depend on regional or averaged hydraulic properties, this model's performance should be relatively good. Where model predictions depend on local detail, use of this model may result in error or a higher degree of uncertainty.

7. CALIBRATION RESULTS

7.1. Introduction

This section presents a set of model calibration results for steady-state hydraulic conditions. Calibration results are presented in the form of (1) objective function values and other PEST output, (2) mass balance results, (3) comparisons between simulated and observed water levels, (4) comparisons of simulated and observed potentiometric surfaces for each model layer, (5) spatial distribution of K_h and K_v values, (6) distribution of residuals (difference between measured and simulated observations) values, and (7) simulated vertical ground water flow rates.

7.2. Steady-State Calibration Results

Model construction, testing, and calibration invariably result in a large number of simulations. The simulation[17] described in this section was the product of many model development runs and was considered a "base run" for comparison with subsequent predictive analysis simulations.

The base run calibration consisted of 50 PEST iterations and approximately 14,300 individual model runs. Values for objective function (Φ) components are listed in Table 7-1. The largest residuals occurred in the lowest layers. The highest and lowest eigenvalues are within 6 to 7 orders of magnitude, as they should be (Doherty, pers. comm., 2002). A comparison between simulated and observed hydraulic heads is shown in Figure 7-1. The PEST calibration could have been allowed to continue beyond 50 iterations, although attempts to match observation data more closely would have begun to result in simulated heterogeneities that may or may not have corresponded with actual aquifer properties.

7.2.1. Mass Balance

The mass balance for the calibration is shown in Table 7-2[18]; 1996 water budget (Urban and Petrich, 1998) values are listed for comparison in Table 7-3. The well and recharge components in the model are specified values; constant head, river leakage, and Lake Lowell seepage are head-dependent values. The total simulated inflows (1,036,212 af/yr) are similar to the total estimated 1996 inflows (1,035,000 af/yr) (Urban and Petrich, 1998). The total simulated outflows are virtually the same as the simulated inflows (as would be expected with conservation of mass in the steady-state

[17] Simulation *SS2bc*.

[18] In this and similar tables, the difference between inflows and outflows provides an indication of numerical error. Under steady-state hydraulic conditions, the difference between inflows and outflows should be zero. Any deviation from zero indicates some numerical error within the simulations.

model simulations), while the estimated 1996 outflows are approximately 36,000 af/yr less. The 36,000-af/yr difference is within the estimated error of water budget components, and therefore probably not meaningful.

Base Run Results (based on observations with PEST weights greater than zero)				
Contribution to Φ from heads	3,220			
Contribution to Φ from regularization	3,150			
Contribution to Φ from gradients	56.46			
Highest eigenvalue	1.176			
Lowest eigenvalue	1.89×10^{-7}			
Number of PEST iterations	50			
Number of MODFLOW runs	~14,300			
Run Statistics				
	Total	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	73.59	62.86	57.05	73.59
Minimum negative residual	-67.08	-67.08	-52.48	-44.14
Average absolute residual	14.62	12.42	16.01	23.29
Median absolute residual	9.49	8.74	9.714	19.03
Number of values	200	140	29	31

Table 7-1: Run information for steady-state simulation (base simulation).

7.2.2. Potentiometric Surfaces

Comparisons between potentiometric surface contours based on simulated and observed water level measurements are shown in Figure 7-2 through Figure 7-5. Potentiometric surface contours based on observed data are limited to those areas within the model domain containing actual data. The simulated potentiometric surface contours extend throughout the model domain because they are based on simulated head values in each active model cell.

The potentiometric surface contours based on simulated and observed data are in closer agreement in areas where there are abundant data than in areas of less data. For instance, potentiometric surface contours are closer in the central portion of the valley than in the southeastern portion of the model domain. The general agreement between simulated and observed head values are shown in Figure 7-1.

It is important to note that the contours drawn in Figure 7-2 through Figure 7-5 are drawn from different data. The observation heads were drawn from observation data (the locations of these data are shown in each plot). Contours drawn a long distance from an observation point (e.g., near model boundaries) are likely in error. The model-generated heads are calculated at every cell, although the uncertainty of hydraulic parameters in areas void of observation points also may be high. These contours should be compared with caution, especially in areas void of observation points.

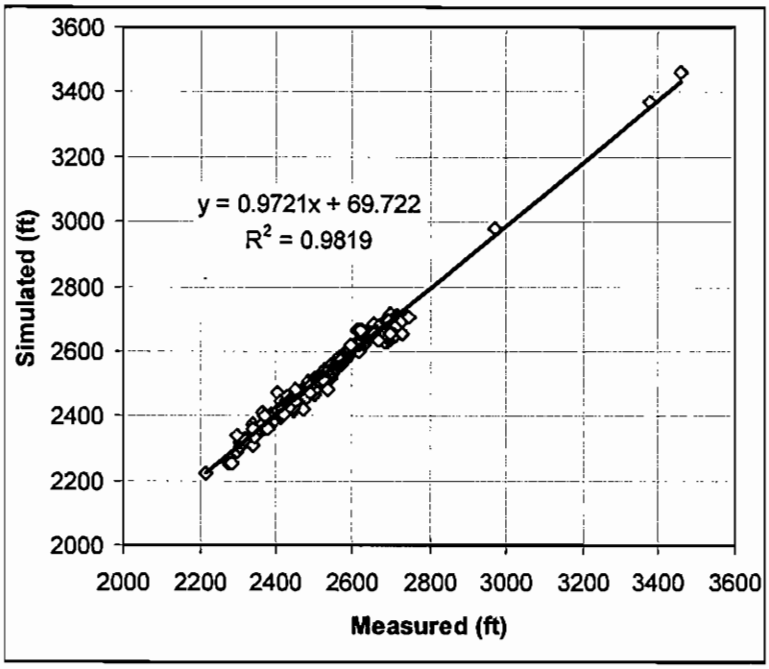

Figure 7-1: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (base simulation).

Base Simulation Inflows	Flux (ft3/day)	Flux (af-yr)
Constant head (Snake River)	28,891	242
Wells (underflow)	108,000	905
Drains	-	-
River leakage (Boise River)	5,784,138	48,467
Head-dependent boundaries (Lake Lowell)	1,537,895	12,886
Recharge (excluding recharge from underflow, wells, drains, river leakage, and head-dependent boundaries)	116,205,088	973,711
Total Inflows	123,664,008	1,036,211
Base Simulation Outflows		
Constant head (Snake River)	17,350,556	145,385
Wells	23,076,956	193,368
Drains	36,667,716	307,248
River leakage (Boise River)	46,486,872	389,525
Head-dependent boundaries (Lake Lowell)	81,962	687
Recharge	-	-
Total Outflows	123,664,064	1,036,212
Summary		
Inflows–Outflows	(56)	(0)
Percent discrepancy	0.00	0.00

Table 7-2: Base simulation mass balance.

1996 Water Budget – Inflows	Annual flux (af-yr)
Canal seepage, seepage from rivers and streams, flood irrigation and precipitation, recharge by other uses, and recharge from rural domestic septic systems	1,008,000
Seepage from Lake Lowell	19,000
Underflow	8,000
Total Inflows	1,035,000
1996 Water Budget – Outflows	**af-yr**
Domestic and industrial withdrawals, municipal irrigation, self-supplied industrial, agricultural irrigation, rural domestic withdrawals, and stock watering	199,000
Discharge to rivers and streams	800,000
Total Outflows	999,000
Difference	+36,000

Table 7-3: 1996 Water budget components (Urban and Petrich, 1998).

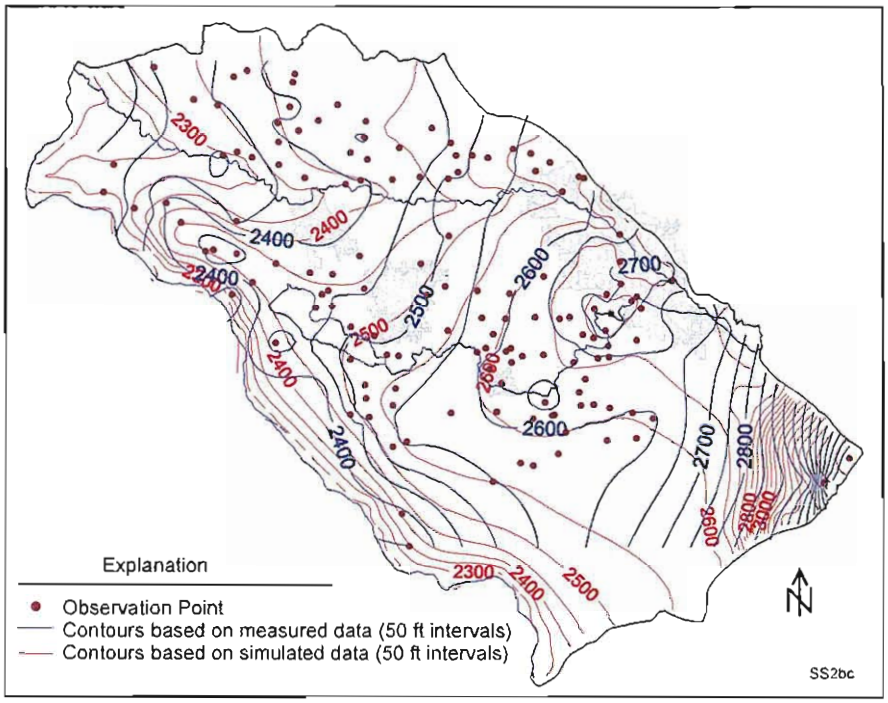

Figure 7-2: Simulated and observed potentiometric contours, layer 1.

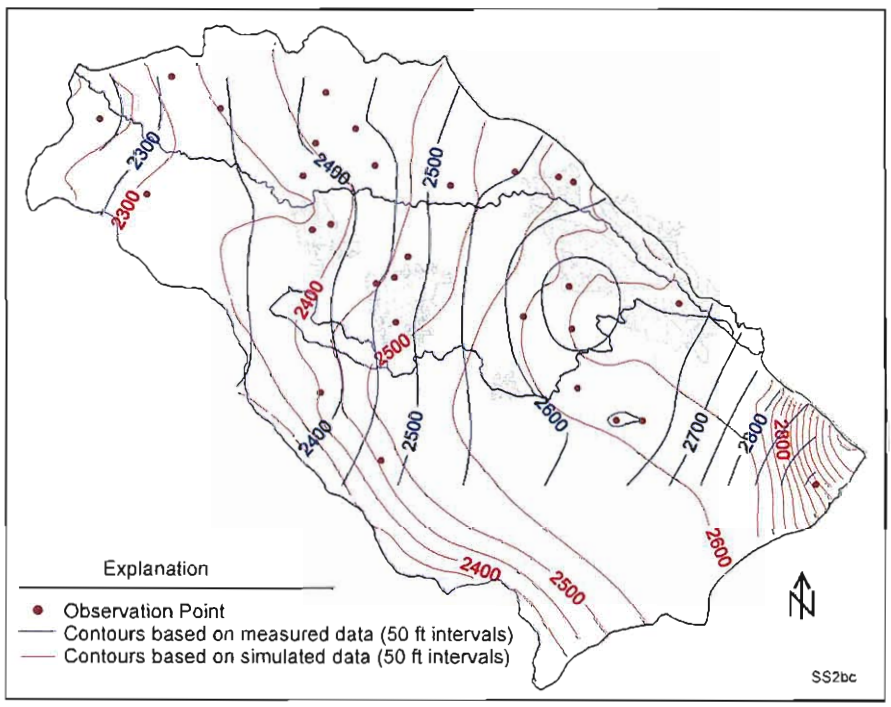

Figure 7-3: Simulated and observed potentiometric contours, layer 2.

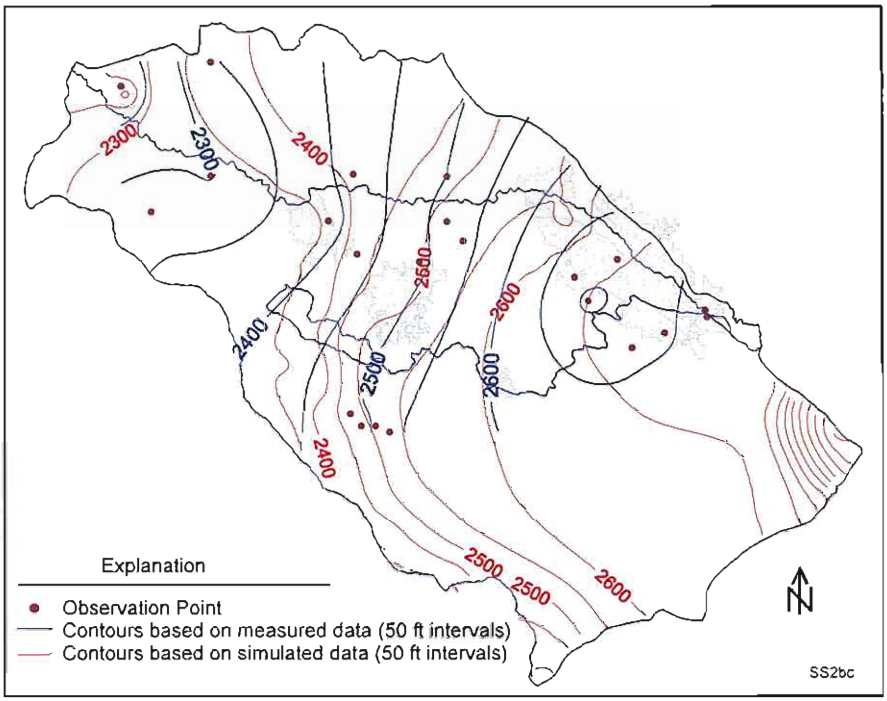

Figure 7-4: Simulated and observed potentiometric contours, layer 3.

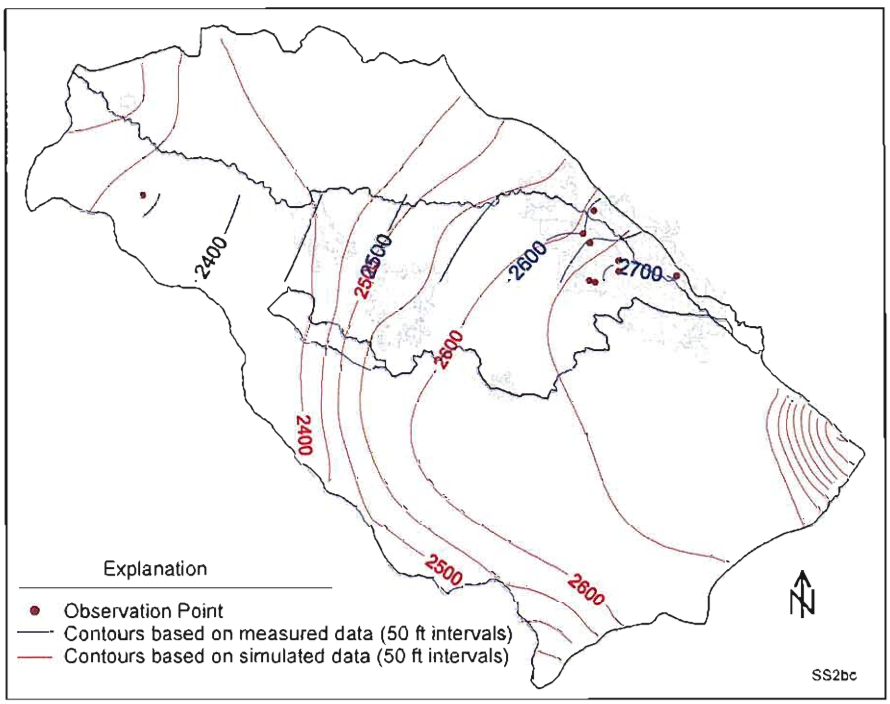

Figure 7-5: Simulated and observed potentiometric contours, layer 4.

7.2.3. Spatial Distribution of Residuals

The distribution of residuals between simulated and observed head values is another measure of calibration results. Two areas of positive residuals occurred along the northeastern and southwestern boundaries (Figure 7-6). Negative residuals occurred in one area in the northern portion of the model (based mostly on 2 to 3 observations) near the New York Canal and west of Lake Lowell. Residual values in layers 2, 3, and 4 show more spatial bias; there are larger areas of positive or negative residuals. In addition, there are several areas (e.g., the north central portion of the model domain) where observations with positive and negative residuals are located in close proximity. The residuals may reflect differences in observed water levels, errors in estimated well elevations, local heterogeneities (e.g., faults) not expressly incorporated into the model, or differences in local drawdown conditions. The residuals in these areas may also reflect averaged-cell characteristics. PEST attempts to reconcile the differences during the model calibration but ends up estimating hydraulic parameter values that lead to minimized residuals.

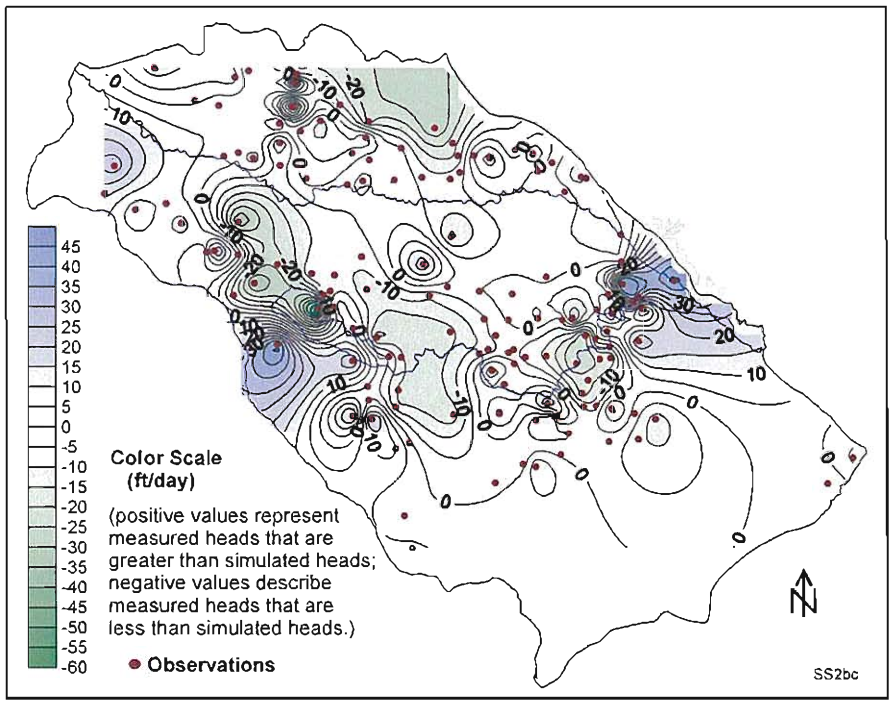

Figure 7-6: Base simulation residuals, layer 1.

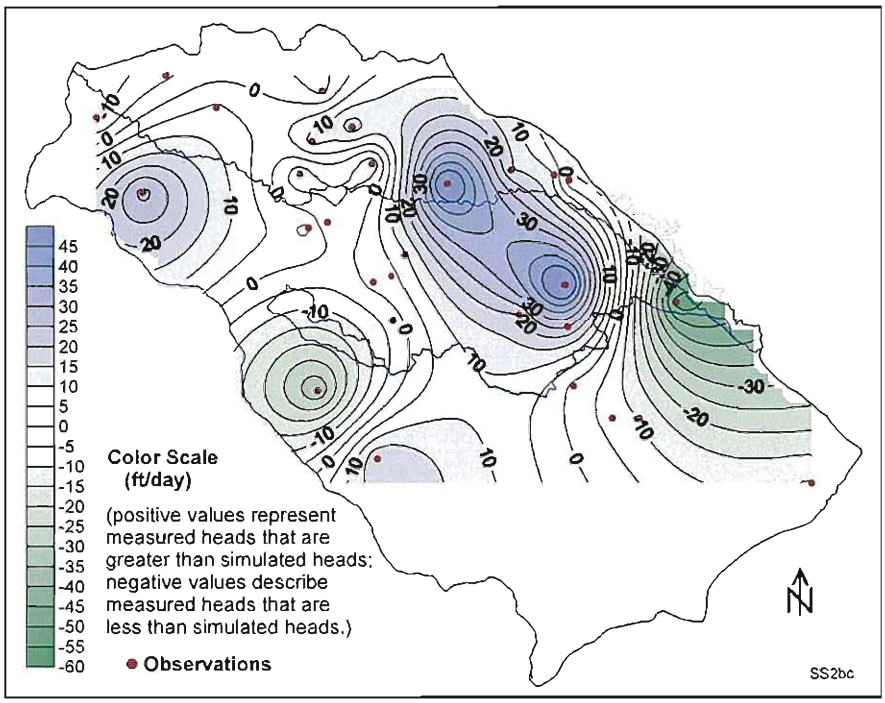

Figure 7-7: Base simulation residuals, layer 2.

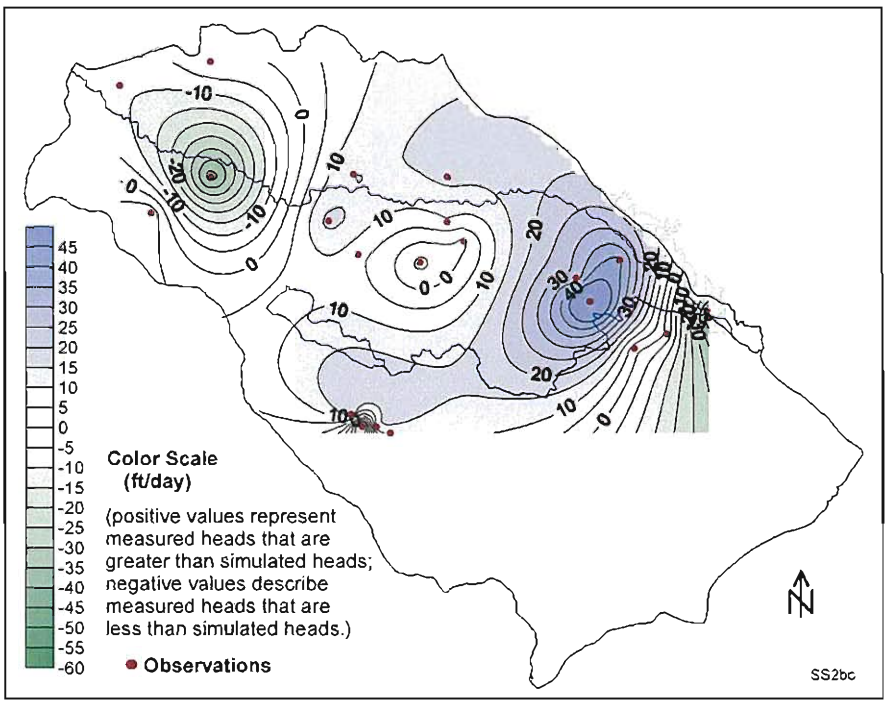

Figure 7-8: Base simulation residuals, layer 3.

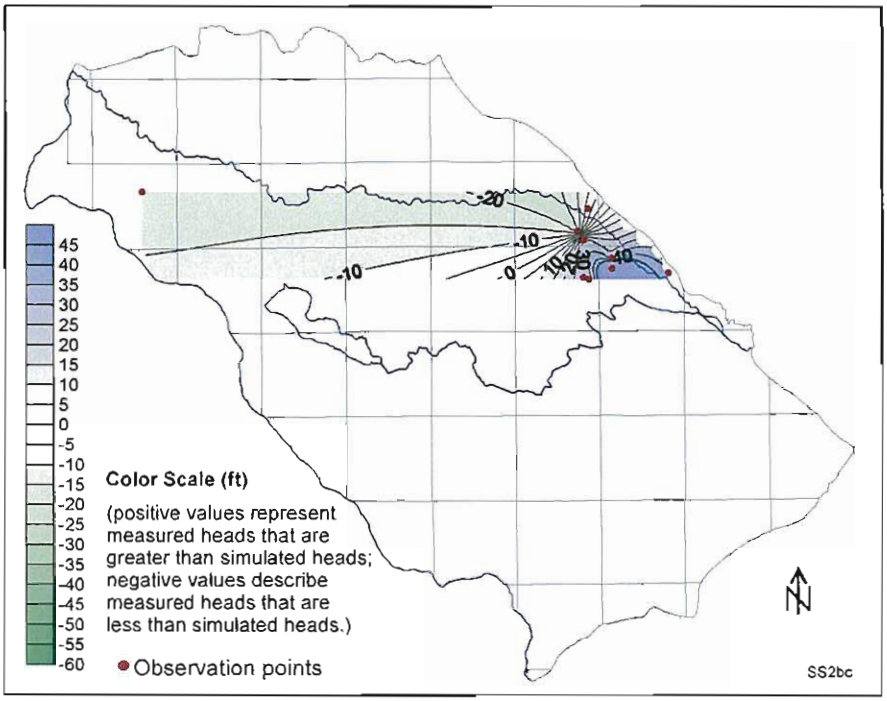

Figure 7-9: Base simulation residuals, layer 4.

It should be noted that the degree of spatial correlation exhibited by the residuals is not cause for concern (Doherty, 2003), in spite of the commonly-held belief that residuals should be uncorrelated at the completion of the model calibration process (see, for example, Anderson and Woessner, 1992). In fact, wherever regularization is used in the solution of the inversion problem (whether this be explicitly through PEST's regularization functionality or implicitly through the use of zones), model-to-measurement residuals will show spatial correlation (Christensen and Cooley, 2002; Nolet et al., 1999).

7.2.4. Estimated Parameter Value Distributions

The distribution of K_h and K_v values within the model domain are shown in Figure 7-10 through Figure 7-15. The K_h and K_v values for layers 3 and 4 are the same because the parameters are tied together (Section 5.6).

Several patterns emerge from the PEST-calibrated K_h and K_v values. First, the calibration suggested a higher K_h zone in the Boise vicinity, especially in layers 3 and 4. This corresponds with coarse-grained alluvial and fluvial sediments present in this area. The higher K_v values extend toward the central portions of the basin in layers 3 and 4, which appear to correspond with the occurrence of fluvial deltaic sediments. The higher K_h values also extend south and southeast of the Boise area, which may be unsupported because of the lack of observation points in this portion of the model domain.

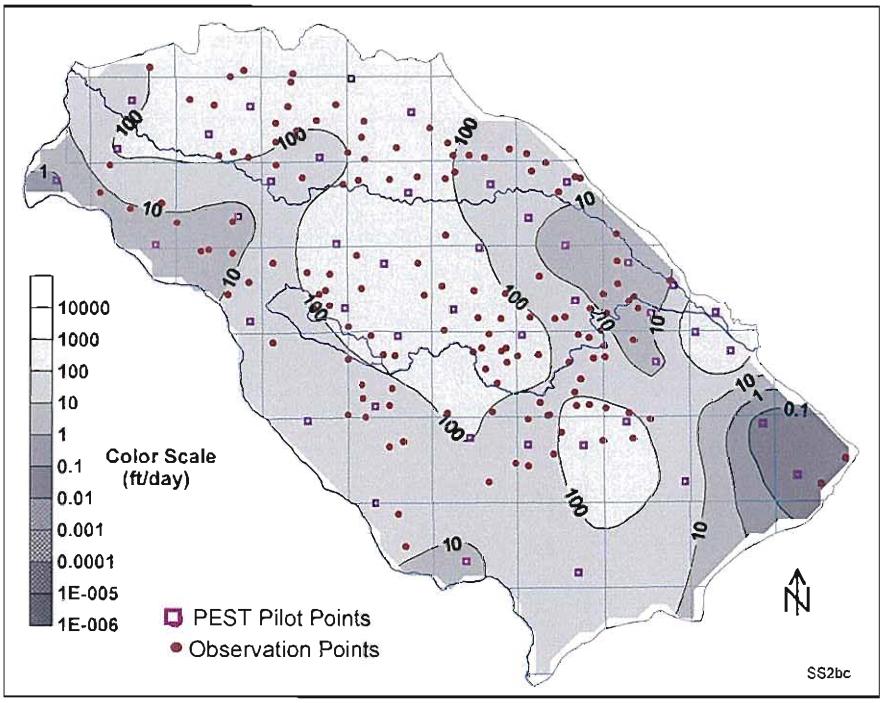

Figure 7-10: Estimated horizontal hydraulic conductivity distribution, layer 1.

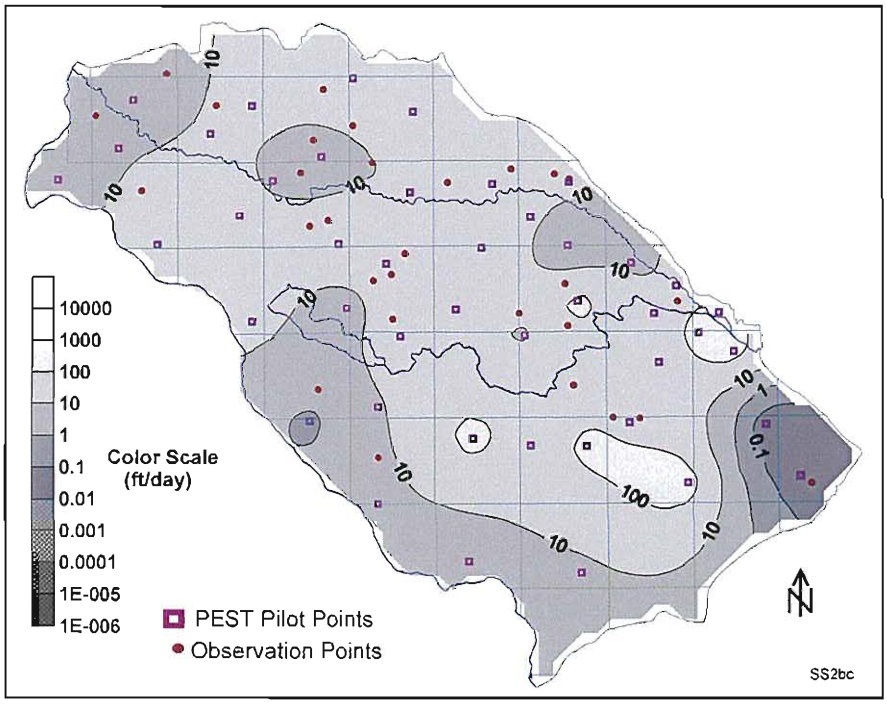

Figure 7-11: Estimated horizontal hydraulic conductivity distribution, layer 2.

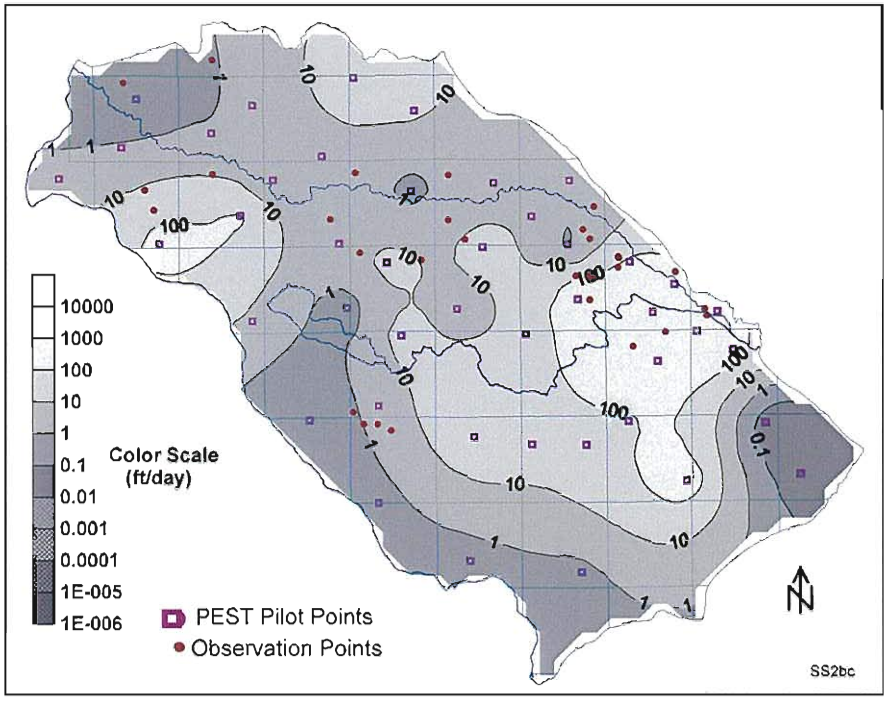

Figure 7-12: Estimated horizontal hydraulic conductivity distribution, layers 3 and 4.

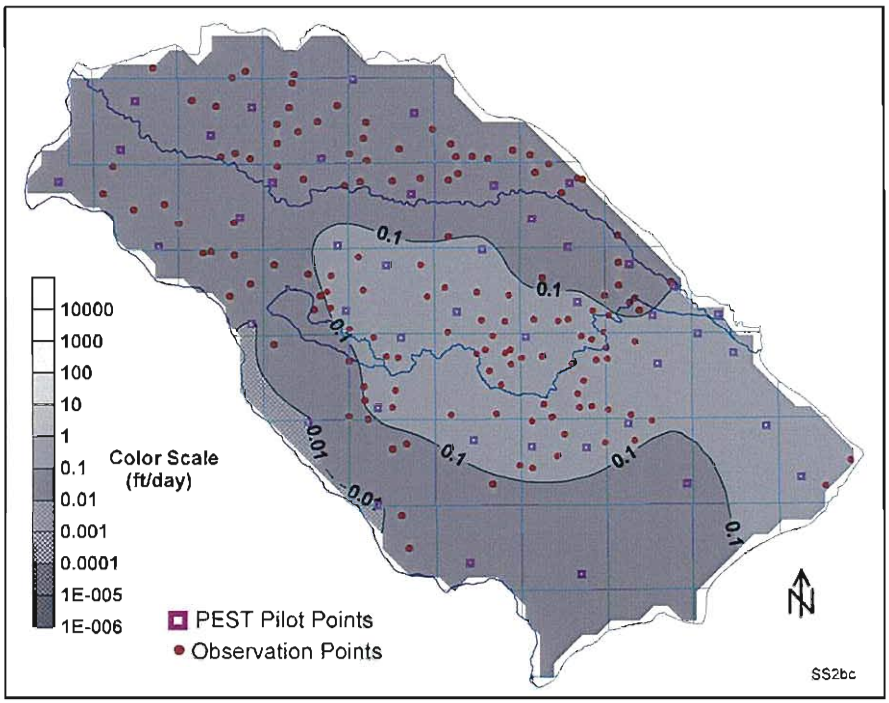

Figure 7-13: Estimated vertical hydraulic conductivity distribution, layer 1.

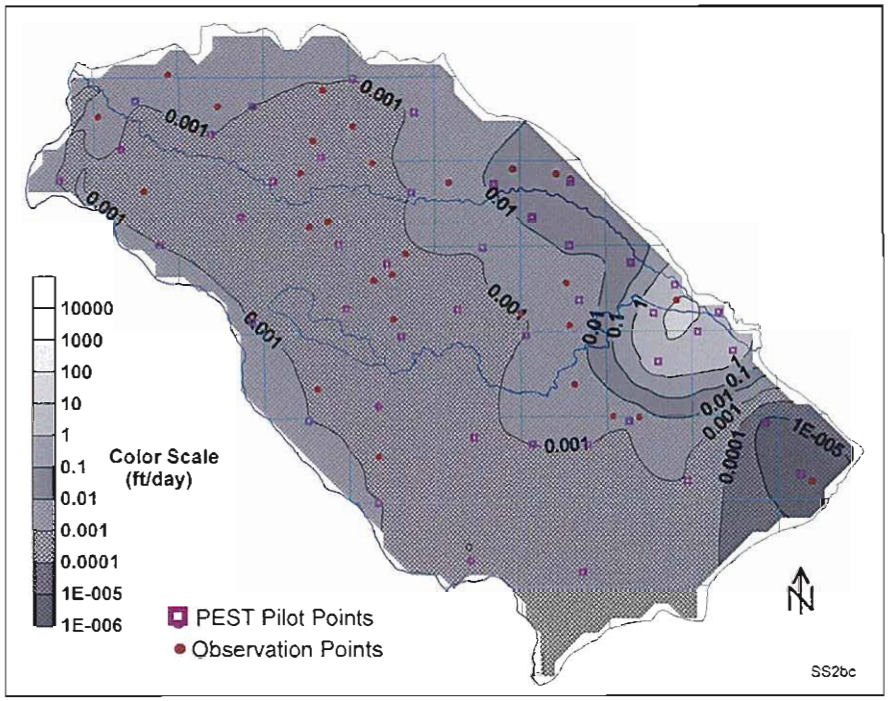

Figure 7-14: Estimated vertical hydraulic conductivity distribution, layer 2.

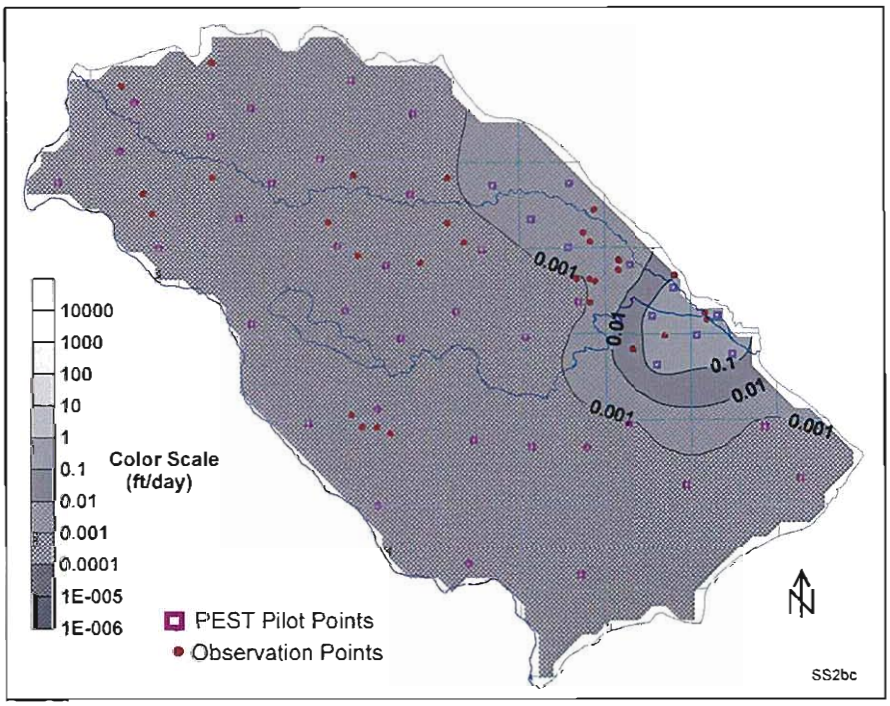

Figure 7-15: Estimated vertical hydraulic conductivity distribution, layers 3 and 4.

Second, low K_h values are seen in the far eastern portion of the model domain. This represents the model's attempt to maintain ground water levels that are substantially higher in this area than other parts of the model domain.

Third, a low K_h zone appears in the northwest Boise–Eagle area. This appears to correspond with fine-grained sediments (clay and silt) that are present in this area (such as those profiled in the TVHP#1 monitoring well).

Next, calibrated K_v values are lower in the central and western portions of the model domain than in the Boise area. The maximum K_v values were limited to an upper value of 1×10^{-3} ft/day in layers 2 through 4 in a large portion of this area (Section 5.4 and Figure 5-8), which is consistent with the extensive layers of lacustrine clays in this area. Upper limits for simulated K_v values in the eastern portion of the model domain (e.g., Boise area) were much higher (e.g., 1×10^{3} ft/day), allowing the model to simulate greater downward movement of water to deeper zones (although PEST-estimated K_v values remained below 10 ft/day). The higher K_v values are consistent with coarser-grained silts and sands in this area.

Finally, it is important to recognize that simulated parameter values are much less certain at the model boundaries, especially in areas of few data. Parameters in these areas were generally less sensitive than in areas with more data and may be highly correlated with one another. In fact, estimation of parameters in this area is only possible through deployment of PEST's regularization functionality.

7.2.5. Potentiometric Cross-Sections

Cross-sections of potentiometric contours in model row 18 and column 36 (Figure 7-16) provide an indication of hydraulic gradients at depth. These potentiometric contours should, however, be read with caution because the ground water flow directions (based on observed gradients) may not be along the x-y axes shown in the cross-sections.

Several general flow characteristics are evident in the cross-sections. First, there is a general upward gradient over much of the central portion of the basin. A ground water flow divide is evident in the north-south cross-section in the vicinity of the New York Canal. Simulated ground water flow (in the north-south cross-section) moves from the New York Canal area toward the Boise River, but deeper (simulated) ground water flow has a more southerly component toward the Snake River.

7.2.6. Flooded Cells

The water table is very close to ground surface in some parts of the basin, such as the central portion in which substantial flood irrigation occurs. Irrigation system drains were installed to collect and remove shallow ground water from these areas. Simulating ground water flow in these areas resulted in a number of "flooded" cells, as indicated in Figure 7-17. However, the median residuals in this calibration run, at 9.5 feet, is very close to the difference in drain elevation and ground surface (10 feet,

Section 4.4). Therefore, it is not surprising that some cells appear to be flooded. This simulated flooding represents a natural process (drainage) and is not cause for concern. Theoretically, increasing drain conductances should reduce cell flooding (if simulated ground water levels are below those of the drains), but excessively high drain conductances can lead to numerical instability.

7.2.7. Vertical Ground Water Flow Rates

The vertical flow rates into and out of each model layer were estimated from the steady-state simulations (Table 7-4). The total amount of vertical downward flow through the aquifer system is a small portion of the total amount of recharge from ground surface to the uppermost aquifer (Table 7-3). Most of the difference between downward and upward flux between the lower model layers was attributed to extraction by wells.

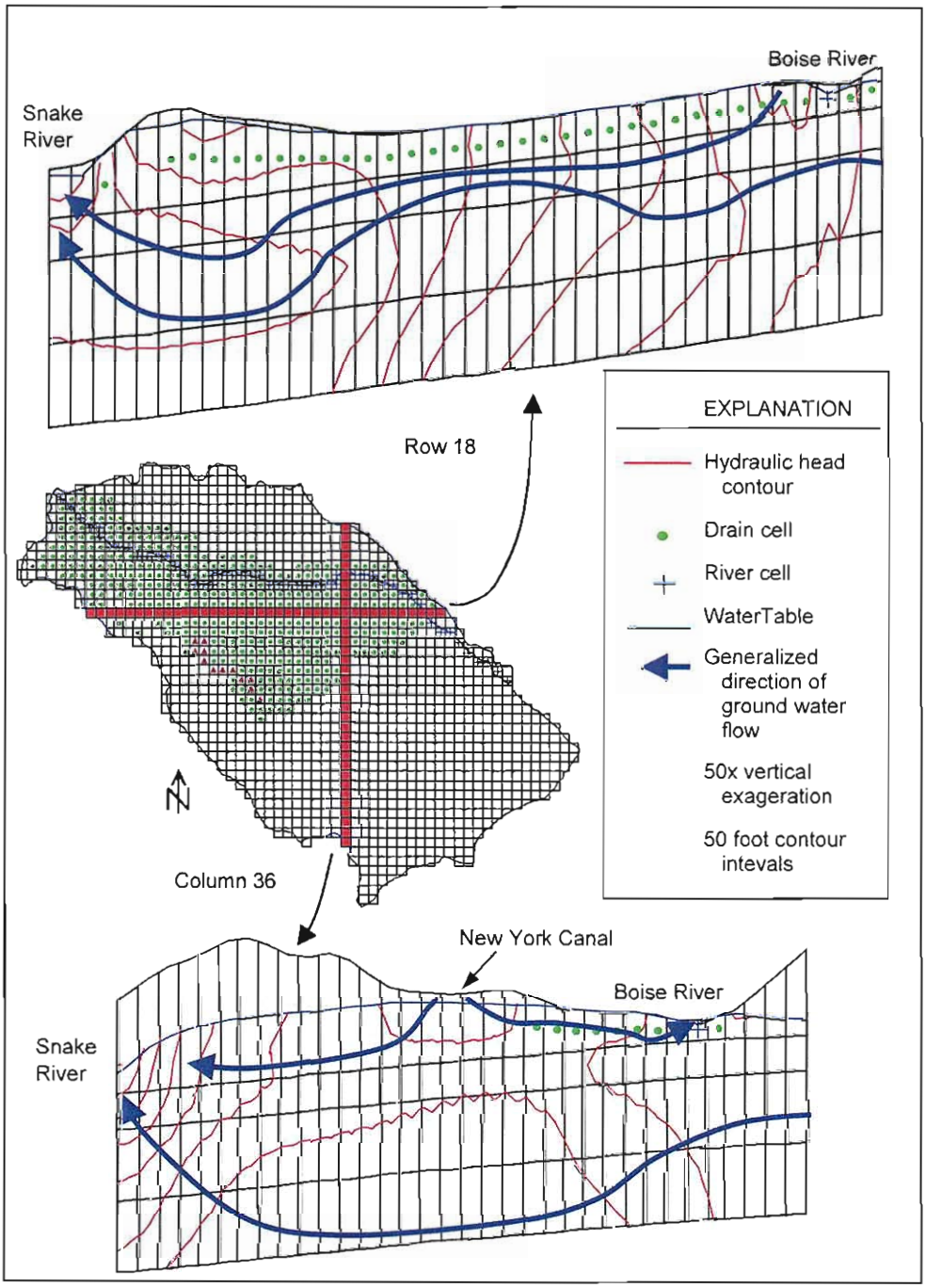

Figure 7-16: Potentiometric contours, base simulation, row 18 and column 36.

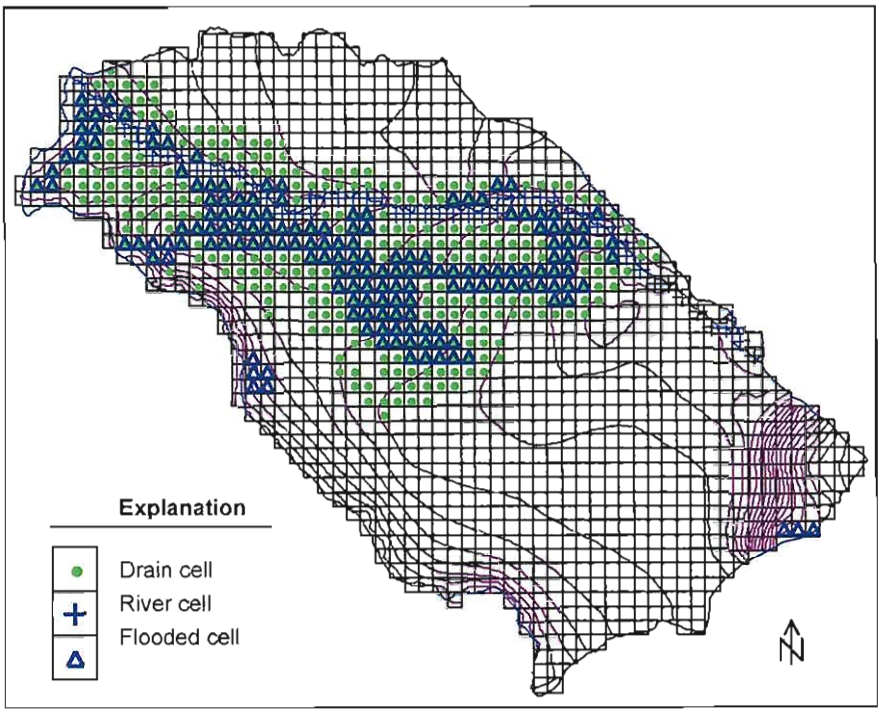

Figure 7-17: Flooded cells and layer 1 simulated water level contours (50-foot contour interval) in base simulation (*SS2bc*).

Flux Direction	Simulated Downward Flux Between Model Layers (af/yr)	Flux Direction	Simulated Upward Flux Between Model Layers (af/yr)	Difference (af/yr)	Estimated Withdrawals by Wells (af/yr)
Layer 1 to Layer 2	146,257	Layer 2 to Layer 1	38,976	107,282	(60,538)
Layer 2 to Layer 3	68,406	Layer 3 to Layer 2	21,436	46,970	(42,934)
Layer 3 to Layer 4	15,633	Layer 4 to Layer 3	11,371	4,263	(4,489)

Table 7-4: Simulated flux between model layers, base simulation.

8. SENSITIVITY ANALYSES

Two general types of parameter sensitivity influence model results and predictions. First, individual parameters have different degrees of influence in any given simulation. Some individual parameters may have substantial influence on model results; others may have very little influence. Some individual correlated parameters may be highly sensitive. However, there is a certain linear combination of these parameters that is relatively insensitive. PEST calculates these parameter sensitivity values during a calibration.

Second, there is parameter sensitivity to various model input variables, such as recharge or underflow. The model sensitivity to these inputs is often evaluated by varying the parameter by a certain amount (e.g., 10%), running the calibrated model and evaluating the effect on model output (e.g., water levels or observation residuals). However, change in an input stress, such as recharge, alters the hydrologic conditions under which the model was originally calibrated. A more thorough evaluation of sensitivity to different inflow rates is to recalibrate the model using the altered sensitivity stress.

Three sensitivity calibrations were conducted to evaluate the effect of increases and/or decreases in selected inflow rates. These additional calibrations were based on the following conditions:

1. 10% increase in recharge over estimated 1996 levels
2. 10% decrease in recharge over estimated 1996 levels
3. Increase in underflow along the northeastern model boundary

8.1. Increased Recharge

8.1.1. Description

The first sensitivity simulation consisted of a 10% across-the-board increase in recharge to the model. The 10% increase could represent error in the 1996 recharge estimates or an increase in recharge over 1996 levels.

8.1.2. Results

Results from a calibration with increased recharge are summarized in Table 8-1. The contribution to the objective function from observations (heads) was higher (see Table 7-1) than in the base simulation. The maximum and the average and median absolute residuals were the same as or higher in each layer compared to the base simulation. A water budget comparison (Table 8-2) between this calibration and the base simulation shows that most of the recharge increase ends up as discharge to the Boise River ("river leakage"), Snake River ("constant head"), and drains.

Increased Recharge Simulation Results (SS7a) (based on observations with PEST weights greater than zero)				
Contribution to Φ from heads	3,646			
Contribution to Φ from regularization	2,271			
Contribution to Φ from gradients	0.909			
Highest eigenvalue	2.1			
Lowest eigenvalue	2.24×10^{-7}			
Number of PEST iterations	50			
Number of MODFLOW runs	~14,300			
Run Statistics				
	Total	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	78.21	67.08	66.15	78.21
Minimum negative residual	-65.18	-65.18	-51.52	-53.95
Average absolute residual	15.64	13.01	17.88	25.39
Median absolute residual	10.75	9.40	10.70	19.75
Number of values	200	140	29	31

Table 8-1: Run information for simulation with 10% increase in recharge.

Volumetric Budget Comparison					
		Base Simulation (*SS2bc*)	**10% Increase in Recharge (*SS7a*)**	**Difference from Base Simulation**	**Change as a Percentage of Increased Recharge**
Inflows	Constant head	28,891	32,646	3,755	3%
	Wells	108,000	108,000	0	0%
	Drains	0	0	0	0%
	River leakage	5,784,137	6,576,735	792,598	7%
	Head-dependent boundaries	1,537,895	1,615,971	78,076	1%
	Recharge	116,205,088	127,825,584	11,620,496	100%
	Total In	123,664,008	136,158,944	12,494,936	
Outflows	Constant head	17,350,556	21,689,984	4,339,428	37%
	Wells	23,076,956	23,076,956	0	0%
	Drains	36,667,716	39,523,332	2,855,616	25%
	River leakage	46,486,872	51,759,356	5,272,484	45%
	Head-dependent boundaries	81,961	109,265	27,304	0%
	Recharge	0	0	0	0%
	Total Out	123,664,064	136,158,896	12,494,832	

Table 8-2: Volumetric water budget, 10% increase in recharge.

The simulation resulted in a very slight increase in the number of flooded cells (Figure 8-1). The layer 1 water level contours (Figure 8-1) were almost identical to those for the base simulation (Figure 7-17), so additional contour plots are not provided for the increased recharge simulation.

Residuals for this run (Figure 8-2) were similar to those in the base calibration (Figure 7-1). The residual patterns from the increased recharge simulation run (Figure 8-3 through Figure 8-6) were very similar to those in the base simulation (Figure 7-6 through Figure 7-9). This suggests that the aquifer system is able to accommodate the additional water, especially in the uppermost layer, with the current distribution of hydraulic conductivity. Additional recharge (proportional to current recharge amounts) enters the shallow flow system and discharges in surface channels (e.g., canals and drains) without substantially influencing water levels. Relatively high hydraulic conductivity values estimated for both the increased recharge simulation (Figure 8-7) and the base simulation (Figure 7-10) make this possible. These relatively high K_h values are consistent with the general coarse-grained nature of the Snake River Group sediments.

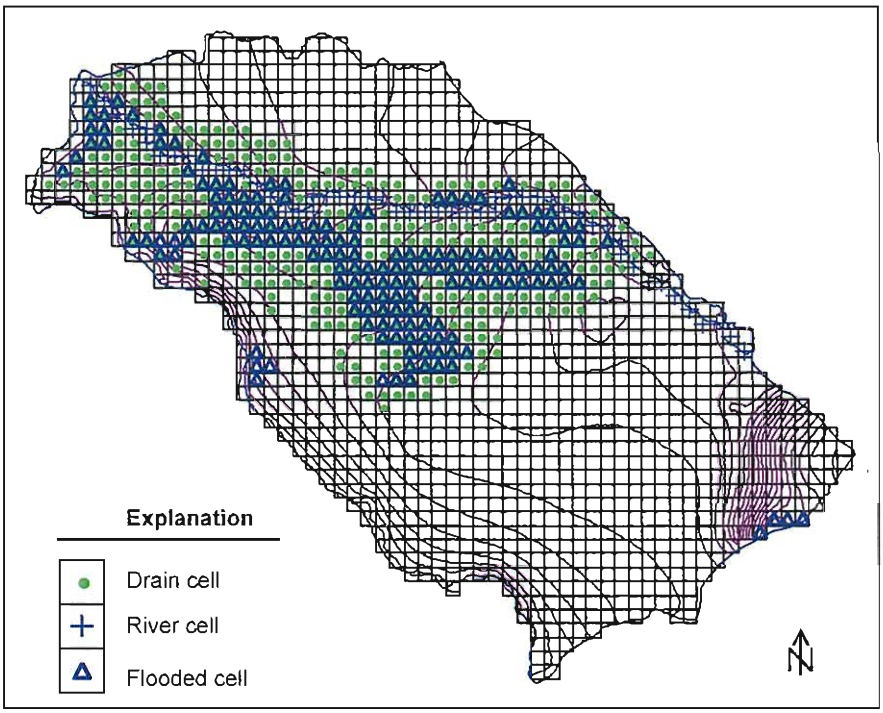

Figure 8-1: Flooded cells and layer 1 simulated water level contours (50-foot contour interval) in increased recharge simulation (*SS7a*).

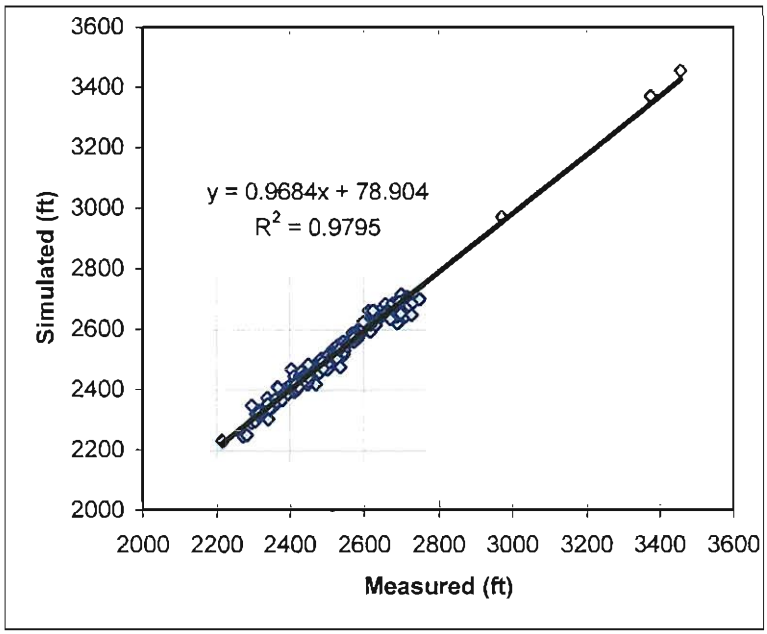

Figure 8-2: Simulated versus measured hydraulic head observations, increased recharge (simulation *SS7a*).

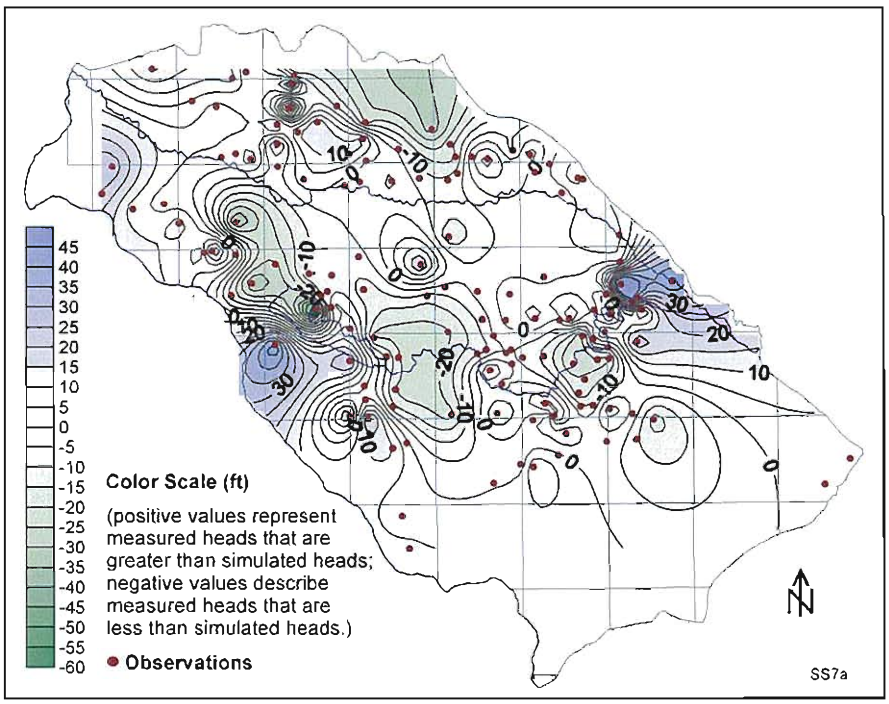

Figure 8-3: Increased recharge simulation residuals, layer 1.

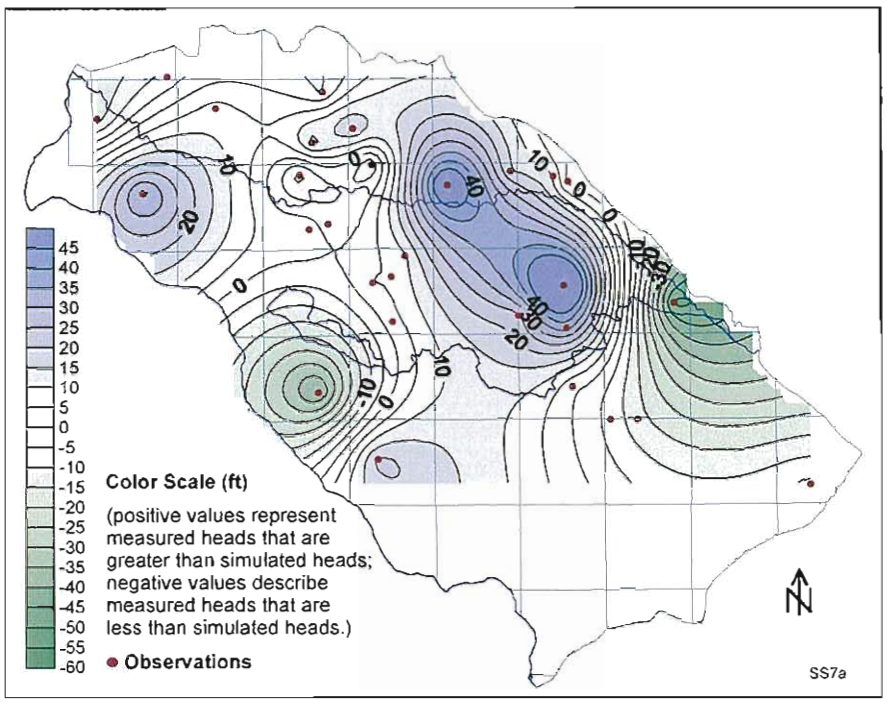

Figure 8-4: Increased recharge simulation residuals, layer 2.

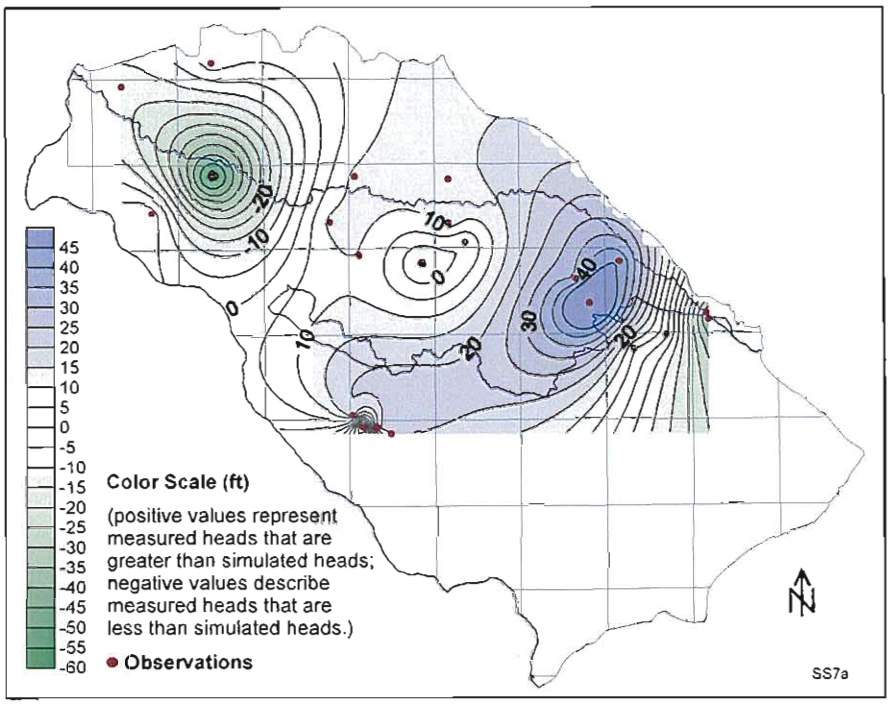

Figure 8-5: Increased recharge simulation residuals, layer 3.

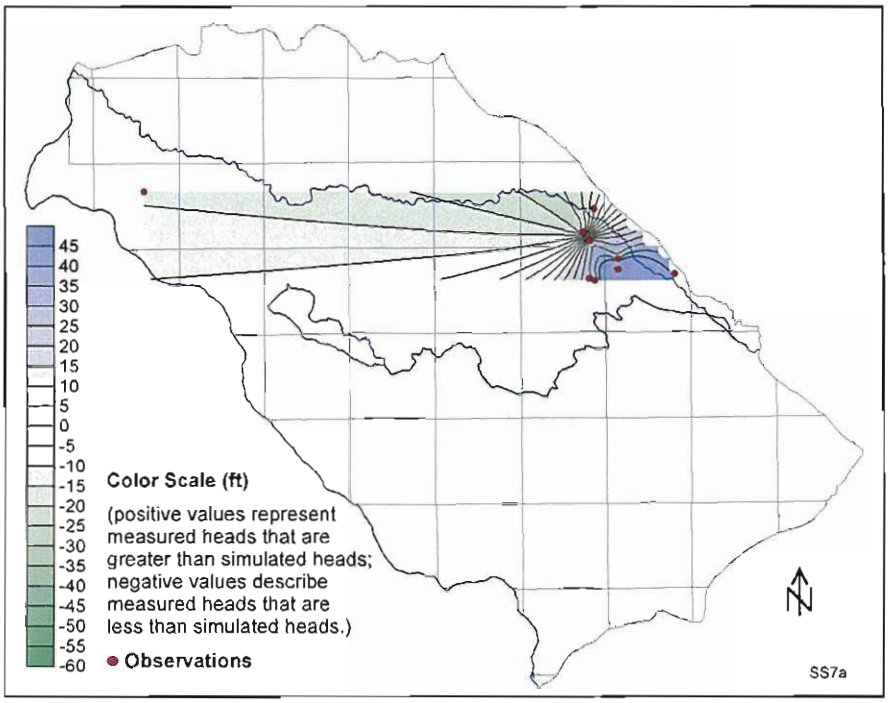

Figure 8-6: Increased recharge simulation residuals, layer 4.

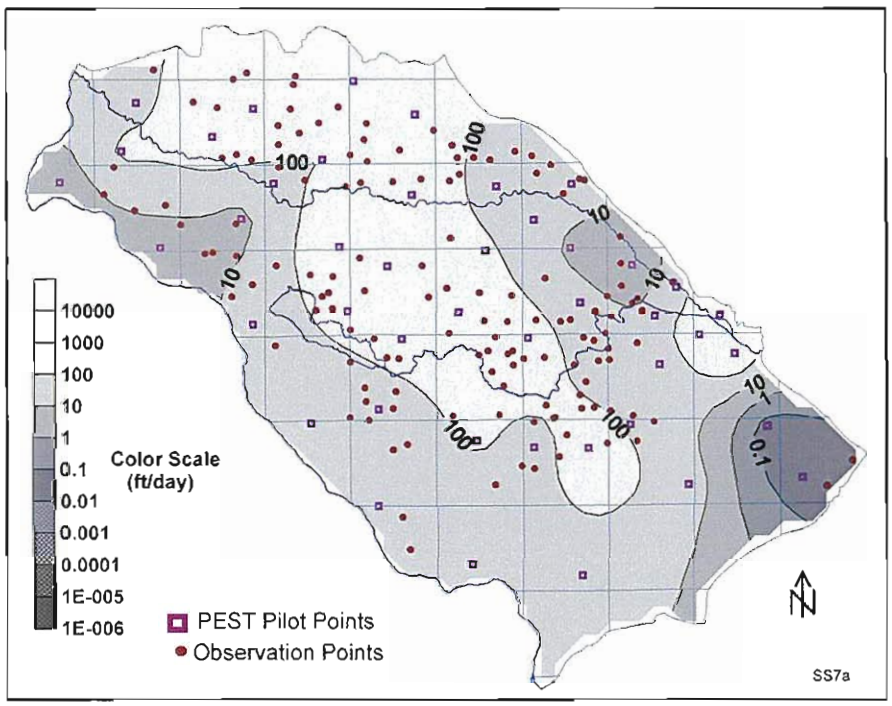

Figure 8-7: Horizontal hydraulic conductivity distribution for increased recharge simulation, layer 1.

8.2. Decreased Recharge

8.2.1. Description

This sensitivity simulation consisted of a 10% across-the-board decrease in recharge to the model. The 10% decrease could represent error in the 1996 recharge estimates or a decrease in recharge over 1996 levels.

8.2.2. Results

Results from a calibration with decreased recharge are summarized in Table 8-3 and Figure 8-8. The contribution to the objective function (ϕ) from head observations was greater than in the base simulation. The sum of the squared residuals from head values was greater than in the base simulation (see Table 7-1). The average and median absolute residuals were similar to those in the base simulation. The maximum absolute residuals (located primarily in the eastern, higher elevation portion of the aquifer – Figure 8-8) were much greater in this simulation. The distribution of residuals in the uppermost layer (Figure 8-9) was similar to that in the base simulation (Figure 7-6), except that the decreased recharge led to much lower simulated water levels in the eastern portion of the basin. The residuals in the second layer (Figure 8-10) were similar to those in the base simulation (Figure 7-7), except in the eastern portion of the basin, in which one well had a simulated water level much less than the observed one. Residuals in layers 3 and 4 (Figure 8-11 and Figure 8-12) were very similar to those of the base simulation (Figure 7-8 and Figure 7-9).

The K_h distribution (Figure 8-13) derived in the decreased recharge simulation for the uppermost model layer was very similar to both that of the base simulation (Figure 7-10) and the increased recharge simulation (Figure 8-7). The parameter estimation suggests that the layer 1 sediments are relatively conductive and increasing or decreasing recharge by 10% does not materially change the conductivity of these sediments. The one exception is in the far eastern portion of the model domain, where PEST indicates very low conductivity sediments in an effort to maintain the relatively steep apparent hydraulic gradient in this area. A water budget comparison (Table 8-4) between this calibration and the base simulation shows that the decrease in recharge results in decreased discharge to the Boise River ("river leakage"), Snake River ("constant head"), and drains.

Decreased Recharge Simulation Results (*SS7b*) (based on observations with PEST weights greater than zero)				
Contribution to Φ from heads	4,767			
Contribution to Φ from regularization	256			
Contribution to Φ from gradients	5.6			
Highest eigenvalue	8.64			
Lowest eigenvalue	1.21×10^{-7}			
Number of PEST iterations	50			
Number of MODFLOW runs	~14,300			
Run Statistics (based on observations with weights > 0)				
	Total	**Layer 1**	**Layer 2**	**Layers and 4**
Maximum positive residual	168.86	168.86	40.57	69.26
Minimum negative residual	-166.23	-60.94	-166.23	-43.41
Average absolute residual	14.48	12.65	16.669	20.69
Median absolute residual	8.64	8.17	4.24	18.97
Number of values	200	140	29	31

Table 8-3: Run information for simulation with 10% decrease in recharge.

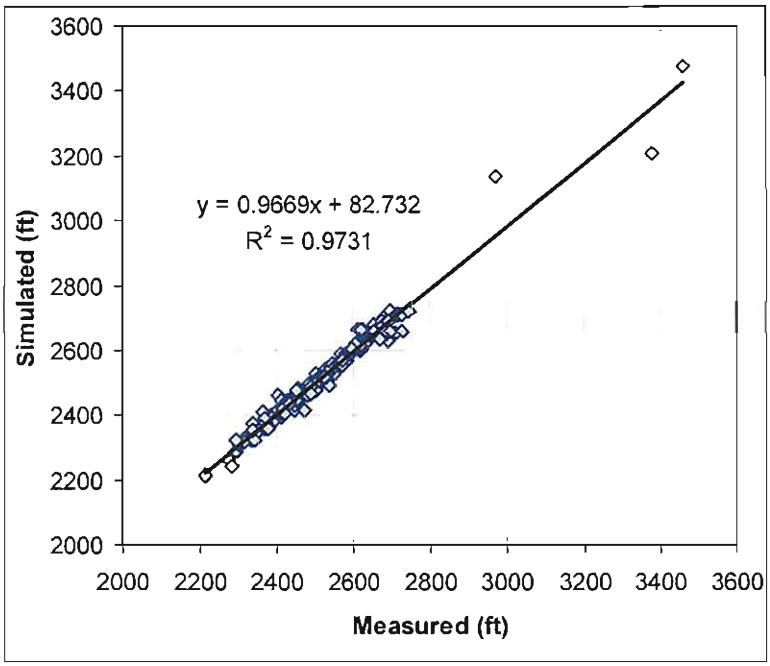

Figure 8-8: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (decreased recharge simulation).

Volumetric Budget Comparison					
		Base Simulation (*SS2bc*)	10% Decrease in Recharge (*SS7b*)	Difference from Base Simulation	Change as a Percentage of Decreased Recharge
Inflows	Constant head	28,891	24,386	-4,505	0%
	Wells	108,000	108,000	0	0%
	Drains	0	0	0	0%
	River leakage	5,784,137	5,904,424	120,287	1%
	Head-dependent boundaries	1,537,895	1,927,328	389,433	3%
	Recharge	116,205,088	104,584,592	11,620,496	-100%
	Total In	123,664,008	112,548,728	-11,115,280	
Outflows	Constant head	17,350,556	14,411,841	-2,938,715	-25%
	Wells	23,076,956	23,076,956	0	0%
	Drains	36,667,716	34,972,756	-1,694,960	-15%
	River leakage	46,486,872	40,042,612	-6,444,260	-55%
	Head-dependent boundaries	81,961	44,520	-37,441	0%
	Recharge	0	0	0	0%
	Total Out	123,664,064	112,548,680	-11,115,384	

Table 8-4: Volumetric water budget comparison, 10% decrease in recharge.

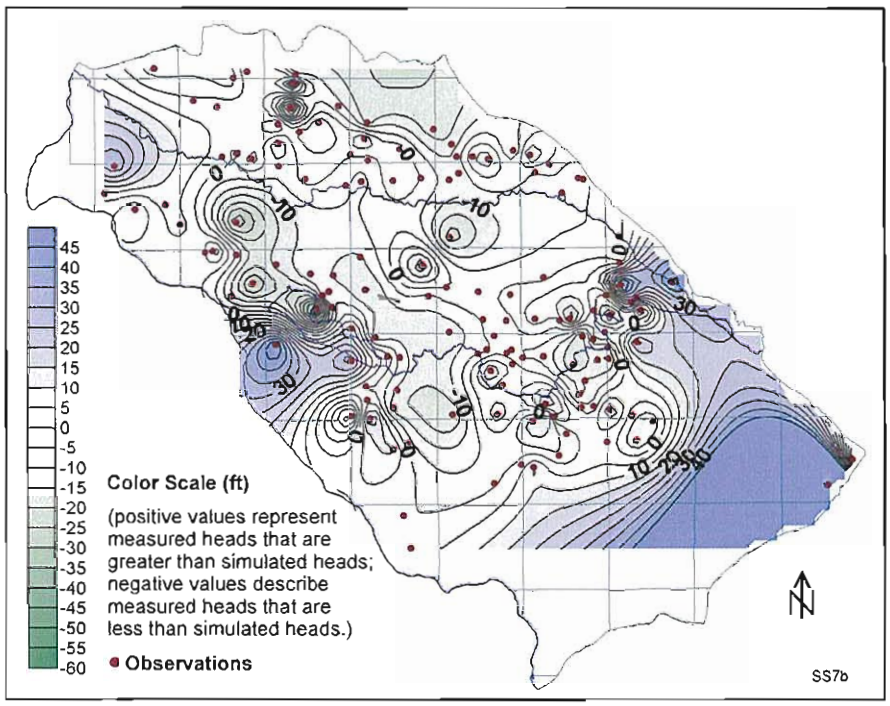

Figure 8-9: Decreased recharge simulation residuals, layer 1.

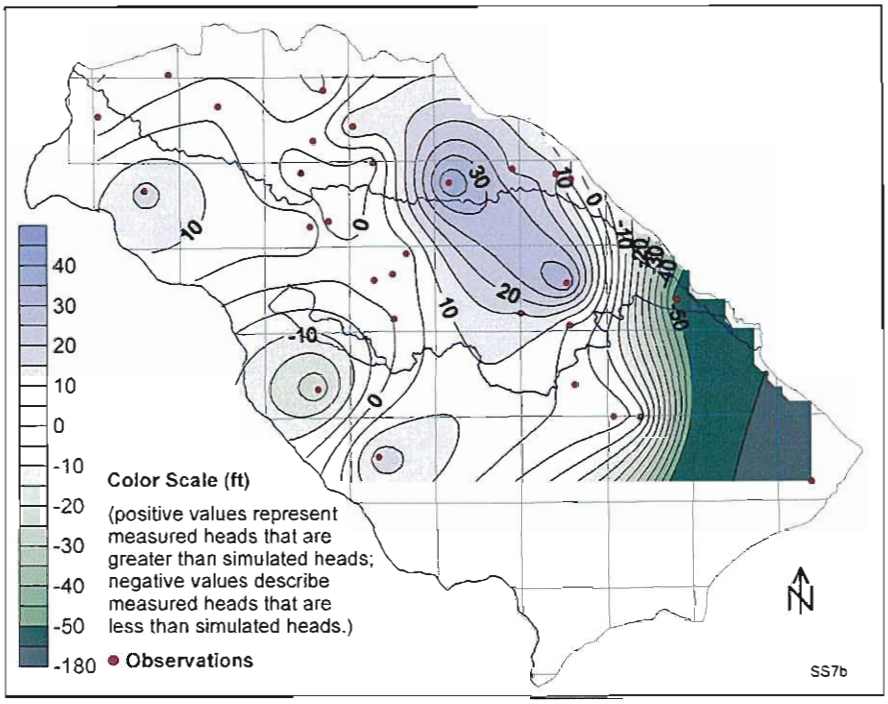

Figure 8-10: Decreased recharge simulation residuals, layer 2.

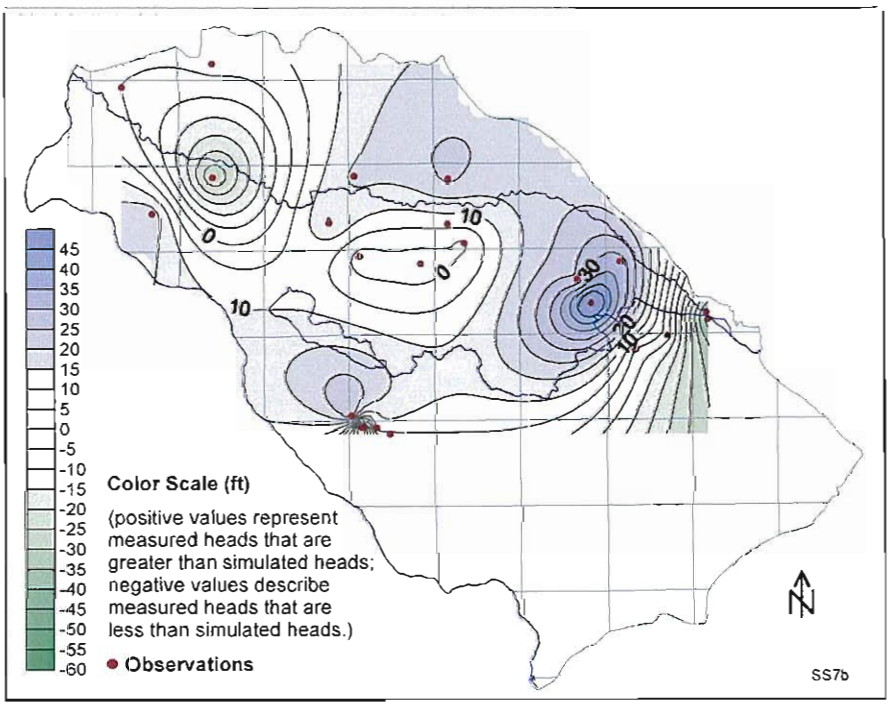

Figure 8-11: Decreased recharge simulation residuals, layer 3.

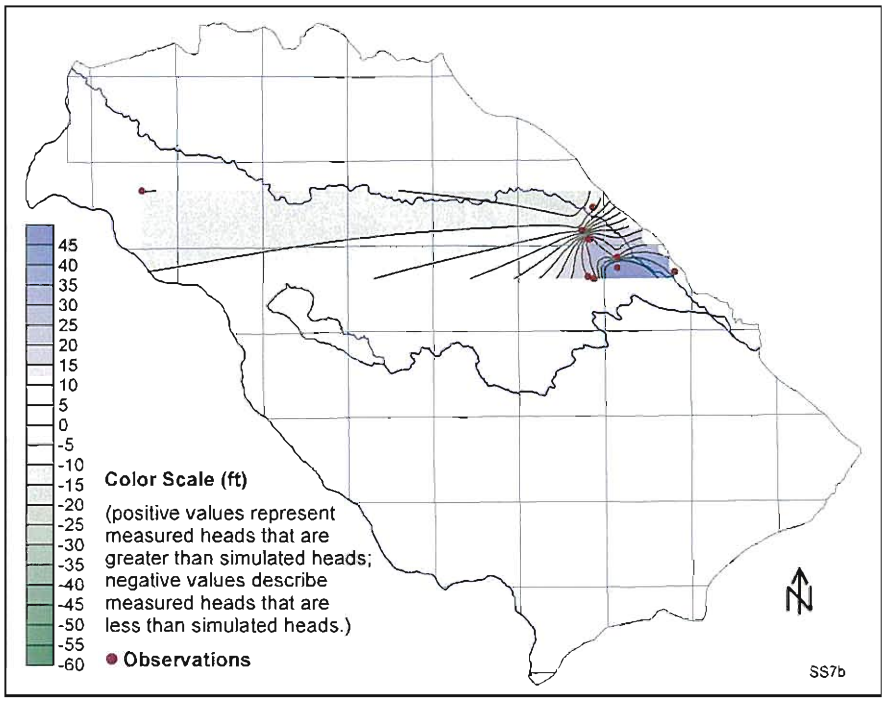

Figure 8-12: Decreased recharge simulation residuals, layer 4.

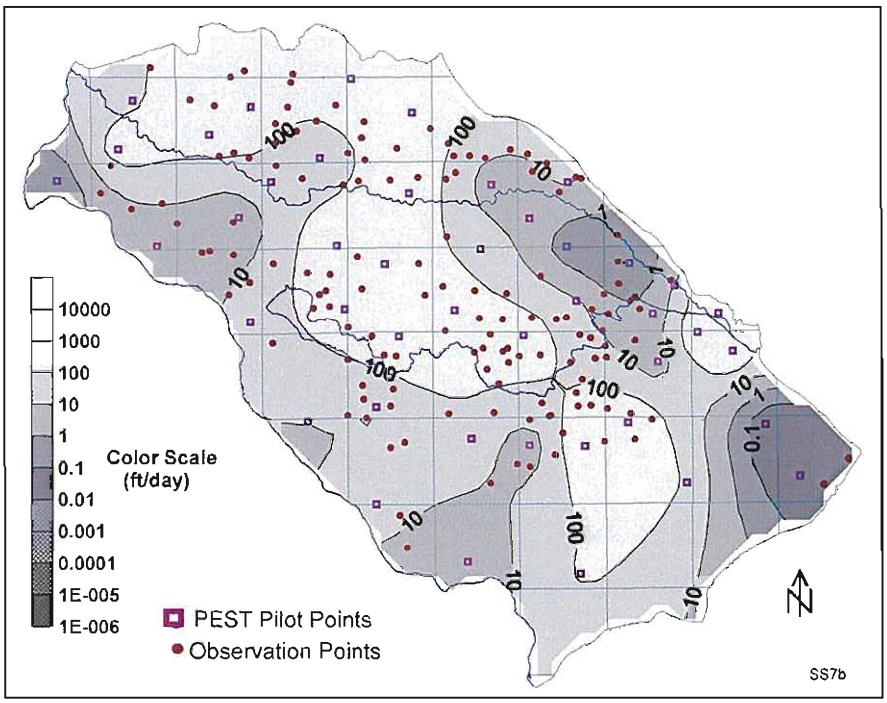

Figure 8-13: Horizontal hydraulic conductivity distribution for decreased recharge simulation, layer 1.

8.3. Increased Underflow

8.3.1. Description

This simulation consisted of increasing underflow (simulated as a specified flux) from 1,000 to 8,000 ft^3/day/cell. Cells in which underflow is specified are shown in Figure 3-5. The 8,000 ft^3/day/cell rate, yielding a total underflow of 7,239 af/yr, is much closer to the 8,000 af/yr estimate in the 1996 water budget (Urban and Petrich, 1998). However, there is substantial uncertainty about the amount and horizontal and vertical distribution of underflow rates into the model domain. Early simulations during initial model construction used lower underflow rates that led to higher objective function (sum of squared residuals) values, suggesting that the model had a difficult time accommodating the higher flux rate. Underflow rates in the base simulation therefore were decreased for the base simulation. The purpose of this model run was to show the effects of the increased underflow rate.

8.3.2. Results

Results from the calibration with increased underflow rates are summarized in Table 8-5. The contribution from head and gradients to the objective function were higher than in the base simulation (Table 7-1). The maximum and minimum residual values were higher and lower, respectively, than the base simulations, although the total average and median residual values were similar. A plot of the measured versus observed water levels (Figure 8-14) shows a slightly poorer fit than the base simulation (Figure 7-1). Residuals are portrayed by layer in Figure 8-15 through Figure 8-18. A water budget comparison between this calibration and the base simulation (Table 8-6) indicates that numerous water budget changes occur as a result of the increased underflow. Some of these are a direct result of the underflow increase, but some are the result of changes in hydraulic conductivity values forced by the increased underflow.

One of the largest hydraulic conductivity differences between this and the base simulations is in the eastern portion of layer 2. Hydraulic conductivity values in this portion of the model domain are low to maintain the steep hydraulic gradient observed in this area. Additional simulated underflow causes simulated heads to rise substantially in the eastern portion of layer 2, suggesting that the model had some difficulty accommodating the extra underflow in this area. This reflects a weakness in the underflow assumption that underflow is probably not uniform along the Boise Front. From these simulations, it appears that the underflow along the eastern portion of the model domain (e.g., east of the Boise River) is probably much less than that west of the Boise River.

Increased Recharge Simulation Results (*SS7c*) (based on observations with PEST weights greater than zero)				
Contribution to Φ from heads	4,183			
Contribution to Φ from regularization	2,797			
Contribution to Φ from gradients	134			
Highest eigenvalue	1.261			
Lowest eigenvalue	1.71×10^{-7}			
Number of PEST iterations	50			
Number of MODFLOW runs	~14,300			
Run Statistics (based on observations with weights > 0)				
	Total	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	86.0	86.0	43.2	68.5
Minimum negative residual	-172.5	-64.6	-172.5	-45.1
Average absolute residual	14.8	12.6	18.7	21.2
Median absolute residual	9.7	8.9	8.6	18.3
Number of values	200	140	29	31

Table 8-5: Run information for simulation with increase in underflow.

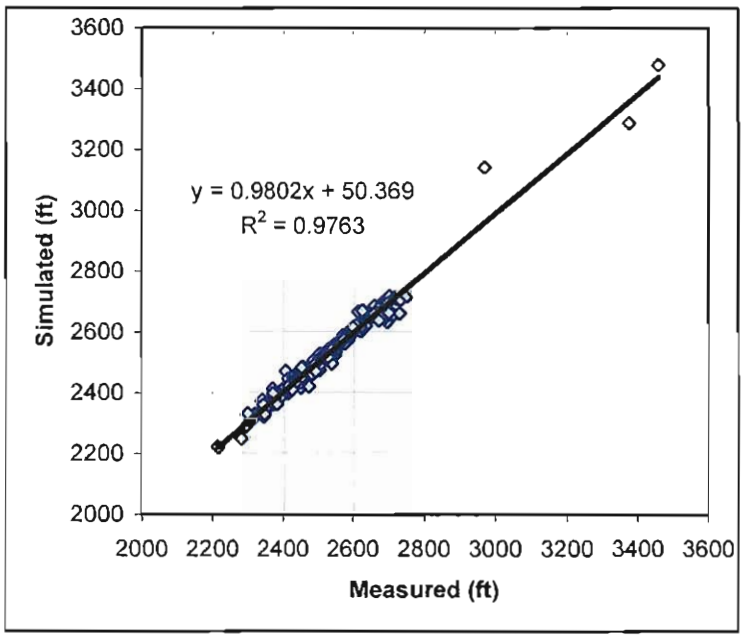

Figure 8-14: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (increased underflow simulation).

Volumetric Budget Comparison					
		Base Simulation (*SS2bc*)	Increase in Underflow (*SS7c*)	Difference from Base Simulation	Change as a Percentage of Increased Underflow
Inflows	Constant head	28,891	26,620	-2,271	0%
	Wells	108,000	864,000	756,000	100%
	Drains	0	0	0	0%
	River leakage	5,784,137	5,010,208	-773,929	-102%
	Head-dependent boundaries	1,537,895	1,697,406	159,511	21%
	Recharge	116,205,088	116,205,088	0	0%
	Total In	123,664,008	123,803,320	139,312	
Outflows	Constant head	17,350,556	16,845,578	-504,978	-67%
	Wells	23,076,956	23,076,956	0	0%
	Drains	36,667,716	38,084,656	1,416,940	187%
	River leakage	46,486,872	45,733,944	-752,928	-100%
	Head-dependent boundaries	81,961	62,260	-19,701	-3%
	Recharge	0	0	0	0%
	Total Out	123,664,064	123,803,392	139,328	

Table 8-6: Volumetric water budget comparison, increase in underflow.

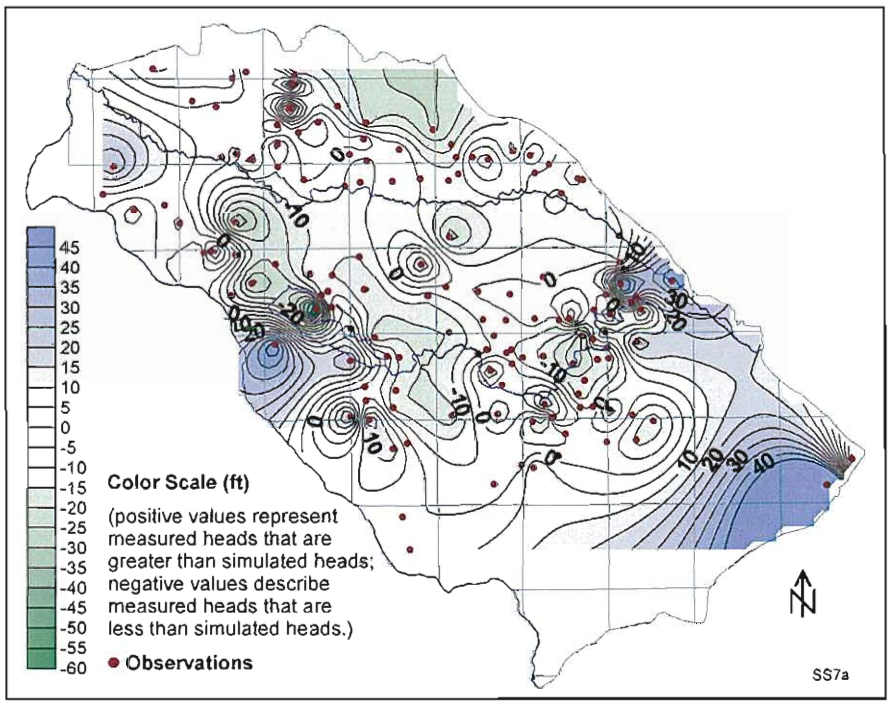

Figure 8-15: Increased underflow simulation residuals, layer 1.

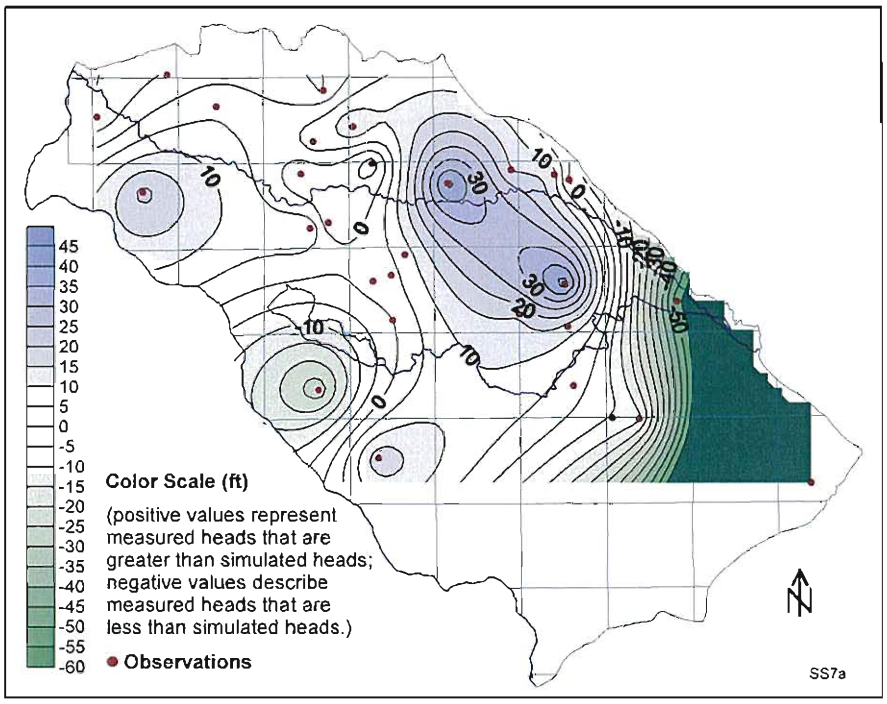

Figure 8-16: Increased underflow simulation residuals, layer 2.

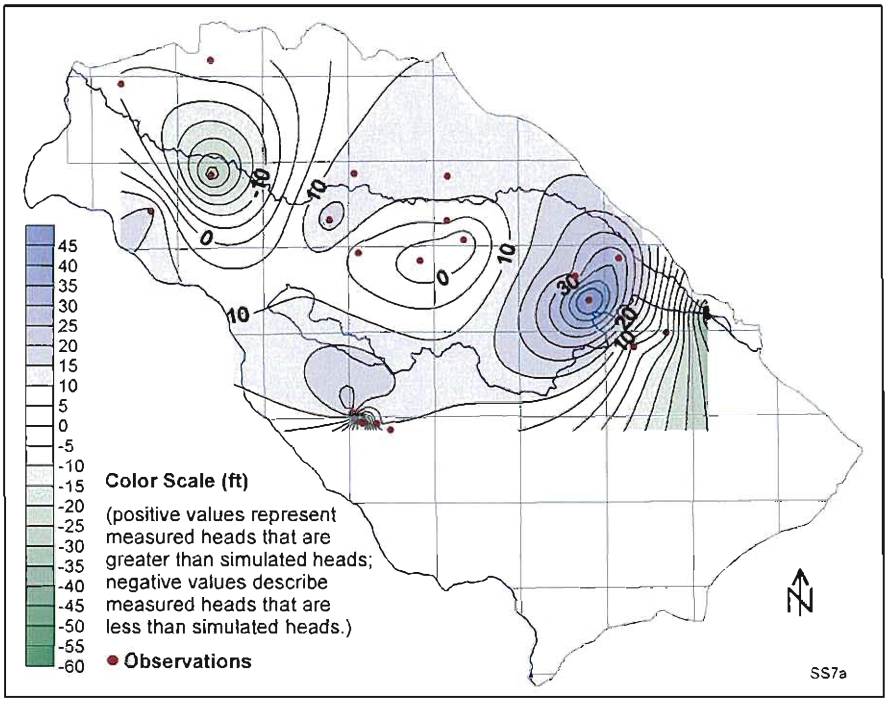

Figure 8-17: Increased underflow simulation residuals, layer 3.

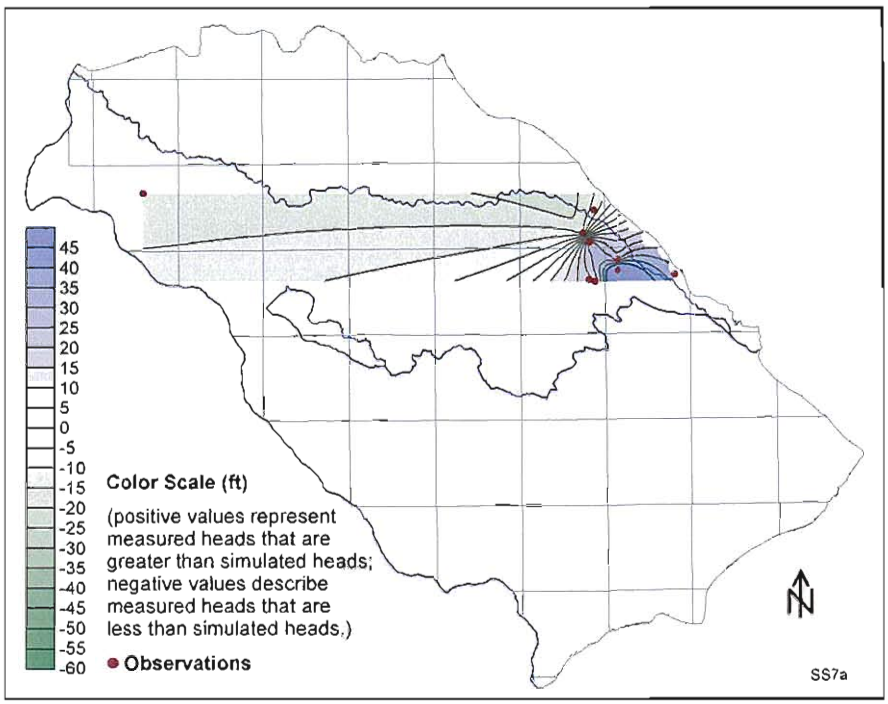

Figure 8-18: Increased underflow simulation residuals, layer 4.

9. PREDICTIVE ANALYSIS

9.1. Introduction

All calibrated ground water models have uncertainty associated with individual parameter values. The goal of predictive analysis is to find the worst (and best) possible outcomes within a set of calibrated model parameters.

In the predictive simulations, two scenarios (base simulation and predictive scenario) were run in succession until PEST found a set of parameter values that would both calibrate the model and provide the minimum (or maximum) water levels associated with the additional withdrawals. That is, PEST was asked to run two model scenarios in succession, while estimating parameters for the base simulation. For the predictive scenario, the model was provided with a set of inputs pertinent to the specific prediction that the model was required to make (e.g., increased withdrawals). PEST was asked to read that specific prediction from output files generated by the second model and then maximize or minimize that prediction. The parameter values required to maximize or minimize the prediction were constrained to the values that would calibrate the first model scenario (i.e., the base simulation).

To do this, it was necessary to define an objective function (i.e., sum of the squared residuals [Φ]) at which the base simulation would no longer be calibrated. This value was set slightly higher than the lowest objective function value achieved through normal calibration of the base simulation. The same regularization weight factor calculated by PEST for the base simulation was used to enforce parameter smoothness in the predictive simulations. Thus, parameters in the predictive simulations were forced to respect both the constraints imposed by the measurement data set and the smoothness attained during the base simulation. This prevented the predictive analysis process from introducing spurious and localized regions of parameter heterogeneity into the model domain, and thereby provided unduly pessimistic (or optimistic) estimates of predictive uncertainty.

Thus, smoothing constraints employed in the regularization process were maintained in the predictive analysis process. The prior information weights from the base simulation were multiplied by the optimized weight factor determined through regularized inversion. The calibration target ("PD0") for the predictive analysis was set slightly higher (Table 9-1) than the prior lowest calibration objective function value.

9.2. Predictive Points

Predictions of the impact from new aquifer stresses (e.g., ground water withdrawals) were calculated at one or more "prediction points" within the model domain. PEST attempted to maximize (or minimize) the average of head values at the selected

prediction points. Thus, the number of points, and the spatial and vertical distribution of the points, influences the simulation results. The predictive simulations were based on 12 points (Figure 9-1) in layers 1, 2, and 3 (36 points total). The prediction points were distributed spatially in the central portion of the valley (i.e., the area of greatest interest and the largest number of observations).

Step
Use PARREP.EXE to transfer optimized parameter values from the calibration run to the prediction PEST control file.
Use WTFACTOR.EXE to multiply regularization weights by the optimized regularization weight factor.
Run PEST once to ensure that the total objective function is the same as that achieved in the parameter estimation mode
Set PD0, PD1, and PD2 as indicated in the PEST documentation (Doherty, 2000).

Table 9-1: Selected steps in preparing a PEST control file for predictive simulations.

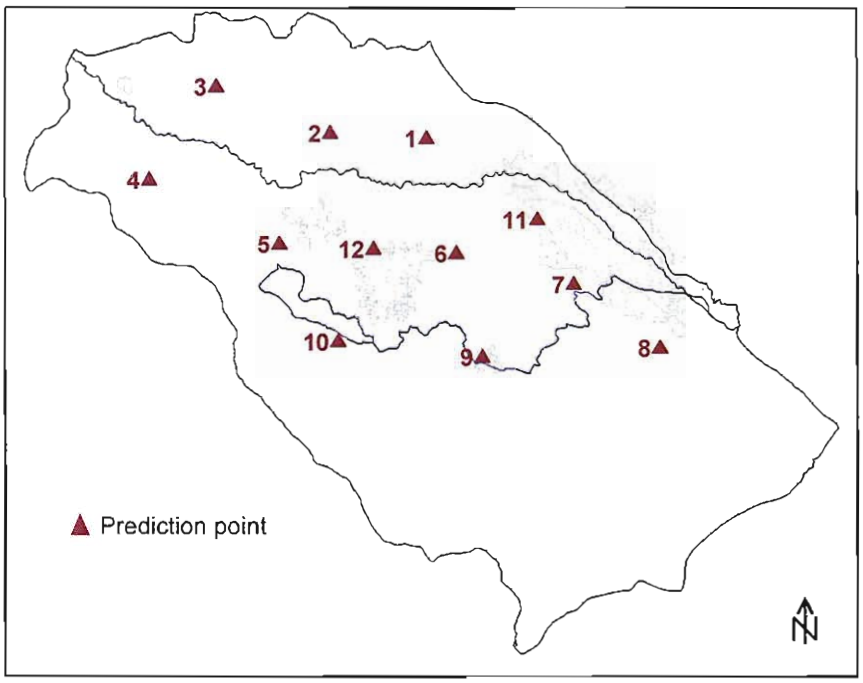

Figure 9-1: Prediction point locations.

9.3. Predictive Analysis Files

Files used for the predictive simulations are listed in Appendix F. These files are similar to those listed for model calibration (Appendix D) but also include files required for the predictive analysis. Output files from the predictive analysis are listed in Appendix G.

9.4. Processing Predictive Analysis Files

The process used for processing predictive analysis files was the same as that described in Section 5.11. In addition, changes in head (e.g., drawdown) were plotted for each predictive analysis simulation. The approach used for plotting changes in head for predictive simulations is outlined in Table 9-2.

	Process	File
1.	Review simulation results (Table 5-6)	
2.	Import hydraulic head file into GMS, and export from GMS as an ASCII *.dat* file. Subtract the predictive analysis head values from a calibration head file (in this case, simulation *SS2bc* was used).	**.hed* *HeadProcessor.xls* *active.bln* *pred-diffs.lvl* MODFLOW output file (**.out*)
3.	Separate head differences by layer in preparation for creating Surfer™ grid files. This can be done using *HeadProcessor.xls* (see instructions in *HeadProcessor.xls*). Save as	
4.	Create Surfer™ maps using default kriging parameters, using *active.bln* for blanking areas surrounding the model domain and using *pred-diffs.lvl* for plotting filled-contour maps.	*active.bln* *pred-diffs.lvl*

Table 9-2: Steps for processing predictive analysis results.

10. SCENARIOS

10.1. Introduction

Two scenarios were conducted using the PEST predictive analysis tools (Doherty, 2000). The results of one of the scenarios are reported here. Results from an additional scenario to simulate the potential impact on water levels from the aggregate withdrawals represented by Basin 63 unprocessed water right applications is reported under separate cover (Petrich, 2004a).

The initial parameters in these predictive simulations were the ending parameters of the base-case simulation (simulation *SS2bc*, Section 7.2). Base simulation results were summarized in Table 7-1). Use of these parameter values does not influence the predictive results; it simply leads to a faster predictive analysis run.

10.2. Scenario 1: 20% Increase in Withdrawals

10.2.1. Description

The purpose of this scenario was to explore potential effects of a 20% across-the-board withdrawal increase on current ground water levels in the lower Boise River basin. Scenario 1 (simulations *SS5e-min* and *SS5e-max*) consisted of an across-the-board ground water withdrawal increase of 20% over estimated 1996 withdrawals. The relative magnitude of the across-the-board increases in this scenario between model layers (Figure 10-1) were defined as being proportional to the estimated 1996 withdrawals by model layer (Urban and Petrich, 1998). A large portion of the assumed increased withdrawals in layer 1 (Figure 10-2) was in areas currently irrigated by ground water, such as the area south of the New York Canal. The largest hypothetical withdrawal increases in layers 2 (Figure 10-3) and 3 (Figure 10-4) were in the urban areas of Boise, Meridian, Nampa, and Caldwell.

The 20% increase is similar in total magnitude to that of the increase represented by the unprocessed, non-supplemental water right applications in the Treasure Valley (Petrich, 2004a). However, the horizontal and vertical distribution of the withdrawals represented by the unprocessed, non-supplemental water right applications is somewhat different than the 20% increase based on the 1996 withdrawal distribution (see Petrich, 2004a).

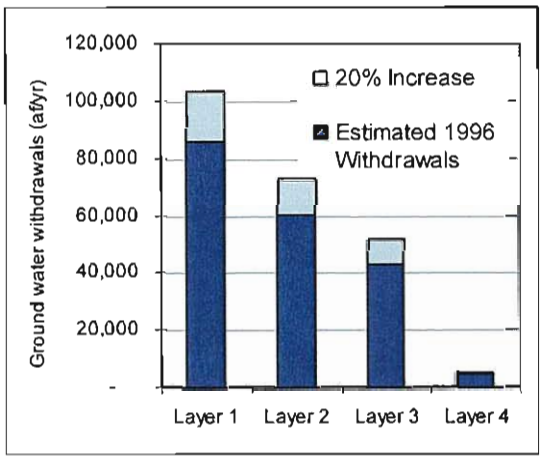

Figure 10-1: Estimated 1996 ground water withdrawals (Urban and Petrich, 1998) and hypothesized 20% increase, by model layer.

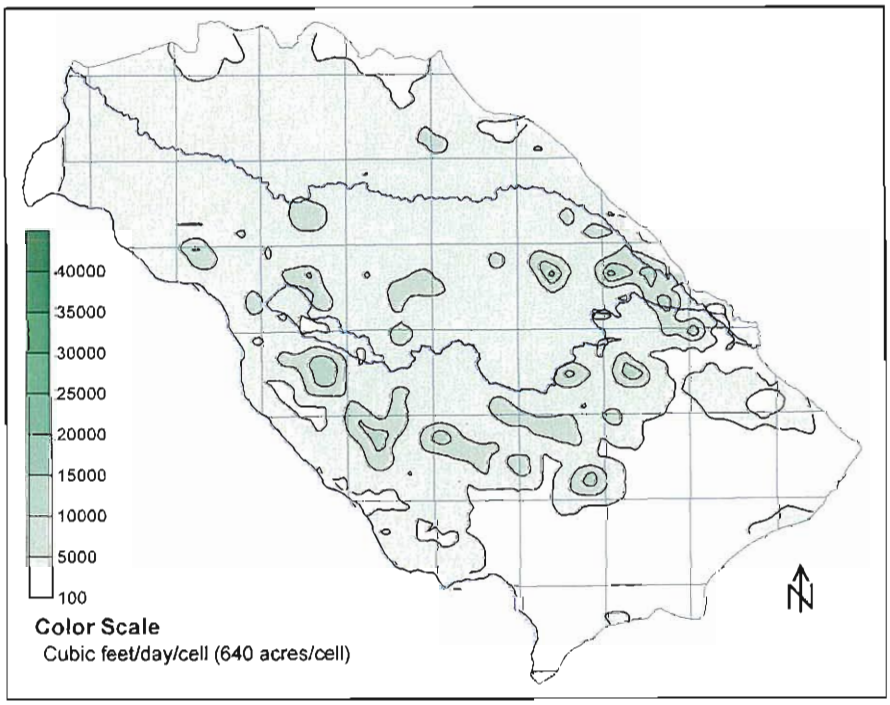

Figure 10-2: Distribution of hypothetical 20% increase in 1996 withdrawals, layer 1.

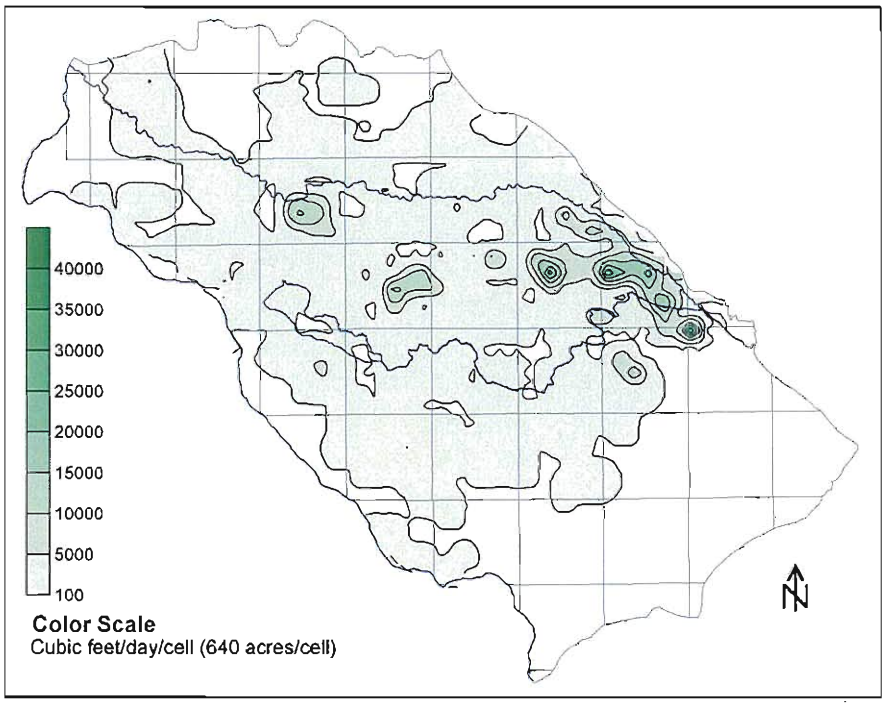

Figure 10-3: Distribution of hypothetical 20% increase in 1996 withdrawals, layer 2.

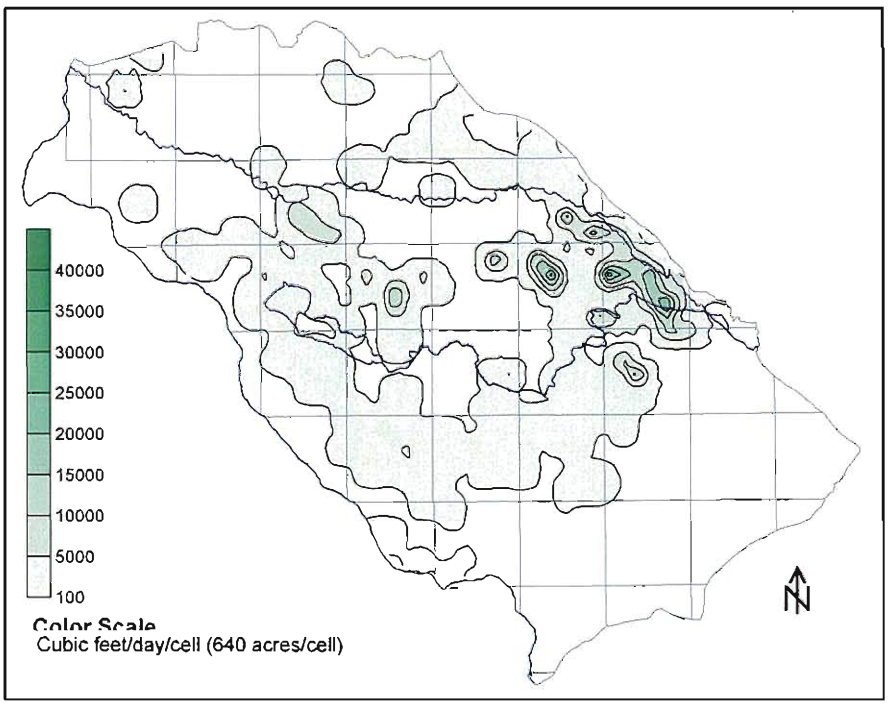

Figure 10-4: Distribution of hypothetical 20% increase in 1996 withdrawals, layer 3.

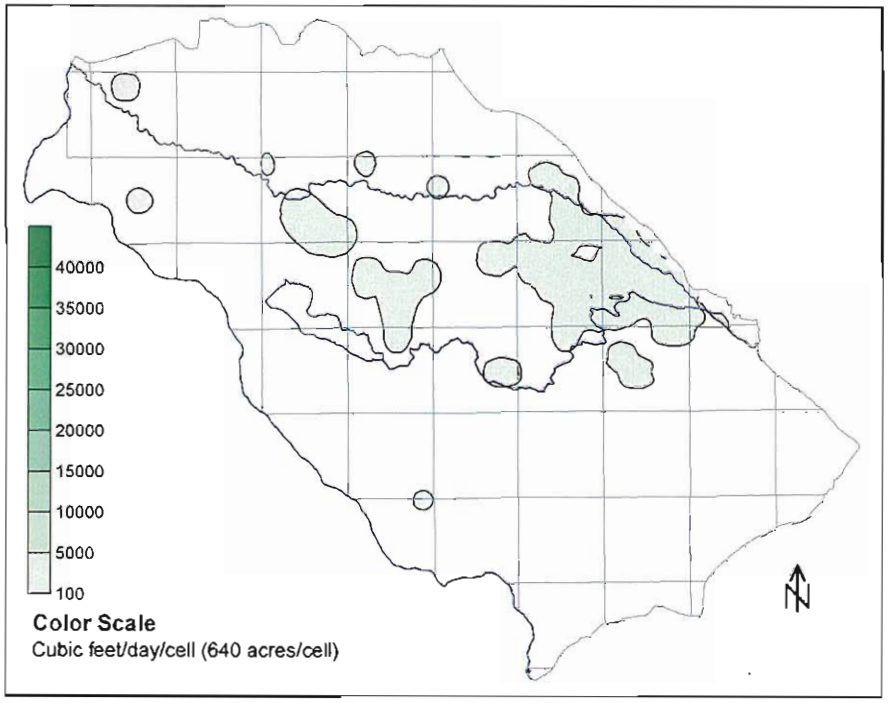

Figure 10-5: Distribution of hypothetical 20% increase in 1996 withdrawals, layer 4.

10.2.2. Results

This scenario simulation resulted in a minimum average simulated water level (based on 36 predictive point locations) of 2,484.7 feet (Table 10-1). This represents a decline of 6.5 feet over the starting average predictive point water level (2,491.3 feet). Residuals (Figure 10-6) were similar to those in the base calibration. The spatial distribution of simulated water level declines is shown in Figure 10-7 through Figure 10-10. The most substantial simulated declines (more than 30 feet) occurred south of Lake Lowell and the New York Canal in layers 2 and 3.

Residuals for the minimum head prediction are shown in Figure 10-11 through Figure 10-14. These are almost identical to the residuals for the base simulation (Figure 7-6 through Figure 7-9).

The K_h and K_v distributions that led to the minimum hydraulic heads are shown in Figure 10-15 through Figure 10-20. These are virtually identical to the K_h and K_v distributions in the base simulation (Figure 7-10 through Figure 7-15), with the exception of slight differences in the K_v distribution in layer 2 (Figure 7-14 and Figure 10-19).

Scenario 1 Simulation Results (*SS5d-min*) (based on observations with PEST weights greater than zero)				
Beginning prediction (ft)	2,491.3			
Ending prediction (ft)	2,484.7			
Initial objective function	6,427.2			
Initial contribution to Φ from heads	3,220.4			
Initial contribution to Φ from regularization	3,150.3			
Initial contribution to Φ from gradients	56.5			
Ending objective function (Φ)	6,565			
Ending contribution to Φ from heads	3,380			
Ending contribution to Φ from regularization	2,797			
Ending contribution to Φ from gradients	62.5			
Highest eigenvalue	1.247			
Lowest eigenvalue	1.76×10^{-7}			
Number of PEST iterations	3			
Number of MODFLOW runs	877			
Run Statistics (based on observations with weights > 0)				
	Total	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	73.89	64.87	66.09	73.89
Minimum negative residual	-65.61	-65.61	-51.66	-43.72
Average absolute residual	14.98	12.10	18.47	24.72
Median absolute residual	11.03	8.14	13.28	21.80
Number of values	200	140	29	31

Table 10-1: Summary of results, Scenario 1, minimum head levels.

A summary of the simulation residuals and simulation results are presented in Figure 10-21 and Table 10-2, respectively. The maximum prediction of average heads at the predictive points was 2,500.1 feet (Table 10-2), about 8.8 feet above the starting average head of 2,491.3 feet.

The difference between the minimum and maximum heads (2,487.7 feet versus 2,500.1 feet) represents the uncertainty inherent in the model calibration. It is highly unlikely that average heads would increase in response to increased withdrawals. Thus, the finding of this predictive simulation is that heads (given the current model calibration) would decline no more than those indicated by the minimum head prediction in response to the increased withdrawals. This uncertainty inherent to the model calibration does not include or quantify the uncertainty inherent in model input variables or basic model construction.

A water budget for the increased withdrawal simulations is given in (Table 10-3). The largest impacts of the simulated increases (Figure 10-22) were decreased discharge to drains (62%) and increased (induced) leakage from the Boise River to the underlying aquifer (23%).

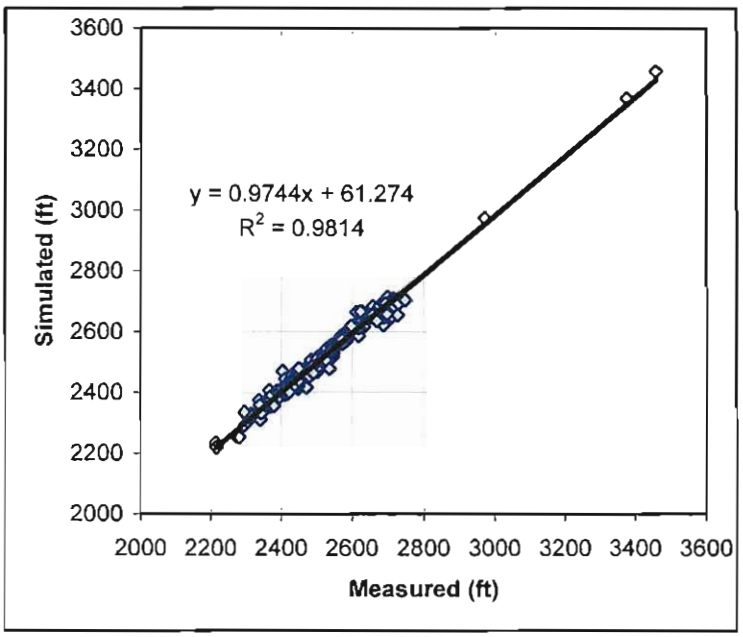

Figure 10-6: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (increased withdrawals simulation, minimum prediction).

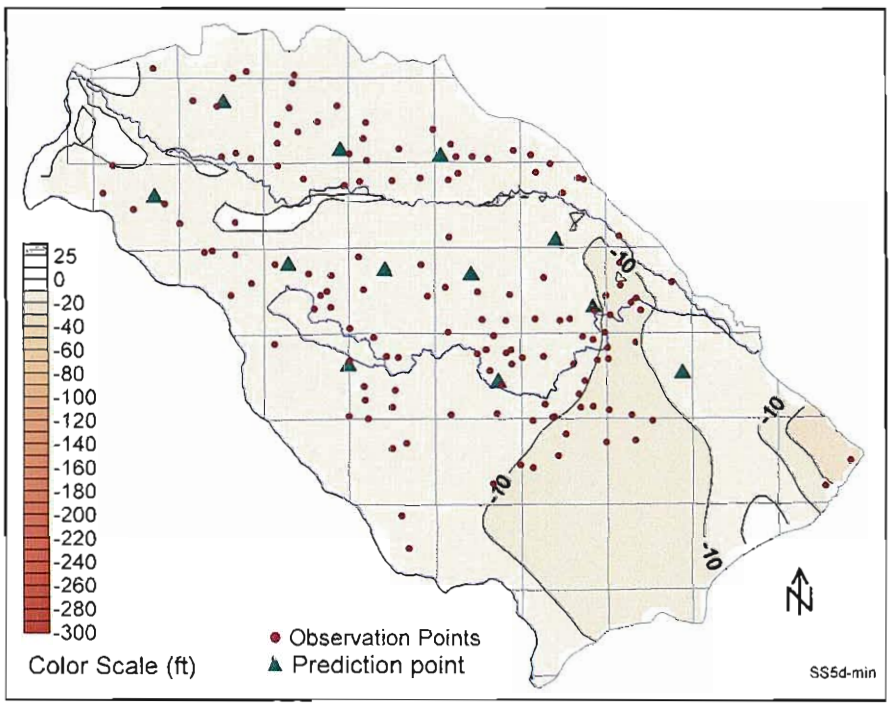

Figure 10-7: Head difference between base case and minimum predictive values, Scenario 1, layer 1.

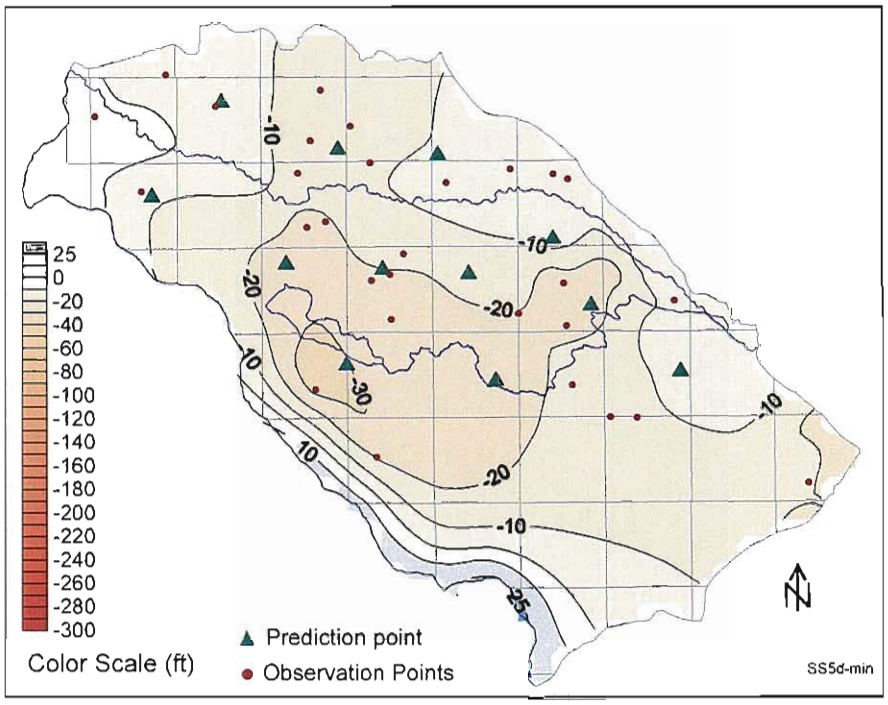

Figure 10-8: Head difference between base case and minimum predictive values, Scenario 1, layer 2.

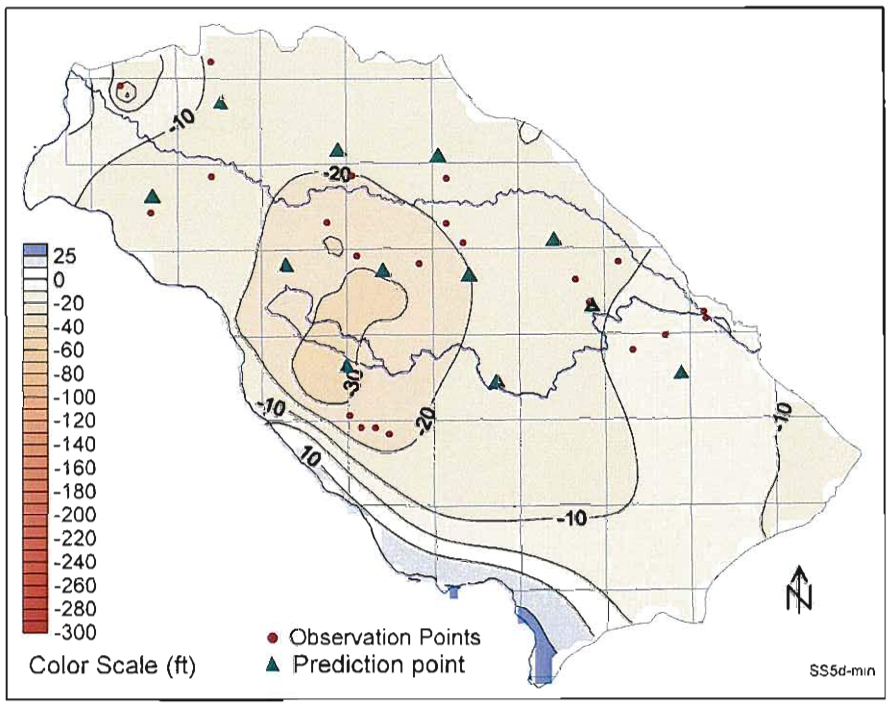

Figure 10-9: Head difference between base case and minimum predictive values, Scenario 1, layer 3.

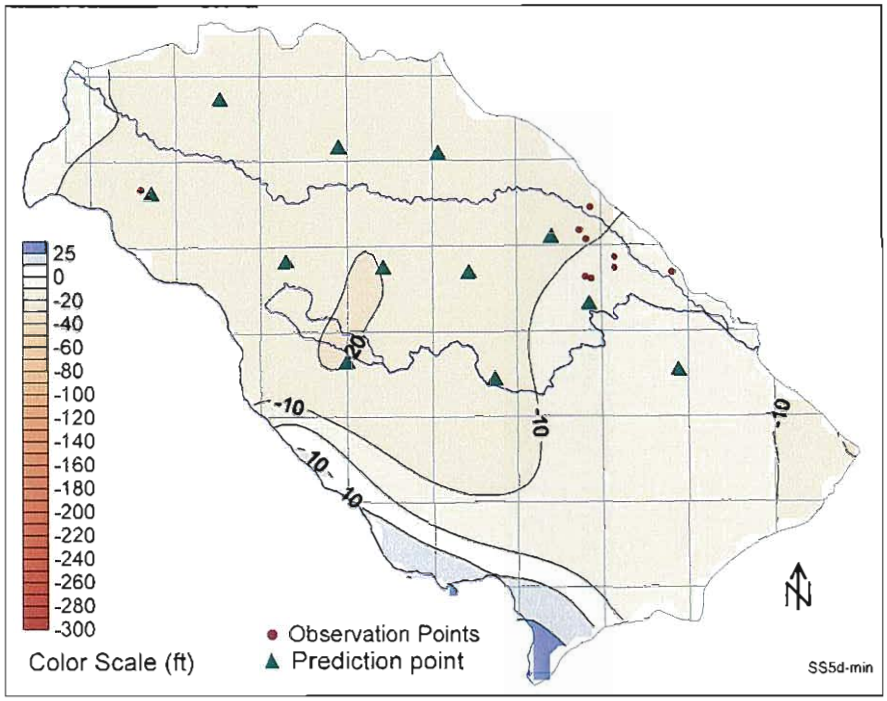

Figure 10-10: Head difference between base case and minimum predictive values, Scenario 1, layer 4.

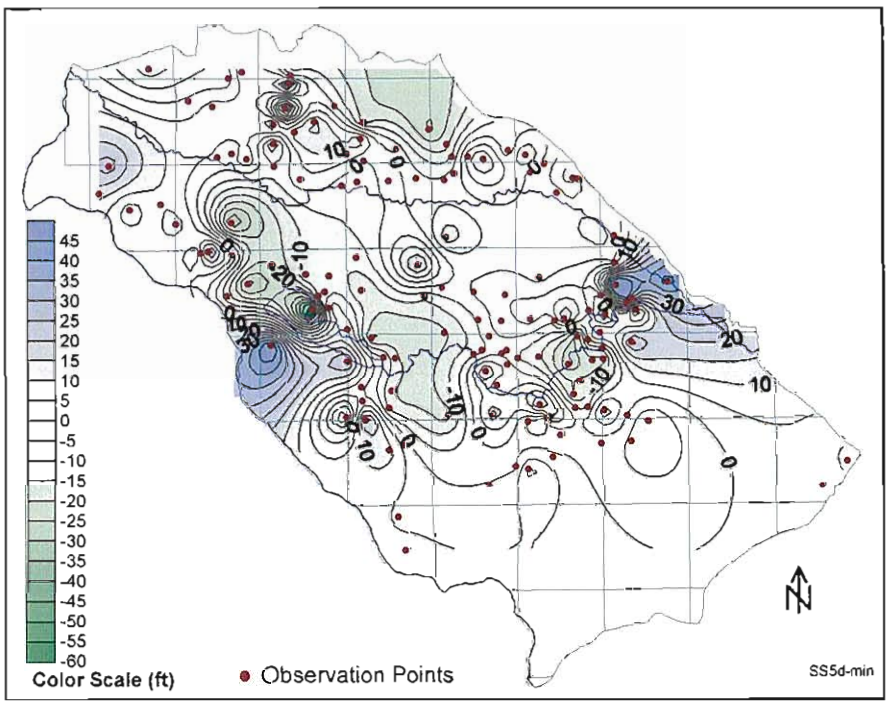

Figure 10-11: Scenario 1 simulation residuals, minimum heads, layer 1.

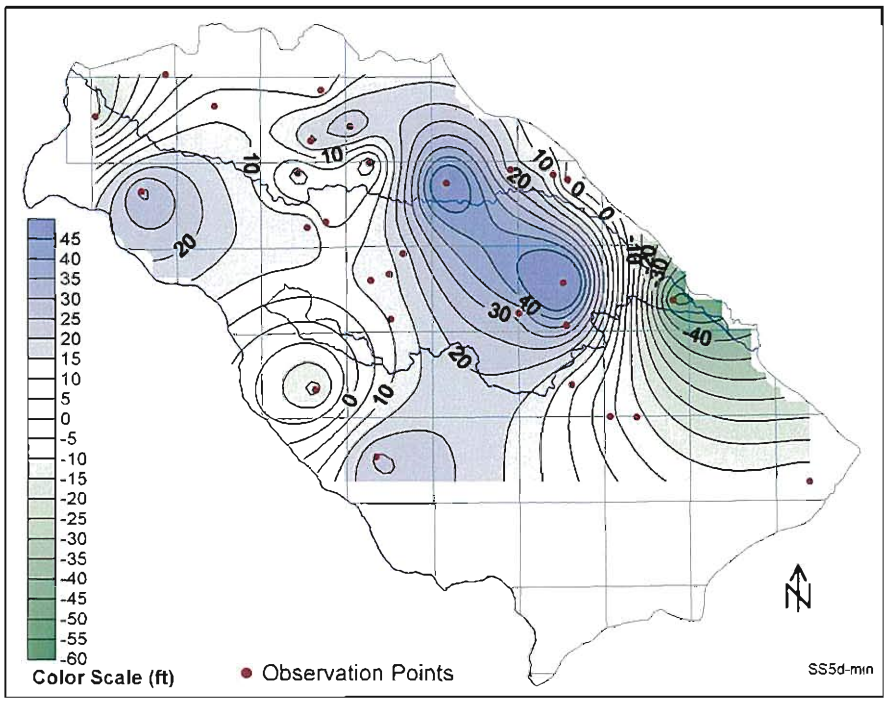

Figure 10-12: Scenario 1 simulation residuals, minimum heads, layer 2.

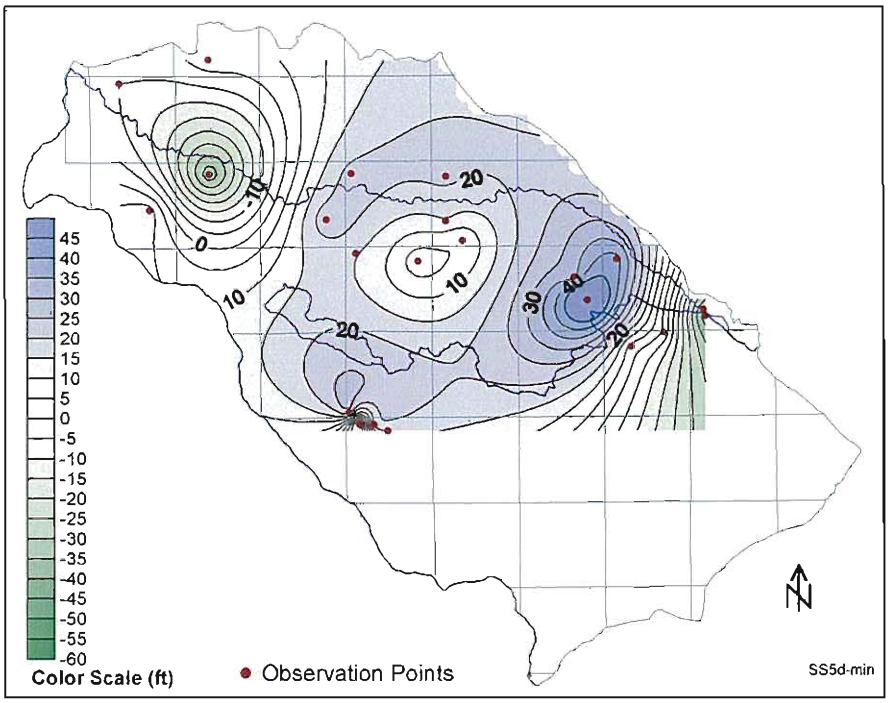

Figure 10-13: Scenario 1 simulation residuals, minimum heads, layer 3.

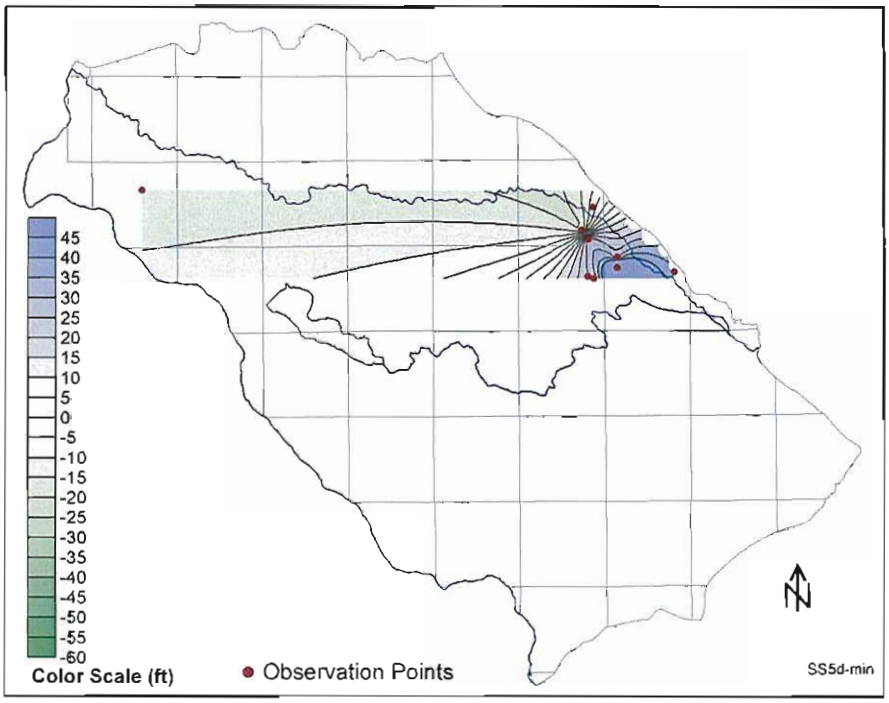

Figure 10-14: Scenario 1 simulation residuals, minimum heads, layer 4.

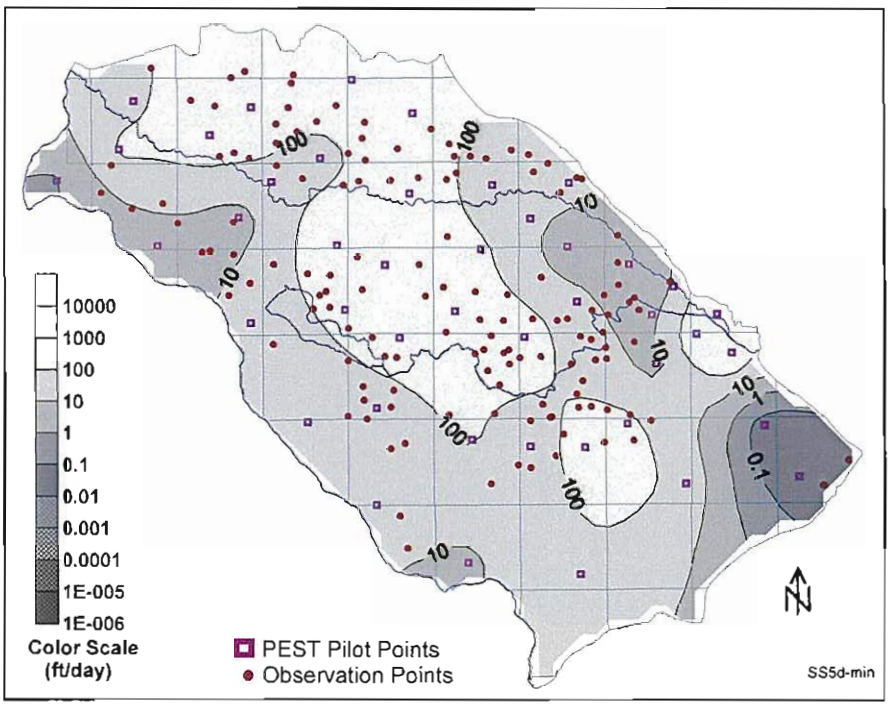

Figure 10-15: Simulated horizontal hydraulic conductivity distribution, Scenario1, layer 1.

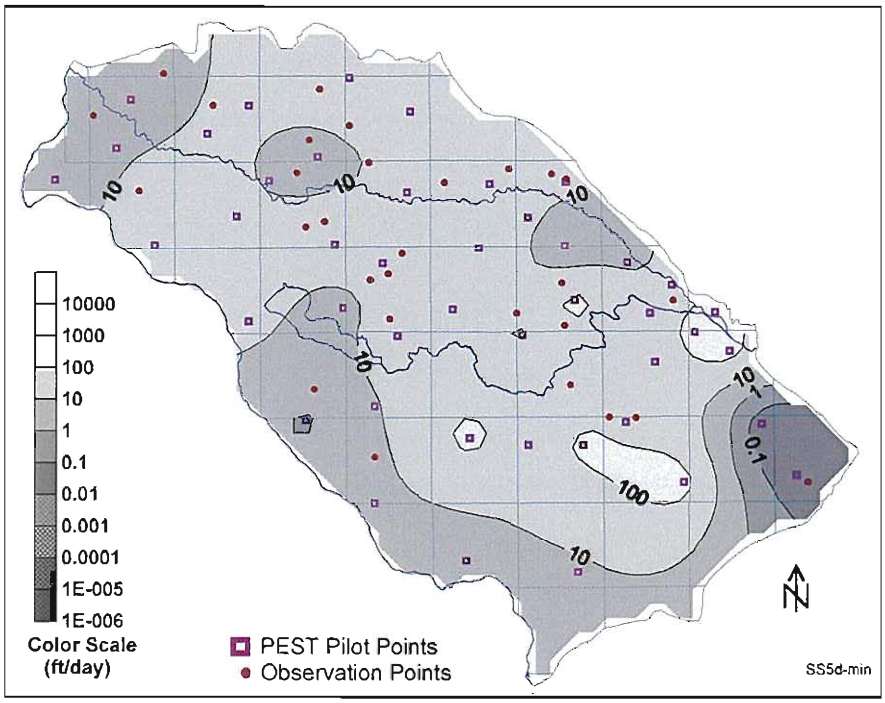

Figure 10-16: Simulated horizontal hydraulic conductivity distribution, Scenario1, layer 2.

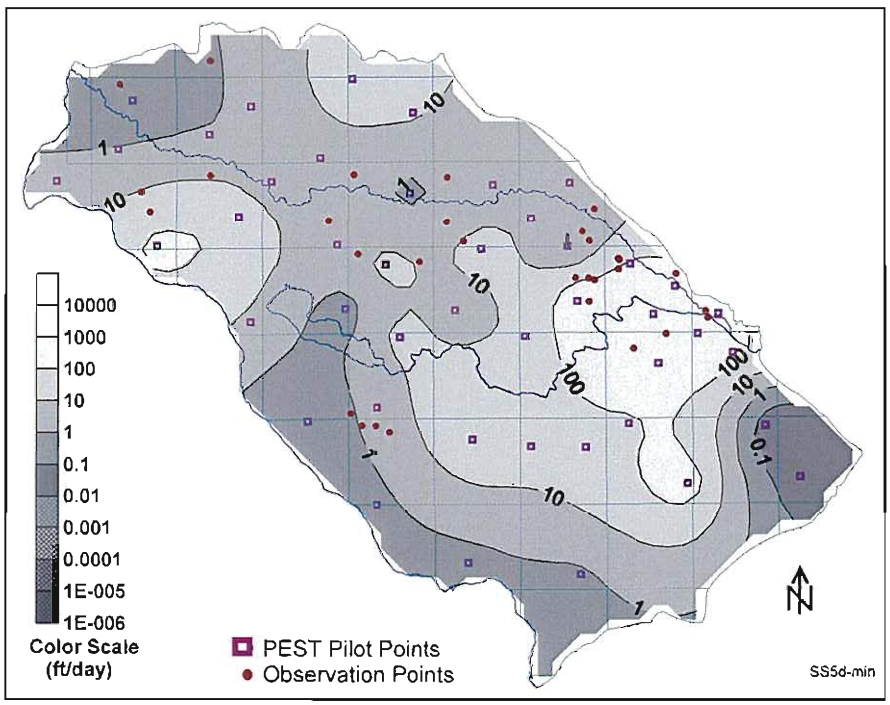

Figure 10-17: Simulated horizontal hydraulic conductivity distribution, Scenario1, layers 3 and 4.

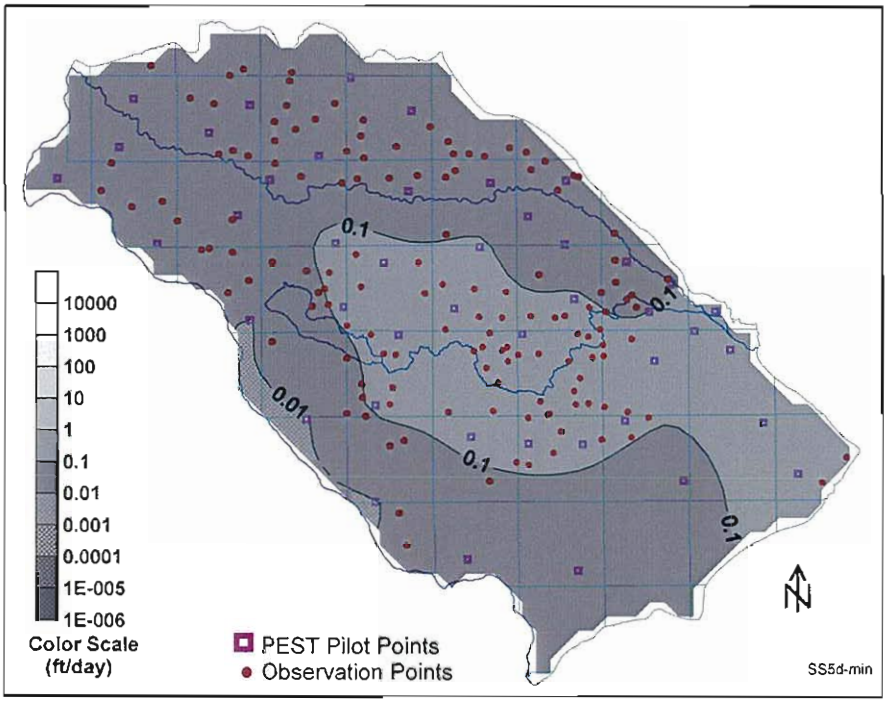

Figure 10-18: Simulated vertical hydraulic conductivity distribution, Scenario1, layer 1.

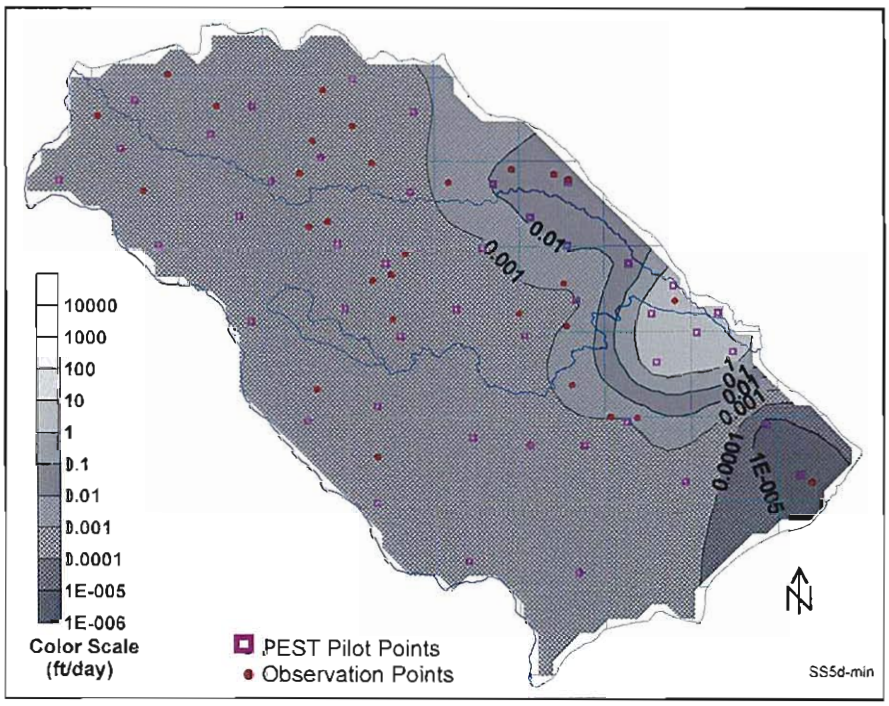

Figure 10-19: Simulated vertical hydraulic conductivity distribution, Scenario1, layer 2.

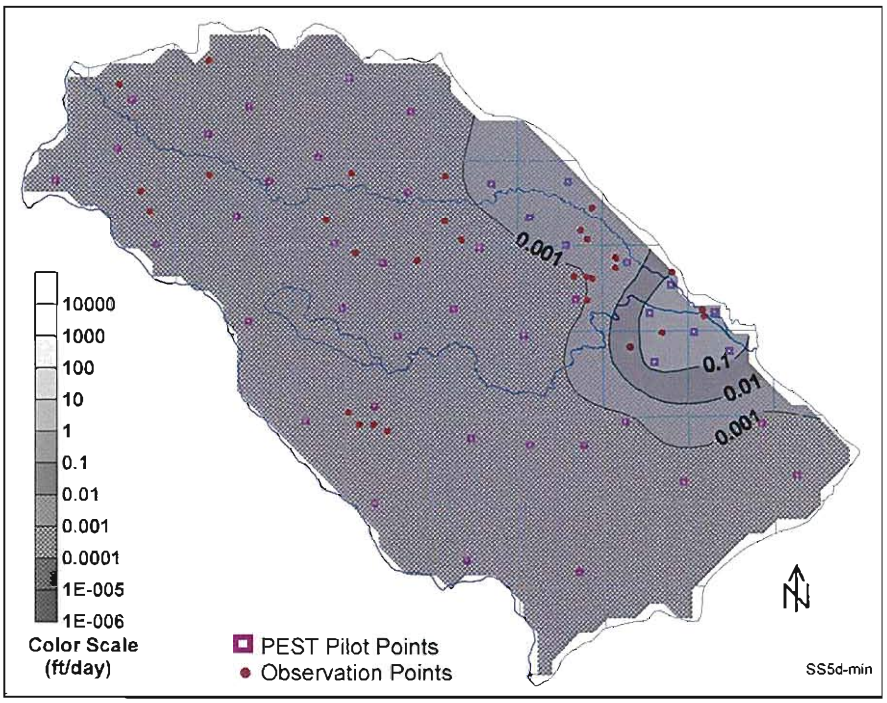

Figure 10-20: Simulated vertical hydraulic conductivity distribution, Scenario1, layers 3 and 4.

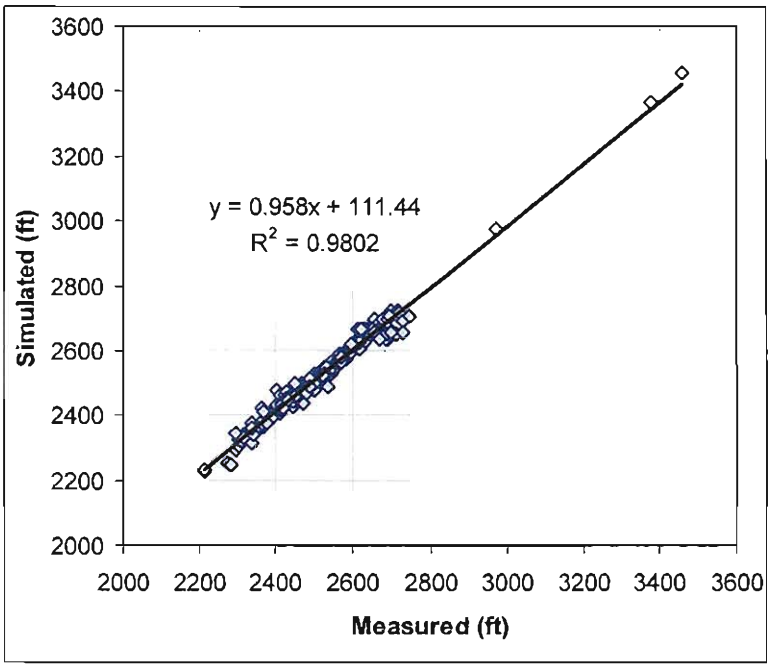

Figure 10-21: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (increased withdrawals simulation, maximum prediction).

Scenario 1 Simulation Results (*SS5b-max*) (based on observations with PEST weights greater than zero)				
Beginning prediction (ft)	2,491.3			
Ending prediction (ft)	2,500.1			
Initial objective function	6,427.2			
Initial contribution to Φ from heads	3,220.4			
Initial contribution to Φ from regularization	3,150.3			
Initial contribution to Φ from gradients	56.5			
Ending objective function (Φ)	7,020			
Ending contribution to Φ from heads	3,799			
Ending contribution to Φ from regularization	3,022			
Ending contribution to Φ from gradients	199			
Highest eigenvalue	1.41			
Lowest eigenvalue	2.69×10^{-7}			
Number of PEST iterations	3			
Number of MODFLOW runs	868			
Run Statistics (based on observations with weights > 0)				
	Total	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	74.65	57.46	53.55	74.65
Minimum negative residual	-73.54	-73.54	-53.93	-51.52
Average absolute residual	16.59	15.19	16.34	23.12
Median absolute residual	11.63	11.20	12.26	19.84
Number of values	200	140	29	31

Table 10-2: Summary of results, Scenario 1, maximum head levels.

Simulation Volumetric Budget Comparison			
	Base Simulation (*SS2bc*)	**20% Increase in 1996 Withdrawal Rates (Minimum heads) (*SS5d-min*)**	**20% Increase in 1996 Withdrawal Rates (Maximum heads) (*SS5d-max*)**
Inflows			
Constant head	28,891	28,133	30,850
Wells	108,000	108,000	108,000
Drains	0	0	0
River leakage	5,784,137	6,827,901	7,270,731
Head-dependent boundaries	1,537,895	1,673,447	1,267,186
Recharge	116,205,088	116,205,088	116,205,088
Total In	123,664,008	124,842,568	124,881,856
Outflows:			
Constant head	17,350,556	16,939,652	16,091,218
Wells	23,076,956	27,692,348	27,692,348
Drains	36,667,716	33,778,404	38,858,980
River leakage	46,486,872	46,368,532	42,127,248
Head-dependent boundaries	81,961	63,698	112,129
Recharge	0	0	0
Summary			
Total	123,664,064	124,842,624	124,881,920
In - Out	-56	-56	-64
Percent discrepancy	0	0	0

Table 10-3: Simulation volumetric budget comparison (ft^3/day).

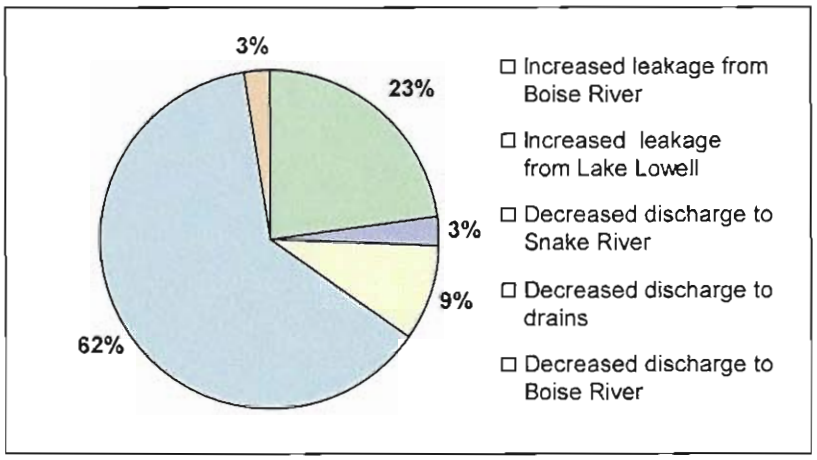

Figure 10-22: Sources of water for increased simulated withdrawals (*SS5d-min*).

11. SUMMARY AND DISCUSSION

A numerical model was constructed to simulate regional-scale ground water flow in the Treasure Valley of southwestern Idaho. The MODFLOW (McDonald and Harbaugh, 1996) model was calibrated to steady-state hydraulic conditions using the PEST automated parameter estimation code (Doherty, 2000).

Several sensitivity calibrations were conducted with the model to investigate potential variability in fixed model variables. In addition, one predictive (scenario) simulation was conducted for an across-the-board 20% increase in ground water withdrawals. This section provides a summary and discussion of results from these simulations. A second predictive simulation was performed to evaluate the potential effects on regional ground water levels associated with currently-unprocessed water right applications, which is described under separate cover (Petrich, 2004a).

As a regional-scale model, this model is appropriate for use in simulating regional-scale flow characteristics. It is not appropriate for simulating small-scale, local conditions or drawdowns in single wells. A regional-scale model can form the framework for constructing submodels or refined-grid models to simulate more detailed, local conditions. Model results from the calibration, sensitivity, and predictive simulations yielded several observations. These are discussed in the following sections.

11.1. Residuals Between Simulated and Observed Water Levels

Simulations generally resulted in reasonable agreement between simulated and observed water levels, with median absolute residuals ranging between about 8.5 and 9.5 feet. These magnitudes are probably within the error associated with some of the well elevations (well elevations were generally taken from USGS 7.5-minute quadrangle maps or by field-grade GPS devices).

The maximum absolute residuals, however, ranged to over 74 feet in the base simulation (Table 7-1) and over 165 feet in one of the sensitivity simulations (Table 8-3). Large residuals can occur for three general reasons: (1) observation data do not reflect local conditions, (2) well elevations are incorrect, or (3) local hydrologic conditions are incorrectly represented in the model. An observation may not reflect local conditions because the observation well was being pumped, influenced by pumping in a nearby well, completed in an aquifer zone other than that to which the well is attributed, or because of measurement errors. The average water levels (averaged between spring and fall measurements) may not reflect equilibrium water levels. Several observations were discarded upon review of specific local conditions in the context of abnormally large residuals. Several of the wells for which simulated water levels were substantially different than those measured (therefore resulting in a large residual) may not adequately reflect local conditions.

Two of the wells experiencing large residuals (Figure 8-8) in one of the simulations (10% decrease in recharge) are higher elevation wells in the eastern portion of the model domain. This entire portion of the model was problematic because of a lack of stratigraphic and water level data for this area. There is an apparent steep hydraulic gradient between this area and the remainder of the model domain. The hydraulic continuity of aquifer(s) in the far eastern portion of the model domain with the rest of the Treasure Valley aquifers is uncertain.

PEST could be forced to reduce model residuals by relaxing regularization constraints or by simply allowing the calibration to proceed through a greater number of iterations. Aquifer parameter values can be adjusted to meet individual observations more closely (resulting in decreased residuals), but the resulting distortion of aquifer parameter values is probably unjustified in most places, given (1) the potential for erroneous observations and (2) the relatively consistent regional-scale lacustrine/deltaic depositional environment that covers much of the model domain.

11.2. Mass Balance

The aquifer inflows and outflows reported in the base simulation mass balance (Section 7.2.1) are very similar to those estimated in the 1996 water budget (Urban and Petrich, 1998) because many of the simulated inflows and outflows are specified values. Flux rates through head-dependent model boundaries (e.g., drain, general head, and river cells) could be better constrained through the calibration of conductance parameters with better estimates of discharge to drains, canals, and rivers. There is a substantial effort underway to compile these data by the USBR, but the data were not available at the time of model calibration.

11.3. Potentiometric Surfaces

Comparisons of observed and simulated potentiometric surfaces in the base simulations were relatively close in areas of numerous observation data (i.e., the central portion of the basin). Areas of substantial discrepancy included the eastern, southeastern, and southern portions of the model domain. The discrepancies were attributed to inconsistent data, interpolation errors, and uncertain boundary conditions.

11.4. Boundary Conditions

Boundary conditions influenced the model simulations, especially in the vicinity of the Boise Front, the eastern model corner, and along the Snake River. For instance, the amount of underflow entering the northeastern boundary is highly uncertain, yet influences the estimation of aquifer parameter values in this area. Similarly, layer surfaces extend downward from the northern part of the model domain to the southern boundary along the Snake River. The stratigraphic nature of these sediments underlying the Snake River is unknown because there are few deep wells in this area.

The K_v of these sediments has substantial influence on the vertical movement of water from deeper aquifers upward toward the Snake River. Boundary conditions may be refined as more information becomes available.

11.5. A Discharge-Limited Flow System?

The conceptual model for ground water flow in the regional aquifer system (Section 2) outlines three possible reasons for the large ground water residence times (e.g., greater than 20,000 years) estimated from carbon-14 age-date analyses (Hutchings and Petrich, 2002a). Large residence times could be the result of (1) low aquifer transmissivity, (2) low recharge rates, and/or (3) low discharge rates.

It is unlikely that high residence times are the result of low transmissivity characteristics. Although there are abundant silt and clay layers with low hydraulic conductivity, productive sand layers are present throughout central portions of the valley. These sand zones are tapped by many irrigation and municipal wells. Thus, low aquifer transmissivity is probably not the sole cause of large ground water residence times.

More likely explanations for large residence times might be low discharge and/or recharge rates. Thick lacustrine clays throughout large portions of the basin limit vertical ground water flow. Thick clay layers at the distal end of the basin likely inhibit upward (discharge) flow, limiting the amount of water from deeper aquifers that can flow upward through the system. Numerous deep wells (and some relatively shallow wells) with artesian flow and/or substantial upward gradients in the western portion of the valley (e.g., TVHP#2 well, Figure 2-5) point to a system that is at least partially confined and discharge-limited by these clay aquitards. Similarly, the aggregate effects of lacustrine clays also limit recharge to the deep aquifer system over large portions of the basin (based on lithologic observations and water chemistry differences). The primary area of downward flow (e.g., TVHP#4 well,) is through alluvial/fluvial sediments in the far eastern portion of the basin.

Are the deep aquifers, particularly in the western portion of the basin, completely confined? If the deeper aquifers were completely confined, and if there were no withdrawals from the deeper aquifers, one would expect head differences between the bottom of deep wells and ground surface to be much greater than they currently are (possibly as much as 200 feet, based on elevation differences between recharge elevations and down-valley well elevations). However, artesian heads are often less; 40-foot head differences between screen and ground surface are more common (E. Squires, per. comm., 2000), such as those indicated in the TVHP Caldwell monitoring well (Figure 2-5). The difference between the theoretical and observed vertical head differences could be attributed to (1) leaky confining conditions and/or (2) the effects of current levels of withdrawals.

The simulations reflected the aggregate effects of fine-grained silt and clay layers that are present in much of the basin. The simulations indicated a relatively small amount of vertical flux between model layers (Table 7-4) compared to the magnitude of total flux into and out of the aquifer system (Table 7-3). The difference between downward and upward simulated flux rates in the lower model layers was accounted for primarily by simulated aquifer withdrawals.

It is unclear from these simulations to what extent the deep, regional Treasure Valley flow system is discharge- or recharge-limited. The implication of a discharge-limited flow system is that additional withdrawals could induce greater recharge from the eastern portion of the model area (e.g., Boise area) where downward flux occurs. At some point, recharge rates and/or aquifer transmissivities would limit the amount of water that can be withdrawn without substantial ground water level declines. Additional data collection and simulations with greater withdrawal levels are warranted to estimate the extraction levels at which discharge might exceed recharge and substantial water level declines occur.

11.6. Impact of Variations in Total Recharge

Results from model simulations with increased and decreased total recharge (Sections 8.2 and 8.3) indicated small water level differences. It appears that the ground water levels in the shallow system are not very sensitive to this amount of variation (e.g., ± 10%) in recharge. There are two probable reasons for this.

First, shallow ground water levels are close to ground surface in many portions of the central basin, especially in flood-irrigated areas. Shallow ground water levels are controlled by the elevations of canals and ditches, a portion of which were installed solely to collect shallow ground water. These surface channels (Boise River, Snake River, and drains) appear to prevent ground water level rises in response to a 10% increase in recharge. Similarly, a decrease in recharge results in a decrease in discharge to surface channels. Second, relatively high PEST-calibrated K_h values (Figure 7-10, Figure 8-7, and Figure 8-13) facilitate effective movement of excess shallow recharge.

The implication of this is that increased recharge in areas drained by surface channels (e.g., drains, canals, and rivers) would lead to more surface water discharge. Decreased recharge (i.e., resulting from changing land use) would lead to decreasing surface water discharge, as long as local aquifer levels remain above those of the surface channels. Shallow ground water levels could decrease rapidly on a local basis if recharge decreased to the point where shallow ground water levels were below that of the surface channels. Additional simulations based on more detailed local data might help identify the amount of decrease necessary for this to occur.

The prime areas of recharge to the deeper flow system in the central portion of the valley include underflow from basin margins, the upper reaches of the lower Boise

River (e.g., below Barber Dam and upstream of Capital Street Bridge), and areas underlain by alluvial fan sediments in the eastern portion of the basin. The latter two areas experience downward hydraulic gradients (e.g., Boise Municipal Park well, Figure 2-5). These areas would not appear to be substantially impacted by decreases in recharge to the shallow system in central portions of the valley.

11.7. Role of Basin Underflow

The rate and spatial and vertical distribution of underflow into the valley and into the model domain is highly uncertain. The amount of underflow estimated in the 1996 water budget (Urban and Petrich, 1998) was based on the difference between precipitation falling in the Boise Foothills, runoff, and evapotranspiration. However, even if the total volume is correct, it is highly unlikely that the underflow is equally distributed with depth or along the Boise Foothills. Both of these conditions were assumed in the model for lack of better information.

The amount of underflow is relatively small compared to other water budget components but is large (Section 8.3.1) compared to downward simulated fluxes into lower model layers (Table 7-4). The amount of underflow affects both K_h and K_v parameter estimates in areas near the northeastern model boundary. Additional simulations with various combinations and distributions of underflow values may provide insight into actual underflow conditions.

11.8. Impact of Increased Ground Water Withdrawals

Ground water levels appear to be relatively sensitive to regional increases in ground water withdrawals from the regional flow system. This was seen in areas of maximum simulated ground water level declines in response to the 20% increase in withdrawals (Section 10.2 and Figure 10-7 through Figure 10-10). Areas of predicted shallow aquifer declines developed in the Boise area and south of Boise, east of the New York Canal[19]. The greatest regional simulated declines began to develop in deeper aquifers near and south of Lake Lowell.

Several factors may have contributed to these simulated declines. First, the simulated declines are partly the result of increased withdrawals and partly the result of parameter uncertainty. Second, more water may be leaking from Lake Lowell, at least into shallow zones, than was described in the model because of uncertainty regarding the conductance values used in the Lake Lowell general head boundary. More leakage would mitigate the simulated declines. Third, simulated K_h values may have been lower in this area because the model attempted to calibrate to current declines in this area. Fourth, because of the current declines, it is unlikely that substantial increases in

[19] Areas of decline extending south to the model boundary are unsubstantiable because of a lack of withdrawals and observations in this area.

withdrawals would be permitted in this area. Finally, simulated K_v values in this area may be too low, preventing simulated vertical downward movement of water that might help mitigate some of the deeper declines.

Part of the simulated declines can be attributed to parameter uncertainty. The predictive simulations found a combination of parameter values that minimized (or maximized) simulated heads and minimized the residuals between simulated and measured observations in the base simulation. The resulting head values were compared to head values from the pre-predictive analysis simulations, which are not optimized for a minimum (or maximum) outcome. Thus, a comparison between the two represents changes in the calibration and hydraulic stress. This also applies to the base balance comparisons between the base simulation and predictive scenario (e.g., Figure 10-22). The changes in mass balance reflect both increased withdrawals and parameter uncertainty.

An alternative approach to evaluating potential head declines would have been to first run predictive analyses using the base simulation. Heads (or mass balance terms) could be minimized (or maximized) with no changes in model stresses (e.g., increase in withdrawals). The resulting head distribution from these simulations would then form the basis for the comparison between base simulation and predictive scenarios.

Another approach would have been to simulate the maximum or minimum change in water levels (instead of simulating minimum or maximum heads) in the predictive analyses with increased withdrawals. This approach would have eliminated some of the parameter uncertainty inherent to the base simulation. In other words, one might not be able to determine the precise head level at a given point in the base simulation (because of parameter uncertainty), but one would be able to predict the maximum head decrease at that point in response to additional simulated withdrawals. This approach also would have eliminated the interpolation error that arose in comparing two surfaces.

What do these results from increased withdrawal simulations mean for a water manager? Predicted regional declines in some areas based on model simulations should not necessarily preclude additional ground water development in these areas. First, additional simulations (see recommendations in Section 12) may allow improved predictions regarding possible declines. Second, managers might consider enhanced water level monitoring in these areas to detect possible changes should increased withdrawals occur.

Model predictions for some areas (i.e., some shallow aquifers) indicate that additional withdrawals are probably possible without changing water levels. However, additional extractions in these areas may increase losses from, or decrease discharge to, surface water channels. Such interaction between ground and surface water is of increasing interest to water users and water managers in the Treasure Valley. One approach to better evaluate the current (or future) effects of ground water withdrawals on surface

flows would be through the development of response functions. Response functions have been developed in the ESRP to better define the impact of ground water withdrawals on specific reaches of the Snake River (Johnson and Cosgrove, 1999). The precision of such simulations could be enhanced using a more refined grid than, and/or submodels of, the current model.

11.9. Transient Flow Simulations

Model results for a steady-state simulation describe equilibrium conditions. The time required to reach equilibrium is not estimated in a steady-state simulation. A transient model can be constructed to simulate temporal conditions and estimate the time required to reach a steady-state equilibrium. However, a transient model was not developed as part of this project. Construction of a transient model for the regional Treasure Valley domain faces two challenges.

First, transient simulations require more detailed temporal flux data than were available during the course of this project. The USBR and IDWR are currently compiling more detailed irrigation diversion and return data for the valley, which would be essential for transient simulations (especially those focusing on shallow aquifer conditions). However, these data were not available at the time of model construction and simulation.

Second, a transient simulation requires the estimation of aquifer storativity values[20]. Often storativity is correlated with hydraulic conductivity. Temporal water level change data are required to help calibrate the storativity parameters. Transient simulations with temporal data can be conducted over short or long periods of time, depending on data availability. With several exceptions, Treasure Valley water levels have remained relatively steady over the last several decades, and therefore may not provide adequate long-term changes that could be used to calibrate a transient model. Exceptions include an area south of Lake Lowell and southeast Boise, but these two areas are probably not extensive enough to provide a sufficient basis for a regional transient model calibration. Seasonal water levels do fluctuate (see hydrographs in Petrich and Urban, 2004); fluctuations are dominated by two general patterns. Water levels in wells are influenced either by water level rises corresponding with irrigation applications or by summer irrigation withdrawals, or both. However, many of the seasonal water level fluctuations are within median residual ranges (e.g., ± 10-15 feet) or within the error range associated with well elevations[21] (also about ± 10-15 feet). These seasonal water level fluctuations may be insufficient for a solid seasonal transient calibration for a model covering the entire Treasure Valley area.

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[20] Aquifer storativity is assumed to be zero during a steady-state simulation, because water levels do not change with time in a steady-state simulation.

[21] Many of the water levels used for calibration come from wells for which elevations have been estimated from USGS quad map contours or from field-grade GPS devices.

However, transient calibrations may be feasible for local ground water flow models within the Treasure Valley or submodels of the regional model. These calibrations would be possible (depending on the specific type of question to be answered by the model) given the availability of detailed local water level and surface recharge/ discharge data.

11.10. Parameter Uncertainty and Model Limitations

The range of predicted head values for Scenario 1 (Section 10.2.2) reflects uncertainty associated with the model calibration. The minimum and maximum water levels that are possible with virtually the same distribution of K_h and K_v values is a quantification of uncertainty in these estimated parameter values. The uncertainty stems from parameter insensitivity (insufficient observations to constrain estimated parameter values) and parameter correlation (simultaneous changes in two parameter values yield the same outcome). The underlying cause of the uncertainty is a lack of observation data, insufficient information about aquifer stratigraphy and characteristics, including structural controls, and possible error in input data and/or model construction. A more detailed discussion of model limitations and factors contributing to model uncertainty is included in Section 6.

12. CONCLUSIONS AND RECOMMENDATIONS

A numerical model was constructed to simulate regional-scale, steady-state, ground water flow in the Treasure Valley of southwestern Idaho. Conclusions from simulations using this model consist of the following:

1. PEST-calibrated parameter values indicate relatively higher K_h values in the uppermost aquifer zones, corresponding with known areas of coarser-grained sediments. PEST-calibrated parameter values also indicate relatively higher K_h and K_v values in areas of the eastern and central portion of the valley associated with fluvial deltaic deposition.
2. Simulated fluxes between model layers in the base calibration indicates a relatively small amount of water moving vertically between model layers, especially in the lower layers. Based on simulation results, most recharge occurring in shallow aquifer zones does not reach lower zones.
3. A 10% increase or decrease in recharge led to minimal changes in water levels or parameter value estimates. This is because shallow ground water levels in central portions of the basin are controlled, in part, by elevations of surface water channels. Decreased or increased recharge resulted in changes in the rates of water discharging to model drain, general head boundary (Lake Lowell), constant head (Snake River), and river (Boise River) cells.
4. Underflow does not appear to be consistently distributed along the Boise Front. The model experienced difficulty in applying rates as high as 8,000 ft^3/day/cell (similar to water budget estimates) in some model areas, especially in the far eastern portions of the model domain.
5. Simulated minimum water levels (maximum impact) indicated that some ground water level declines might occur with a 20% increase over 1996 levels. Simulated modest declines were observed in the Boise area in layers 1 and 2. Greater simulated declines were observed in the central portion of the valley (especially in the Lake Lowell area) in layers 3 and 4. Simulated water level declines and/or changes in mass balance components reflect a combination of parameter uncertainty and response to a changed hydraulic stress.
6. The simulated 20% increase in ground water withdrawals resulted in increased losses from the Boise River (23%), decreased discharge to agricultural drains (62%), and decreased discharge to the Snake River (9%). Again, simulated water level declines and/or changes in mass balance components reflect a combination of parameter uncertainty and response to a changed hydraulic stress.
7. Uncertainty in the model calibration limits a more precise description of responses to changes in recharge and/or withdrawals.
8. Changes in land use that lead to decreases in shallow-aquifer recharge may not have a substantial effect on shallow ground water levels until the water table elevations remain below those of nearby surface channels.

Additional simulations should be considered to better define aquifer system characteristics or scenario predictions. These include the following:

1. Maximum and minimum hydraulic head predictions with no changes in model stresses from the base simulation. Use the results from these simulations for comparisons in scenario predictions.
2. Increases and decreases of 30% (over 1996 levels) in aquifer recharge.
3. Across-the-board withdrawal increases and decreases in aquifer withdrawals over 1996 levels.
4. Increased local withdrawals in various locations in the valley to test responses in water levels and in recharge rates to lower model layers.
5. Simulations with reductions in recharge and increases in withdrawals to estimate at what point shallow ground water levels drop below drain elevations in the central portion of the valley.
6. Horizontal and vertical variations in underflow along the Boise Front.
7. Conduct additional simulations to refine the understanding of ground and surface water interaction in the Boise River corridor using a more refined grid than, and/or submodel of, the current model .
8. Develop response ratios for the interaction between ground water extractions and seepage from or discharge to surface channels.

Additional recommendations include the following:

1. Expand monitoring in areas showing recent ground water level declines.
2. Consider incorporating new monitoring data into the model as they become available.
3. Better define discharge rates to surface water channels to allow more constraint on simulated discharge.
4. Better define temporal diversion and return rates for transient simulations.
5. Refine model based on newly compiled diversion and return data.
6. Install additional multi-completion monitoring wells to expand vertical gradient data.
7. Search for opportunities to enhance ground water level monitoring in portions of the valley with relatively few current data.

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Appendix A: Conversion Factors

Volume

1 cubic foot of water = 7.4805 gallons = 62.37 pounds of water
1 acre-foot (af) = enough water to cover 1 acre of land 1 foot deep
1 acre-foot (af) = 43,560 cubic feet
1 acre-foot (af) = 325,850 gallons
1 million gallons = 3.0689 acre-feet

Flow Rates

1 cubic foot per second (cfs) = 448.83 gallons per minute (gpm) = 26,930 gallons per hour
1 cubic foot per second (cfs) = 646,635 gallons per day = 1.935 acre-feet per day
1 cubic foot per second (cfs) for 30 days = 59.502 acre-feet
1 cubic foot per second (cfs) for 1 year = 723.94 acre-feet
1 cubic meter per second (cms) = 25.31 cubic feet per second
1 cubic meter per second (cms) = 15,850 gallons per minute
1 million gallons per day (mgd) = 1,120.147 acre-feet per year
1 miner's inch = 9 gallons per minute
1 miner's inch = 0.02 cubic feet per second

Hydraulic Conductivity

1 gallon per day per foot^2 (gal/day/ft^2) = 0.134 foot/day = 0.0408 meters/day

Economic

$0.10 per 1,000 gallons = $32.59 per acre-foot

Appendix B: Listing of Model Files

Extension	Code	Description	Reference
.bas	MODFLOW	Basic package	(Harbaugh et al., 2000)
.bcf	MODFLOW	Block-centered flow package	(Harbaugh et al., 2000)
.wel	MODFLOW	Well package	(Harbaugh et al., 2000)
.drn	MODFLOW	Drain package	(Harbaugh et al., 2000)
0.ghb	MODFLOW	General head boundary package	(Harbaugh et al., 2000)
.oc	MODFLOW	Output control package	(Harbaugh et al., 2000)
.pcg	MODFLOW	Solver	(Harbaugh et al., 2000)
.rch	MODFLOW	Recharge package	(Harbaugh et al., 2000)
.2dg	GMS	2-D grid file	GMS Documentation
.ba6	GMS	Basic package	GMS Documentation
.bc6	GMS	Block-centered flow package	GMS Documentation
.dis	GMS		GMS Documentation
.dxf	GMS	DXF file	GMS Documentation
.gpr	GMS	GMS project file	GMS Documentation
.hed		Simulated hydraulic head values	GMS Documentation
.hob	GMS		GMS Documentation
.img	GMS	Identifies background image, lists registration points	GMS Documentation
.ini	GMS	Initialization file	GMS Documentation
.lmt	GMS		GMS Documentation
.mfn	GMS	MODFLOW name file	GMS Documentation
.mfr	GMS		GMS Documentation
.mfs	GMS	MODFLOW super file	GMS Documentation
.mst	GMS		GMS Documentation
.obs	GMS	Observation file	GMS Documentation
.xy	GMS		GMS Documentation
*2g.dat	GMS		GMS Documentation
*2s.dat	GMS		GMS Documentation
*3g.dat	GMS		GMS Documentation
.map	GMS	Map file	GMS Documentation

Table B-1: Listing of model files.

Appendix C: Steady-State Observation Data

GMS & PEST ID	WELL_NUMBER	Easting (ft)	Northing (ft)	Layer	Spring Water Level (ft)	Fall Water level (ft)	Average Water Level (ft)	Initial PEST Weight	Group
1_1	05N06W-26CAA1	1634246	15888187	1	2103	2102	2102.5	0.196	head
2_1	05N06W-11AAD1	1637331	15905899	1	2188	2190	2189	0.000	head
3_1	05N05W-20CCD1	1649875	15891124	1	2236	2241	2238.5	0.000	head
4_1	05N06W-35CAC1	1634612	15882114	1	2248	2256	2252	0.000	head
5_1	04N05W-07DCD1	1646212	15870172	1	2273	2272	2272.5	0.196	head
6_1	05N05W-04BCC1	1653386	15909343	1	2270	2274	2272	0.000	head
7_1	05N05W-32CDC1	1649953	15880396	1	2280	2283	2281.5	0.196	head
8_1	05N05W-13CBC1	1669236	15897821	1	2288	2290	2289	0.000	head
9_1	05N04W-34BCB1	1690172	15883790	1	2294	2296	2295	0.196	head
10_1	04N05W-21AAB2	1657600	15864207	1	2305	2305	2305	0.196	head
11_1	06N05W-35BAC1	1664741	15916539	1	2307	2305	2306	0.196	head
12_1	05N04W-35BBB1	1695527	15885118	1	2312	2318	2315	0.196	head
13_1	03N04W-15DCC1	1693674	15832283	1	2314	2318	2316	0.196	head
14_1	05N04W-08BCC1	1679420	15904617	1	2332	2333	2332.5	0.196	head
15_1	04N04W-22DDD1	1695298	15859411	1	2339	2335	2337	0.196	head
16_1	05N04W-36BCC1	1701110	15883109	1	2335	2338	2336.5	0.196	head
17_1	04N03W-16DDDC1	1721289	15864855	1	2348	2347	2347.5	0.000	head
18_1	01S02W-14CCC2	1760025	15738521	1	2347	2352	2349.5	0.196	head
19_1	04N03W-30ADA1	1711174	15857837	1	2353	2353	2353	0.000	head
20_1	05N04W-09DCA1	1688370	15902510	1	2353	2354	2353.5	0.196	head
21_1	04N04W-25BDD3	1702874	15856800	1	2356	2354	2355	0.000	head
22_1	04N03W-06AAA1	1711175	15880407	1	2360	2364	2362	0.196	head
23_1	05N03W-08DDC1	1715505	15901979	1	2366	2366	2366	0.196	head
24_1	06N04W-34DDB1	1694357	15913050	1	2368	2366	2367	0.196	head
25_1	04N03W-13BAA1	1734710	15870172	1	2374	2374	2374	0.000	head
26_1	04N03W-27CBAD1	1722863	15856461	1	2374	2376	2375	0.000	head
27_1	04N03W-04DDCD1	1720809	15875582	1	2376	2378	2377	0.196	head
28_1	04N03W-12ACDD1	1736018	15873214	1	2377	2378	2377.5	0.196	head
29_1	01S02W-03DBC1	1757302	15750550	1	2386	2390	2388	0.196	head
30_1	05N03W-30ADD1	1711074	15888807	1	2391	2385	2388	0.196	head
31_1	04N02W-07AAC1	1741740	15874656	1	2391	2391	2391	0.196	head
32_1	04N03W-24ACB1	1735179	15863494	1	2392	2392	2392	0.000	head
33_1	06N04W-35ADC1	1699408	15915391	1	2394	2393	2393.5	0.196	head
34_1	03N03W-27ABB1	1724960	15827320	1	2408	2399	2403.5	0.196	head
35_1	06N03W-33CBA1	1717369	15914131	1	2403	2402	2402.5	0.196	head
36_1	03N04W-13BBC1	1701386	15836756	1	2418	2405	2411.5	0.196	head
37_1	05N03W-19AAD1	1710978	15895891	1	2410	2411	2410.5	0.196	head
38_1	04N05W-14DAD1	1669057	15866243	1	2411	2412	2411.5	0.196	head
39_1	06N03W-30DCC1	1708709	15917645	1	2411	2412	2411.5	0.000	head
40_1	04N03W-25DAA3	1737559	15856926	1	2410	2414	2412	0.000	head
41_1	04N02W-21CBB1	1748187	15862542	1	2414	2416	2415	0.000	head
42_1	04N02W-10BBCB1	1753560	15875018	1	2423	2422	2422.5	0.196	head
43_1	04N04W-21CAA2	1687357	15861720	1	2418	2423	2420.5	0.000	head
44_1	03N02W-06ACD1	1741283	15846620	1	2422	2425	2423.5	0.196	head
45_1	05N03W-21CAD1	1718764	15893084	1	2423	2425	2424	0.196	head
46_1	05N02W-20BBA1	1743912	15896630	1	2424	2426	2425	0.196	head

GMS & PEST ID	WELL_NUMBER	Easting (ft)	Northing (ft)	Layer	Spring Water Level (ft)	Fall Water level (ft)	Average Water Level (ft)	Initial PEST Weight	Group
47_1	05N02W-24DAB1	1768647	15894129	1	2433	2427	2430	0.196	head
48_1	04N02W-31AAA1	1742863	15854217	1	2425	2428	2426.5	0.000	head
49_1	05N02W-32CBD1	1744199	15882461	1	2426	2428	2427	0.196	head
50_1	05N03W-12CCA1	1733322	15902756	1	2430	2429	2429.5	0.196	head
51_1	03N03W-11DAC1	1731237	15839794	1	2430	2433	2431.5	0.196	head
52_1	03N03W-10CBA3	1722777	15840368	1	2441	2435	2438	0.196	head
53_1	03N02W-08BCCC1	1743293	15841365	1	2436	2439	2437.5	0.000	head
54_1	04N02W-02DDD1	1763908	15875985	1	2441	2441	2441	0.196	head
55_1	05N02W-31BBC1	1737802	15884962	1	2435	2441	2438	0.196	head
56_1	05N02W-27DCC1	1756141	15886772	1	2442	2440	2441	0.196	head
57_1	04N02W-33ABC1	1751025	15853447	1	2439	2442	2440.5	0.000	head
58_1	04N04W-28ACB1	1687733	15857773	1	2434	2443	2438.5	0.000	head
59_1	03N03W-23DCD1	1731065	15827952	1	2451	2452	2451.5	0.196	head
60_1	03N02W-17CCB2	1743114	15834481	1	2442	2444	2443	0.196	head
61_1	03N03W-06DDC1	1710190	15843765	1	2452	2451	2451.5	0.196	head
62_1	02N03W-36DAD1	1737866	15787497	1	2460	2446	2453	0.196	head
63_1	05N03W-15DDC1	1726086	15896856	1	2442	2447	2444.5	0.196	head
64_1	05N03W-04BCB1	1716647	15911092	1	2448	2447	2447.5	0.196	head
65_1	03N03W-14CDA1	1729643	15833816	1	2446	2448	2447	0.196	head
66_1	03N04W-05AAB1	1683784	15848252	1	2460	2443	2451.5	0.196	head
67_1	05N01W-29CBA1	1775355	15888601	1	2457	2446	2451.5	0.196	head
68_1	03N03W-23BBC1	1727294	15832390	1	2453	2452	2452.5	0.196	head
69_1	04N04W-30BBB2	1674652	15858964	1	2451	2456	2453.5	0.196	head
70_1	05N02W-29BBC2	1742986	15890654	1	2454	2456	2455	0.196	head
71_1	03N02W-10ACC1	1756318	15841430	1	2455	2456	2455.5	0.000	head
72_1	04N02W-24CCC1	1764217	15860299	1	2454	2457	2455.5	0.000	head
73_1	03N02W-29BCD1	1744399	15825681	1	2459	2461	2460	0.000	head
74_1	04N02W-26CAD1	1761374	15856133	1	2461	2462	2461.5	0.000	head
75_1	04N01W-07AAAD1	1774411	15875340	1	2464	2466	2465	0.196	head
76_1	04N01W-19DADA1	1774422	15861980	1	2461	2467	2464	0.000	head
77_1	03N02W-15DCDA1	1757364	15834047	1	2468	2467	2467.5	0.000	head
78_1	05N01W-32ACC1	1777285	15883959	1	2469	2468	2468.5	0.196	head
79_1	02N03W-06DBA1	1710064	15814111	1	2470	2470	2470	0.196	head
80_1	03N04W-03AAD1	1695402	15847367	1	2468	2471	2469.5	0.196	head
81_1	04N01W-05DBD1	1777994	15877789	1	2479	2476	2477.5	0.196	head
82_1	02N02W-05ABA1	1746866	15816788	1	2487	2481	2484	0.196	head
83_1	03N04W-11ADA1	1700785	15841308	1	2480	2483	2481.5	0.000	head
84_1	03N02W-12BBB1	1764300	15843802	1	2480	2483	2481.5	0.196	head
85_1	04N01W-16CAAA1	1782320	15867797	1	2481	2483	2482	0.000	head
86_1	03N02W-26BAA1	1761740	15828098	1	2482	2486	2484	0.000	head
87_1	04N01W-30ADAA2	1774367	15858639	1	2482	2488	2485	0.000	head
88_1	03N02W-31BCC1	1738014	15820086	1	2500	2492	2496	0.196	head
89_1	04N01W-22DBB1	1788154	15862675	1	2501	2502	2501.5	0.000	head
90_1	04N01W-32BBBC1	1774688	15854085	1	2500	2504	2502	0.196	head
91_1	03N02W-24BAD2	1766644	15832174	1	2496	2504	2500	0.196	head
92_1	04N01W-03CDDA1	1787622	15876334	1	2501	2503	2502	0.000	head
93_1	04N04W-33CDC2	1686650	15848764	1	2497	2505	2501	0.196	head
94_1	03N02W-35DBAC1	1762609	15819804	1	2502	2505	2503.5	0.000	head
95_1	05N01W-33ACD1	1783231	15883997	1	2508	2507	2507.5	0.196	head
96_1	02N02W-10CAA2	1755960	15809345	1	2518	2514	2516	0.196	head

GMS & PEST ID	WELL_NUMBER	Easting (ft)	Northing (ft)	Layer	Spring Water Level (ft)	Fall Water level (ft)	Average Water Level (ft)	Initial PEST Weight	Group
97_1	03N01W-08BDAC1	1777852	15841858	1	2514	2516	2515	0.000	head
98_1	02N02W-02CACC1	1760797	15813722	1	2516	2518	2517	0.000	head
99_1	02N02W-09ACC1	1751540	15809727	1	2524	2518	2521	0.196	head
100_1	03N01W-18DAC1	1773331	15835454	1	2517	2521	2519	0.196	head
101_1	02N02W-29BCC1	1743809	15793496	1	2530	2528	2529	0.196	head
102_1	04N01W-33ADAD1	1784987	15852735	1	2526	2528	2527	0.000	head
103_1	02N02W-20CBB1	1743417	15798554	1	2531	2527	2529	0.196	head
104_1	03N01W-31DDA1	1774316	15818760	1	2527	2530	2528.5	0.196	head
105_1	04N01W-28ADD1	1785102	15857594	1	2526	2531	2528.5	0.000	head
106_1	02N02W-07CBC1	1737923	15808043	1	2535	2531	2533	0.196	head
107_1	03N01W-09AACB1	1784314	15843215	1	2528	2532	2530	0.000	head
108_1	04N01W-13DDB1	1799663	15866296	1	2531	2532	2531.5	0.000	head
109_1	05N01W-34DBAD1	1788971	15883124	1	2539	2536	2537.5	0.196	head
110_1	02N01W-07BBC1	1769722	15811142	1	2534	2538	2536	0.000	head
111_1	01N02W-09DDD2	1753851	15775530	1	2538	2538	2538	0.196	head
112_1	02N02W-22CCA1	1754845	15797194	1	2540	2539	2539.5	0.196	head
113_1	02N02W-32CDB1	1744948	15786518	1	2546	2543	2544.5	0.196	head
114_1	05N01W-36ABB1	1798277	15886327	1	2542	2545	2543.5	0.196	head
115_1	02N02W-28DDD1	1753846	15790914	1	2545	2546	2545.5	0.196	head
116_1	01N01W-27ADD1	1790967	15762594	1	2551	2547	2549	0.196	head
117_1	04N01E-21DCCC1	1814182	15860334	1	2548	2550	2549	0.000	head
118_1	04N01E-17CDDD1	1808556	15865755	1	2553	2554	2553.5	0.000	head
119_1	03N01W-16DDD1	1785185	15833808	1	2554	2557	2555.5	0.196	head
120_1	01N02W-10DAA1	1759078	15777481	1	2551	2562	2556.5	0.196	head
121_1	04N01E-16AAA1	1816378	15870574	1	2561	2562	2561.5	0.196	head
122_1	04N01E-05CBBD1	1806478	15878189	1	2566	2564	2565	0.196	head
123_1	03N01W-11BDCC1	1791973	15841647	1	2561	2565	2563	0.000	head
124_1	04N01W-35AAA1	1795557	15854528	1	2561	2566	2563.5	0.000	head
125_1	01N01W-24AAA1	1801028	15769548	1	2562	2569	2565.5	0.196	head
126_1	03N01W-27CDCB1	1786873	15823496	1	2568	2572	2570	0.196	head
127_1	05N01E-31ACA1	1804668	15884653	1	2572	2572	2572	0.196	head
128_1	02N01W-32CBB1	1775534	15788101	1	2562	2573	2567.5	0.196	head
129_1	04N01E-11BBB1	1822502	15876090	1	2582	2574	2578	0.196	head
130_1	05N01E-33CCCD1	1811740	15881367	1	2572	2575	2573.5	0.196	head
131_1	02N02E-12AAC1	1864868	15811601	1	2583	2577	2580	0.000	head
132_1	01N01E-19ADB1	1805684	15768570	1	2584	2581	2582.5	0.196	head
133_1	01N02E-08ADA2	1843812	15778806	1	2591	2581	2586	0.196	head
134_1	02N01W-09ADA1	1785116	15810731	1	2572	2585	2578.5	0.196	head
135_1	01N01E-16ACC1	1814946	15772993	1	2589	2585	2587	0.196	head
136_1	03N01E-06BBAB1	1801771	15849409	1	2583	2586	2584.5	0.000	head
137_1	03N01W-12CBBB1	1796166	15841474	1	2587	2588	2587.5	0.000	head
138_1	02N01W-10ABB1	1788273	15812270	1	2577	2589	2583	0.196	head
139_1	01N01E-12DAA1	1832904	15778000	1	2595	2592	2593.5	0.196	head
140_1	02N02E-34CCD1	1850160	15786153	1	2593	2592	2592.5	0.196	head
141_1	03N01W-26DDDC1	1795486	15823150	1	2593	2594	2593.5	0.196	head
142_1	04N01E-29CCCD1	1806728	15855013	1	2584	2593	2588.5	0.000	head
143_1	04N01E-11BAA1	1824342	15875599	1	2597	2590	2593.5	0.196	head
144_1	01N01E-03CCC1	1817759	15781011	1	2599	2596	2597.5	0.196	head
145_1	02N02E-32DBA1	1842401	15788206	1	2599	2596	2597.5	0.196	head
146_1	02N01W-02BBA1	1790962	15817450	1	2585	2597	2591	0.196	head

GMS & PEST ID	WELL_NUMBER	Easting (ft)	Northing (ft)	Layer	Spring Water Level (ft)	Fall Water level (ft)	Water Level (ft)	Initial PEST Weight	Group
147_1	03N01W-24BBDA1	1796964	15832775	1	2592	2599	2595.5	0.196	head
148_1	04N01E-24BCA1	1828483	15863691	1	2599	2599	2599	0.000	head
149_1	03N01E-06DDD1	1805775	15844884	1	2600	2602	2601	0.000	head
150_1	02N01E-26BBC1	1822651	15795929	1	2612	2602	2607	0.196	head
151_1	02N01E-35BBC1	1823281	15790975	1	2606	2604	2605	0.196	head
152_1	02N01E-36BBB1	1827923	15791317	1	2606	2604	2605	0.196	head
153_1	03N01E-17BBB1	1806326	15838512	1	2601	2605	2603	0.000	head
154_1	02N01E-33CCA2	1812684	15787247	1	2606	2605	2605.5	0.196	head
155_1	02N01E-31DDC1	1805554	15785977	1	2607	2609	2608	0.196	head
156_1	02N01W-11ADA1	1795645	15811107	1	2599	2610	2604.5	0.196	head
157_1	04N01E-33AADC1	1816219	15853771	1	2606	2612	2609	0.000	head
158_1	02N01W-23ACC1	1794033	15799254	1	2604	2616	2610	0.196	head
159_1	02N01W-12BAA1	1797478	15812233	1	2604	2616	2610	0.196	head
160_1	03N01E-08DCDC1	1809498	15839145	1	2613	2616	2614.5	0.196	head
161_1	02N01E-23BAD1	1824821	15800805	1	2623	2616	2619.5	0.196	head
162_1	04N01E-21DDDC1	1816385	15860554	1	2614	2618	2616	0.000	head
163_1	02N02E-31BCA1	1833905	15790053	1	2620	2618	2619	0.196	head
164_1	02N01W-35BDC1	1792266	15788513	1	2611	2619	2615	0.196	head
165_1	02N01E-07CBBC1	1801623	15809328	1	2607	2620	2613.5	0.196	head
166_1	02N01W-15ADC1	1789715	15804488	1	2615	2623	2619	0.196	head
167_1	04N02E-30ACDB1	1836178	15858393	1	2623	2624	2623.5	0.000	head
168_1	02N01E-05CBDC1	1807113	15813822	1	2624	2627	2625.5	0.000	head
169_1	02N01W-13BAB1	1797736	15806972	1	2608	2626	2617	0.196	head
170_1	04N02E-31ACAB1	1836142	15853434	1	2630	2626	2628	0.000	head
171_1	04N02E-31AAB2	1837534	15854661	1	2627	2624	2625.5	0.196	head
172_1	02N01E-08ACC1	1809427	15809791	1	2625	2627	2626	0.196	head
173_1	02N01E-15ABA1	1820570	15807045	1	2630	2630	2630	0.196	head
174_1	04N01E-26CDD1	1824440	15855154	1	2632	2636	2634	0.000	head
175_1	03N01E-30DDD1	1806306	15823736	1	2632	2637	2634.5	0.196	head
176_1	04N01E-35DAA1	1826968	15851734	1	2646	2640	2643	0.000	head
177_1	03N01E-10BDA1	1819400	15842462	1	2638	2642	2640	0.000	head
178_1	04N01E-35CCA1	1823227	15850792	1	2639	2643	2641	0.000	head
179_1	02N02E-07CBC1	1833591	15808977	1	2643	2644	2643.5	0.196	head
180_1	04N02E-29ACC1	1840654	15857825	1	2642	2646	2644	0.000	head
181_1	02N01E-12CDB1	1829470	15808537	1	2646	2647	2646.5	0.196	head
182_1	02N01E-33CAC1	1813431	15787454	1	2608	2656	2632	0.196	head
183_1	03N01E-15CBD1	1817920	15835666	1	2648	2659	2653.5	0.000	head
184_1	03N03E-32BBA1	1870712	15823302	1	2661	2659	2660	0.000	head
185_1	02N01E-02BACB1	1823947	15817296	1	2656	2660	2658	0.196	head
186_1	03N02E-04DAB1	1847903	15846557	1	2663	2662	2662.5	0.000	head
187_1	03N01E-28DCDD2	1815424	15823198	1	2653	2663	2658	0.196	head
188_1	03N01E-27CDDB1	1819101	15823836	1	2665	2675	2670	0.196	head
189_1	03N01E-15AAD1	1821873	15838026	1	2664	2666	2665	0.000	head
190_1	02N02E-04CBB1	1843919	15815244	1	2671	2670	2670.5	0.196	head
191_1	03N02E-15BDB2	1850559	15837272	1	2674	2667	2670.5	0.000	head
192_1	03N02E-06DDD2	1837755	15844642	1	2676	2664	2670	0.196	head
193_1	03N02E-06DDD1	1837836	15844543	1	2675	2676	2675.5	0.000	head
194_1	03N02E-28BDB1	1845649	15827103	1	2684	2676	2680	0.196	head
195_1	02N02E-06CCC2	1833265	15813123	1	2676	2678	2677	0.196	head
196_1	03N02E-03BAAD2	1851238	15849423	1	2677	2678	2677.5	0.000	head

GMS & PEST ID	WELL_NUMBER	Easting (ft)	Northing (ft)	Layer	Spring Water Level (ft)	Fall Water level (ft)	Average Water Level (ft)	Initial PEST Weight	Group
197_1	03N01E-12BCD1	1828512	15842032	1	2679	2681	2680	0.000	head
198_1	03N01E-13BDB1	1828845	15837177	1	2684	2685	2684.5	0.000	head
199_1	03N01E-24ADA1	1832727	15832554	1	2690	2689	2689.5	0.196	head
200_1	02N01E-29DCA1	1810005	15792083	1	2690	2695	2692.5	0.196	head
201_1	03N02E-18DAA1	1837988	15836343	1	2691	2694	2692.5	0.196	head
202_1	03N02E-30CAC1	1834247	15825280	1	2700	2699	2699.5	0.196	head
203_1	02N01E-01BCBC1	1827859	15816114	1	2688	2701	2694.5	0.196	head
204_1	03N02E-15DDDD1	1854110	15834268	1	2705	2704	2704.5	0.000	head
205_1	03N02E-14ACB2	1857177	15837536	1	2706	2703	2704.5	0.196	head
206_1	03N01E-25BCB1	1828218	15826947	1	2709	2720	2714.5	0.196	head
207_1	03N01E-36DDB1	1832263	15818783	1	2713	2726	2719.5	0.196	head
208_1	03N02E-21BCC1	1843988	15831642	1	2728	2733	2730.5	0.196	head
209_1	03N03E-30BCBD1	1865301	15826890	1	2733	2739	2736	0.000	head
210_1	03N02E-25AAC1	1864112	15827585	1	2737	2745	2741	0.000	head
211_1	03N03E-30DAAD2	1869950	15825723	1	2745	2745	2745	0.000	head
212_1	03N02E-20DBD1	1842092	15830005	1	2734	2762	2748	0.196	head
213_1	03N03E-29ADD2	1874947	15826484	1	2768	2769	2768.5	0.000	head
214_1	02N03E-11ACC1	1888740	15810845	1	2826	2824	2825	0.000	head
215_1	01N04E-27CBD1	1914095	15762154	1	3377	3374	3375.5	0.196	head
216_1	01N04E-13CCCB1	1923419	15771584	1	3458	3457	3457.5	0.196	head
217_1	01N04E-28CAC1	1909385	15762696	2	2970	2970	2970	0.196	head
218_1	02N03E-02CDD1	1888439	15814175	2	2998	2926	2962	0.196	head
219_1	02N03E-18BAC1	1866563	15807159	2	2705	2703	2704	0.000	head
220_1	03N01E-15CDA1	1818012	15836472	2	2686	2689	2687.5	0.196	head
221_1	03N01E-34CAA1	1819077	15820670	2	2672	2678	2675	0.196	head
222_1	03N01W-25DAD1	1801236	15825210	2	2615	2619	2617	0.196	head
223_1	02N01E-22DCA1	1821181	15798742	2	2620	2615	2617.5	0.196	head
224_1	02N01W-27BCC1	1786308	15795224	2	2589	2602	2595.5	0.000	head
225_1	01N02E-04BBA1	1845243	15786606	2	2600	2599	2599.5	0.196	head
226_1	01N02E-06BAA1	1835434	15786820	2	2599	2597	2598	0.196	head
227_1	03N02E-23DDBC2	1858980	15830108	2	2629	2595	2612	0.196	head
228_1	04N01E-04DCC1	1814148	15877031	2	2571	2574	2572.5	0.196	head
229_1	04N01E-10ACB2	1819598	15875151	2	2569	2573	2571	0.196	head
230_1	03N02E-36CDD1	1862177	15819361	2	2614	2566	2590	0.000	head
231_1	04N01W-01CAA1	1798201	15878834	2	2545	2549	2547	0.196	head
232_1	04N01W-13AACC1	1774589	15873818	2	2536	2535	2535.5	0.196	head
233_1	03N02W-34BBCB1	1754151	15822991	2	2482	2484	2483	0.196	head
234_1	03N02W-03DAA1	1758711	15847309	2	2468	2469	2468.5	0.196	head
235_1	03N02W-09DDDD1	1753615	15839694	2	2458	2459	2458.5	0.196	head
236_1	01N02W-17DDA1	1748651	15771853	2	2500	2458	2479	0.196	head
237_1	03N02W-04ADD1	1752978	15848144	2	2453	2454	2453.5	0.000	head
238_1	05N02W-19CBA1	1739024	15894784	2	2445	2450	2447.5	0.196	head
239_1	03N02W-17ACDB1	1746794	15837430	2	2448	2449	2448.5	0.196	head
240_1	05N02W-25BCD1	1765464	15889959	2	2443	2443	2443	0.000	head
241_1	05N02W-22CAD1	1755977	15893754	2	2426	2421	2423.5	0.000	head
242_1	05N03W-27CAA1	1724224	15889357	2	2417	2418	2417.5	0.196	head
243_1	04N02W-05ABB1	1746345	15881114	2	2417	2414	2415.5	0.196	head
244_1	05N03W-02CCD1	1728038	15908198	2	2416	2412	2414	0.196	head
245_1	04N03W-27AACD1	1729851	15859318	2	2372	2372	2372	0.196	head
246_1	04N03W-28ADDD1	1722951	15857266	2	2369	2369	2369	0.196	head

GMS & PEST ID	WELL_NUMBER	Easting (ft)	Northing (ft)	Layer	Spring Water Level (ft)	Fall Water level (ft)	Average Water Level (ft)	Initial PEST Weight	Group
247_1	02N03W-22DDC1	1726125	15796956	2	2369	2365	2367	0.196	head
248_1	04N03W-04DCB1	1719571	15877294	2	2359	2361	2360	0.196	head
249_1	05N04W-16ABA1	1688605	15902205	2	2342	2344	2343	0.196	head
250_1	04N05W-10CDD1	1661279	15870583	2	2340	2342	2341	0.196	head
251_1	06N05W-36CDB1	1670327	15913913	2	2318	2316	2317	0.196	head
252_1	05N05W-18CAC1	1644161	15898408	2	2213	2214	2213.5	0.196	head
253_1	03N01E-23DDD1	1826984	15830010	3	2706	2717	2711.5	0.196	head
254_1	03N02E-07DAAC1	1837857	15845448	3	2690	2687	2688.5	0.196	head
255_1	03N01E-15ADD1	1821966	15838831	3	2677	2673	2675	0.196	head
256_1	02N02E-02BBC1	1855118	15818123	3	2660	2658	2659	0.196	head
257_1	02N02E-08AAD1	1843197	15812727	3	2665	2649	2657	0.196	head
258_1	03N03E-30DDAA1	1870045	15826528	3	2639	2613	2626	0.196	head
259_1	03N03E-32CDD1	1870806	15824105	3	2636	2609	2622.5	0.196	head
260_1	01N02W-04DDC1	1753250	15781492	3	2549	2533	2541	0.196	head
261_1	04N01W-33CBB1	1780662	15852263	3	2535	2533	2534	0.196	head
262_1	04N01W-31AAA1	1774457	15859444	3	2527	2524	2525.5	0.196	head
263_1	01N02W-05ADD1	1748150	15783795	3	2544	2506	2525	0.196	head
264_1	04N01W-07DAAA1	1774502	15876146	3	2503	2498	2500.5	0.196	head
265_1	03N02W-14DBA1	1764399	15844608	3	2486	2488	2487	0.196	head
266_1	02N02W-31CBA1	1738779	15788335	3	2496	2484	2490	0.196	head
267_1	03N02W-06DCC1	1741369	15847425	3	2434	2431	2432.5	0.196	head
268_1	04N02W-06CDD1	1739682	15877084	3	2424	2421	2422.5	0.196	head
269_1	01N02W-06ADD1	1742841	15783869	3	2485	2413	2449	0.196	head
270_1	04N03W-26ABCC1	1730456	15859795	3	2381	2377	2379	0.196	head
271_1	06N04W-28CDC1	1686724	15918933	3	2347	2347	2347	0.196	head
272_1	04N05W-23BCC1	1664646	15863156	3	2342	2345	2343.5	0.196	head
273_1	04N04W-04CDC1	1686895	15876555	3	2297	2295	2296	0.196	head
274_1	05N05W-04DCD1	1653470	15910153	3	2218	2213	2215.5	0.196	head
275_1	03N01E-14AAC2	1828938	15837981	4	2683		2683	0.196	head
276_1	03N01E-14AAC3	1826815	15838670	4	2683		2683	0.196	head
277_1	03N02E-06DDC1	1837580	15845923	4	2685		2685	0.196	head
278_1	04N01E-36BAC1	1827060	15852540	4	2670		2670	0.196	head
279_1	04N01E-24DABB1	1828576	15864497	4	2606		2606	0.196	head
280_1	03N02E-11BABD1	1837594	15842005	4	2720	2736	2728	0.196	head
281_1	03N02E-13BABA1	1858867	15840383	4	2700	2696	2698	0.196	head
282_1	04N02E-30ACAC1	1836190	15859214	4	2618	2611	2614.5	0.000	head
283_1	04N01E-27AADA1	1824532	15855960	4	2619	2574	2596.5	0.196	head
284_1	04N05W-14CCC2	1661284	15870583	4	2340	2340	2340	0.196	head

Taken from "SS Obs Pts" in "Final 1996 Obs Data.xls"

Vertical Gradient Observations

PEST-ID		Easting (ft)	Northing (ft)				Estimated Value	Weight	Group
grad1		1666612	15870975				40	25	grad
grad2		1665066	15902407				40	25	grad
grad3		1717624	15862215				40	25	grad
grad4		1793886	15854486				30	25	grad
grad5		1765546	15876128				30	25	grad
grad6		1865510	15817901				-30	25	grad

Appendix D: Model Calibration Input Files

Program or File	Calls these Files	Requires these files	Creates these files
pest.exe	*.pst *PEST control file*	Model3.bat	
		pph1.tpl	pph1.dat
		pph2.tpl	pph2.dat
		pph3.tpl	pph3.dat
		ppv1.tpl	ppv1.dat
		ppv2.tpl	ppv2.dat
		ppv3.tpl	ppv3.dat
		structh1.tpl	structh1.dat
		structh2.tpl	structh2.dat
		structh3.tpl	structh3.dat
		structv1.tpl	structv1.dat
		structv2.tpl	structv2.dat
		structv3.tpl	structv3.dat
		sswel.tpl	ss.wel
		ssmoo.ins	ss.moo
		modvgrad.ins	modvgrad.out

Table D-1: Treasure Valley model calibration files.

File	Process	Requires these files		Requires these files	Additional required files and/or Comments	
Model3.bat *Prepares files for each MODFLOW run, initates MODFLOW run, deletes intermediate files*	*The *.ref files (a remainder of the previous run) are deleted*	kh1.ref	kv1.ref			
		kh2.ref	kv2.ref			
		kh3.ref	kv3.ref			
		kh1s.ref	kh2s.ref			
		kh3s.ref	kv1s.ref			
		kv2s.ref	kv3s.ref			
	Delete head file from previous run	*.hed				
	Build hydraulic property arrays with fac2real.exe	frh1.in		fach1.dat pph1.dat kh1.ref	Produces "kh1.ref"	
		frh2.in		fach2.dat pph2.dat kh2.ref	Produces "kh2.ref"	
		frh3.in		fach3.dat pph3.dat kh3.ref	Produces "kh3.ref"	
		frv1.in		facv1.dat ppv1.dat kv1.ref	Produces "kv1.ref"	
		frv2.in		facv2.dat ppv2.dat kv2.ref	Produces "kv2.ref"	
		frv3.in		facv3.dat ppv3.dat kv3.ref	Produces "kv3.ref"	
	strips headers from the array files with striphead.exe	sh1.in		kh1.ref		
		sh2.in		kh2.ref		
		sh3.in		kh3.ref		
		sv1.in		kv1.ref		
		sv2.in		kv2.ref		
		sv3.in		kv3.ref		
	Run model with MODFLOWs.exe ("MODFLOWs.exe" is a modified MODFLOW code provided with GMS)	modflows.in → *.mfs *"modflows.in" is the input file for modflows.exe; gives GMS super file name). The *.mfs file should not have any quotes surrounding the file names (quotes around units are OK).*		*.mfn (MODFLOW super file, which lists files for MODFLOW packages)	*.out *.bas *.bcf *.oc *.hed *.drw *40.ccf *50.ccf *.pcg *.riv *.wel *.drn *.ghb *.rch *.hff	*These files are described in Table B-1*
				*.lyr	?	
	Calculate the *vertical hydraulic head difference for specified well pairs (e.g., multi-completed piezometers)* with modvgrad.exe	modvgrad.in		tvm.spc *grid specification file*		
				vgradpairs.lst *ID number for each completion fo the vertical gradient pairs*		
				vgradpairs.dat *x-y locations of vertical gradient wells*		
				Modvgrad.out		

Table D-2: Treasure Valley model calibration files.

Appendix E: Model Calibration Output Files

File	Description
*.ccf	Cell to cell flow terms
*.fnn	Flag file that indicates PEST run is complete
*.hed	MODFLOW head file
*.hld	Parameter hold file
*.jac	Jacobian matrix from the current optimization iteration (for a possible restart)
*.jco	Jacobian matrix pertaining to the best parameters for access by the JACWRIT utility
*.jst	Jacobian matrix from the previous optimization iteration
*.moo	MODFLOW output file for PEST
*.mtt	Parameter statistical matrices (PEST)
*.out	MODFLOW output file
*.par	Best parameter values achieved
*.rec	Run record file
*.res	Tabulated observation residuals
*.rst	Restart information stored at the beginning of each optimization iteration
*.sen	Parameter sensitivities
*.seo	Observation sensitivities
*.wel	Well file (produced with calibration if underflow is a calibration parameter)
Kh1.ref	Hydraulic conductivity arrays
Kh2.ref	
Kh3.ref	
Kv1.ref	
Kv2.ref	
Kv3.ref	
Kh1s.ref	Hydraulic conductivity arrays with stripped headers
Kh2s.ref	
Kh3s.ref	
Kv1s.ref	
Kv2s.ref	
Kv3s.ref	
modvgrad.out	Interpolated simulated vertical gradient data
pph1.dat	Pilot point parameter values (layer 1 K_h)
pph2.dat	Pilot point parameter values (layer 2 K_h)
pph3.dat	Pilot point parameter values (layer 3-4 K_h)
ppv1.dat	Pilot point parameter values (layer 1 K_v)
ppv2.dat	Pilot point parameter values (layer 2 K_v)
ppv3.dat	Pilot point parameter values (layer 3-4 K_v)
structh1.dat	Variogram structure data for K_h, layer 1
structh2.dat	Variogram structure data for K_h, layer 2
structh3.dat	Variogram structure data for K_h, layer 3-4
structv1.dat	Variogram structure data for K_v, layer 1
structv2.dat	Variogram structure data for K_v, layer 2
structv3.dat	Variogram structure data for K_v, layer 3-4

Table E-1: Files produced during a Treasure Valley model calibration.

Appendix F: Predictive Analysis Input Files

Program or File	Calls these Files	Requires these files	Creates these files	Notes
pest.exe	*.pst *PEST control file* *Specifies predicitive analysis mode*	Model4.bat *(see also Table F-2)*		
		pph1.tpl	pph1.dat	
		pph2.tpl	pph2.dat	
		pph3.tpl	pph3.dat	
		ppv1.tpl	ppv1.dat	
		ppv2.tpl	ppv2.dat	
		ppv3.tpl	ppv3.dat	
		structh1.tpl	structh1.dat	
		structh2.tpl	structh2.dat	
		structh3.tpl	structh3.dat	
		structv1.tpl	structv1.dat	
		structv2.tpl	structv2.dat	
		structv3.tpl	structv3.dat	
		sswel.tpl	ss.wel	
		ssmoo.ins	ss.cow	
		modvgrad.ins	modvgrad.out	
		modave.ins	modave.out	

Table F-1: Files required for PEST predictive simulations.

File	Process	Requires these files		these files	Additional required files and/or Comments
Model4.bat *Prepares files for each MODFLOW run, initates MODFLOW run, deletes intermediate files*	*The *.ref files (a remainder of the previous run) are deleted*	kh1.ref	kv1.ref		
		kh2.ref	kv2.ref		
		kh3.ref	kv3.ref		
		kh1s.ref	kh2s.ref		
		kh3s.ref	kv1s.ref		
		kv2s.ref	kv3s.ref		
	Delete head file from previous run	*.hed			
	Build hydraulic property arrays with fac2real.exe	frh1.in		fach1.dat pph1.dat kh1.ref	Produces "kh1.ref"
		frh2.in		fach2.dat pph2.dat kh2.ref	Produces "kh2.ref"
		frh3.in		fach3.dat pph3.dat kh3.ref	Produces "kh3.ref"
		frv1.in		facv1.dat ppv1.dat kv1.ref	Produces "kv1.ref"
		frv2.in		facv2.dat ppv2.dat kv2.ref	Produces "kv2.ref"
		frv3.in		facv3.dat ppv3.dat kv3.ref	Produces "kv3.ref"
	strips headers from the array files with striphead.exe	sh1.in		kh1.ref	
		sh2.in		kh2.ref	
		sh3.in		kh3.ref	
		sv1.in		kv1.ref	
		sv2.in		kv2.ref	
		sv3.in		kv3.ref	
	Copy calibration pumping values to well file	sscal.wel		ss.wel	
	Run MODFLOW under calibration conditions with modflows.exe	modflows.in → *.mfs *"modflows.in" is the input file for modflows.exe; gives GMS super file name). The *.mfs file should not have any quotes surrounding the file names (quotes around units are OK).*		*.mfn (MODFLOW super file, which lists files for MODFLOW packages)	*.out *.bas *.bcf *.oc *.hed *.drw *40.ccf *50.ccf *.lyr *.pcg *.riv *.wel *.drn *.ghb *.rch *.hff

Continued on next page

Table F-2: Predictive analysis files.

Continued from previous page				
File	**Process**	**Requires these files**	**Requires these files**	**Requires these files or Comments**
Model4.bat (*continued*)	Calculate the *vertical hydraulic head difference for specified well pairs (e.g., multi-completed piezometers) with* modvgrad.exe	modvgrad.in	tvm.spc *grid specification file*	
			vgradpairs.lst *ID number for each completion fo the vertical gradient pairs*	
			vgradpairs.dat *x-y locations of vertical gradient wells*	
			Modvgrad.out	
	Copy scenario well file to model well file	ssinq.wel	ss.wel	
	Run MODFLOW under predicitive analysis conditons	modflows.in → *.mfs *"modflows.in" is the input file for modflows.exe; gives GMS super file name).*	*.mfn (MODFLOW super file, which lists files for MODFLOW packages)	*.out *.bas *.bcf *.oc *.hed *.drw *40.ccf *50.ccf *.pcg *.riv *.wel *.drn *.ghb *.rch *.hff
	Average head values at prediction points with modave.exe	modave.in (creates modave.out)	tvm.spc	Grid specification file
			Predpoints.lst	Prediction point locations
			Predpoints.dat	Prediction point locations
			ss.hed	MODFLOW head file

Table F-3: Treasure Valley model predictive analysis files (*continuation from Table F-2*).

Appendix G: Predictive Analysis Output Files

File	Description
*.ccf	Cell to cell flow terms
*.fnn	A file containing a flag indicating that a PEST calibration is complete
*.hed	MODFLOW head file
*.hld	Parameter hold file
*.jac	Jacobian matrix from the current optimization iteration (for a possible restart)
*.jco	Jacobian matrix pertaining to the best parameters for access by the JACWRIT utility
*.jst	Jacobian matrix from the previous optimization iteration
*.moo	MODFLOW output file for PEST
*.mtt	Parameter statistical matrices (PEST)
*.out	MODFLOW output file
*.par	Best parameter values achieved
*.rec	Run record file
*.res	Tabulated observation residuals
*.rst	Restart information stored at the beginning of each optimization iteration
*.sen	Parameter sensitivities
*.seo	Observation sensitivities
*.wel	Well file (produced with calibration if underflow is a calibration parameter)
Kh1.ref	Hydraulic conductivity arrays
Kh2.ref	
Kh3.ref	
Kv1.ref	
Kv2.ref	
Kv3.ref	
Kh1s.ref	Hydraulic conductivity arrays with stripped headers
Kh2s.ref	
Kh3s.ref	
Kv1s.ref	
Kv2s.ref	
Kv3s.ref	
modvgrad.out	Interpolated simulated vertical gradient data
pph1.dat	Pilot point parameter values (layer 1 K_h)
pph2.dat	Pilot point parameter values (layer 2 K_h)
pph3.dat	Pilot point parameter values (layer 3-4 K_h)
ppv1.dat	Pilot point parameter values (layer 1 K_v)
ppv2.dat	Pilot point parameter values (layer 2 K_v)
ppv3.dat	Pilot point parameter values (layer 3-4 K_v)
structh1.dat	Variogram structure data for K_h, layer 1
structh2.dat	Variogram structure data for K_h, layer 2
structh3.dat	Variogram structure data for K_h, layer 3-4
structv1.dat	Variogram structure data for K_v, layer 1
structv2.dat	Variogram structure data for K_v, layer 2
structv3.dat	Variogram structure data for K_v, layer 3-4

Table G-1: Files produced during a predictive analysis simulation.

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SIMULATION OF INCREASED GROUND WATER WITHDRAWALS IN THE LOWER BOISE RIVER BASIN

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Abstract

Currently there are over 450 unprocessed applications for new water rights in the lower Boise River basin, an area of southwestern Idaho that is home to approximately 35% of Idaho's population. The additional water is being requested for irrigation, municipal, commercial, and aesthetic uses. The water requested for non-supplemental purposes could represent approximately a 20% increase over 1996 levels of ground water withdrawals. The potential impact of processing these new well applications on regional ground water levels was evaluated using the Treasure Valley ground water flow model (Petrich, 2004a).

The Treasure Valley ground water flow model was constructed with the USGS MODFLOW code (McDonald and Harbaugh, 1996) and calibrated to steady-state hydraulic conditions using the PEST parameter estimation code (Doherty, 2000). The calibration was based on over 200 water level and 6 vertical head difference observations. Predictive analysis (Doherty, 2000) was used to estimate worst (and best) potential outcomes given parameter non-uniqueness in the calibrated model.

The simulation results indicated that aquifer level declines might occur if all of these currently unprocessed, non-supplemental, ground water rights were granted. Water level declines could be in the range of 10 feet to over 40 feet, depending on valley location, actual amount of withdrawals, and depth of extraction. Local areas of simulated declines were noted south of Lake Lowell in an area in the northwestern portion of the model and in portions of an area between Boise, Meridian, and Kuna. These may be associated with unrealistically high simulated stresses or excessively low simulated aquifer parameter values. The simulated declines also may indicate potential problems in supplying the increasing ground water demands in these areas.

The least declines were predicted in the uppermost model layer, which corresponds roughly with the uppermost 200 feet of aquifer. Most of the estimated new simulated withdrawals in the uppermost layer resulted in decreased discharge to drains.

The simulated declines presented in this report are the result of both calibration effects and increased withdrawals. Additional comparisons between minimum base calibration heads and prediction heads should be conducted to refine these predicted declines.

Acknowledgements

The work described in this report was conducted as part of the Treasure Valley Hydrologic Project (TVHP). Participants in the TVHP include the Idaho Department of Water Resources (IDWR), the Idaho Water Resources Research Institute (IWRRI), University of Idaho (UI), United Water Idaho, Inc. (UWI), Boise State University (BSU), U.S. Geological Survey (USGS), U.S. Bureau of Reclamation (USBR), Idaho Water Resource Board (IWRB), Ada and Canyon Counties, and the cities of Boise, Nampa, Caldwell, Meridian, Kuna, and Eagle. The project was funded by the U.S. Environmental Protection Agency, the Idaho State Legislature, UWI, and the IWRB. In addition, in-kind services were provided by UWI, USGS, and the USBR.

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- Scott Urban (IDWR) provided initial model development assistance and prepared the recharge and withdrawal data for the base-case simulations.
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Simulation Files (CD-ROM)

Simulation SS5e-min (minimum predicted head values) ..... CD-ROM
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1. INTRODUCTION

1.1. Background

The lower Boise River basin (Treasure Valley) of southwestern Idaho has experienced substantial population growth, local ground water declines, and periodic drought conditions in the last two decades. There is a substantial demand for new ground water withdrawals.

New water uses in Idaho require an application to the Idaho Department of Water Resources (IDWR) for a new water right. As of May 2002, there were over 450 unprocessed new water right applications in the Idaho Administrative Basin 63, which includes the lower Boise River basin (Figure 1-1). The unprocessed applications include water right requests filed since July 1987 for primary and supplemental irrigation, commercial, and aesthetic uses. The IDWR wanted to evaluate the potential impact of new ground water withdrawals associated with unprocessed well applications.

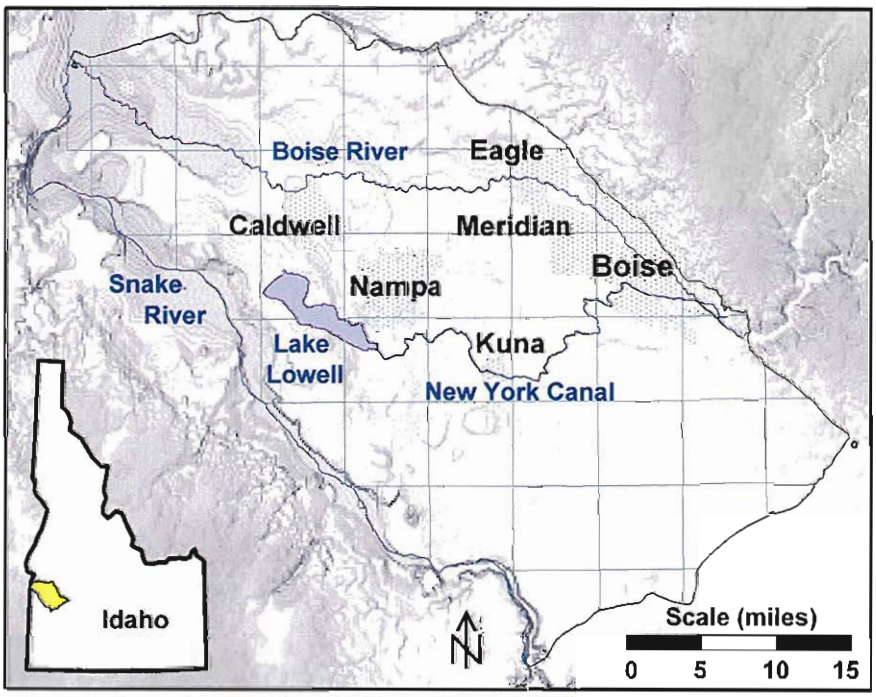

Figure 1-1: The lower Boise River basin and adjoining areas of southwestern Idaho.

1.2. Purpose and Objectives

The purpose of these simulations was to evaluate the potential impacts of increased ground water demands on current ground water levels. Specific objectives included the following:

1. Estimate the amount and nature of water use associated with the unprocessed water right applications.
2. Estimate the spatial and vertical distribution of new ground water withdrawals represented in the unprocessed claims.
3. Simulate the potential impact on ground water levels if the currently unprocessed, non-supplemental[1] water right applications were processed.

1.3. Report Scope

This report describes one water use scenario evaluated as part of the TVHP. The simulations described herein are based on the hydrologic conditions presented in Petrich and Urban (Petrich and Urban, 2004) and the numerical ground water flow model described in Petrich (Petrich, 2004a). Other research conducted as part of the TVHP is summarized in Petrich (Petrich, 2004b).

[1] See Section 2.1 for an explanation of non-supplemental irrigation.

2. METHODS

This section describes the (1) scenario development, (2) Treasure Valley ground water flow model development and calibration process, (3) predictive analysis simulations, and (4) assumptions and limitations inherent to the predictive analyses.

2.1. Scenario Development

This scenario consisted of evaluating potential impacts of unprocessed water right applications for non-supplemental water[2] on regional ground water levels. This scenario was limited to new non-supplemental withdrawals for the following reason. The simulations were conducted under steady-state conditions, for which withdrawals were assumed to represent equilibrium values. The use of non-supplemental water was thought to be more consistent on a year-to-year basis. The amount of water required for supplemental irrigation varies from site to site and season to season, depending on the availability of surface water (i.e., the amount of supplemental water used for irrigation presumably is much less for a wet year with adequate surface water storage and availability of irrigation water than for a dry year). Because of the variability, the supplemental withdrawals are more difficult to estimate. Supplemental withdrawals would represent additional withdrawals from those simulated in this scenario. Additional simulations that include estimates for these withdrawals should be conducted.

Estimates for the amount of water represented by the unprocessed water right applications were made from the information provided in the water right applications. Water right applications for ground water uses generally include all or some of the following information: anticipated diversion rate, diversion volume, diversion location, specific water use (e.g., irrigation, commercial, stockwater, domestic, aesthetic, etc.), acreage to be irrigated, whether or not the water will be used for supplementing surface water rights, and a target well depth. Some of the uses are mixed (e.g., commercial and stockwater use). The listed diversion rates are generally listed as maximum rates and do not necessarily reflect average application rates. The season of use, which for some uses is limited, is generally not included in the water rights applications but is established by IDWR in the permitting process.

[2] Supplemental withdrawals are generally used to supplement surface water irrigation. Non-supplemental withdrawals are used for (1) non-irrigation purposes and/or (2) irrigation in areas where surface water is unavailable.

A summary of currently unprocessed water right applications was prepared by the IDWR. Ground water withdrawals were estimated from the water right application data in the following way:

1. Applications for new ground water withdrawals in Basin 63 submitted between July 9, 1987, and February 19, 2002, were compiled; applications for new surface water uses were excluded from the analysis.
2. Requested diversion data were separated based on whether or not the request was for supplemental (to surface water) uses.
3. Anticipated withdrawals of ground water from geothermal aquifers underlying the "cold water" system were excluded from the analysis.
4. Some applications listed a total diversion rate for a given area and listed the same diversion rate for individual points of diversion within the area. In these cases, the total diversion rate was divided equally among the multiple points of diversion.
5. Consumptive use for irrigation withdrawals was estimated in two ways. First, per-acre consumptive use was estimated based on the average per-acre Surface Energy Balance Algorithm for Land (SEBAL) evapotranspiration (ET) rate between March 15, 2000 and October 15, 2000 (Kramber, 2002). The annual consumptive use for new irrigation withdrawals was assumed to be the average ET within the model cell in which the new irrigation would occur. The average ET for these cells was 2.03 feet per year (ft/yr) (Table 2-1). However, this average ET rate was deemed too low. The SEBAL ET is based on current land use. Some of the applications for new withdrawals are to irrigate non-irrigated lands, in which case the current ET does not necessarily reflect the ET rate under irrigated conditions.

   The second approach was to assume a uniform 2.5 feet per acre (ft/ac) consumptive use rate for the entire model domain. This approach does not capture the variability inherent in the spatial distribution of consumptive use in the valley but may represent a more realistic average consumptive use rate. Thus, the diversion rates for requested irrigation water were limited to these estimated withdrawal amounts based on a uniform consumptive use of 2.5 ft/ac, regardless of the diversion requests.
6. It was assumed that the requested diversion rate for non-irrigation water would generally be a maximum rate. The actual rates used over a 12-month average are often less than the maximum requested rate. Thus, the anticipated ground water diversion rate for non-irrigation uses was assumed to be one-half the requested amount, unless other information was available. For some applications, such as fire protection, aesthetic uses, etc., it was assumed that the average annual rate would be substantially less than the requested rate.

7. For those applications listing anticipated target depths, the ground water withdrawals were assigned to model layers[3] based on the target depth listed in the water right application (Table 2-2). This was done using the MODFLOW layer top and bottom data (exported from GMS-MODFLOW files).
8. Many applications did not include anticipated target depths. Ground water withdrawals from these applications were distributed among model layers based on the same *volume* proportion represented by the applications that did include target depths.

Statistic	Value (ft/yr)
Maximum ET	3.66
Minimum ET	0.30
Mean ET	2.03
Range	3.37
Standard Deviation	0.67

Table 2-1: Summary of SEBAL ET rates for the model cells in which new withdrawals would occur.

	Layer 1	Layer 2	Layer 3	Layer 4	Total
Number of unprocessed applications specifying target depth within assigned model layer	117	17	4	2	140
Percent (based on applications specifying target depths)	83.57%	12.14%	2.86%	1.43%	100%
Total estimated withdrawal rate (represented by unprocessed applications) within model layers (ft^3/d):	1,591,011	364,591	128,890	30,432	2,114,924
Total estimated withdrawal rate (represented by unprocessed applications) within model layers (acre-feet/yr):	13,331	3,055	1,080	255	17,721
Percent (based on applications specifying target depths)	75.23%	17.24%	6.09%	1.44%	100%
Number of non-supplemental applications included in scenario analysis (with and without target depths)					304
Total estimated withdrawals (in ft^3/day) (based on applications with and without estimated target depths)					4,646,819
Total estimated withdrawals (in af/yr) (based on applications with and without estimated target depths)					38,937
Total estimated withdrawals (in af/yr) in 1996 (Urban and Petrich, 1998).					194,000

Table 2-2: Relative numbers of applications and withdrawal rates by model layer (with irrigation ET assumed to be 2.5 ft/yr).

[3] Model grid and layers are described in Section 2.2 and in Petrich (2004a).

The amount of estimated ground water represented in the non-processed water right applications for non-supplemental withdrawals (Table 2-2) was approximately 39,000 acre-feet per year (af/yr)[4]. The spatial distribution of these estimated new ground water withdrawals is shown in Figure 2-1 through Figure 2-4. This represents approximately 20% of the estimated 194,000 af of total ground water withdrawals in 1996 (Urban and Petrich, 1998)[5]. However, the new applications represent a larger proportion of water being withdrawn from the uppermost layer (Figure 2-5 and Figure 2-6) than the estimated 1996 withdrawals. These figures (Figure 2-1 through Figure 2-6) illustrate both the estimated withdrawals based on applications in which target depths were specified, as well as those applications for which estimated withdrawals were distributed among four model layers.

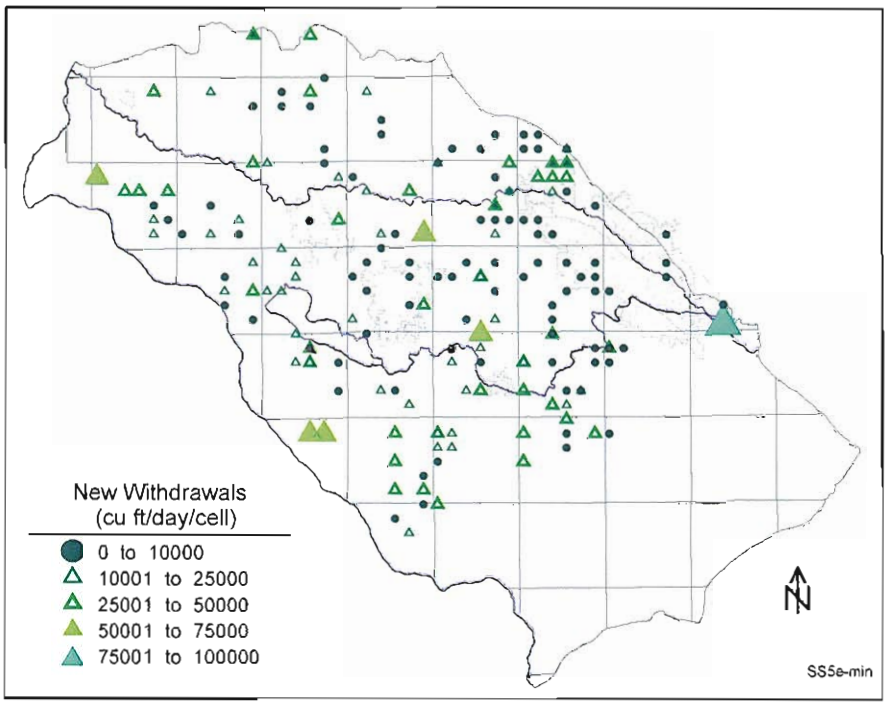

Figure 2-1: Distribution of estimated increased ground water withdrawals, layer 1.

[4] Data contained in "*Basin 63 Applications.xls*."
[5] The original estimates for total 1996 ground water withdrawals were 197,000 af; these estimates have since been revised downward to 194,000 af (S. Urban, written comm., 2003).

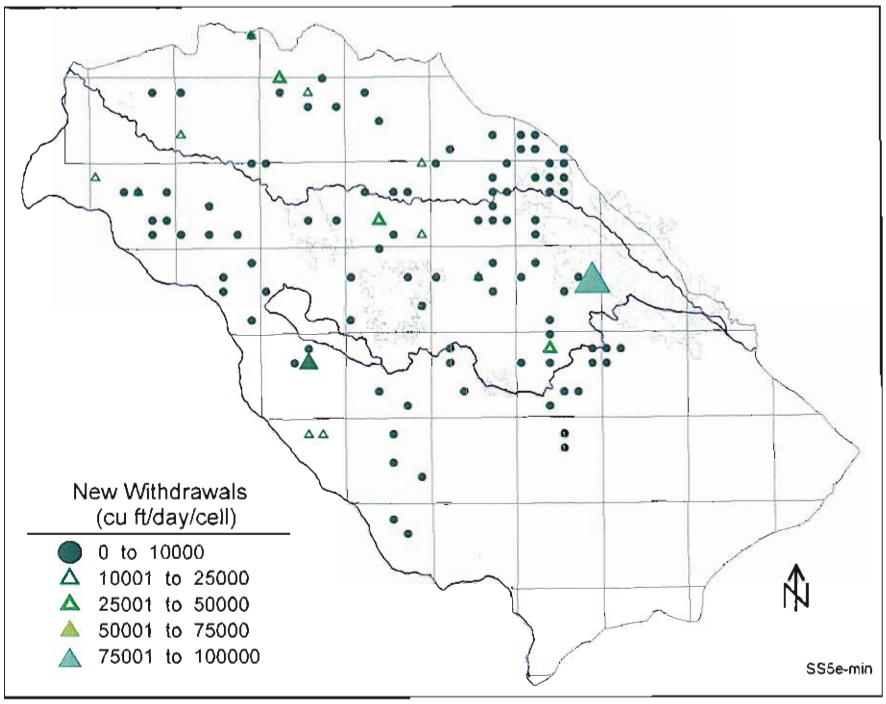

Figure 2-2: Distribution of estimated increased ground water withdrawals, layer 2.

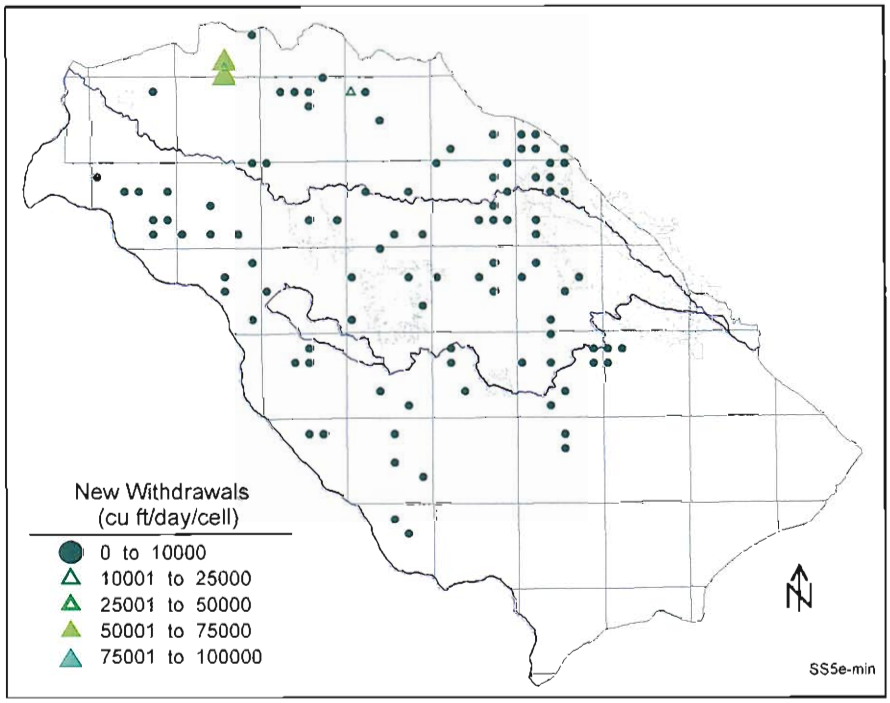

Figure 2-3: Distribution of estimated increased ground water withdrawals, layer 3.

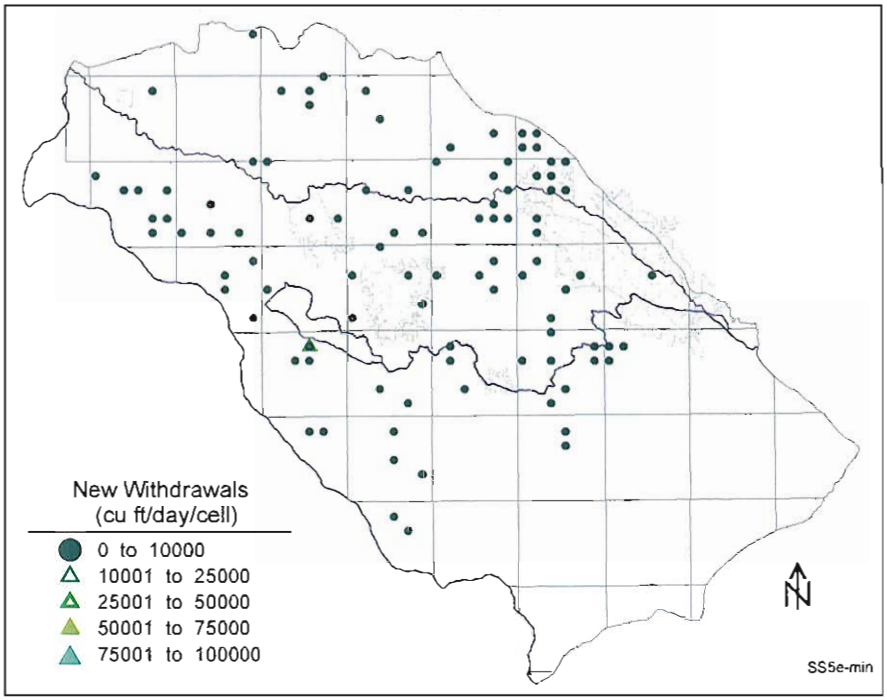

Figure 2-4: Distribution of estimated increased ground water withdrawals, layer 4.

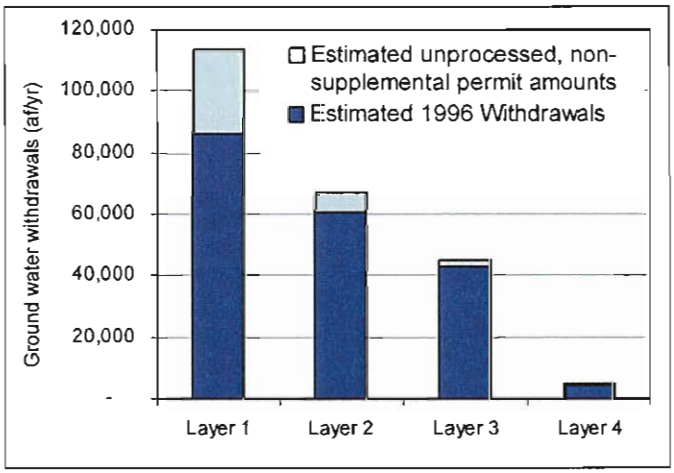

Figure 2-5: Estimated combined 1996 and unprocessed, non-supplemental permit withdrawals.

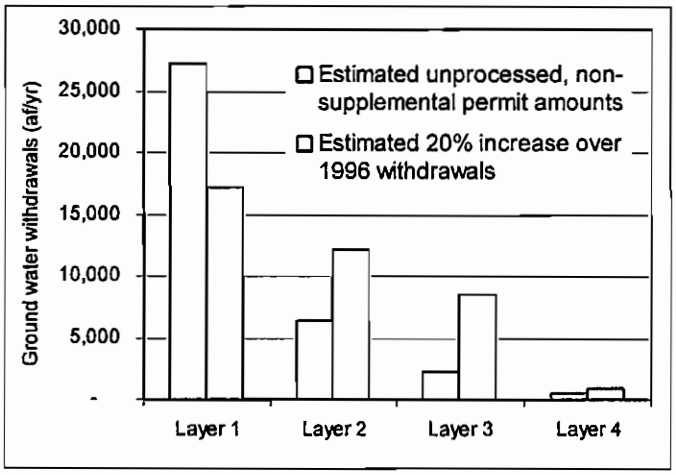

Figure 2-6: Comparison of estimated unprocessed, non-supplemental permit withdrawals and a 20% increase over estimated 1996 withdrawals (Petrich, 2004a).

2.2. Model Description

These scenario simulations were conducted with the Treasure Valley ground water flow model (Petrich, 2004a). The model is based on the three-dimensional, finite difference, USGS MODFLOW code (Harbaugh et al., 2000; McDonald and Harbaugh, 1988; McDonald and Harbaugh, 1996). The Treasure Valley ground water flow model was designed to simulate ground water flow on a regional (basin) scale. A model simulating flow on this scale is suitable for evaluating changes in water levels resulting from regional changes in land use and/or increases in withdrawals.

The model domain was discretized into a four-layer, 61× 49 uniform grid with square cells representing an area of one square mile (Figure 2-7). Model layers in the Treasure Valley model were defined based on an arbitrary datum connecting the Boise and Snake River elevations (Petrich, 2004a). The two upper model layers were each 200 feet thick; the two lower layers were each 400 feet thick.

Boundary conditions were simulated as no-flow (perimeter and bottom surface), specified flux (Snake River and along Boise Foothills), head-dependent flux (Boise River[6] and Lake Lowell[7]), or free surface (Figure 2-7). Simulated fluxes included recharge, withdrawals, flow to and from the Boise River and Lake Lowell, and discharge to drains and to the Snake River. Model inputs (underflow, recharge, extraction rates, etc.) were averaged over one-year periods.

[6] Simulated using the MODFLOW "River" package.
[7] Simulated using MODFLOW "General Head Boundary" package.

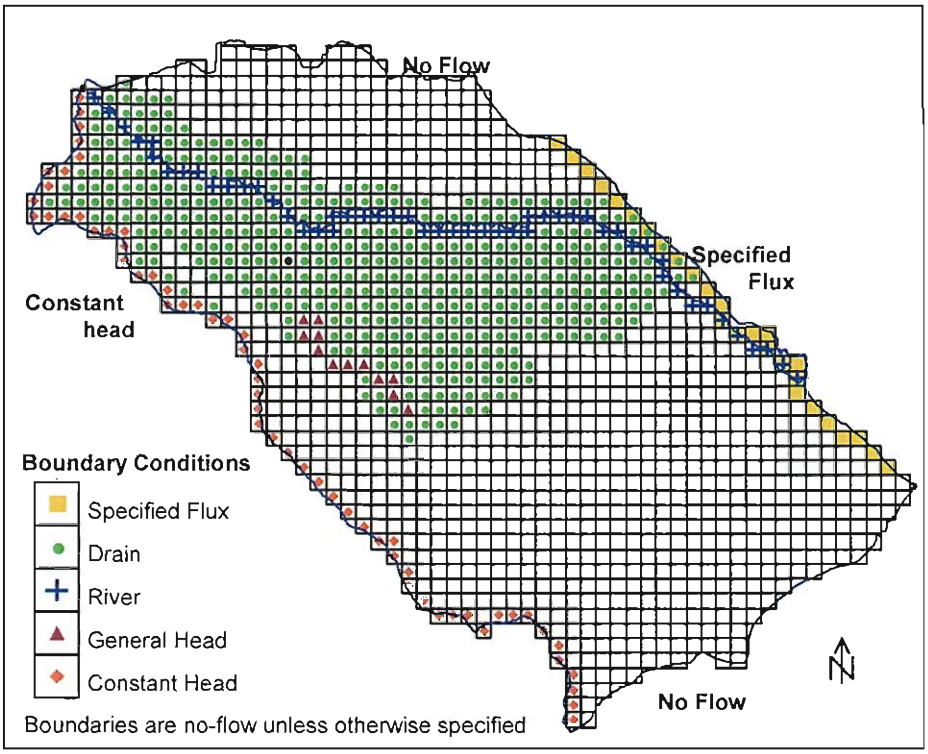

Figure 2-7: Model grid and boundary conditions.

The Treasure Valley model was calibrated to steady-state hydraulic conditions using the parameter estimation code PEST (Doherty, 1998; Doherty, 2000). Primary calibration parameters for the steady-state calibration were horizontal hydraulic conductivity (K_h) and vertical hydraulic conductivity (K_v). These parameters were defined for each layer at 42 pilot point[8] locations (Figure 2-8), resulting in a total of 143 model parameters (plus 121 tied parameters).

Observations included 200 head measurements ("head" observation group) and 6 assumed or observed vertical head difference values ("grad" observation group). The head measurements consisted of average water levels based on measurements conducted in spring and fall 1996. Regularization was used to incorporate 2,747 articles of "prior information" describing "zero difference" relationships between parameters, which increased the number of parameters that could be estimated while maintaining numerical stability in the inversion process.

[8] See Petrich (2004a) for an explanation of pilot points.

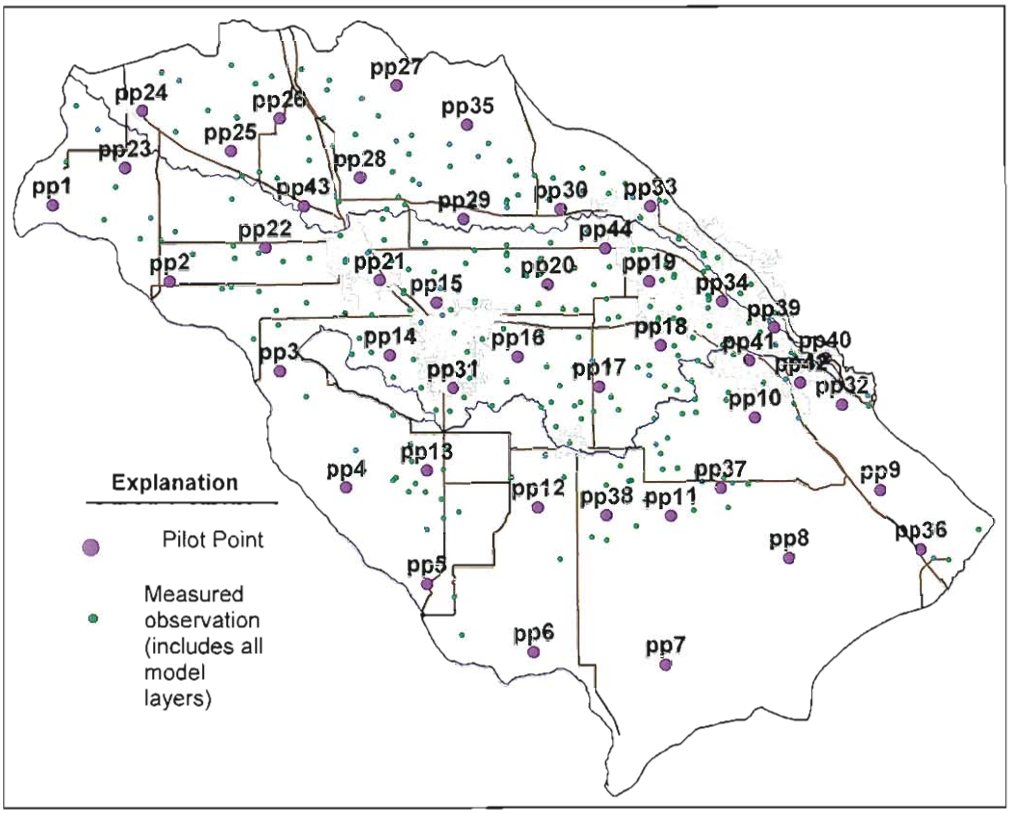

Figure 2-8: Pilot point locations.

2.3. Predictive Analysis

All calibrated ground water models have uncertainty associated with individual parameter values. Because the model predictions depend on these parameter values, it follows that the model predictions also have uncertainty. The goal of predictive analysis is to find the worst (and best) possible outcomes while constraining parameter values to those that provide a good fit between calculated and measured observations under base simulation stresses. Thus, PEST ran base simulation stresses (i.e., base-simulation withdrawals) and prediction stresses (i.e., increased withdrawals) iteratively until it found a set of parameter values that would both calibrate the model (under base conditions) and provide the minimum (or maximum) water levels associated with the additional withdrawals.

Thus, calibration with predictive analysis results in a parameter set that gives the worst (and best) outcome within the context of a calibrated model. There are a number of variables influencing the operation of PEST's predictive analyzer. The base calibration is influenced by (1) the number and disposition of measurements used for calibration and (2) the level of fit between these and model outputs achieved through the calibration process (as represented by the objective function, i.e., sum of the squared residuals [Φ]). Setting the target too low forces PEST to introduce heterogeneities into

the model domain that may or may not exist; that is, it results in "over-fitting" of parameters. The target objective function was therefore set to achieve a reasonably good fit without unrealistic parameter value distortion.

Smoothing constraints employed in the regularization process were maintained in the predictive analysis process. The prior information weights from the base simulation were multiplied by the optimized weight factor determined through regularized inversion (Petrich, 2004a). Thus, the predictive analysis process was prevented from introducing excessive heterogeneity into the model domain under predictive conditions in order to achieve unduly pessimistic predictions. The calibration target for the predictive analysis was set approximately 7% higher than the prior lowest calibration objective function value. These and other model construction choices influenced the predictive analysis.

Predictions of the impact from new aquifer stresses (e.g., ground water withdrawals) are calculated at one or more prediction points within the model domain. PEST attempts to maximize (or minimize) the average head values at the selected prediction points[9]. Thus, the number of points and the spatial and vertical distribution of the points influence the simulation results. Twelve prediction points (Figure 2-9) were distributed throughout the central portion of the model domain (which was of primary interest for model predictions). Predictions were calculated within the top three layers at each prediction point (i.e., 36 total points).

[9] The hydrologic impacts of the additional withdrawals are being simulated throughout the model domain. PEST simply uses the prediction points during the calibration process as reference points for simulating maximum or minimum responses.

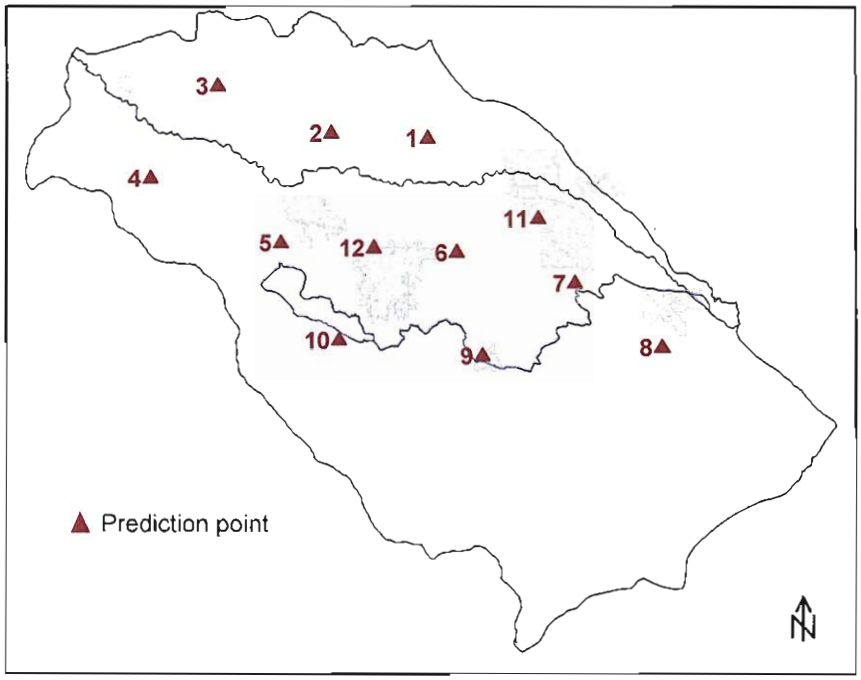

Figure 2-9: Prediction point locations.

2.4. Assumptions and Limitations

There are many assumptions, limitations, and potential errors associated with the numerical simulation of ground water flow (Table 2-3). These assumptions and limitations should be kept in mind when reviewing model results.

There are several specific potential sources of error in this Treasure Valley model. First, there is a high degree of geologic uncertainty throughout the system. Many strata, although substantial, are not spatially continuous over the model domain. While it is clear that there are shallow and deep aquifers, with markedly different flow characteristics, residence times, and recharge rates, there are not clearly identifiable strata that separate these aquifers over the entire model domain. There are some areas within the model domain with little or no hydrogeologic data (e.g., southern Ada County) because few or no wells have been drilled in these areas. Horizontal and vertical aquifer heterogeneity is seen in lithologic, chemical, and aquifer test data. In addition, faulting can and does influence ground water flow. The locations of some faults are known or have been inferred, and offsets of some of the faults appear to be greater than 800 feet, but the hydraulic influences of most faults are unknown.

It is impossible for a model to fully represent the hydraulic heterogeneity existing in a system as geologically complex as that in the Treasure Valley. Hydraulic properties in a calibrated model are "integrated" or "averaged" hydraulic properties. There is potential for substantial error in a model prediction that depends on geological

heterogeneity beyond that captured by the calibration process. Fortunately, the greater the spatial scale over which predictions are made, the smaller the error is likely to be.

Second, flux rates at boundaries are unknown. There is substantial uncertainty regarding estimates of the quantity and distribution of underflow into the model domain. Streambed and drain conductances are unknown, as are lakebed conductance values. However, streambed and drain conductances are relatively insensitive if they are high values, as was the case in this model.

Observation data were collected from a variety of wells. Some are clearly influenced by ground water pumping, either from within the observation well or from nearby wells. The elevations of some of the wells are known only within general limits (e.g., ±10 feet). Spatial discretization of areas with substantial variations in potentiometric surfaces (e.g., drawdown) can lead to model errors. Some water level measurements from shallow wells, if influenced by surface drainage, may lead to model calibration errors. Wells in which water levels were clearly influenced by surface topography were removed from the calibration (e.g., weights set to zero).

Parameter uncertainty is high in some portions of the model domain because of the lack of observation data. For example, there are few or no wells in some portions of southern Ada County. In general, there are fewer deep wells than shallow wells, and the distribution of deep wells is limited primarily to more highly populated areas, which limits the number of observation points for deeper aquifers in some portions of the model domain.

The water table elevation in some parts of the model domain is controlled by the elevation of land surface. The water table elevations in these areas do not contain information for estimating hydraulic conductivities in these areas, leading to high uncertainty in local K_h estimates.

The nature of the steady-state simulations also contributes to parameter uncertainty. Flux data (e.g., recharge, withdrawals, etc.) were averaged over an entire year, even though the stress may have occurred during only one season (e.g., irrigation season). Observation data for the steady-state simulations also consisted of averaged water levels, based on spring and fall 1996 measurements.

Category	Potential Limitations, Assumptions, and Errors
Potential conceptualization errors	Incorrect flow system conceptualization
	Incorrect application of numerical approach
	Incorrect layer and/or grid definitions
	Errors in assumed boundary conditions
	Errors in parameter regularization assumptions (*see note below)*
Basic ground water flow assumptions required for using MODFLOW	Ground water flow does not meet Darcian flow assumptions, which include the following: flow is laminar, fluid is incompressible, fluid density is constant, gravitational acceleration is constant, and water movement is caused by mechanical (e.g., hydraulic) gradients.
	Borehole storage is negligible.
	There is no change in hydraulic characteristics with respect to degree of saturation.
Limitations and assumptions associated with the discretization of space and time	Grid resolution is inappropriate for model objectives.
	Simulated head values are based on heads in surrounding nodes; steeply sloping and/or non-linear heads (or other dependent variable) and may not be accurately represented by finite difference grid.
	Aquifer characteristics, inflows, outlows, and other properties are assumed to be constant within a grid cell.
	Flux characteristics are assumed to be constant within time steps.
	Hydraulic properties are assumed to be constant in time.
	Wells are assumed to be fully penetrating in assigned layers.
	Simulated observations are averaged over too large an area (this may be a concern if water level observations are based on wells experiencing substantial drawdown). Model grid is not fine enough to reproduce head curvature in the vicinity of lines and points of groundwater extraction and inflow.
Potential causes for numerical errors	Model cells go dry
	Incorrect solution closure criteria
	Truncation error, roundoff error
Potential model input errors	Errors in recharge package inputs (e.g., data errors, interpolation errors, etc).
	Errors in well package inputs (e.g., data errors, interpolation errors, etc).
	Errors in drain package inputs (e.g., data errors, interpolation errors, etc).
	Errors in river package inputs (e.g., data errors, interpolation errors, etc).
	Errors in general head boundary package inputs (e.g., data errors, interpolation errors, etc).
Potential observation measurement errors	Physical measurement errors
	Water levels are influenced by pumping in observation well.
	Water levels are influenced by nearby pumping.
	Water levels observation are based on approximated or incorrect well elevation.

Table 2-3: Sources of possible error leading to parameter uncertainty.

Calibration errors can result from incorrect parameterization, assignments of pilot point locations, and parameter regularization relationships. Parameter non-uniqueness and/or correlation can also lead to calibration errors.

Some indication of parameter uncertainty is given during the calibration process. PEST output includes parameter sensitivity values, which are strongly influenced by parameter correlation. However, it is important to remember that some parameter values may be highly uncertain but not relevant to a particular model prediction. Predictive analysis (Doherty, 2000) is therefore probably a more useful approach for evaluating a scenario in the context of various parameter uncertainties.

It is also important to note that no ground water model can be calibrated without some form of implicit or explicit regularization. Regularization is the process by which model parameterization is simplified to the extent that parameter estimation can take place. Where zones are used, regularization is implicit. Where PEST's regularization functionality is used, regularization is explicit, with regularization constraints enforced to the extent necessary (through calculation of an appropriate regularization weight factor). In either case, the complexity of the parameter estimation problem is reduced to a level that is compatible with the information content of the data used for calibration. The less the observation data, the greater the role of regularization in the calibration process.

The parameter field that results from the calibration process cannot be considered as the "true" hydraulic property field prevailing within the model domain; even if the fit between model outputs and field data is perfect. It is one of many possible parameter fields that could fit the data. Where PEST's regularization functionality is used, it is the smoothest of all of these fields; where zones are used, it is the "blockiest" of these fields. In either case, the calibrated field cannot reflect small- or even medium-scale heterogeneity of true aquifer hydraulic properties, for these are simply beyond the ability of the calibration process to capture.

In general, where model predictions depend on regional or averaged hydraulic properties, this model's performance should be relatively good. Where model predictions depend on local detail, use of this model may result in error, or a higher degree of uncertainty.

3. RESULTS AND DISCUSSION

3.1. Introduction

Two simulations were conducted to explore potential effects of the increased withdrawals represented by unprocessed water right applications. The purpose of the first simulation (*SS5e-min*) was to find the minimum water levels resulting from the increased withdrawals (i.e., the maximum possible water level decline from the base case). The purpose of the second simulation (*SS5e-max*) was to find the maximum water levels (minimum decline from the base simulation) under the increased withdrawal scenario. Results from these simulations were compared to the base simulation (*SS2bc*) (see Petrich, 2004a, for a more detailed description of the base simulation).

3.2. Base Simulation

Parameter values from the base simulation (Petrich, 2004a) were used as starting points for the predictive analysis. Results from the base simulation are summarized in Table 3-1 and Figure 3-1. Potentiometric surface contour comparisons between observed and simulated heads from the base run are shown in Figure 3-2 through Figure 3-5 (see Petrich, 2004a, for more information about these comparisons).

Base Run Results (based on observations with PEST weights greater than zero)				
Contribution to objective function (Φ) from heads			3,220	
Contribution to Φ from regularization			3,150	
Contribution to Φ from gradients			56.46	
Highest eigenvalue			1.176	
Lowest eigenvalue			1.89×10^{-7}	
Number of PEST iterations			50	
Number of MODFLOW runs			~14,300	
Run Statistics	**Total**	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	73.59	62.86	57.05	73.59
Minimum negative residual	-67.08	-67.08	-52.48	-44.14
Average absolute residual	14.62	12.42	16.01	23.29
Median abslute residual	9.49	8.74	9.714	19.03
Number of values	200	140	29	31
(Simulation *SS2bc*)				

Table 3-1: Run information for steady-state base simulation (Petrich, 2004a).

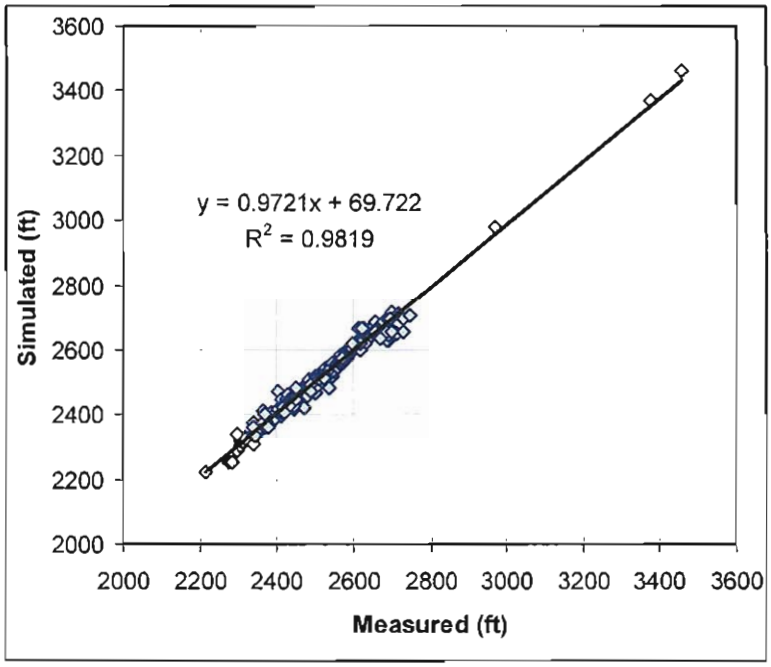

Figure 3-1: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (base simulation).

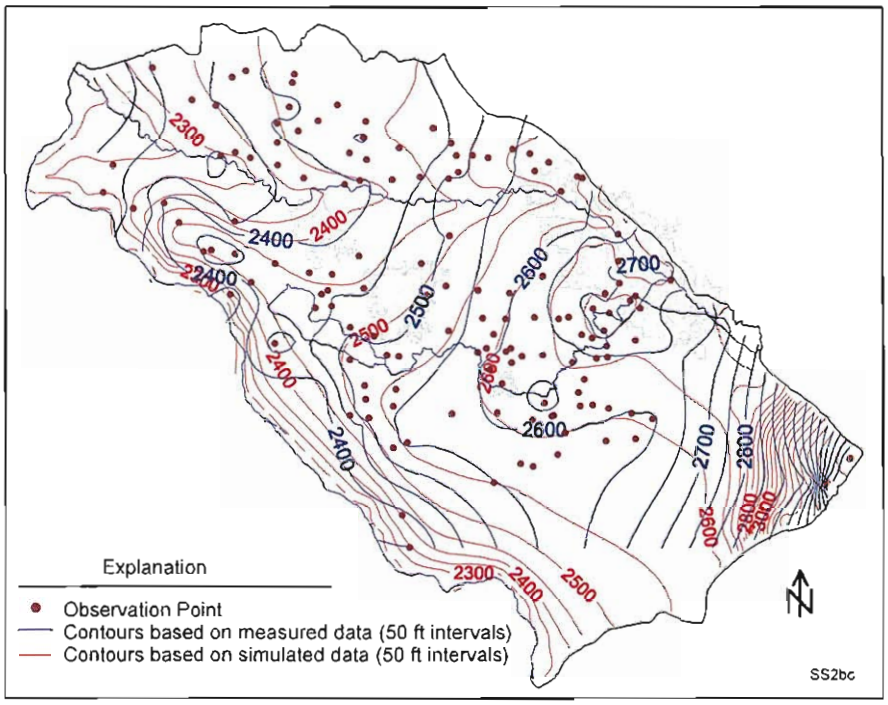

Figure 3-2: Simulated and observed potentiometric contours, layer 1 (base simulation).

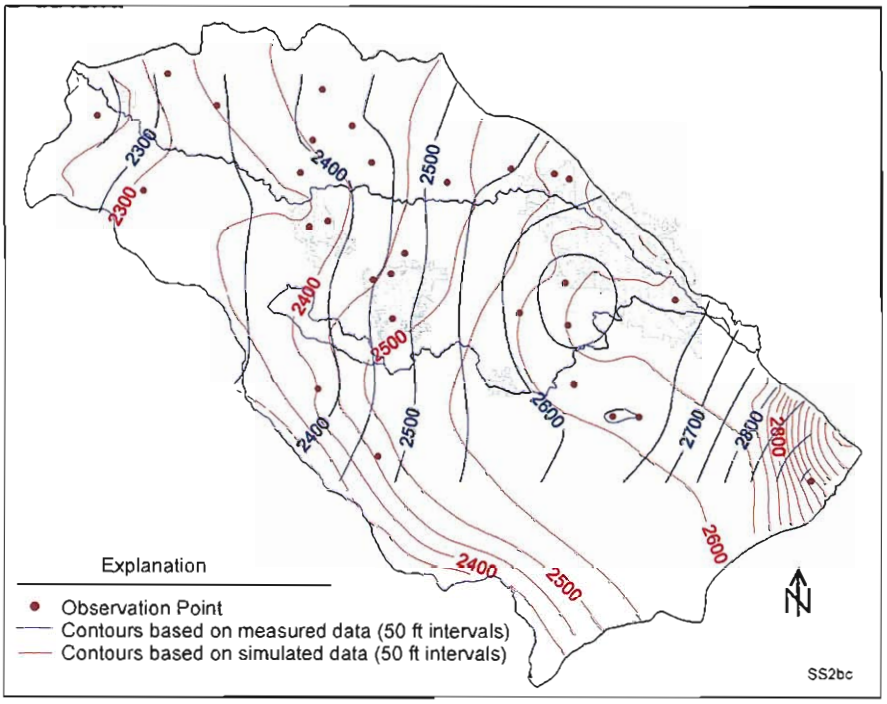

Figure 3-3: Simulated and observed potentiometric contours, layer 2 (base simulation).

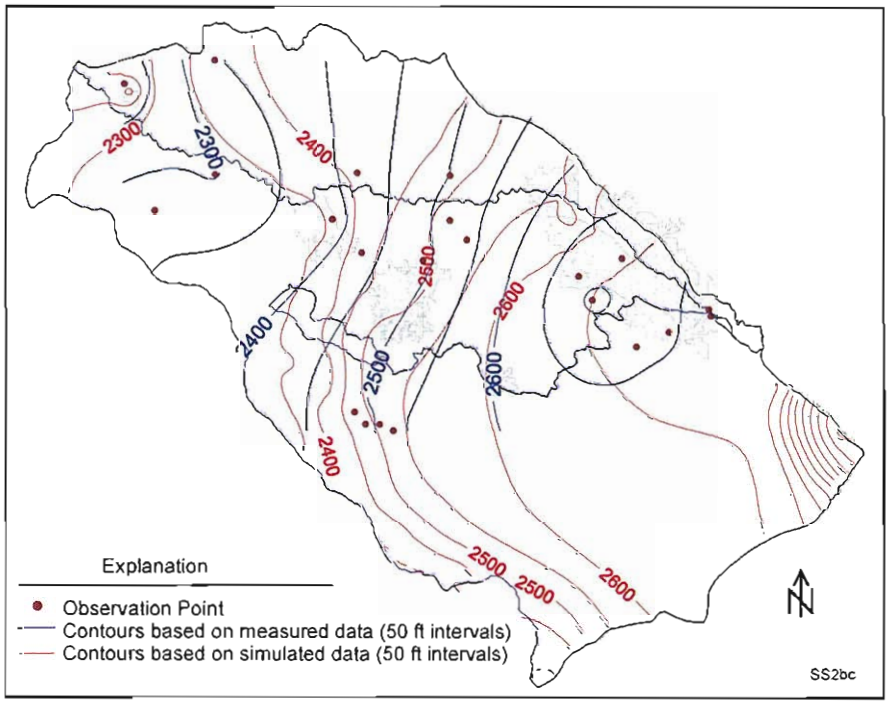

Figure 3-4: Simulated and observed potentiometric contours, layer 3 (base simulation).

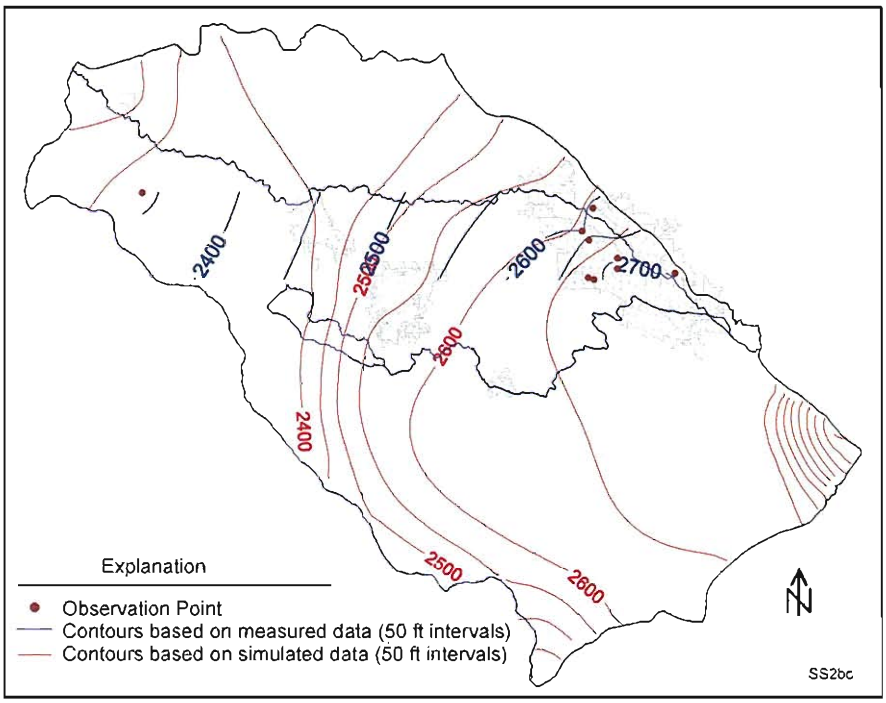

Figure 3-5: Simulated and observed potentiometric contours, layer 4 (base simulation).

3.3. Predictive Simulations

A summary of results for the minimum prediction (minimum average hydraulic head elevation at the predictive points) is given in Table 3-2 and Figure 3-6. Results for the maximum prediction are given in Table 3-3 and Figure 3-7.

Simulation of increased withdrawals using predictive analysis resulted in an average decline among 36 prediction points of 11.5 feet (Table 3-4) during the course of the predictive analysis simulation. The maximum simulated average predictive point elevation with the increased withdrawals was 9.5 feet above the beginning elevation, although a rise in water levels in response to increased withdrawals is conceptually impossible. The simulated water level changes are partly the result of increased withdrawals and partly the result of parameter uncertainty (see discussion in Section 3.4, beginning on page 31).

A comparison of volumetric budget components is given in Table 3-5. The comparison includes values from the base simulation (Petrich, 2004a), simulation of 20% across the board withdrawal increase over 1996 levels (Petrich, 2004a), and the minimum and maximum head elevations resulting from the simulation of increased withdrawals associated with unprocessed well applications. As with predicted water level changes, any changes in the volumetric budget components are the result of both increased withdrawals and parameter uncertainty (see discussion in Section 3.4).

Results – Minimum Head Level Prediction (*SS5e-min*) (based on observations with PEST weights greater than zero)				
Initial objective function (Φ_{total})			6427	
Contribution to objective function (Φ) from heads			3220	
Contribution to Φ from regularization			3150	
Contribution to Φ from gradients			56.5	
Ending objective function (Φ_{total})			7061	
Contribution to Φ from heads			3742	
Contribution to Φ from regularization			3146	
Contribution to Φ from gradients			172.5	
Highest eigenvalue			1.34	
Lowest eigenvalue			1.84×10^{-7}	
Number of PEST iterations			3	
Number of MODFLOW runs			880	
Run Statistics	**Total**	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	74.36	68.64	73.01	74.36
Minimum negative residual	-64.47	-64.47	-51.12	-43.28
Average absolute residual	15.76	12.13	21.98	26.33
Median abslute residual	11.84	7.73	22.45	25.29
Number of values	200	140	29	31

Table 3-2: Summary of results, minimum head levels.

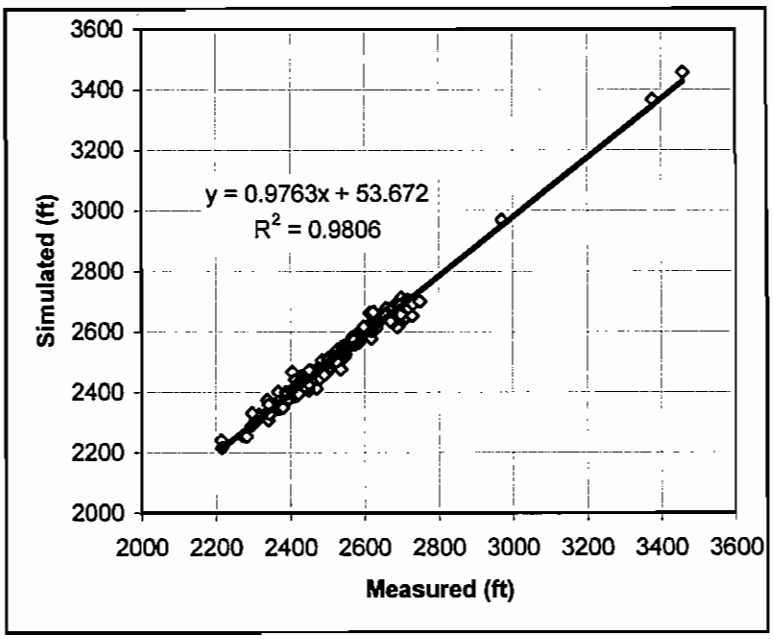

Figure 3-6: Simulated versus measured hydraulic head observations (minimum prediction; simulation *SS5e-min*).

Results – Minimum Head Level Prediction (*SS5e-max*) (based on observations with PEST weights greater than zero)				
Initial objective function (Φ_{total})			6427	
Contribution to objective function (Φ) from heads			3220	
Contribution to Φ from regularization			3150	
Contribution to Φ from gradients			56.5	
Ending objective function (Φ_{total})			6908	
Contribution to Φ from heads			3895	
Contribution to Φ from regularization			2992	
Contribution to Φ from gradients			20.5	
Highest eigenvalue			1.45	
Lowest eigenvalue			2.83×10^{-7}	
Number of PEST iterations			3	
Number of MODFLOW runs			871	
Run Statistics	**Total**	**Layer 1**	**Layer 2**	**Layers 3 and 4**
Maximum positive residual	74.93	57.01	53.72	74.93
Minimum negative residual	-73.93	-73.93	-53.91	-52.87
Average absolute residual	16.91	15.48	16.72	23.54
Median abslute residual	12.21	11.29	13.19	21.48
Number of values	200	140	29	31

Table 3-3: Summary of results, maximum head levels.

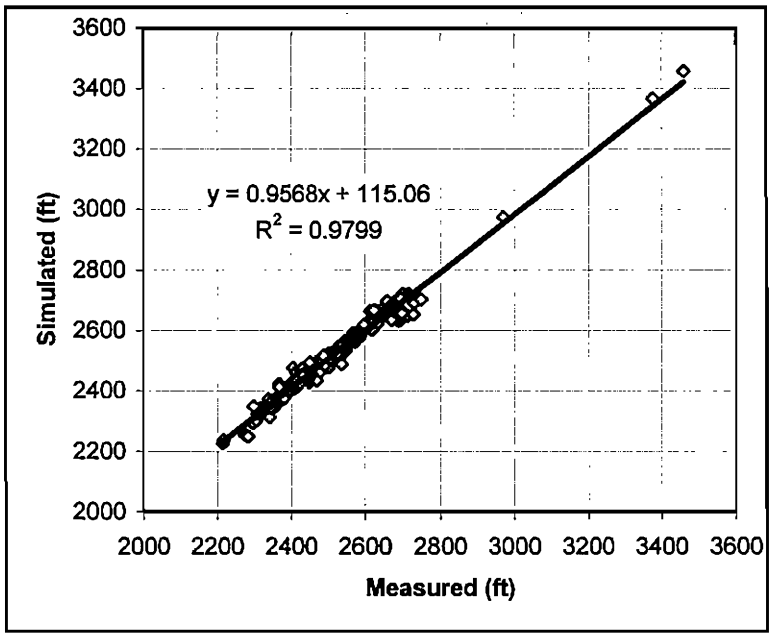

Figure 3-7: Simulated versus measured hydraulic head observations (minimum prediction; simulation *SS5e-max*).

Average Prediction Point Heads (ft)	Base Simulation (*SS2bc*)	Scenario with Currently Unprocessed, Non-Supplemental Withdrawals	
		Minimum Heads (*SS5e-min*)	Maximum Heads (*SS5e-max*)
Beginning head (36 points)	—	2,492.7	2,492.7
Ending head (36 points)	2,497.8	2,481.2	2,502.1
Change	—	-11.5	+9.6

Table 3-4: Average predictive point hydraulic head elevations.

Simulation Volumetric Budget Comparison				
	Base Simulation (*SS2bc*)	20% Increase in 1996 Rates (Minimum heads) (*SS5d-min*)	Unprocessed Non-SupplementalWater Rights(Minimum Heads) (*SS5e-min*)	Unprocessed Non-SupplementalWater Rights (Maximum Heads) (*SS5e-max*)
IN				
Constant head	28,891	28,133	27,942	30,524
Wells	108,000	108,000	108,000	108,000
Drains	0	0	0	0
River leakage	5,784,137	6,827,901	6,102,998	6,566,623
Head-dependent boundaries	1,537,895	1,673,447	1,761,545	1,286,633
Recharge	116,205,088	116,205,088	116,205,088	116,205,088
Total In	123,664,008	124,842,568	124,205,568	124,196,864
OUT				
Constant head	17,350,556	16,939,652	17,141,098	15,928,110
Wells	23,076,956	27,692,348	27,410,502	27,410,502
Drains	36,667,716	33,778,404	33,119,472	39,231,744
River leakage	46,486,872	46,368,532	46,475,412	41,511,812
Head-dependent boundariies	81,961	63,698	59,170	114,744
Recharge	0	0	0	0
SUMMARY				
Total	123,664,064	124,842,624	124,205,648	124,196,904
In–Out	-56	-56	-80	-40
Percent discrepancy	0	0	0	0

Table 3-5: Simulation volumetric budget comparison.

Drawdown associated with the new withdrawals represented by the unprocessed, non-supplemental water right applications was calculated by subtracting the minimum (or maximum) head elevations from the predictive simulations from the base simulation head elevations. The maximum drawdowns (based on minimum simulated hydraulic head elevations) calculated in this fashion are shown in Figure 3-8 through Figure 3-11. The minimum drawdowns (based on maximum simulated head elevations) are shown in Figure 3-12 and Figure 3-15.

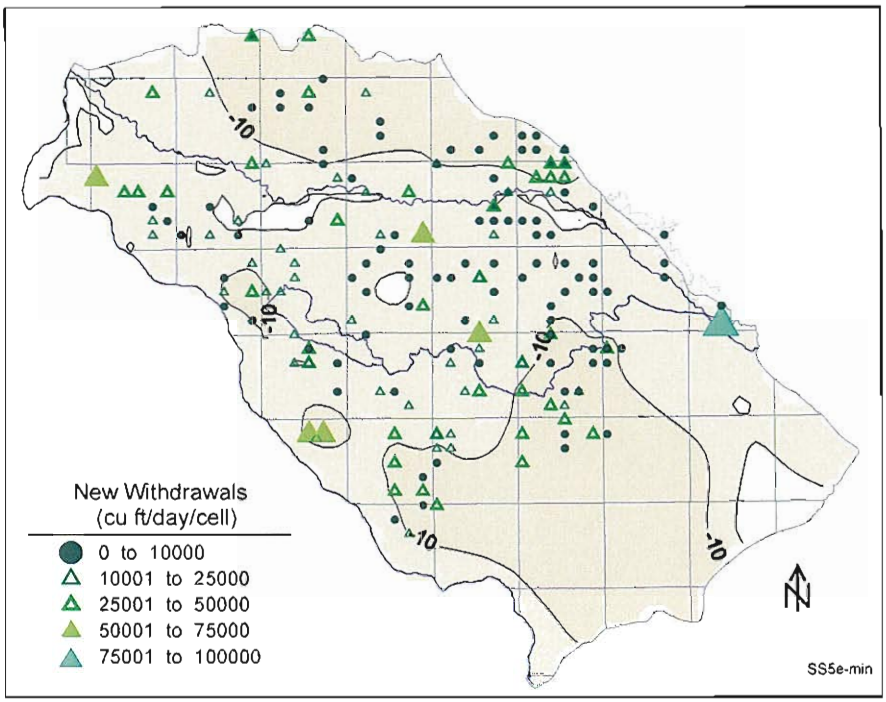

Figure 3-8: Head difference between base case and minimum predictive values, layer 1.

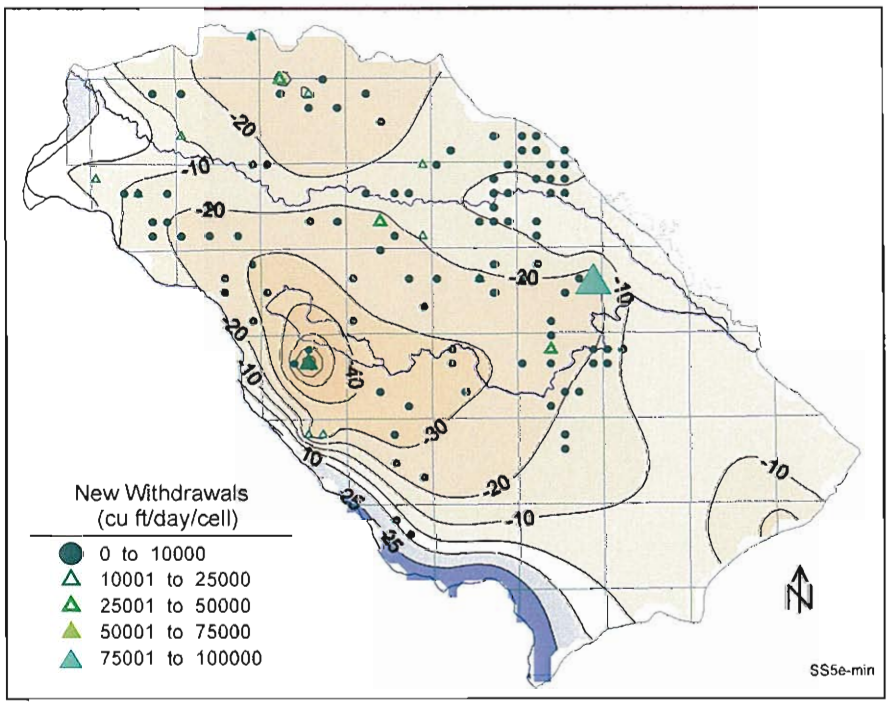

Figure 3-9: Head difference between base case and minimum predictive values, layer 2.

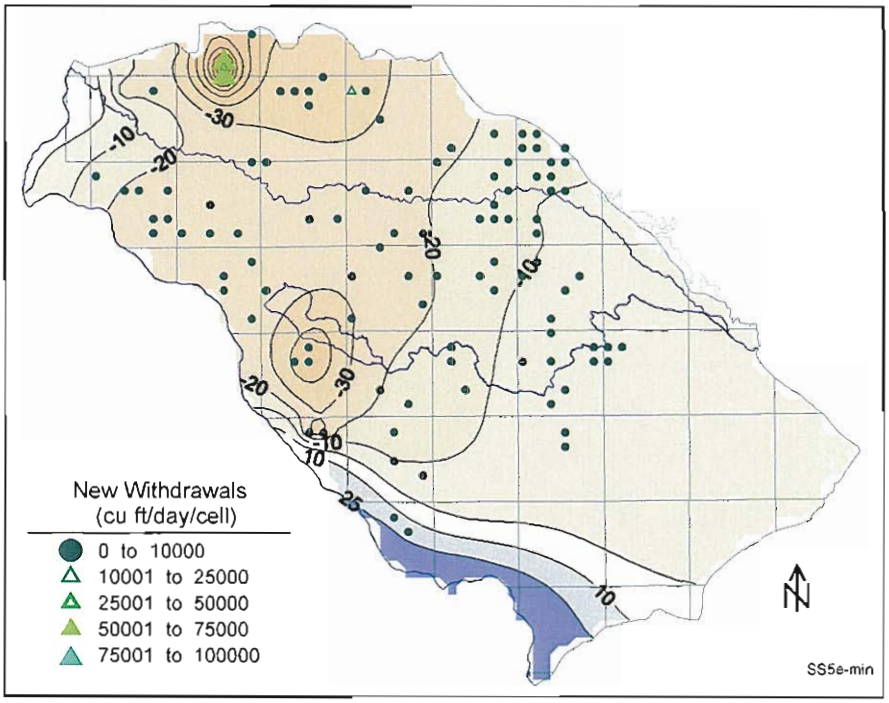

Figure 3-10: Head difference between base case and minimum predictive values, layer 3.

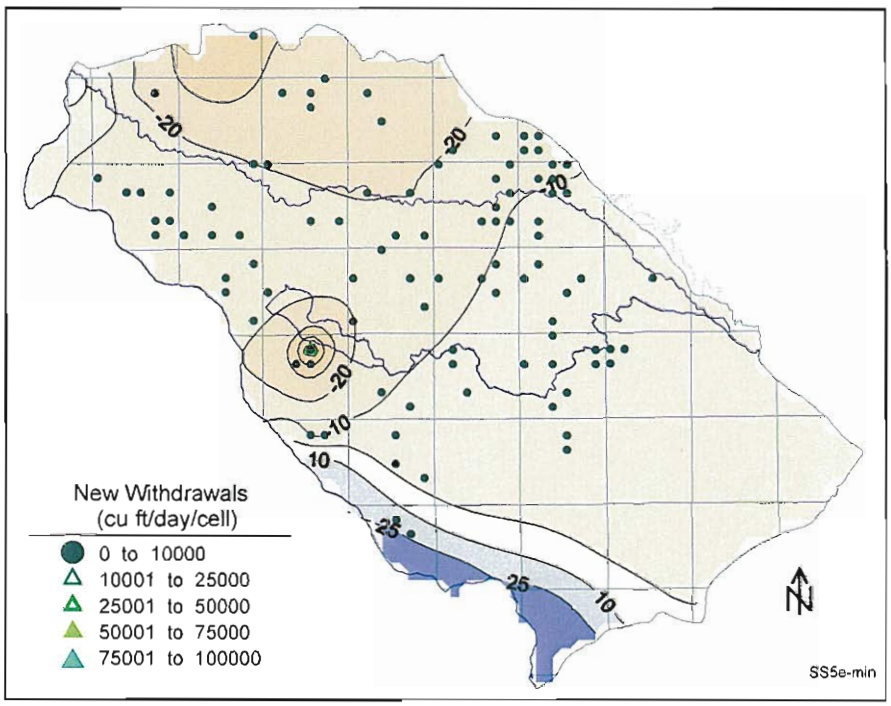

Figure 3-11: Head difference between base case and minimum predictive values, layer 4.

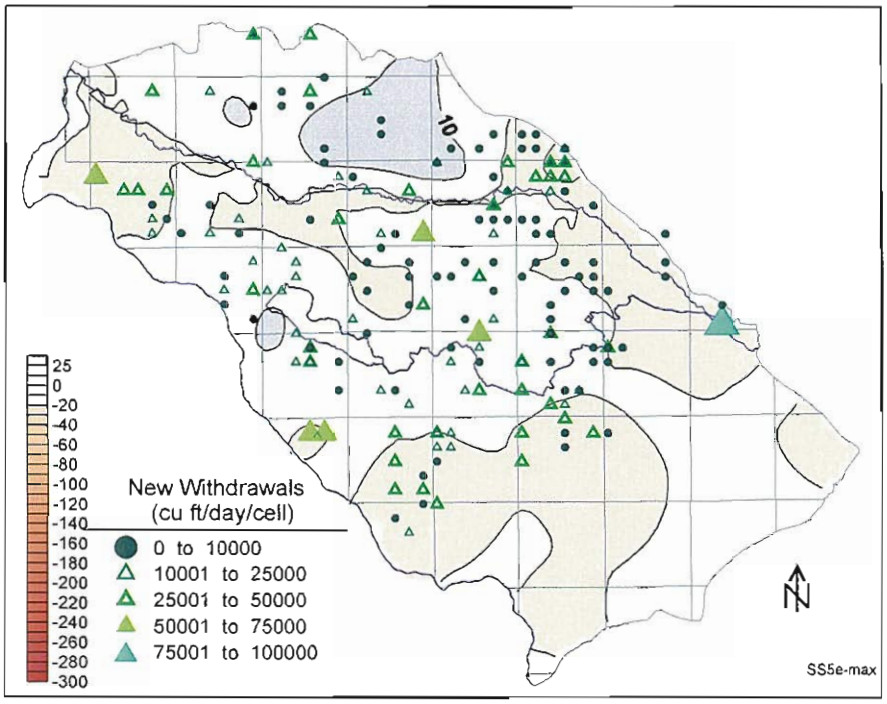

Figure 3-12: Head difference between base case and maximum predictive values, layer 1.

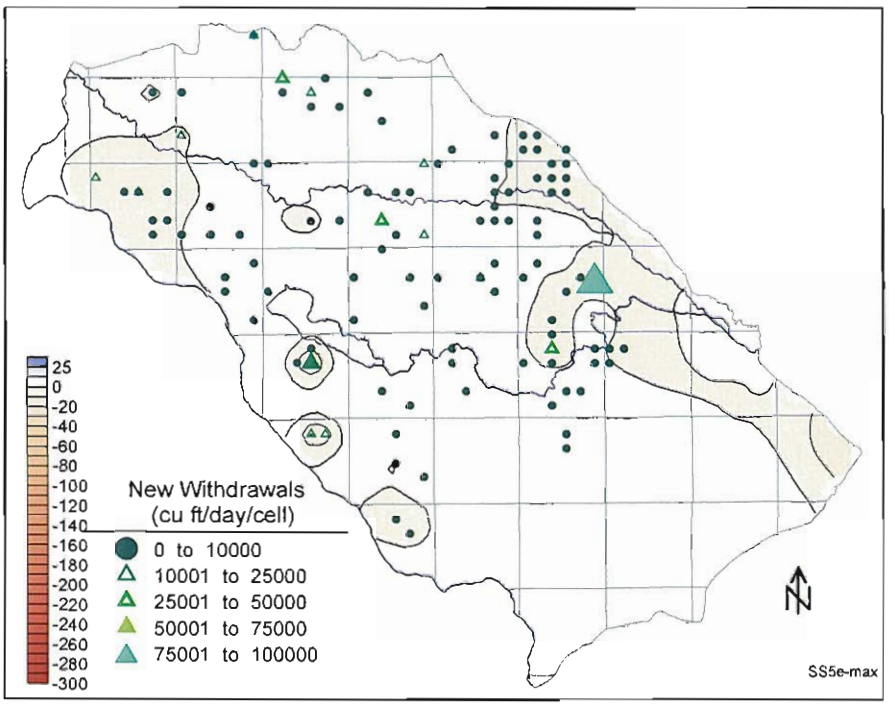

Figure 3-13: Head difference between base case and maximum predictive values, layer 2.

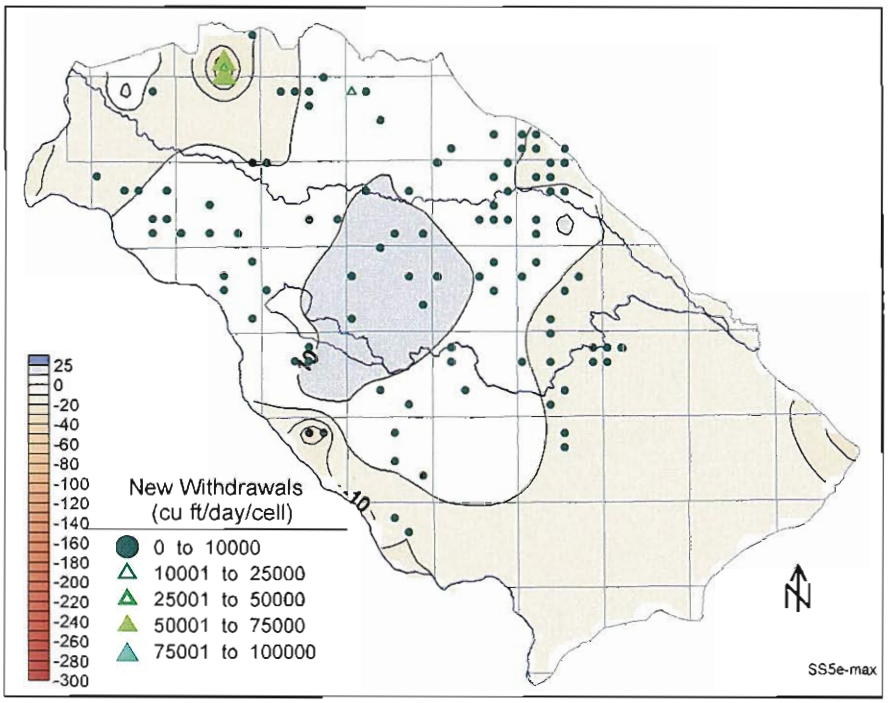

Figure 3-14: Head difference between base case and maximum predictive values, layer 3.

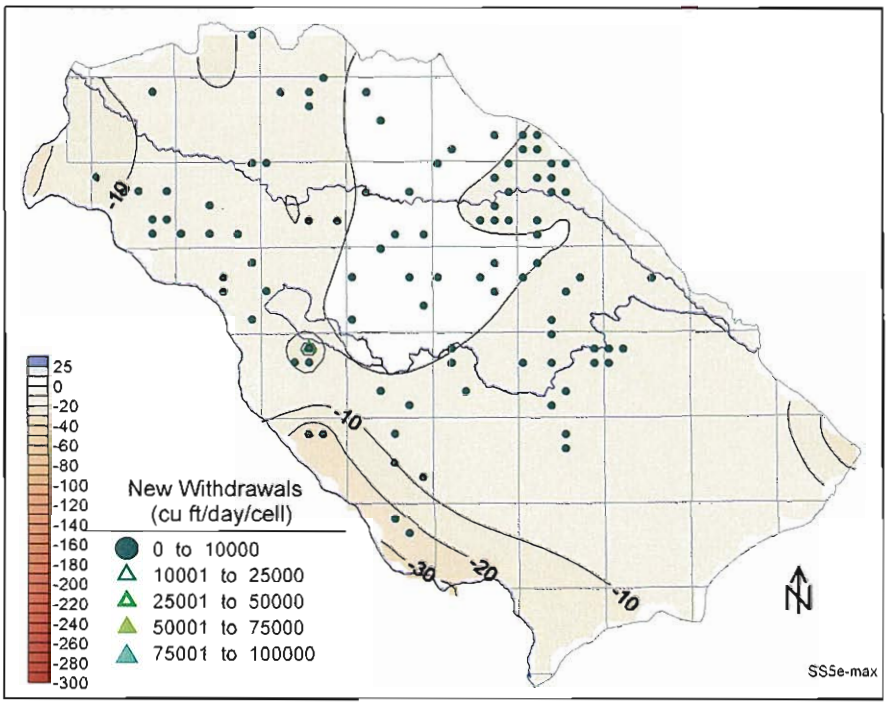

Figure 3-15: Head difference between base case and maximum predictive values, layer 4.

The horizontal and vertical hydraulic conductivity distributions that led to these maximum drawdowns are shown in Figure 3-16 through Figure 3-21. These are very similar to the hydraulic conductivity distributions for the base simulation (Petrich, 2004a).

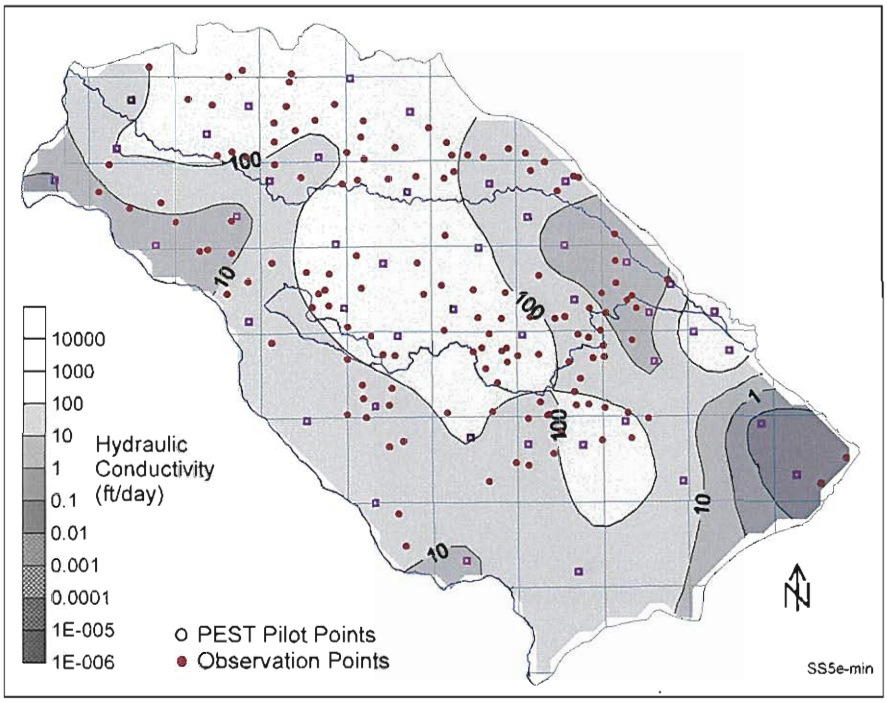

Figure 3-16: Horizontal hydraulic conductivity distribution for minimum predictive values, layer 1.

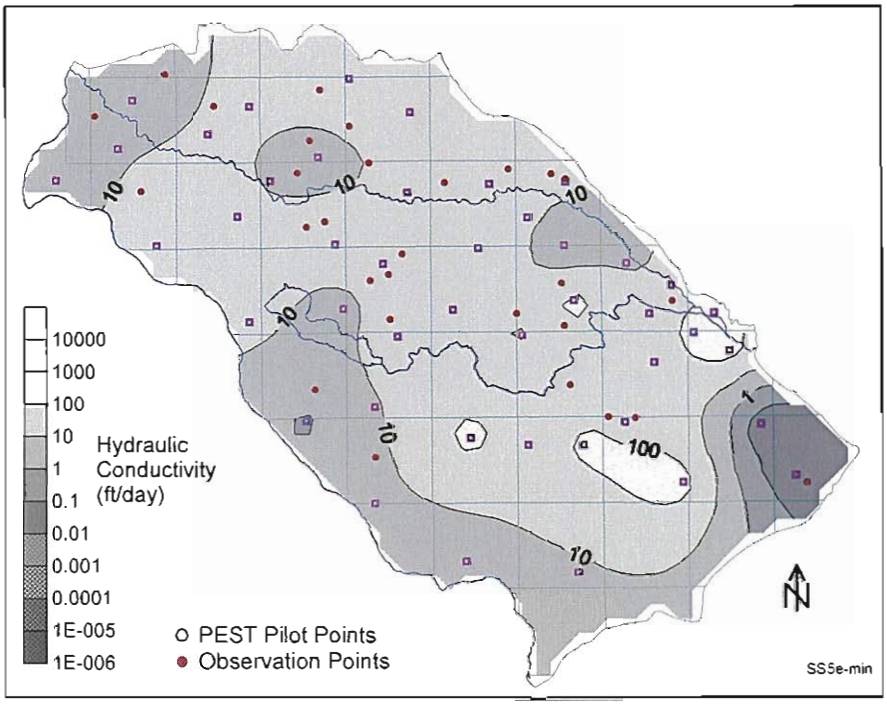

Figure 3-17: Horizontal hydraulic conductivity distribution for minimum predictive values, layer 2.

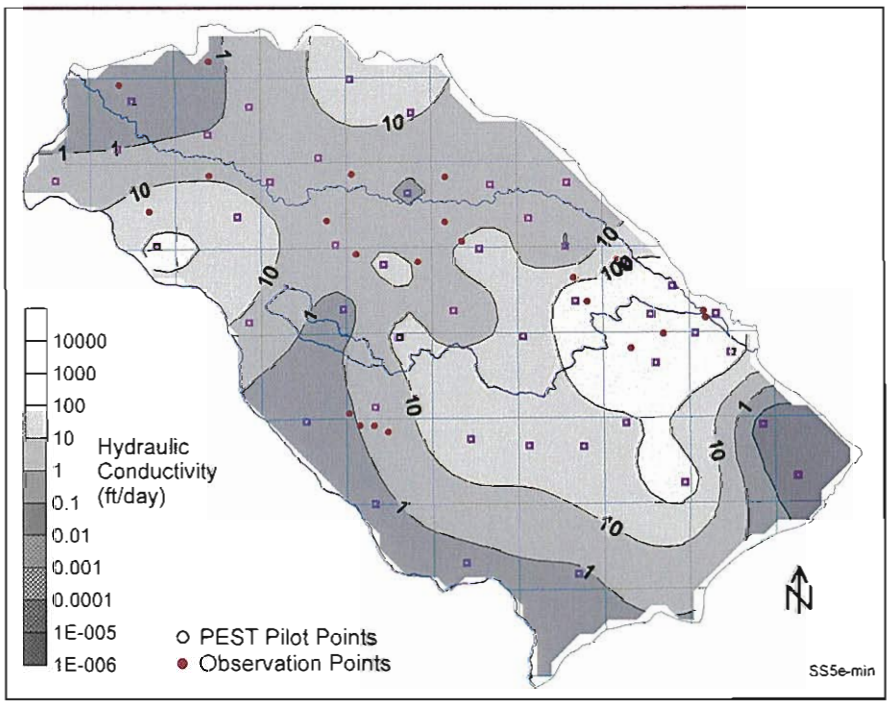

Figure 3-18: Horizontal hydraulic conductivity distribution for minimum predictive values, layers 3 and 4.

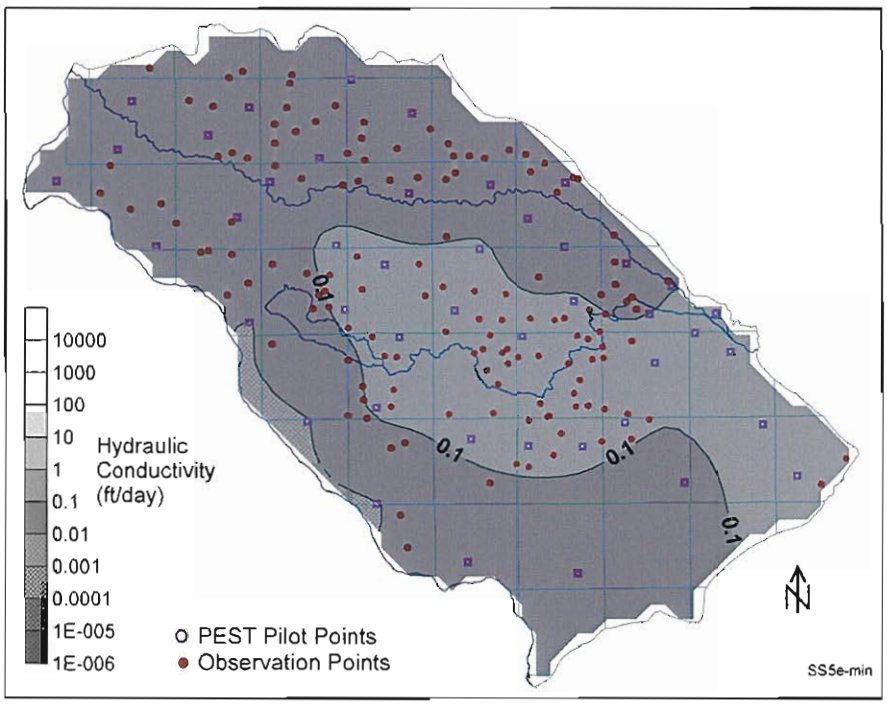

Figure 3-19: Vertical hydraulic conductivity distribution for minimum predictive values, layer 1.

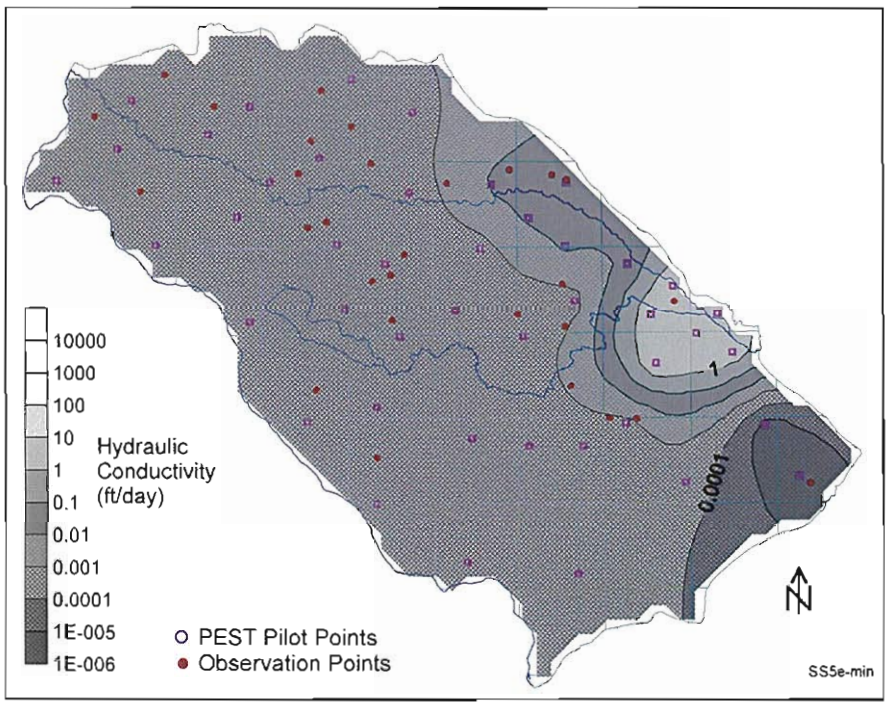

Figure 3-20: Vertical hydraulic conductivity distribution for minimum predictive values, layer 2.

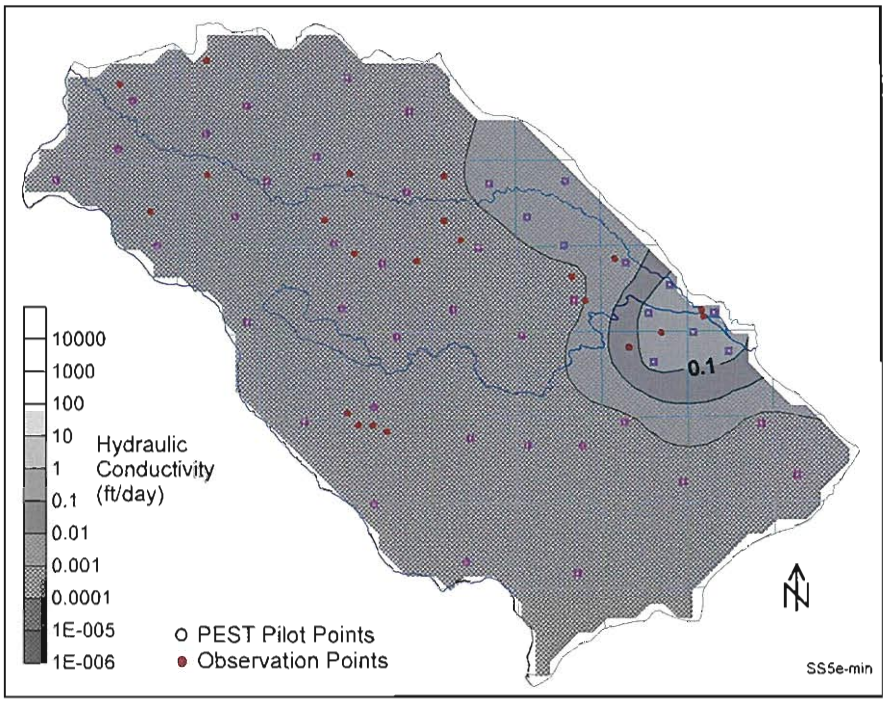

Figure 3-21: Vertical hydraulic conductivity distribution for minimum predictive values, layers 3 and 4.

3.4. Discussion

Several simulations were conducted to evaluate potential impact of unprocessed, non-supplemental water right applications on regional ground water levels. The simulations were conducted using the Treasure Valley ground water flow model (Petrich, 2004a) under steady-state conditions.

The difference between minimum and maximum average hydraulic heads at the predictive points represents the uncertainty inherent in the model predictions. Each of these predictions represents a simulation that is similarly well calibrated. In addition to calibration uncertainty, conceptualization errors, discretization of space, numerical errors, model input errors, lack of nearby observations, and/or potential observation errors also may have influenced the model calibration and simulation results.

The predicted head values were compared to head values from the base simulations, which are not optimized for a minimum (or maximum) outcome. Thus, a comparison between the two represents changes in the calibration *and* hydraulic stress. This also applies to the mass balance comparisons between the base simulation and predictive scenario (e.g., Table 3-5). The changes in mass balance reflect both increased withdrawals and parameter uncertainty.

An alternative approach to evaluating potential head declines would have been to first run predictive analyses using the base simulation. Heads (or mass balance terms)

could be minimized (or maximized) with no changes in model stresses (e.g., increase in withdrawals). The resulting head distribution from these simulations would then form the basis for the comparison between base simulation and predictive scenarios. Thus, additional comparisons should be done between minimized heads from a base calibration and minimum water levels associated with the increase in withdrawals (see "Recommendations" in Section 4).

The maximum potential drawdowns predicted with the unprocessed water right applications were simulated in an area south of Lake Lowell (layers 2, 3, and 4) and in an area in the northwestern portion of the model domain. The latter simulated cone of depression may have been caused by two withdrawal estimates that were unreasonably high. The general drawdown in the area south of Lake Lowell is consistent with known drawdowns in this area.

Some water level increases were predicted for the very southern portion of the model along the Snake River (Figure 3-10 and Figure 3-11). These appear highly suspect and may be artifacts of near-boundary conditions.

The drawdowns based on maximum predicted head elevations (Figure 3-12 through Figure 3-15) bracket the prediction uncertainty. For instance, an indicated decline of 20 feet in one of these plots might be a minimum decline expected with the additional stress. Again, changes of ± 10 feet, especially near model boundaries, are probably not very meaningful, as this is within the range of error for observation, river, drain elevations, and other inputs.

One area of decline seen in the drawdowns calculated from the maximum predicted head elevations (minimum decline) is a small area of south of Lake Lowell in layer 2 (Figure 3-13). This suggests that additional withdrawals in this area might lead to at least some further water level declines. Another area of decline in layer 2 based on the maximum predicted head elevations (minimum decline) is in the area between Boise, Meridian, and Kuna (Figure 3-13). This area also showed some declines in the maximum predicted drawdowns (Figure 3-9), apparently corresponding, in part, with a large proposed withdrawal in the west Boise–Meridian area.

The comparison of volumetric budget components in Table 3-5 reflected the increased withdrawals over the base simulations. Both scenarios (20% across-the-board increase over 1996 withdrawals reported in Petrich [2004a] and the withdrawals associated with the unprocessed water right applications) represented a 20% increase over 1996 withdrawals. However, the spatial and vertical distribution of withdrawals in these scenarios was substantially different. The additional withdrawals in both scenarios (1) induced more recharge from the Boise River ("river leakage") and from Lake Lowell ("head-dependent boundaries"), (2) less flow to drains, and (3) less discharge into Lake Lowell. The remaining sources of new withdrawals were split among increased recharge from rivers, Lake Lowell, and reduced discharge to Lake Lowell.

Again, these simulated changes represent both parameter uncertainty and response to an increased stress.

Hydraulic conductivity patterns (Figure 3-16 through Figure 3-21) show relatively high K_h characteristics in the central portions of layers 1 and 2 and higher K_h values presumably corresponding with alluvial/deltaic sediments in layers 3 and 4. Estimated K_h values ranging over 100 ft/day enable the movement of simulated ground water between surface sources and sinks to the points of withdrawal. High K_v characteristics in the eastern portion of the basin enable simulated recharge from the Boise River to move vertically downward through the system. As with the base simulation, interpolated parameter characteristics along the model boundaries, especially in areas of few observations, may be uncertain. These simulations represent equilibrium conditions. The time to reach this equilibrium cannot be estimated with a steady-state model.

These simulations included only additional ground water withdrawals associated with non-supplemental withdrawals. Processing permits for supplemental withdrawals would increase the total ground water extraction and would increase the year-to-year variability of the extraction. Increased withdrawals could exacerbate the predicted declines associated with the non-supplemental extraction.

What do these predictions mean for water managers? First, predicted water level declines based on the comparisons between base and predictive simulations reflect both calibration and stress changes. Additional simulations should be conducted to compare minimized base water levels with predicted water levels. These simulations may reduce the area and magnitude of predicted declines. Second, additional withdrawal increases might be considered in areas of stable water levels, even if predictions suggest possible water level decreases. Increases in withdrawals should be accompanied by monitoring of water levels and extraction rates. Third, continued monitoring is warranted in areas experiencing substantially decreased water levels and predicted water level declines. Finally, model predictions for some areas (some shallow aquifers, for instance) indicate that additional withdrawals are probably possible without affecting ground water levels. Additional ground water withdrawals might be considered in these areas. However, additional extractions in these areas may increase losses from, or decrease discharge to, surface water channels.

4. CONCLUSIONS AND RECOMMENDATIONS

Results from these simulations of increased aquifer stresses associated with currently unprocessed, non-supplemental ground water right applications in the Treasure Valley aquifer system suggest that:

1. Aquifer level declines may occur if all of these currently unprocessed, non-supplemental ground water rights were granted.
2. Average water level declines would vary, depending on location within the valley, the actual amount of withdrawals, and the depth of extraction.
3. Local areas of simulated declines were noted south of Lake Lowell, in an area in the northwestern portion of the model, and in portions of an area between Boise, Meridian, and Kuna. These may be associated with unrealistically high simulated stresses or excessively low simulated aquifer parameter values. The simulated declines also may indicate potential problems in supplying the increasing ground water demands in these areas.
4. The least declines were predicted in the uppermost model layer, which corresponds roughly with the uppermost 200 feet of aquifer. Approximately 82% of the estimated new withdrawals in the uppermost layer represented water that would otherwise have discharged to drains.

Recommendations include the following:

1. Simulate the maximum and minimum hydraulic head predictions with no changes in model stresses from the base simulation. Use these values for comparisons with scenario predictions.
2. Quantify the increased withdrawals associated with new applications for supplemental water.
3. Conduct additional simulations that include additional withdrawals associated with supplemental withdrawals.
4. Review specific water rights requests that are predicted to result in greater-than average local drawdowns.
5. Consider additional simulations with lower PD0 values (a PEST parameter) in an attempt to tighten the range between minimum and maximum predicted head elevations.
6. Conduct additional simulations increasing the amount of new withdrawals in specific portions of the basin to help identify areas that may be able to sustain additional withdrawals.
7. Identify potential water right applications may have predicted impact on existing water rights, and conduct additional simulations to assess the cumulative predicted impact of approving these applications.
8. Continue to collect data that will result in improvement of the predictive capabilities of this model.

5. REFERENCES

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Appendix A: Conversion Factors

Volume

1 cubic foot of water = 7.4805 gallons = 62.37 pounds of water
1 acre-foot = enough water to cover 1 acre of land 1 foot deep
1 acre-foot = 43,560 cubic feet
1 acre-foot = 325,850 gallons
1 million gallons = 3.0689 acre-feet

Flow Rates

1 cubic foot per second = 448.83 gallons per minute = 26,930 gallons per hour
1 cubic foot per second = 646,635 gallons per day = 1.935 acre-feet per day
1 cubic foot per second for 30 days = 59.502 acre-feet
1 cubic foot per second for 1 year = 723.94 acre-feet
1 cubic meter per second = 25.31 cubic feet per second
1 cubic meter per second = 15,850 gallons per minute
1 million gallons per day = 1,120.147 acre-feet per year
1 miner's inch = 9 gallons per minute
1 miner's inch = 0.02 cubic feet per second

Hydraulic Conductivity

1 gallon per day per foot^2 = 0.134 foot/day = 0.0408 meters/day

Economic

$0.10 per 1,000 gallons = $32.59 per acre-foot

Appendix B: Summary of Permit Applications

This appendix summarizes increased withdrawals represented by unprocessed water right applications for non-supplemental ground water (for the period between July 9, 1987 and February 19, 2002). Further explanation of estimated extraction levels is provided in Section 2.1.

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft^3/s)	Total Estimated Extraction (af/yr)	Water Use List
ID number	Sequence number used by IDWR for tracking permit applicaitons	Priority date of permit application	Model row	Model column	Target depth	Assigned model layer; based on anticipated depth listed in application. Applications for which no depths were listed (i.e., "none") were assigned to a model layer proportionately to those for which anticipated depths were listed.	Northing (Universal Transverse Mercatur) (feet)	Easting (Universal Transverse Mercatur) (feet)	Requested diversion listed in the permit application	Estimated rate (see text)	Type of use

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft^3/s)	Total Estimated Extraction (af/yr)	Water Use List
1	11638	2/5/92	19	40	102	1	1817504.7	15845684	0.14	17.5	IRRIGATION
2	11666	2/19/92	11	34	80	1	1788413.9	15883817	0.19	12.5	DOMESTIC, IRRIGATION
3	11706	2/13/92	14	35	170	2	1791525.7	15867857	0.2	25	DOMESTIC, IRRIGATION, RECREATION, RECREATION STORAGE
4	11748	4/2/92	17	27	150	1	1750250.4	15854560	1.6	200	IRRIGATION
5	11754	4/6/92	24	21	400	1	1716091.5	15815695	1.48	185	IRRIGATION
6	11755	4/6/92	24	34	200	1	1788759.1	15816266	3.48	435	IRRIGATION
7	11764	4/8/92	24	26	100	1	1743993.7	15816752	0.07	2.5	DOMESTIC, INDUSTRIAL, IRRIGATION
8	11769	4/14/92	23	35	250	1	1791345.9	15822904	1.4	175	IRRIGATION
9	11775	4/8/92	16	38	U	none	1806805.7	15858800	0.06	5	DOMESTIC, IRRIGATION
10	11778	4/17/92	35	28	308	1	1754717	15757782	2	255	IRRIGATION
11	11780	4/17/92	17	35	100	1	1795114.8	15854733	0.69	86.25	IRRIGATION
12	11784	4/23/92	37	29	200	1	1760535.4	15750102	0.68	85	IRRIGATION
13	11791	4/21/92	15	42	15	1	1828021.2	15862840	0.2	0.2	AESTHETIC, AESTHETIC STORAGE, DIVERSION TO STORAGE
14	11803	4/29/92	21	18	400	1	1701572.2	15833831	1.5	270	IRRIGATION
15	11803	4/29/92	21	18	400	1	1700246.5	15833826	1.5	270	IRRIGATION
16	11803	4/29/92	21	18	400	1	1700256.3	15831191	1.5	270	IRRIGATION
17	11803	4/29/92	21	18	400	1	1701576.9	15832511	1.5	270	IRRIGATION
18	11809	5/7/92	16	17	175	1	1696167.4	15859256	1.2	150	IRRIGATION
19	11811	5/7/92	20	46	100-200	4	1849547.7	15839118	0.15	12.5	IRRIGATION
20	11824	5/13/92	11	23	100	1	1731780.7	15883449	0.19	12.5	DOMESTIC, IRRIGATION
21	11826	5/14/92	19	21	300	1	1718645.4	15842147	1.58	197.5	IRRIGATION
22	11826	5/14/92	20	21	300	1	1718648.8	15840820	1.58	197.5	IRRIGATION
23	11827	5/14/92	18	20	300	1	1713268.9	15850139	1.64	205	IRRIGATION
24	11828	5/14/92	10	13	300	2	1678961.1	15893488	1.6	200	IRRIGATION
25	11830	5/14/92	36	31	400	1	1769293.4	15755170	2	285	IRRIGATION
26	11830	5/14/92	35	30	400	1	1766617.6	15759128	2	285	IRRIGATION
27	11834	5/18/92	31	31	200	1	1771774.3	15782978	2.4	300	IRRIGATION
28	11836	5/21/92	14	10	500	2	1661965.4	15868280	1.6	200	IRRIGATION
29	11849	6/8/92	22	39	90	1	1813678.8	15828395	0.09	7.5	IRRIGATION
30	11862	6/12/92	36	30	300	1	1766645.4	15755164	0.03	2.5	IRRIGATION
31	11864	6/15/92	22	39	100	1	1813678.8	15828395	0.09	7.5	IRRIGATION
32	11865	6/15/92	26	22	330	1	1721412.3	15807809	2	400	IRRIGATION
33	11869	6/18/92	12	40	U	none	1821290.2	15881350	0.1	6.25	IRRIGATION, STOCKWATER

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft^3/s)	Total Estimated Extraction (af/yr)	Water Use List
34	11900	5/4/92	15	39	U	none	1813431.6	15867384	0	0	AESTHETIC STORAGE
35	11900	5/4/92	14	39	U	none	1814084.6	15868685	0	0	AESTHETIC STORAGE
36	11900	5/4/92	15	39	U	none	1812099.9	15866785	0	0	AESTHETIC STORAGE
37	11900	5/4/92	14	39	U	none	1812101.2	15868344	0	0	AESTHETIC STORAGE
38	11900	5/4/92	14	39	U	none	1812099.7	15869609	0	0	AESTHETIC STORAGE
39	11900	5/4/92	15	39	U	none	1813430.7	15865338	0	0	AESTHETIC STORAGE
40	11900	5/4/92	15	39	U	none	1814760.3	15865335	0	0	AESTHETIC STORAGE
41	11900	5/4/92	15	39	U	none	1812099.7	15865316	0	0	AESTHETIC STORAGE
42	11912	8/7/92	12	30	300	2	1768786.5	15881077	1.2	150	IRRIGATION
43	11935	8/10/92	12	23	78	1	1727805.8	15882062	0.03	2.5	IRRIGATION
44	11947	10/26/92	26	37	300	1	1803248.8	15808358	3.1	387.5	IRRIGATION
45	11965	12/1/92	25	39	400	2	1811162.5	15813736	3	391	IRRIGATION
46	12058	8/31/93	11	38	171	1	1809307	15885182	0.12	10	DOMESTIC, IRRIGATION, STOCKWATER
47	12071	11/1/93	14	29	pond	none	1763430.3	15867784	3.6	450	IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE
48	12071	11/1/93	14	29	pond	none	1759479.4	15868125	3.6	450	IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE
49	12090	12/17/93	5	16	700	3	1690665.1	15918740	3.55	435	DOMESTIC, IRRIGATION, STOCKWATER
50	12090	12/17/93	6	16	700	3	1690706.4	15913466	3.55	435	DOMESTIC, IRRIGATION, STOCKWATER
51	12097	1/26/94	24	39	200	1	1815091	15817790	2.3	287.5	IRRIGATION
52	12145	9/20/94	0	0	400	0	1945674.3	15922240	0.18	22.5	IRRIGATION
53	12219	6/9/95	25	43	200	1	1833796.1	15812618	2.9	362.5	IRRIGATION
54	12223	6/29/95	16	27	350	2	1750235.9	15861167	0.67	242.52893	COMMERCIAL, DOMESTIC, HEATING, STOCKWATER
55	12224	6/7/95	10	37	U	none	1803974.3	15889110	0.2	25	DOMESTIC, IRRIGATION
56	12231	7/6/95	17	47	307	1	1853441.7	15855055	0.42	52.5	IRRIGATION
57	12235	6/7/95	10	37	U	none	1803974.3	15889110	0.2	25	DOMESTIC, IRRIGATION

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft^3/s)	Total Estimated Extraction (af/yr)	Water Use List
58	12236	6/7/95	10	37	U	none	1803974.3	15889110	0.2	25	DOMESTIC, IRRIGATION
59	12236	6/7/95	10	37	U	none	1805300.8	15889124	0.2	25	DOMESTIC, IRRIGATION
60	12237	6/7/95	10	37	U	none	1805300.8	15889124	0.2	25	DOMESTIC, IRRIGATION
61	12237	6/7/95	10	37	U	none	1803974.3	15889110	0.2	25	DOMESTIC, IRRIGATION
62	12238	6/7/95	10	37	U	none	1805300.8	15889124	0.2	25	DOMESTIC, IRRIGATION
63	12239	6/7/95	10	37	U	none	1805300.8	15889124	0.2	25	DOMESTIC, IRRIGATION
64	12240	6/7/95	10	37	U	none	1803974.3	15889110	0.2	25	DOMESTIC, IRRIGATION
65	12240	6/7/95	10	37	U	none	1805300.8	15889124	0.2	25	DOMESTIC, IRRIGATION
66	12242	7/5/95	13	35	U	none	1795010.7	15875840	0.2	25	IRRIGATION
67	12243	7/11/95	4	9	300	1	1657386.3	15924037	0.2	25	IRRIGATION
68	12248	6/29/95	11	23	100	1	1727816.9	15886084	0.15	18.75	IRRIGATION
69	12249	7/19/95	17	38	180	1	1809498.8	15852187	0.1	12.5	IRRIGATION
70	12253	6/2/95	31	37	500	1	1803557.5	15780609	2.78	347.5	IRRIGATION
71	12260	7/21/95	30	40	400	1	1818022.4	15784642	3.22	403	IRRIGATION
72	12263	9/1/95	19	42	50	1	1829502.9	15843111	0.04	1.5	IRRIGATION
73	12264	7/17/95	21	43	200	1	1832222.2	15835162	0.29	35.75	IRRIGATION
74	12265	7/17/95	21	43	200	1	1833611.2	15833831	0.22	28	IRRIGATION
75	12274	9/19/95	20	47	100	1	1855275.6	15840012	0.17	3	IRRIGATION
76	12274	9/19/95	19	47	100	1	1854871.6	15841814	0.17	3	IRRIGATION
77	12276	8/28/95	13	25	100	1	1742300.3	15876921	0.14	11.5	IRRIGATION
78	12277	9/1/95	19	42	50	1	1828194.1	15841776	0.11	9.25	IRRIGATION
79	12278	7/7/95	32	32	460	1	1774434	15776395	0.4	144.79339	COMMERCIAL, STOCKWATER
80	12278	7/7/95	31	31	460	1	1773106.5	15779029	0.4	144.79339	COMMERCIAL, STOCKWATER
81	12278	7/7/95	31	32	460	1	1774426.8	15779045	0.4	144.79339	COMMERCIAL, STOCKWATER
82	12278	7/7/95	32	31	460	1	1770507.3	15777677	0.4	144.79339	COMMERCIAL, STOCKWATER
83	12278	7/7/95	32	31	460	1	1773110.6	15777704	0.4	144.79339	COMMERCIAL, STOCKWATER
84	12279	8/18/95	28	28	250	1	1754586.5	15796172	0.39	49	IRRIGATION, STOCKWATER
85	12288	10/27/95	14	28	140	2	1755537.7	15871776	0.06	5	IRRIGATION
86	12293	11/6/95	17	39	150	1	1816104.9	15856241	0.32	40.5	IRRIGATION
87	12294	11/6/95	20	32	125	1	1774098.1	15836150	0.07	2.5	DOMESTIC, IRRIGATION
88	12299	11/29/95	10	27	154	1	1752878.5	15891511	0.09	7.5	IRRIGATION
89	12303	12/26/95	16	36	U	none	1796423.5	15857380	0.08	12.5	IRRIGATION, STOCKWATER
90	12309	1/3/96	11	37	124	1	1802674	15886462	0.19	12.5	DOMESTIC, IRRIGATION
91	12320	2/13/96	3	10	300	1	1658732.5	15930522	0.4	50	IRRIGATION

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92	12321	2/13/96	3	10	300	1	1658739.2	15927883	0.9	112.5	COMMERCIAL, IRRIGATION, STOCKWATER
93	12327	2/26/96	20	37	100	1	1802983.4	15837556	0.06	5	IRRIGATION
94	12328	2/26/96	20	37	100	1	1801770.9	15836205	0.15	12.5	IRRIGATION
95	12331	4/10/96	6	23	345	2	1727685.5	15913553	0.2	42.5	IRRIGATION
96	12333	4/4/96	31	42	400	1	1831339.3	15779386	1.96	245	IRRIGATION
97	12371	11/21/96	0	0	218	0	1662639.8	15959781	0.14	12.5	DOMESTIC, IRRIGATION, STOCKWATER
98	12372	11/29/96	12	31	U	none	1770037.7	15882412	0.06	5	IRRIGATION
99	12373	12/4/96	10	42	400	1	1827738.5	15890662	0.2	25	IRRIGATION
100	12392	4/11/97	21	42	100	1	1830927	15832500	0.1	36.198347	DOMESTIC
101	12408	8/25/97	7	15	400	1	1685343.6	15905513	1.64	200	DOMESTIC, IRRIGATION
102	12418	9/12/97	20	16	U	none	1690961.5	15840427	0.58	50	DOMESTIC, IRRIGATION, STOCKWATER
103	12419	9/18/97	26	24	245	1	1735969.4	15807999	0.04	5	IRRIGATION
104	12421	10/24/97	33	37	440	1	1804939.9	15769971	3	400	DOMESTIC, IRRIGATION, STOCKWATER
105	12426	11/12/97	10	42	250	1	1829079.8	15889347	0.14	12.5	DOMESTIC, IRRIGATION
106	12429	1/8/98	10	38	235	1	1807946.5	15889149	0.12	10	IRRIGATION
107	12433	1/14/98	28	41	320	1	1825852.8	15796648	1	115	DOMESTIC, IRRIGATION, STOCKWATER
108	12435	1/20/98	19	26	100	1	1743715.2	15843910	0.05	18.099174	INDUSTRIAL
109	12439	2/11/98	10	43	130	1	1834507.1	15889335	0.19	23.75	IRRIGATION
110	12441	4/17/98	7	26	U	none	1743521.5	15908606	1.6	200	IRRIGATION
111	12459	3/11/98	14	36	U	none	1796343.8	15871889	0.004	1.4479339	AESTHETIC STORAGE, DIVERSION TO STORAGE, RECREATION STORAGE
112	12459	3/11/98	14	36	U	none	1796348.7	15870619	0.004	1.4479339	AESTHETIC STORAGE, DIVERSION TO STORAGE, RECREATION STORAGE
113	12475	9/24/98	22	29	83	1	1762395.6	15828140	0.01	1.25	IRRIGATION
114	12486	9/14/98	12	40	216	1	1821263.3	15882664	0.08	10	IRRIGATION
115	12487	8/28/98	26	34	120	1	1784863.1	15808289	0.1	15	IRRIGATION
116	12489	10/2/98	21	20	160	1	1712049	15835377	0.28	101.35537	COMMERCIAL
117	12490	9/30/98	25	42	299	1	1829758.4	15809953	0.34	37.5	DOMESTIC, IRRIGATION
118	12503	12/29/98	3	22	200	1	1726291.8	15929383	3.2	400	IRRIGATION
119	12503	12/29/98	3	22	200	1	1724965.7	15929377	3.2	400	IRRIGATION
120	12503	12/29/98	3	22	200	1	1724972.2	15928059	3.2	400	IRRIGATION

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121	12503	12/29/98	3	22	200	1	1723648.4	15928053	3.2	400	IRRIGATION
122	12520	4/23/99	28	24	200	1	1733389.1	15797362	0.2	25	IRRIGATION
123	12524	4/30/99	19	29	185	1	1759591.7	15845345	0.07	2.5	DOMESTIC, IRRIGATION
124	12541	4/15/99	31	43	400	1	1832652	15780715	0.02	7.2396694	INDUSTRIAL
125	12541	4/15/99	31	43	400	1	1832659.3	15779385	0.02	7.2396694	INDUSTRIAL
126	12542	3/24/99	20	31	U	none	1770177.4	15837452	0.069	24.97686	STOCKWATER
127	12563	1/13/00	7	20	U	none	1713229.8	15907202	0.36	45	IRRIGATION
128	12571	2/2/00	7	25	500	3	1739581.3	15907254	1.6	200	IRRIGATION
129	12592	7/14/00	25	43	U	none	1835184	15809947	0.19	12.5	DOMESTIC, IRRIGATION
130	31192	3/1/01	6	20	250	2	1715792.1	15914821	2	300	IRRIGATION
131	31256	6/7/01	7	13	400	2	1676098.6	15908106	0.3	37.5	IRRIGATION
132	31256	6/7/01	7	13	400	2	1676098.6	15908106	0.3	37.5	IRRIGATION
133	31271	4/10/98	28	28	260	1	1755902	15798823	0.15	8.75	DOMESTIC, IRRIGATION, STOCKWATER
134	31325	10/1/01	21	42	250	1	1830927	15832500	0.24	30	IRRIGATION
135	31325	10/1/01	21	43	250	1	1832237.4	15833836	0.24	30	IRRIGATION
136	31327	10/1/01	20	42	168	1	1828232.7	15837793	0.14	17.5	IRRIGATION
137	31406	1/18/02	20	42	320	2	1826906.7	15837785	2	723.96694	MUNICIPAL
138	31407	1/18/02	23	51	200	1	1877335.3	15822022	2	723.96694	MUNICIPAL
139	31408	2/6/02	11	40	200	1	1819891	15885320	0	0	AESTHETIC STORAGE, DIVERSION TO STORAGE, STOCKWATER STORAGE
140	31415	12/16/99	14	36	LAKE	none	1800312.1	15871938	0	0	AESTHETIC STORAGE, WILDLIFE STORAGE
141	31415	12/16/99	14	36	LAKE	none	1800312.1	15871938	0	0	AESTHETIC STORAGE, WILDLIFE STORAGE
142	11677	2/10/92	21	16	0	none	1693643.9	15832491	1.28	160	IRRIGATION
143	11686	3/4/92	17	11	0	none	1663346.6	15852308	1.6	200	IRRIGATION
144	11694	3/6/92	28	27	0	none	1751935.4	15798807	1.56	195	IRRIGATION
145	11716	3/13/92	29	39	0	none	1812619.9	15791205	1.6	442.5	IRRIGATION
146	11718	3/17/92	20	25	0	none	1737195	15838558	0.72	90	IRRIGATION
147	11741	5/22/92	31	28	0	none	1755952.9	15780288	2.3	287.5	IRRIGATION
148	11747	4/2/92	16	11	0	none	1667278.6	15860317	0.98	197.5	IRRIGATION
149	11756	3/18/92	13	7	0	none	1646040.9	15873565	3.7	559.5	IRRIGATION
150	11761	4/7/92	21	19	0	none	1708080.4	15833960	1	127.75	IRRIGATION
151	11761	4/7/92	21	19	0	none	1706817.1	15833932	1	127.75	IRRIGATION
152	11763	4/8/92	20	34	0	none	1784668	15836143	3	500	IRRIGATION
153	11772	4/15/92	33	28	0	none	1753341.2	15768346	2.19	385	IRRIGATION
154	11773	4/16/92	25	22		4	1724050.3	15810490	1.18	242.5	DOMESTIC, IRRIGATION

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155	11774	4/7/92	21	40	0	none	1818968.8	15832421	0.12	10	IRRIGATION
160	11783	4/10/92	24	54	0	none	1894418.3	15818180	0.3	37.5	DOMESTIC, IRRIGATION, STOCKWATER
161	11797	4/16/92	38	29	0	none	1761885.9	15740875	1.8	225	IRRIGATION
162	11799	4/20/92	25	32	0	none	1776926.6	15809612	0.06	2.5	DOMESTIC, IRRIGATION
163	11802	4/29/92	20	16	0	none	1693595	15840429	0.52	65	IRRIGATION
164	11835	5/20/92	17	28	0	none	1754229.5	15853259	0.7	87.5	IRRIGATION
165	11848	5/21/92	20	29	0	none	1759655.4	15837401	0.09	7.5	IRRIGATION
166	11860	6/11/92	20	34	0	none	1785983	15837475	2	257.5	IRRIGATION
167	11866	6/16/92	14	9	0	none	1656659.7	15870926	2.2	375	IRRIGATION
168	11866	6/16/92	14	10	0	none	1657990.8	15868258	2.2	375	IRRIGATION
169	11870	6/18/92	37	28	0	none	1757912.8	15748782	0.8	100	IRRIGATION
170	11874	6/25/92	23	39	0	none	1811086.9	15820408	0.72	90	IRRIGATION
171	11874	6/25/92	24	39	0	none	1812427.9	15819087	0.72	90	IRRIGATION
172	11874	6/25/92	23	39	0	none	1812413.6	15820422	0.72	90	IRRIGATION
173	11875	6/2/92	19	18	0	none	1701537	15841764	0.7	208	IRRIGATION
174	11876	6/12/92	12	19	0	none	1706629.9	15883405	1.66	207.5	IRRIGATION
175	11885	6/24/92	23	18	0	none	1701618.2	15821971	0.19	12.5	DOMESTIC, IRRIGATION
176	11891	6/3/92	17	15	0	none	1688309.4	15853825	2	250	IRRIGATION
177	11892	6/29/92	7	11	0	none	1663245.2	15906654	3.2	402.5	IRRIGATION
178	11907	7/20/92	12	31	0	none	1773935.5	15878425	1.6	200	IRRIGATION
179	11910	8/4/92	20	41	0	none	1824228.9	15839097	0.06	2.5	DOMESTIC, IRRIGATION
180	11911	8/10/92	23	25	0	none	1737243.6	15822663	1.3	162.5	IRRIGATION
181	11933	9/28/92	12	18	0	none	1705285	15883053	3	402.5	IRRIGATION
182	11962	11/13/92	34	30	0	none	1765268.1	15765734	0.72	90	IRRIGATION
183	11971	12/16/92	22	30	0	none	1766396.4	15825506	3.48	435	IRRIGATION
184	11984	12/28/92	11	37	0	none	1805310	15887797	0.11	14	IRRIGATION
185	12001	3/5/93	31	40	0	none	1816810.8	15778010	0.24	30	IRRIGATION
186	12007	4/14/93	25	22	0	none	1725374.3	15810503	3.4	400	IRRIGATION, STOCKWATER
187	12007	4/14/93	26	22	0	none	1725380	15809175	3.4	400	IRRIGATION, STOCKWATER
188	12070	10/28/93	26	42	0	none	1831100.8	15808629	0.64	75	DIVERSION TO STORAGE, DOMESTIC, IRRIGATION, STOCKWATER STORAGE, WILDLIFE STORAGE

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189	12070	10/28/93	26	43	0	none	1832434.9	15808633	0.64	75	DIVERSION TO STORAGE, DOMESTIC, IRRIGATION, STOCKWATER STORAGE, WILDLIFE STORAGE
190	12075	11/4/93	28	40	0	none	1817919.2	15793907	0.2	25	IRRIGATION
191	12089	11/23/93	10	38	0	none	1809267.8	15889160	0.15	12.5	IRRIGATION
192	12096	1/4/94	17	30	0	none	1766175.2	15854647	2	723.96694	AESTHETIC, AESTHETIC STORAGE, DOMESTIC
193	12108	3/22/94	15	35	0	none	1793761.7	15862661	0.13	7.5	DOMESTIC, IRRIGATION
194	12114	6/2/94	22	51	0	none	1876045.1	15825954	0.14	17.5	DIVERSION TO STORAGE, IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE
195	12115	5/27/94	26	39	0	none	1813868.7	15804453	0.03	2.5	IRRIGATION
196	12142	8/2/94	15	35	0	none	1795073.7	15864150	4.87	87.5	DOMESTIC, FIRE PROTECTION, IRRIGATION
197	12142	8/2/94	15	35	0	none	1791120.4	15863956	4.87	87.5	DOMESTIC, FIRE PROTECTION, IRRIGATION
198	12142	8/2/94	16	35	0	none	1792454	15861329	4.87	87.5	DOMESTIC, FIRE PROTECTION, IRRIGATION
199	12150	10/7/94	3	37	0	none	1805220.1	15927152	0.94	112.5	DOMESTIC, IRRIGATION, STOCKWATER
200	12156	10/27/94	16	12	0	none	1671244.1	15861671	0.52	60	DOMESTIC, IRRIGATION, STOCKWATER
201	12177	3/2/95	26	32	0	none	1775639.2	15805628	0.96	120	IRRIGATION
202	12187	3/8/95	15	35	0	none	1791120.4	15863956	2.98	372.5	AESTHETIC STORAGE, IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE

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203	12190	4/6/95	3	18	0	none	1701249.2	15926690	0.66	75	DIVERSION TO STORAGE, DOMESTIC, IRRIGATION, WILDLIFE, WILDLIFE STORAGE
204	12194	4/5/95	12	31	0	none	1771303.6	15881078	0.2	25	IRRIGATION
205	12204	4/26/95	10	38	0	none	1806625.2	15889136	0.12	10	IRRIGATION
206	12222	6/27/95	15	15	0	none	1688214.6	15864468	0.06	5	IRRIGATION
208	12498	10/7/98	28	33	0	none	1779682.5	15794982	0.4	144.79339	COMMERCIAL, STOCKWATER
209	12525	2/24/99	11	32	0	none	1775250.9	15883782	0.2	25	IRRIGATION
210	12526	2/24/99	11	32	0	none	1775250.9	15883782	0.2	25	IRRIGATION
211	12527	2/24/99	11	32	0	none	1775250.9	15883782	0.2	27.5	IRRIGATION
212	12528	2/24/99	11	32	0	none	1775243.6	15885115	0.2	25	IRRIGATION
213	12529	2/24/99	11	32	0	none	1775243.6	15885115	0.2	25	IRRIGATION
214	12531	2/24/99	11	32	0	none	1775243.6	15885115	0.2	25	IRRIGATION
215	10960	9/7/89	25	34	50	1	1787502.6	15809633	0.8	100	IRRIGATION, STOCKWATER
216	11645	2/10/92	17	17	U	none	1697518.7	15855294	0.2	20	DOMESTIC, IRRIGATION
217	11998	2/26/93	29	40	300	1	1817945.4	15789943	0.7	87.5	IRRIGATION
218	12050	8/31/93	8	20	250	1	1714566.9	15901928	0.42	52.5	IRRIGATION
219	12105	3/4/94	13	24	120	1	1737095.7	15875538	0.56	202.71074	COMMERCIAL
220	12153	10/24/94	0	0	75	0	1941771.2	15920929	0.4	50	IRRIGATION
221	12160	11/2/94	10	35	U	none	1791028.6	15889097	0.12	10	IRRIGATION
222	12161	11/21/94	19	18	100	1	1701530.5	15843090	1	200	IRRIGATION
223	12166	12/19/94	19	33	139	1	1783294.9	15845422	0.16	10	DOMESTIC, IRRIGATION
224	12169	1/20/95	7	22	300	2	1722463.9	15907193	1.3	162.5	IRRIGATION
225	12188	4/4/95	15	11	300	1	1663303.2	15862953	0.54	50	COMMERCIAL, DOMESTIC
226	12206	5/5/95	28	41	300	1	1824549	15795302	0.2	25	IRRIGATION
227	12207	5/8/95	28	34	250	1	1784955	15796349	2.76	345	IRRIGATION
228	12208	5/11/95	20	49	U	none	1864141.2	15840547	1.62	200	DOMESTIC, IRRIGATION
229	12210	5/19/95	21	26	15	1	1745128.1	15832006	0.03	2.5	IRRIGATION
230	12211	5/11/95	28	37	300	1	1804657.9	15797783	1.8	225	IRRIGATION
231	12212	5/23/95	22	39	140	1	1812359	15827066	0.05	2.25	DOMESTIC, IRRIGATION
232	12214	5/9/95	25	22	U	none	1725374.3	15810503	0.54	67.5	DOMESTIC, IRRIGATION
233	12220	6/13/95	19	38	200	1	1806890.4	15845590	0.2	62.5	IRRIGATION
234	12226	7/3/95	8	18	200	1	1701189.2	15900257	0.2	25	DOMESTIC, IRRIGATION, STOCKWATER
235	12227	7/5/95	11	40	100	1	1821235.5	15884001	0.7	87.5	IRRIGATION
236	12233	7/10/95	17	17	U	none	1697518.7	15855294	0.1	7.5	DOMESTIC, IRRIGATION, STOCKWATER

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (af/yr)	Water Use List
237	12241	7/14/95	33	31	300	1	1773149.8	15768438	0.2	20	DOMESTIC, IRRIGATION, STOCKWATER
238	12245	9/14/95	23	33	300	1	1783433.9	15824204	0.17	12.5	IRRIGATION, STOCKWATER
239	12246	7/21/95	7	21	500	3	1717188.1	15907196	0.16	10	DOMESTIC, IRRIGATION
240	12252	8/3/95	10	27	200	1	1750226.5	15892818	0.14	12.5	DOMESTIC, IRRIGATION
241	12262	8/22/95	10	38	280	1	1810589.2	15889173	0.1	12.5	IRRIGATION
242	12269	8/28/95	26	22	600	2	1721416.6	15806483	2	492.5	IRRIGATION
243	12270	9/7/95	20	50	400	1	1870541.3	15840535	0.16	150	DOMESTIC, IRRIGATION
244	12280	10/10/95	28	41	500	2	1823227	15795288	0.2	25	IRRIGATION
245	12282	8/28/95	12	40	U	none	1819939.9	15882651	0.34	42.5	DOMESTIC, IRRIGATION, STOCKWATER
246	12283	10/17/95	8	20	200	1	1714563.1	15903245	0.62	77.5	IRRIGATION
247	12285	10/30/95	25	42	U	none	1829750.1	15811282	0.44	50	DOMESTIC, IRRIGATION
248	12286	10/30/95	25	42	U	none	1829758.4	15809953	0.24	25	DOMESTIC, IRRIGATION
249	12287	10/30/95	26	42	U	none	1829766.7	15808624	0.24	25	DOMESTIC, IRRIGATION
250	12289	11/1/95	31	40	350	1	1818135.4	15779344	0.2	25	DOMESTIC, IRRIGATION
251	12291	11/2/95	28	28	300	1	1755902	15798823	0.16	10	DOMESTIC, IRRIGATION
252	12302	1/5/96	16	37	130	1	1804177.9	15857441	0.08	10	IRRIGATION
253	12306	1/18/96	0	0	U	0	1943075.6	15920925	0.14	17.5	IRRIGATION
254	12313	1/30/96	1	11	200	1	1664007.1	15937160	0.8	100	IRRIGATION
255	12337	5/10/96	32	40	U	none	1816812.5	15776685	0.28	30	DOMESTIC, IRRIGATION, STOCKWATER
256	12341	6/13/96	10	38	32	1	1810589.2	15889173	0.1	5	DOMESTIC, IRRIGATION
257	12357	8/16/96	22	16	150	1	1691014.2	15828554	0.12	10	IRRIGATION
258	12404	7/29/97	26	22	350	1	1725390.3	15806523	0.82	100	DOMESTIC, IRRIGATION
259	12473	10/2/98	8	24	314	2	1734353.5	15903269	0.15	12.5	IRRIGATION
260	12522	5/17/99	11	38	350	2	1806633.8	15887804	0.09	7.5	DIVERSION TO STORAGE, IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE, RECREATION STORAGE

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (af/yr)	Water Use List
261	11460	2/25/91	16	24	0	none	1734399.5	15860993	2.96	370	IRRIGATION
262	11661	2/13/92	19	35	0	none	1791230.5	15845441	0.4	50	IRRIGATION
263	11808	5/5/92	26	37	0	none	1800734.6	15804376	1.6	200	IRRIGATION
264	11810	5/7/92	12	36	0	none	1800294.5	15881176	3.34	417.5	IRRIGATION
265	11872	6/19/92	14	39	0	none	1814752.6	15872099	0.93	200	IRRIGATION
266	11937	10/1/92	14	12	0	none	1672562.8	15868318	2.4	300	IRRIGATION
267	11966	12/11/92	0	0	replaced with 67-7322	0	1625932.6	16079740	0.42	52.5	IRRIGATION
268	11976	1/19/93	26	21	0	none	1720094	15806466	1.6	200	IRRIGATION
269	11996	2/25/93	6	34	0	none	1788237.8	15912731	2	407.5	IRRIGATION
270	11999	3/19/93	21	40	0	none	1818957	15833749	0.14	11.25	IRRIGATION
271	12015	4/16/93	12	39	0	none	1811995.7	15882569	0.09	3.75	DOMESTIC, IRRIGATION, STOCKWATER
272	12020	5/21/93	20	37	0	none	1801770.5	15838855	0.44	50	DOMESTIC, IRRIGATION
273	12020	5/21/93	20	37	0	none	1802981.1	15838881	0.44	50	DOMESTIC, IRRIGATION
274	12021	5/21/93	11	38	0	none	1810613.3	15886512	0.12	12.5	IRRIGATION, STOCKWATER
275	12027	6/14/93	17	13	0	none	1677739	15852467	0.7	87.5	IRRIGATION
276	12028	6/15/93	17	38	0	none	1809498.8	15852187	0.09	7.5	AESTHETIC, AESTHETIC STORAGE, DIVERSION TO STORAGE, DOMESTIC, IRRIGATION
277	12091	12/30/93	9	27	0	none	1748898.1	15894139	0.09	21.5	DOMESTIC, IRRIGATION, STOCKWATER
278	12094	1/21/94	25	44	0	none	1837818	15812566	0.12	12.5	DOMESTIC, IRRIGATION
279	12129	6/24/94	12	31	0	none	1770037.7	15882412	0.1	12	DOMESTIC, IRRIGATION
280	12130	6/6/94	12	31	0	none	1770037.7	15882412	0.11	14	DOMESTIC, IRRIGATION
281	12148	10/3/94	12	39	0	none	1813395.1	15878663	0.1	5	DOMESTIC, IRRIGATION
282	12154	10/14/94	12	39	0	none	1813368.6	15879979	0.07	3.25	DOMESTIC, IRRIGATION
283	12165	12/16/94	21	35	0	none	1793956.6	15830863	0.13	17.5	DIVERSION TO STORAGE, IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE
284	12182	2/28/95	22	56	0	none	1902105.1	15830171	0.09	11.25	IRRIGATION

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (af/yr)	Water Use List
285	12205	4/3/95	8	22	0	none	1725121.3	15903238	0.4	50	DIVERSION TO STORAGE, IRRIGATION, IRRIGATION FROM STORAGE, IRRIGATION STORAGE
286	12228	7/6/95	14	40	0	none	1821379.6	15870852	0.19	2.5	COMMERCIAL, IRRIGATION
287	12425	12/16/97	19	38	0	none	1810854.7	15842995	0.3	52.5	AESTHETIC, AESTHETIC STORAGE, DIVERSION TO STORAGE, IRRIGATION
288	12448	4/8/98	12	40	0	none	1817363.8	15878701	1	361.98347	MUNICIPAL
289	12448	4/8/98	13	40	0	none	1817392.3	15877391	1	361.98347	MUNICIPAL
290	12448	4/8/98	13	39	0	none	1812101.6	15877332	1	361.98347	MUNICIPAL
291	12448	4/8/98	12	39	0	none	1816037.3	15878689	1	361.98347	MUNICIPAL
292	12448	4/8/98	13	38	0	none	1808116.9	15877314	1	361.98347	MUNICIPAL
293	12450	5/4/98	6	34	0	none	1788237.8	15912731	2.16	895	DIVERSION TO STORAGE, IRRIGATION, RECREATION STORAGE, WILDLIFE STORAGE
294	12530	2/24/99	11	32	0	none	1775243.6	15885115	0.2	25	IRRIGATION
295	12555	11/15/99	16	22	0	none	1726446.1	15862201	0.12	15	IRRIGATION
296	31134	1/12/01	15	32	0	none	1779294	15863930	0	0	AESTHETIC STORAGE
297	31135	1/12/01	15	32	0	none	1779278.9	15866791	0	0	AESTHETIC STORAGE
298	31135	1/12/01	15	32	0	none	1779286.7	15865258	0	0	AESTHETIC STORAGE
299	31136	1/12/01	15	32	0	none	1779278.9	15866791	0	0	AESTHETIC STORAGE
300	31145	1/25/01	7	22	0	none	1722463.9	15907193	4	500	IRRIGATION
301	31177	3/29/01	3	18	0	none	1702571.3	15928017	3.96	495	IRRIGATION
302	31178	3/29/01	3	20	0	none	1711787.3	15926688	2.42	302.5	IRRIGATION
303	31207	3/28/01	14	26	0	none	1744929.6	15869020	0.477	172.66612	DOMESTIC, INDUSTRIAL
304	31208	4/20/95	6	23	0	none	1727733.6	15912356	0.1	12.5	IRRIGATION
305	31276	4/6/01	12	28	0	none	1754248.7	15878330	0	0	DOMESTIC
306	31276	4/6/01	12	28	0	none	1754248.7	15878330	0	0	DOMESTIC
307	31311	8/17/01	0	0	0	0	2068656.4	15776857	0.004	1.4479339	COMMERCIAL, DOMESTIC
308	31315	9/17/01	14	36	0	none	1798992.1	15871923	0.5	180.99174	COMMERCIAL, COOLING, HEATING

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft^3/s)	Total Estimated Extraction (af/yr)	Water Use List
311	31355	11/7/01	29	33	0	none	1779686.9	15792323	0	0	COMMERCIAL, DOMESTIC, STOCKWATER
312	31378	11/30/01	11	40	0	none	1821235.5	15884001	0.12	10	IRRIGATION
313	31394	1/4/02	29	29	0	none	1758558.3	15793544	1.34	167.5	IRRIGATION
314	31416	2/8/02	16	34	0	none	1789821.6	15861315	0.001	0.3619835	DIVERSION TO STORAGE, FIRE PROTECTION, FIRE PROTECTION STORAGE
318	31423	1/15/02	31	23	0	none	1726832.4	15781476	2	723.96694	COMMERCIAL, STOCKWATER
319	31423	1/15/02	31	22	0	none	1725509	15781471	2	723.96694	COMMERCIAL, STOCKWATER
320	31430	2/14/02	18	27	0	none	1751625.6	15849268	0.039	14.117355	DOMESTIC
321	31432	2/19/02	0	0	0	0	1948271.5	15920964	0.004	1.4479339	COMMERCIAL

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33D

CHARACTERIZATION OF GROUND WATER FLOW IN THE LOWER BOISE RIVER BASIN

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- Dr. David Tuthill (IDWR)
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EXECUTIVE SUMMARY

The Treasure Valley Hydrologic Project (TVHP) was a multi-year study to develop a better understanding of ground water resources in the lower Boise River basin (Treasure Valley) of southwestern Idaho. This report presents, as part of the TVHP, a summary of hydrologic conditions in the Treasure Valley aquifer system. The report describes (1) Treasure Valley aquifer characteristics, (2) multi-level ground water monitoring wells installed as part of the TVHP, (3) results from water level measurements, and (5) aquifer inflows and outflows. The report concludes with a description of ground water flow in Treasure Valley aquifers. This conceptual model of ground water flow forms the basis for a series of numerical simulations (Petrich, 2004a; Petrich, 2004b) conducted as part of the TVHP.

The Treasure Valley aquifer system resides in a complex series of interbedded, tilted, faulted, and eroded sediments extending to depths of over 6,000 feet (Wood and Clemens, in press). These sedimentary aquifers contain shallow, local flow systems (with ground water residence times ranging from days to tens of years), and a deep, regional flow system (with residence times ranging from hundreds to tens of thousands of years). Only a few wells extend beyond a depth of 1,200 feet.

Water levels indicate general ground water movement in a westerly to southwesterly direction. Individual hydrographs indicate relatively stable water levels in many areas. Some areas, such as southeast Boise and an area south of Lake Lowell, have experienced water level declines of approximately 30 and 65 feet, respectively. A number of wells in other areas (primarily in the eastern portion of the valley) have also experienced water level declines over the last several years. These declines have generally been less than 10 feet.

The largest component of recharge to shallow aquifers is seepage from the canal system and infiltration associated with irrigated agriculture. Recharge to the deeper aquifer occurs in the eastern portion of the valley and along the Boise Front. Ground water discharge to rivers, drains, and canals represents the dominant form of discharge from the Treasure Valley aquifer system. The primary form of natural discharge from the deeper aquifers is thought to be regional upwelling in the southern and western portions of the basin, with ultimate discharge to the Boise River and/or Snake River.

Ground water residence times in the deeper, regional aquifer system were found to increase with depth and with distance along a regional east-to-west-trending flow path. Residence time estimates ranged from thousands to tens of thousands of years.

Relatively long residence times in the regional flow system (over 20,000 years) imply that (1) regional aquifers are marginally transmissive, (2) recharge rates to the deeper regional aquifers are limited, and/or (3) regional aquifers are discharge-limited. Although there are abundant silt and clay layers with low hydraulic conductivity, productive sand layers are present throughout central portions of the valley. These sand zones are tapped by many

irrigation and municipal wells. Recharge to the deeper, regional system is limited, but generally has been sufficient for current rates of withdrawal. Thick lacustrine clays at the distal end of the valley likely inhibit upward (discharge) flow, limiting the amount of water that can flow through the system.

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1. INTRODUCTION

1.1. Project Background

The lower Boise River basin of southwestern Idaho (commonly referred to as the "Treasure Valley") has experienced significant population growth, local ground water declines, and periodic drought conditions in the last two decades. This led to public concern about the status and future of water resources in the valley. The Treasure Valley Hydrologic Project (TVHP) was formed to address some of these issues and to provide a framework for future water management. The purpose of the TVHP was to develop a better understanding of ground water resources in the Treasure Valley and to evaluate changes in regional and local ground water conditions (Petrich, 2004c). The project included numerous components, including (1) water level measurements, (2) monitoring well construction, (3) water budget development, and (4) numerical modeling.

1.2. Report Scope

This report presents a summary of hydrologic conditions in the Treasure Valley aquifer system. The report includes descriptions of the (1) Treasure Valley area, (2) Treasure Valley aquifers, (3) multi-level ground water monitoring wells installed as part of the TVHP, (4) ground water levels based on well measurements, and (5) aquifer inflows and outflows. The report concludes with a description of ground water flow in Treasure Valley aquifers. This description of ground water flow forms the basis for a series of numerical simulations (Petrich, 2004a; 2004b).

This report draws, in part, from other reports and papers prepared as part of the TVHP. These include the following:

1. Geologic and Tectonic History of the Western Snake River Plain, Idaho and Oregon (Wood and Clemens, in press)
2. Water Budget for the Treasure Valley Aquifer System for the years 1996 and 2000 (Urban, 2004)
3. Simulation of Ground Water Flow in the Lower Boise River Basin (Petrich, 2004a)
4. Ground Water Recharge and Flow in the Regional Treasure Valley Aquifer System (Hutchings and Petrich, 2002a)
5. Influence of canal seepage on aquifer recharge near the New York Canal (Hutchings and Petrich, 2002b)

6. Domestic, Commercial, Municipal, and Industrial Water Demand Assessment and Forecast in Ada and Canyon Counties, Idaho (Cook et al., 2001)
7. Stratigraphic Studies of the Boise (Idaho) Aquifer System using Borehole Geophysical logs with Emphasis on Facies Identification of Sand Aquifers (Squires and Wood, 2001)
8. Seismic Reflection Project - UPRR 2000 Profile (Liberty and Wood, 2001)
9. Hydrogeology, Geochemistry, and Well Construction of the Treasure Valley Hydrologic Project Monitoring Well #1 (Dittus et al., 1999)
10. 1996 Water Budget for the Treasure Valley Aquifer System (Urban and Petrich, 1998)
11. New York Canal Geologic Cross Section, Seepage Gain/Loss Data, and Ground Water Hydrographs: Compilation and Findings (Carlson and Petrich, 1998)
12. Seismic Reflection Imaging of a Geothermal Aquifer in an Urban Setting (Liberty, 1998)
13. Structure Contour Map of the Top of the Mudstone Facies, Western Snake Supporting Data for Groundwater Conditions and Aquifer Testing of the Tenmile Ridge Area of South Boise, Ada County, Idaho (Dittus et al., 1998)
14. Ground Water Quality Characterization and Initial Trend Analysis for the Treasure Valley Shallow and Deep Hydrologic Subareas (Neely and Crockett, 1998)
15. Structure Contour Map of the Top of the Mudstone Facies, Western Snake River Plain, Idaho (Wood, 1997c)
16. Cross Section of the Treasure Valley in the Boise Area: Notes on the Geology of the Boise, Ontario, Parma, and Notus areas (Beukelman, 1997a; Beukelman, 1997b; Beukelman, 1997c; Beukelman, 1997d)
17. Preliminary Map of the Base of the Sedimentary Section of the Western Snake River Plain (Wood, 1996b)

1.3. Previous Investigations

Numerous previous investigations have focused on geology and hydrology in the Treasure Valley or Western Snake River Plain (WSRP). Lindgren (1898) provided early geologic descriptions of the Boise River Valley. Mabey (1982), Malde (1991), Wood and Anderson (1981), and Wood and Clemens (in press) described the geological setting. Othberg (1994), Othberg and Stanford (1992), Wood and Anderson (1981), Malde (1991), Clemens (1993), Wood (1994), and Wood and Clemens (in press) described valley stratigraphy. Several authors have described aquifer characteristics, including Dion (1972), Ralston and Chapman (1970), Wood and

Anderson (1981), Squires et al. (1992); and Wood and Clemens (in press). Previous ground water flow models were developed by Lindgren (1982), Newton (1991), and Brockway and Brockway (1999). The work conducted as part of the TVHP builds on these efforts.

2. DESCRIPTION OF PROJECT AREA

2.1. Project Area

The TVHP project area consists of (1) the lower Boise River sub-basin and (2) the area between the lower Boise River sub-basin and the Snake River (Figure 2-1). The lower Boise River sub-basin begins where the Boise River exits the mountains near Lucky Peak Reservoir. From Lucky Peak Dam, the lower Boise River flows about 64 (river) miles northwestward through the Treasure Valley to its confluence with the Snake River. The Boise River drains the central portion of the valley; the Snake River drains the southern portion of the valley. The project area (shown in red) extends south to the Snake River because ground water flows from some portions of the lower Boise River basin south toward the Snake River.

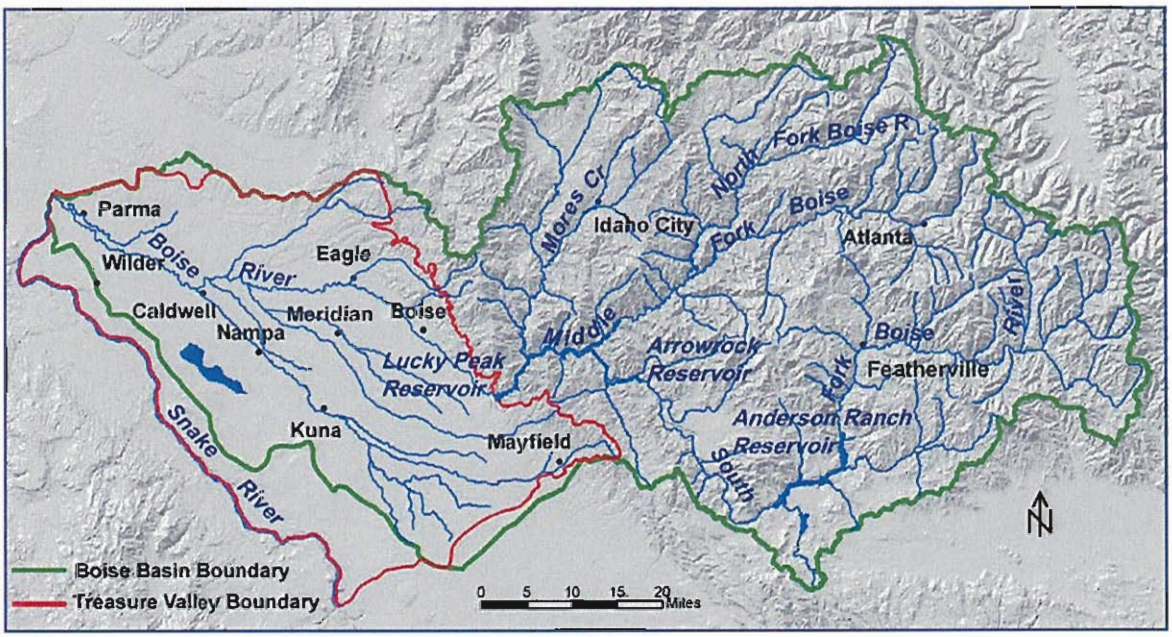


Figure 2-1: Map showing the Boise River basin, lower Boise River sub-basin, and Treasure Valley Hydrologic Project

The entire Boise River basin covers over 4,020 square miles in southwestern Idaho. Elevations in the basin range from a high of 10,174 feet above mean sea level (msl) to a low of 2,185 feet (msl) at the confluence of the Boise and Snake Rivers.

Most of the surface water in the lower Boise River basin originates in the upper Boise River basin. Much of the runoff from high elevation areas is stored in three reservoirs:

Anderson Ranch Reservoir, Arrowrock Reservoir, and Lucky Peak Reservoir (Figure 2-1). The northern portion of the basin drains a large portion of Idaho's south-central mountains. Major surface water bodies in the Treasure Valley include the Boise River, Lake Lowell, and the Snake River (Figure 2-2).

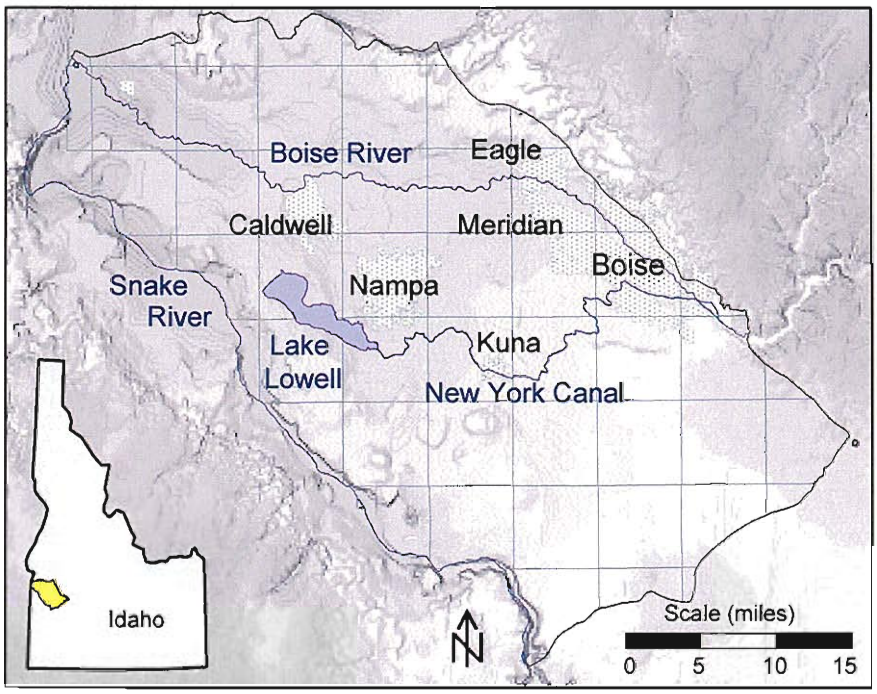


Figure 2-2: Treasure Valley area.

2.2. Population

The Treasure Valley was home to approximately 426,300 people in 2000[1], or about one-third of Idaho's population. Most of the Treasure Valley population is concentrated in the growing cities of Boise, Nampa, Caldwell, and Meridian, as well as a number of smaller communities (Figure 2-2).

Population growth in these areas for the period 1970–2000 is shown in Figure 2-3. The population is projected to grow to approximately 655,000 people by 2020[2], an increase of over 50% in 20 years.

[1] Source: U. S. Census data, presented by the Community Planning Association of Southwest Idaho (http://www.compassidaho.org/demo/profiledemocharacteristics.pdf).
[2] Source: Community Planning Association of Southwest Idaho (http://compassidaho.org)

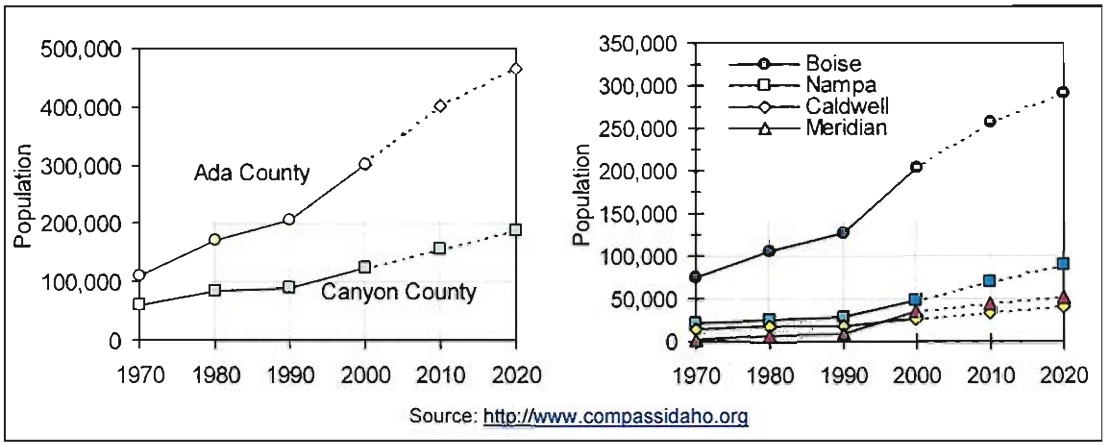
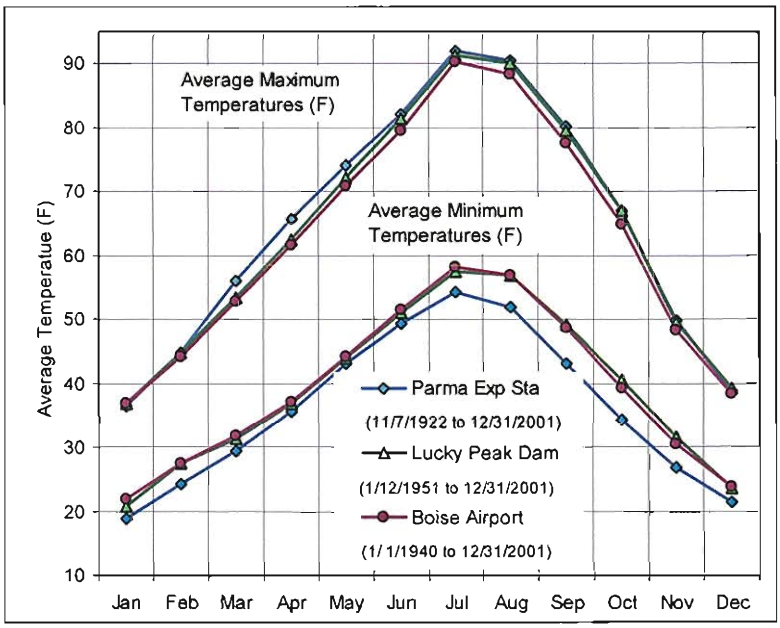


Figure 2-3: Treasure Valley population growth for the period 1970-2000 (solid lines) and projected growth for the period 2000-2020 (dashed lines).

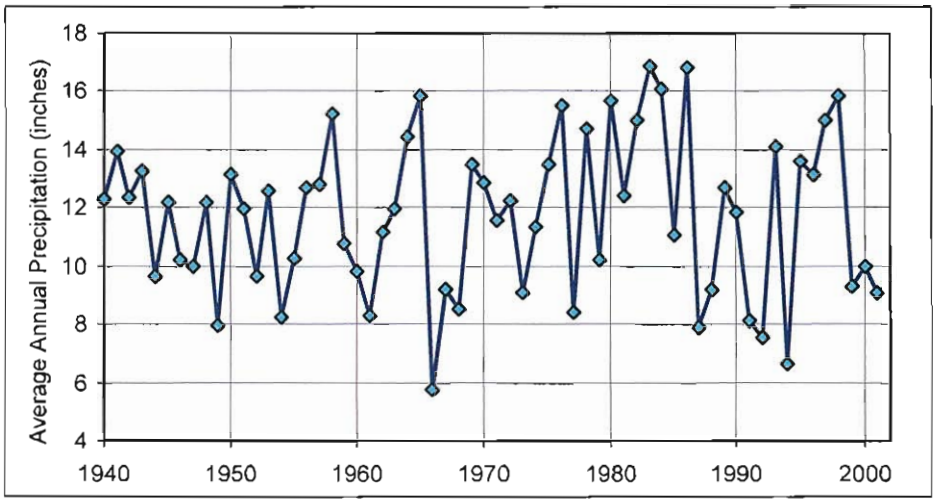
2.3. Climate

The Treasure Valley has a temperate and arid to semi-arid climate. Average high temperatures range from about 90°F in summer to 36°F in winter (Figure 2-4); average low temperatures range from about 20°F in winter to about 56°F in summer. The average precipitation ranges from about 8 to 14 inches throughout most of the valley (Figure 2-5), most of which falls during the colder months (Figure 2-6).



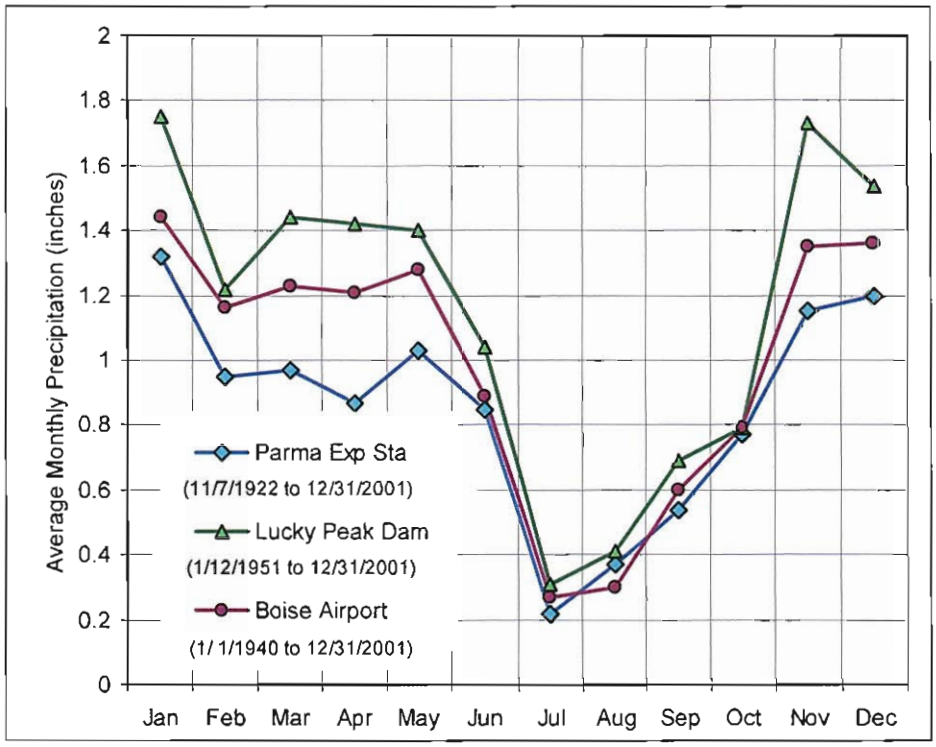
Source: State Climate Services, Biological and Agricultural Engineering Department, University of Idaho.

Figure 2-4: Monthly average temperatures.



Source: State Climate Services, Biological and Agricultural Engineering Department, University of Idaho.

Figure 2-5: Annual precipitation at the Boise Airport between 1940 and 2001.



Source: State Climate Services, Biological and Agricultural Engineering Department, University of Idaho.

Figure 2-6: Boise River basin precipitation at selected sites.

2.4. Land Use

Approximately half of the land area in the Treasure Valley (Figure 2-7) is devoted to irrigated agriculture. Major crops grown in the Treasure Valley include alfalfa and alfalfa seed, sugar beets, wheat, beans, silage and seed corn, onions, and potatoes. Residential and commercial uses account for approximately 10% of the land use, and the remaining land is primarily open range and foothills.

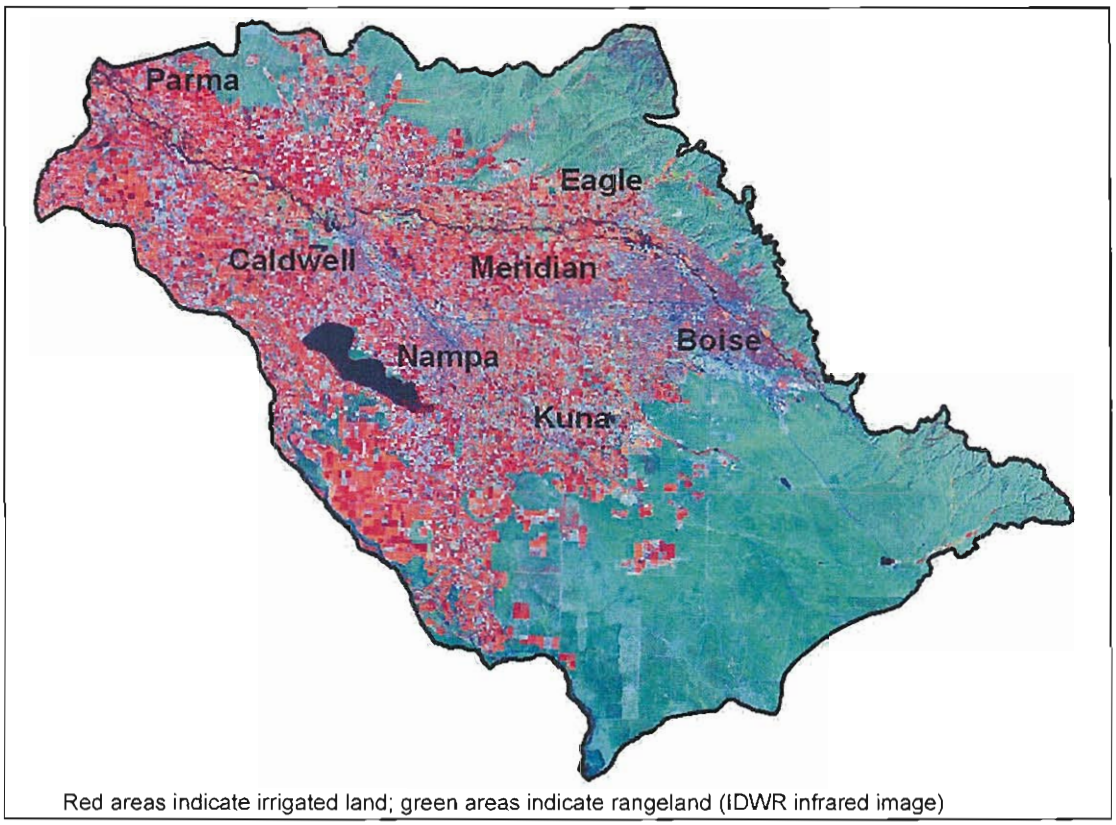


Figure 2-7: Treasure Valley land use.

2.5. Irrigation

Large-scale irrigation in the Treasure Valley began in the late 1800s, and by the 1930s, irrigated lands covered a large portion of the valley (Figure 2-8). The primary application method is flood irrigation, with water diverted from the Boise River. Expansion of irrigated land continued after 1939 (Figure 2-8). Some of the water for expanded irrigation was drawn from the Payette River (through the Black Canyon canal system), and some was obtained from ground water sources. In 1996, approximately 252,000 acres were irrigated with surface water (Urban and Petrich,

1998). An additional estimated 42,300 acres were irrigated with ground water. An increasing amount of irrigated land has been taken out of production in recent decades (Figure 2-8). Most of the loss of irrigated land between 1938–1939 and 2000 can be attributed to urban expansion.

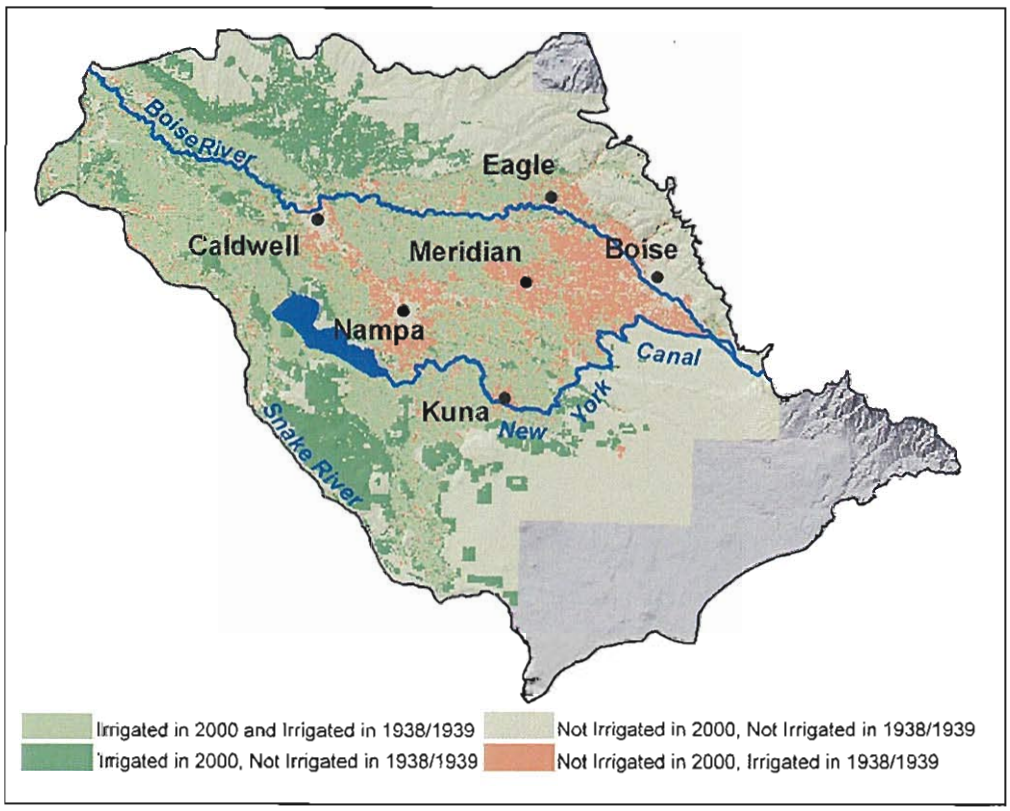


Figure 2-8: Changes in Treasure Valley irrigated lands between 1938–1939 and 2000 (IDWR data).

The region's croplands are irrigated primarily with surface water through an extensive network of reservoirs and canals. The first canals were constructed in the 1860s; there are now over 1,100 miles of major and intermediate canals in the Treasure Valley (Figure 2-9)[3]. The majority of canals are owned and maintained by canal companies and irrigation districts (Figure 2-10). The Treasure Valley also has an extensive network of drains (and ditch companies that service the drains). These channels serve to drain water (often originating from irrigation practices) from low-lying areas. In some cases the drains are also canals, and shallow ground water discharging to drains is used for additional surface water irrigation.

[3] Figure created by IDWR based on canals included in 1:100,000 scale topographic mapping.

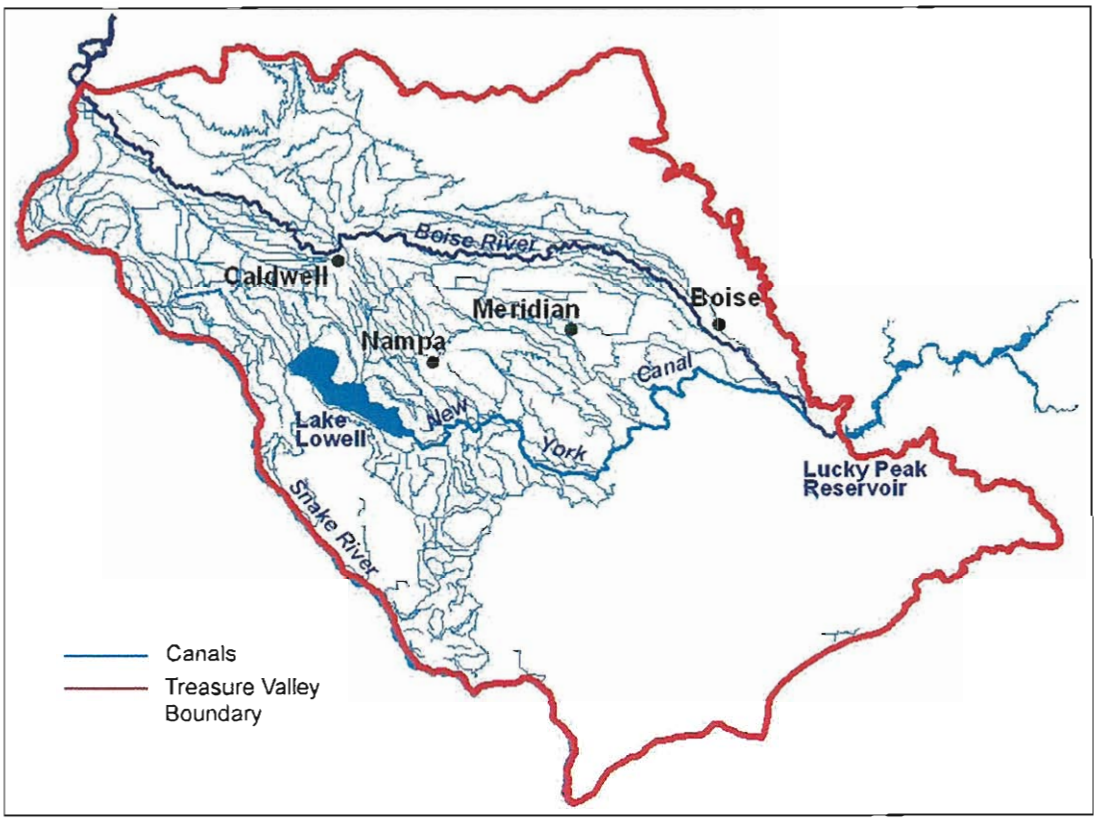


Figure 2-9: Major and intermediate canals in the Treasure Valley (IDWR data).

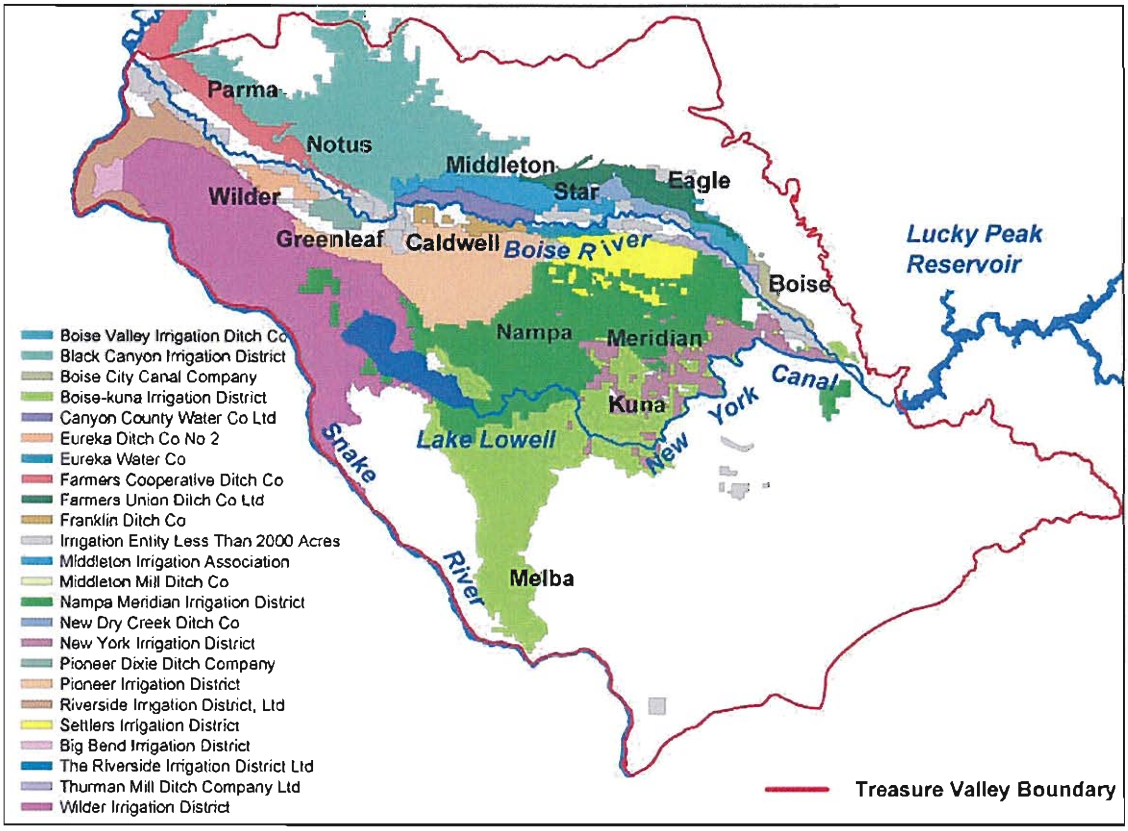


Figure 2-10: Treasure Valley irrigation district boundaries (IDWR data).

Of the estimated 252,000 acres irrigated in 1996 (Figure 2-11), approximately 101,000 acres was irrigated by sprinkler systems (Urban and Petrich, 1998). Of this total, approximately 42,000 acres (42%) are irrigated with ground water and 59,000 acres (58%) are irrigated with surface water. Ground water is used for irrigation in locations where surface water is unavailable or in times of surface water shortages. Irrigation wells were installed during the late 1920s and 1930s to provide supplemental irrigation during times of drought. Additional wells for primary and supplemental irrigation (and domestic uses) have been drilled during the last several decades.

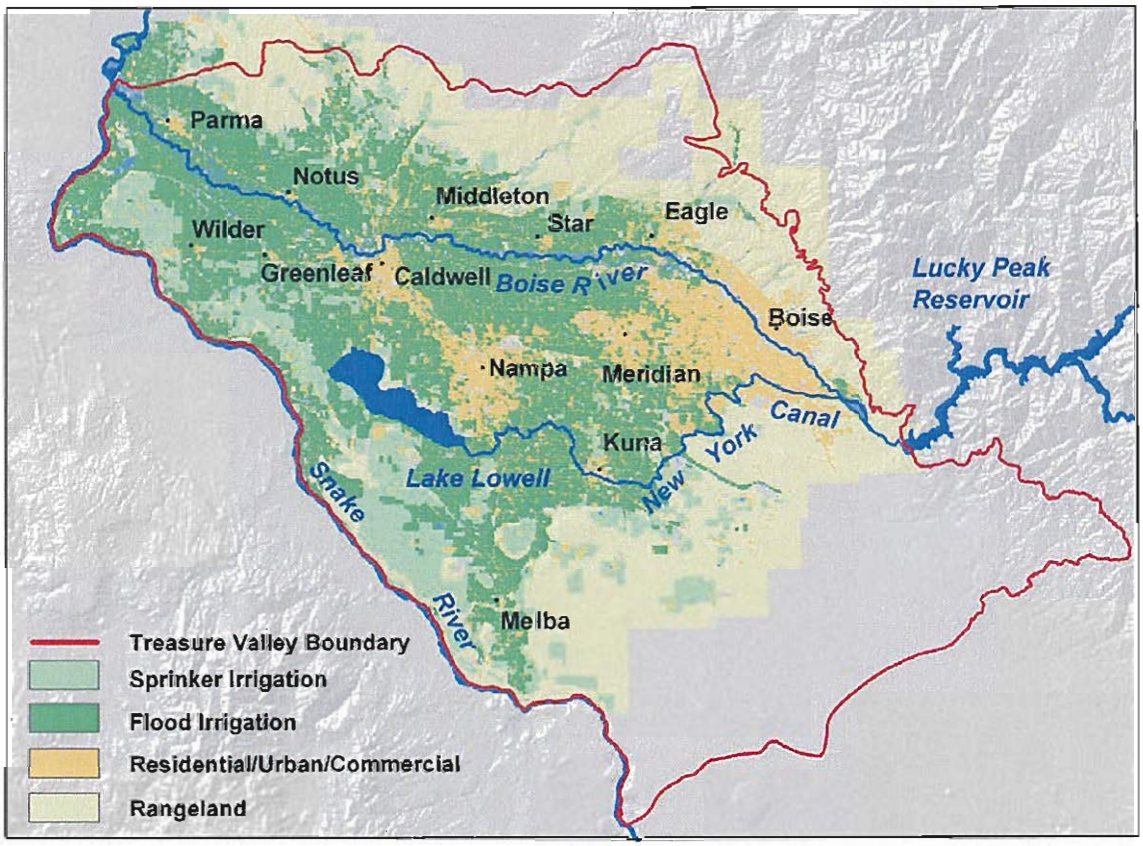


Figure 2-11: Treasure Valley flood and sprinkler irrigation in 1994 (IDWR data).

3. AQUIFER DESCRIPTION

3.1. Introduction

This section provides a description of Treasure Valley aquifer characteristics. Material for this section was drawn from geological investigations conducted prior to and as part of the TVHP. A description of flow characteristics, based on aquifer characteristics, hydraulic heads, hydraulic gradients, and estimates of inflows and outflows, is provided in Section 7.

3.2. Geologic Setting

The lower Boise River sub-basin (Treasure Valley) is located within the northwest-trending topographic depression known as the Western Snake River Plain (WSRP). The WSRP is a Neogene-aged (Table 3-1) continental rift basin (Wood and Clemens, in press), separating Cretaceous granitic mountains of west-central Idaho from the granitic/volcanic Owyhee mountains in southwestern Idaho. The WSRP now has the appearance of a northwest-trending graben associated with continental rifting (Mabey, 1982; Wood and Anderson, 1981). The WSRP extends from around Twin Falls, Idaho, northwestward to Vale, Oregon. The section of the WSRP containing the lower Boise River valley is about 30 miles wide (Figure 2-1 and Figure 2-2).

The WSRP is believed to have been formed by crustal extension (Malde, 1991, p.251). Malde suggests that the basin began forming as early as 17 million years ago (Ma), although Wood and Clemens (in press) suggest that the basin began forming about 11 Ma, with major faulting that occurred between 11 and 9 Ma (Wood and Clemens, in press). Miocene-aged (Table 3-1) rhyolite flows and domes are present along the margins of the WSRP. Rhyolite is present in outcrops in the Boise Foothills near Boise. Geothermal wells in the downtown Boise area draw water from two rhyolite zones separated by arkosic sand and granitic gravels. Deep wells north and west of Boise have not penetrated rhyolite (to the authors' knowledge); for example, the 14,100-foot-deep J.N. James well near Meridian did not encounter rhyolite (S. Wood, pers. comm., 2000). For this reason Wood and Clemens (in press) hypothesize that much of the plain may have been an upland during Miocene silicic volcanism.

The basin dropped, relative to surrounding highlands, by isostatic compensation (Malde, 1991) in response to thick accumulations of volcanics associated with rifting and deposition of overlying sediments (Mabey, 1982). Wood and Clemens (in press), Squires and Wood (2001), and others have described fluvial and lacustrine sediment deposition that occurred in the basin during this time (Section 3.3).

Era	Period		Epoch	Approximate Duration (Millions of Years)	Approximate beginning (Millions of Years Ago)
Cenozoic	Quaternary		Holocene (Recent)	Approx. Last 10,000 years	10,000 years
			Pleistocene	2	2
	Tertiary	Neogene	Pliocene	3	5
			Miocene	18	23
		Paleogene	Oligocene	15	38
			Eocene	16	54
			Paleocene	11	65
Mesozoic	Cretaceous			71	136
	Jurassic			54	190
	Triassic			35	225

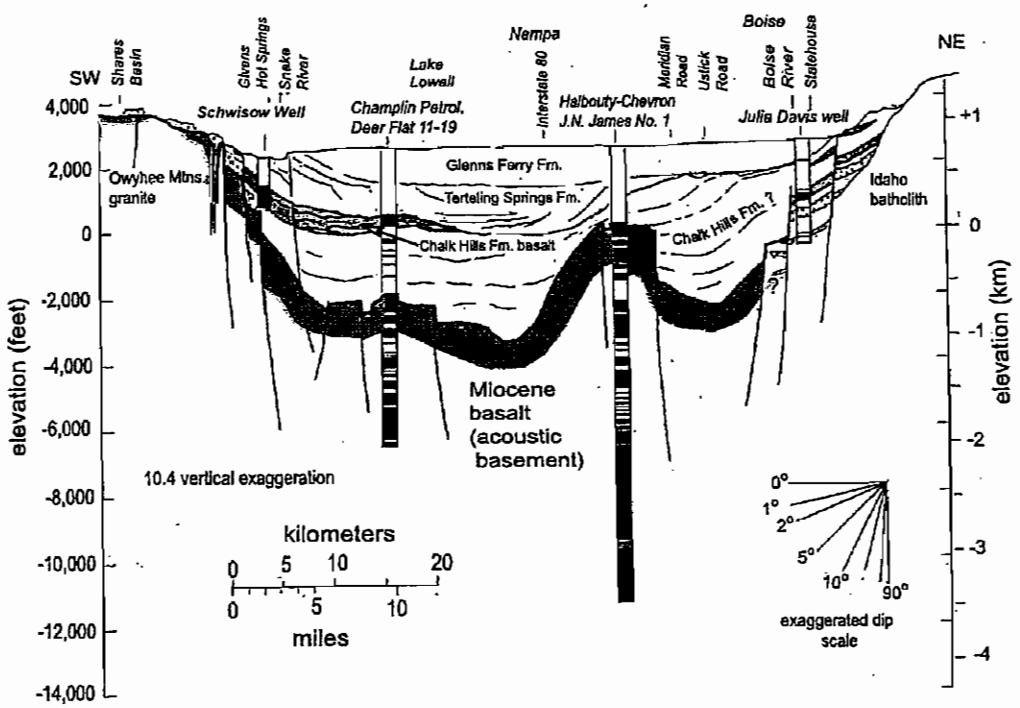
Shading indicates ages represented in Treasure Valley geology.

Table 3-1: Geologic time during the Cenozoic and Mesozoic eras.

Volcanic activity returned to the WSRP during the late stages of Lake Idaho (see Section 3.3) about 5.5 Ma (Wood and Clemens, in press). Lava erupted from a line or series of volcanic vents referred to as the Kuna–Mountain Home volcanic rift. These Quaternary basalt flows, assigned to the upper Snake River Group (Malde, 1991, p.266; Malde and Powers, 1962), flowed across portions of the ancestral Snake River Valley in an area that is now south of the Boise River (Malde, 1991). The Snake River then changed course, incising at its present location along the southern margin of the basalt flows. More recent eruptions (from Kuna Butte and other local sources along the rift) spilled lava into the Snake River Canyon south of Melba. The Snake River has since incised into this basalt (Malde, 1991, p.267).

3.3. Stratigraphic Profile

The general stratigraphy of the WSRP consists of interbedded layers of sand, silt, and clay overlying Miocene tuffaceous sediments and basalt flows (Figure 3-2). The sediments, ranging up to 6,000 feet in thickness in some locations, distinguish the WSRP from the Eastern Snake River Plain (ESRP), which is primarily Quaternary basalt in its upper section (Wood and Anderson, 1981, p.9).

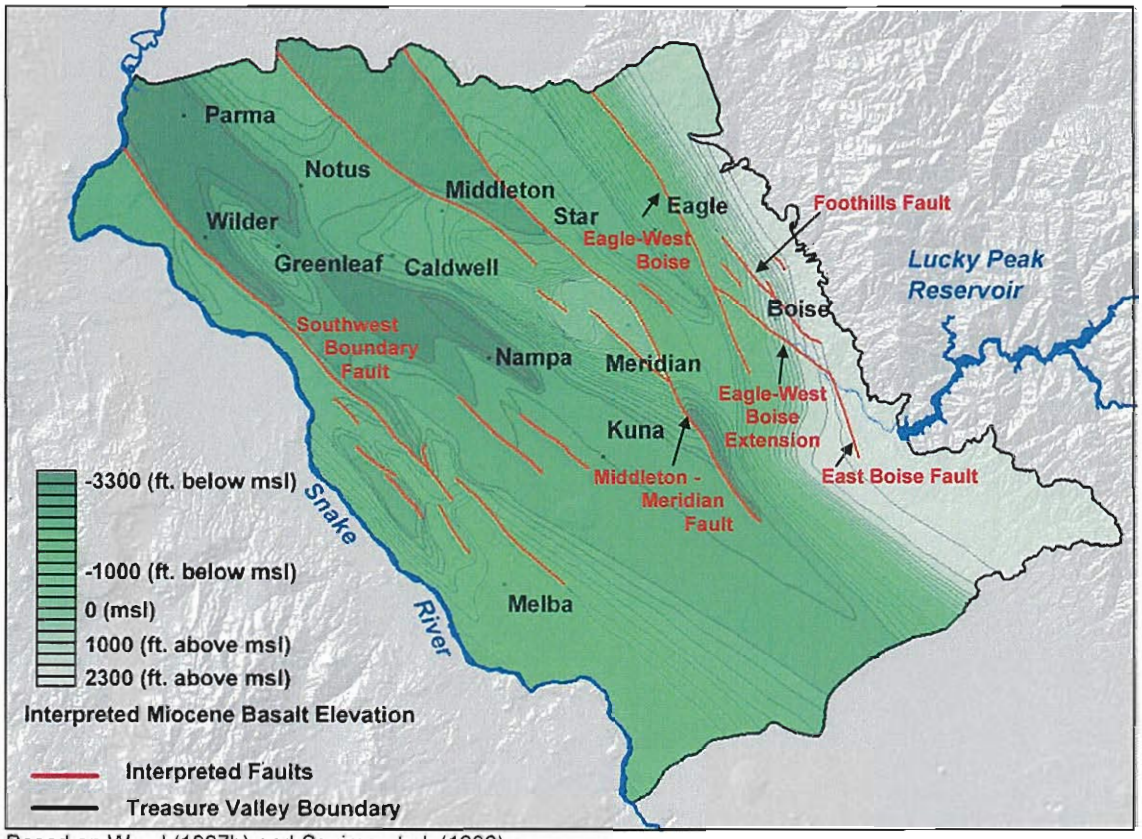


From Wood and Clemens (in press).

Figure 3-1: Cross-section of the WSRP.

The Miocene-aged tuffaceous basalt rests unconformably on granitic rocks of the Idaho Batholith, on late Miocene rhyolite, and/or on basalt of the Miocene Columbia River Group (Wood and Clemens, in press). The basalt assemblage is several hundred feet thick in the Boise area and forms the basement for sediments comprising the Treasure Valley aquifers.

The upper surface of the Miocene basalt forms a highly irregular surface (Figure 3-2), intersected by numerous northwest-southeast trending faults (Figure 3-3). The basalt surface was interpreted by Wood (1996b) based on well data, deep seismic reflection data, subsurface investigations in east Boise (Squires et al., 1992), and shallow seismic data (Liberty, 1996a; Liberty, 1996b).



Based on Wood (1997b) and Squires et al. (1992).

Figure 3-2: Upper Miocene basalt surface.

Faulting has been described by numerous authors (Barrash and Dougherty, 1995; Liberty, 1996a; Liberty, 1996b; Liberty, 1998; Liberty and Wood, 2001; Malde, 1991, p. 259; Othberg and Stanford, 1992; Squires et al., 1993; Squires et al., 1992; Wood, 1994; Wood, 1996b; Wood and Anderson, 1981; Wood and Clemens, in press) on the basis of surface geomorphology, stratigraphic correlations, and seismic reflection surveys and associated interpretations. Displacement along these faults ranges from feet to hundreds of feet. Cumulative fault offsets (up to several hundred feet of displacement) and basinward downwarping account for much of the basin structural relief (Figure 3-3). The East Boise Fault truncates the Boise Fan sediments with 400 to 600 feet of displacement along the fault (Squires et al., 1992). Additional faults are illustrated in Othberg and Stanford (1992).

Other major faults include the Eagle–West Boise Fault, Foothills Fault, Middleton–Meridian Fault, Lake Lowell Fault, and Southwest Boundary Fault (Wood, 1996b). The West Boise–Eagle Fault has about 800 feet of displacement near Chinden Boulevard just west of the Boise Fairgrounds and has been recognized by apparent stratigraphic offsets in wells between Dry Creek and Eagle along Highway 55.

Transmissive sands appear to be rare below a depth of 300 to 400 feet northeast of the fault (R. Dittus, pers. comm., 2003)[4]; productive sands are present at deeper depths southeast of the fault. The clay northeast of the fault is considered to be part of the mudstone facies of the Terteling Springs Formation (Burnham and Wood, 1992). The Foothills Fault also is a recognizable feature along the Boise Foothills near Boise (with an offset of greater than 500 feet in the Boise vicinity), although seismic data in the lower Stewart Gulch area (Wood, written comm., 2003) do not show large displacement along the foothills margin. The Middleton–Meridian Fault (actually seen as four faults distributed over a 1.5-mile-wide area in the Chevron seismic line) has an approximate offset of 1,200 feet (Wood, 1996b). The Lake Lowell Fault is mapped between the southern edge of Lake Lowell and Wilder and has a displacement of about 400 feet. Finally, Wood (1996b) describes about 4,000 feet of subsurface structural relief over a 5 mile area southwest of Marsing, although detailed subsurface studies have not been done in this part of the valley.

A thick sequence of sediments overlies the Miocene volcanics (Figure 3-1). These sediments are categorized into two groups: the older and deeper Idaho Group and younger Snake River Group (Table 3-2). Idaho Group sediments represent a thick series of predominantly lacustrine sediments that include the Chalk Hills, Terteling Springs, and Glenns Ferry Formations (Kimmel, 1982; Wood and Clemens, in press). In general, these sediments range to several thousand feet in thickness and grade finer with depth.

The Idaho Group sediments originated from large lakes in the WSRP during the late Miocene and Pliocene epochs. The base of the sedimentary sequence consists of interbedded arkose, mudstone, and volcanic ash, considered part of the Chalk Hills Formation (Kimmel, 1982). Sediments within the bottom 300 feet are generally coarse sand and pebble gravel originating from the Idaho Batholith and other older volcanics, grading upward into tuffaceous muds, clays, and ash beds (Wood and Clemens, in press). The Chalk Hills sediments are faulted and tilted, dipping 4 to 12 degrees basinward, compared to overlying lacustrine sediments that dip less than 4 degrees (Wood and Clemens, in press). In some areas, an unconformity associated (in part) with the occurrence of gravels separates Chalk Hills sediments from overlying sediments (Squires and Wood, 2001; Wood and Clemens, in press).

A transgressive sequence followed the draining of the Chalk Hills Lake, beginning about 5.5 Ma, resulting in a vast lake referred to as Lake Idaho (Wood and Clemens, in press). At its maximum extent, Lake Idaho reached an elevation of about 3,600 feet (msl) in the Boise Foothills. Most of the exposed sediments in the Boise Foothills appear to have been deposited during this transgressive sequence. These sediments,

[4] The TVHP #1 well (Figure 4-2) was drilled on the northeast side of this fault to a depth of 1,005 feet, with the lower 600 feet in dominantly clay materials (Dittus et al., 1999); see Section 4.

mapped as the Terteling Springs Formation (Burnham and Wood, 1992; Wood and Clemens, in press), include shoreline sand deposits with oolitic sand lenses, small deltaic deposits, and a mudstone facies associated with lacustrine deposition basinward. The Terteling Springs Formation is indicated by a 400-foot-thick section of near-shore sediments marked by oolitic lenses and extends to an elevation of up to 3,200 feet (msl) in the Boise Foothills (Squires and Wood, 2001).

Time	Lithostratigraphic Units		Group
Quaternary	Alluvium		Snake River Group
	Gravel of the Boise Terrace		
	Gravel of the Whitney Terrace		
	Gravel of the Sunrise Terrace		
	Basalt of the Gowen Terrace (0.572 ± 0.210 Ma)		
	Gravel of the Gowen Terrace		
	Basalt of the Fivemile Creek (0.974 ± 0.130 Ma)		
	Gravel of the Fivemile Creek		
~1.8 Ma			
Pliocene	Tenmile Gravel		
	East Boise alluvial fan deposits		
	Pierce Gulch Sand	Glenns Ferry Formation	Idaho Group
~5.0 Ma			
Upper Miocene	Terteling Springs Sand Facies Mudstone Facies	Basalt of Aldape Park (9.4 ± 0.6 Ma	
	Boise Foothill Volcanic Assemblage Basalt of Pickett Pin Canyon Volcaniclastic sediments and tuffs and Barber rhyolite ash Lower basalt flow rocks		
	Rhyolite of Quarry View Park (11.8 ± 0.6 Ma)		Idavada Group
	Rhyolite of Table Rock Road		
	Rhyolite of Cottonwood Creek (11.3 ± 0.6 Ma)		
~38 Ma			
Mesozoic & Eocene	Granitic Rocks		Idaho Batholith
Adapted from Squires and Wood (2001).			

Table 3-2: Stratigraphic names in the WSRP.

Malde and Powers (1962) suggested that the lowest occurrence of oolitic shoreline sands marks the base of the Glenns Ferry Formation, which covered a large area from the Snake River at Glenns Ferry to Homedale. More recently, Burnham and Wood (1992) and Wood and Clemens (in press) have defined the lower portion of these sediments as the Terteling Springs Formation.

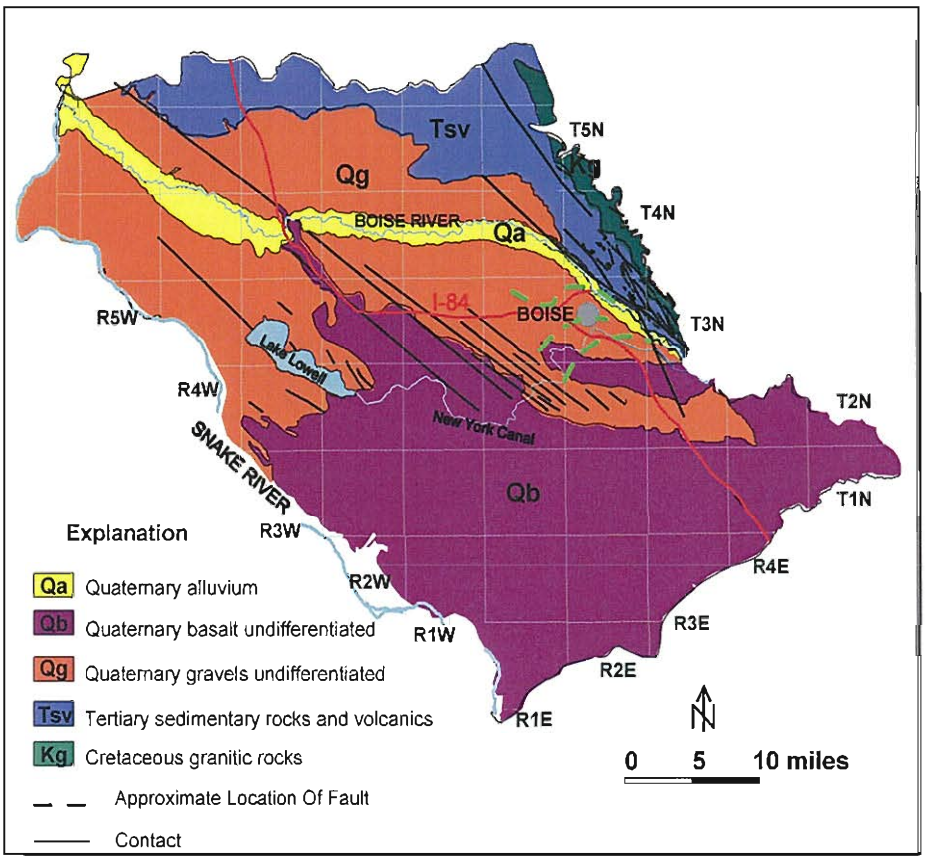
Wood and Clemens (in press) hypothesize that Lake Idaho began to recede about 4 Ma, with the outlet downcutting at a rate of approximately 400 feet per million years. Sediments (originally eroded from uplands and deposited at the basin margins) were further eroded as Lake Idaho water levels dropped. These sediments contributed to filling the receding lake, forming interbedded sand and mud sequences and extensive lacustrine delta systems. Along the Boise Foothills, these sediments are represented by a 200-foot-thick coarse sand unit (Pierce Park Sand) with Gilbert-type foreset bedding. The Pierce Park Sand correlates basinward with the Glenns Ferry Formation (Squires et al., 1993; Wood and Clemens, in press), which overlies the Terteling Springs facies. These sediments were spread basinward as the lake system receded from the valley during the Lake Idaho regression (E. Squires, pers. comm., 2003).

Within the general transgressive (Terteling Springs deposits) and regressive (Pierce Park–Glenns Ferry deposits) sequence, there is evidence of rising and lowering lake levels. The occurrence of gravel layers in the valley several miles from the basin margins within a general lacustrine sediment sequence is evidence of fluvial deposition, indicating multiple episodes of lowering and raising of lake levels within the transgressive-regressive sequence (Squires and Wood, 2001).

The top of the upper Idaho Group is marked in several parts of the Treasure Valley by a widespread fluvial gravel deposit known as the Tenmile Gravel. Tenmile Gravels contain rounded granitic rocks and felsic porphyries originating from the Idaho Batholith to the north and northeast. The Tenmile Gravels may range up to several hundred feet in thickness along the Tenmile Ridge south of Boise but are less than 50 feet thick in the Nampa-Caldwell area (Wood and Anderson, 1981).

Wood (1994) identified a buried lacustrine delta within the Idaho Group sediments in the Nampa-Caldwell area. The location of the delta in the WSRP suggests that the eastern part of the Boise River basin was delta plain and flood plain at the time of deposition, while the western part was a slack-water (e.g., lake) environment. The delta probably prograded northwestward into a lake basin about 850 feet deep based on high-resolution seismic reflection data and resistivity log interpretations. The delta-plain and delta-front sediments were shown to be mostly fine-grained, well-sorted sand with thin layers of mud (Wood, 1994). The northwest trend of the delta indicates a sediment source to the southeast, such as where the Snake River flows today (Wood, 1994).

The uppermost sediments and basalt covering much of the project area (Figure 3-3) belong to the Pleistocene-age Snake River Group (Othberg and Stanford, 1992). The Snake River Group sediments, consisting primarily of coarse-grained sand and gravels, include Quaternary alluvium, a series of Quaternary terrace gravels and sands, and Pleistocene basalt flows (Wood and Anderson, 1981). The basalt flows cover primarily the southern portion of the project area (Figure 3-3).



From Othberg and Stanford (1992)

Figure 3-3: Surficial geology map.

Several stratigraphic cross-sections were drawn by Beukelman (1997a; 1997b; 1997c; 1997d), Wood (1996a), and Squires and Wood (2001) as part of the TVHP. The cross-sections were based on drillers' logs, geophysical logs, geologic outcrops, and seismic data. Surficial deposits were noted as modern flood plain deposits, Bonneville Flood slackwater fine sediments, Pleistocene gravels, and older tertiary-age sediments.

A transition from brown to underlying blue or gray sediments is noted in many drillers' reports and in the various cross-sections. The color transition is observed throughout central and western portions of the valley (Beukelman, 1997b; Beukelman, 1997c; Beukelman, 1997d; Squires and Wood, 2001), as far west as Parma and Ontario and as far east as Boise (Beukelman, 1997a; Squires et al., 1992). The blue-gray sediments are not found in the upper 1,100 feet of alluvial fan sediments east of Boise (Squires et al., 1992). The blue-gray sediments generally consist of clay and/or silt but also may include interbedded sand or even pea gravels. The upper surface of these sediments, frequently referred to as the "blue clay," can be found at depths ranging from tens of feet to over 800 feet below ground surface.

The origin of the contact between brown and blue-gray sediments is not well understood. The bluish color probably reflects chemically-reducing conditions associated with an oxygen-poor environment. Some of the color may be associated with depositional environment, especially when lacustrine sediments become buried under new deposition. Some of the color may be associated with post depositional conditions, as evidenced by gravels and coarse sands within bluish horizons. Local elevation variations in bluish sediments may reflect erosion of the blue-gray sediments, exposure to oxygen, and/or structural movement.

The use of color changes to identify depositional environments can be misleading. Despite the presence of blue-gray sediments throughout much of the valley, the color-change contact does not appear to represent individual areally-extensive strata. Bluish-colored sediments may change color if exposed to oxygen (or oxygen-rich ground water). Thus, the transition from brown to blue-gray sediments probably reflects a combination of deposition and post-depositional conditions and therefore, is not necessarily indicative of current ground water flow conditions.

Multiple layers of clay are found within the Idaho Group sediments. These clay layers, in aggregate, form aquitards separating shallow aquifers from deeper zones. Although the clay layers are often of substantial thickness, individual clay units are not necessarily continuous over large portions of the project area.

3.4. Aquifer Description

Treasure Valley aquifers also have been described in terms of subdivisions based on general material properties and location within the valley (Squires et al., 1992). This section provides a general description of primary aquifers on the basis of sedimentary characteristics.

The sediments included in these subdivisions may span multiple formations or geologic groups (Section 3.3). For instance, some of the East Boise alluvial fan sediments may be contemporaneous to the upper Chalk Hills Formation (Wood and Clemens, in press); lacustrine sediments in the central portion of the valley may belong to the Chalk Hills, Terteling Springs, and/or Glenns Ferry Formations. Distinctions between the specific geologic formations may not necessarily indicate differences in ground water flow characteristics. For instance, lacustrine sediments in the central portion of the valley may have similar ground water flow characteristics, regardless of whether they belong to the Chalk Hills Formation or the Terteling Springs mud facies.

Thus, the Treasure Valley aquifer system consists of a series of sedimentary aquifers within the Idaho Group and Snake River Group sediments. Squires et al. (1992) interpreted five subdivisions (Figure 3-4) within the Idaho Group sediments in the Boise area using geophysical logs, well logs, and aquifer tests. The five subdivisions

are the (1) Boise Fan Sediments, (2) Fan-to-Lake Transition Sediments, (3) Central Boise Lacustrine Sediments, (4) Deep Lacustrine Sands and Alluvial Lake Margin Sands of west Boise, and (5) Lake Margin Sands of northeast Boise.

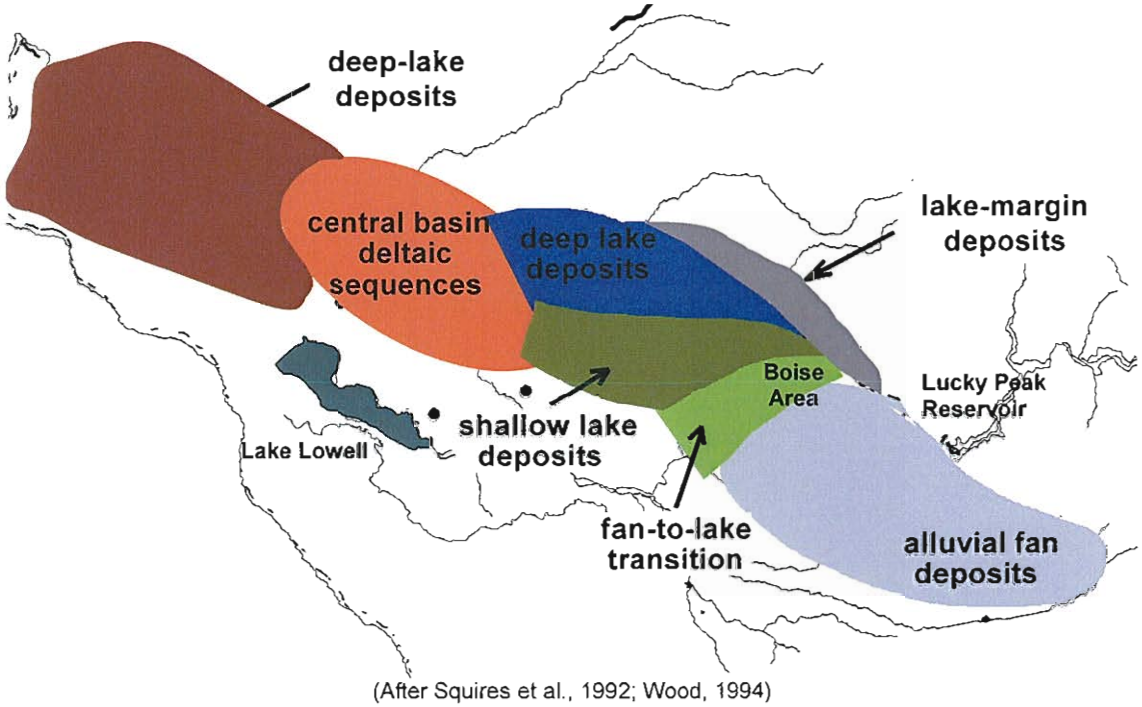


Figure 3-4: Subdivisions of Idaho Group sediments.

The Boise Fan (Squires et al., 1992) covers a large, highly heterogeneous deposit of gravels, sands, and silts, beginning near Lucky Peak Dam and extending about 6 miles to the west-northwest. Predominantly silty sands, the Boise Fan sediments also contain numerous gravel lenses and a few silt lenses. Fan-to-Lake Transition sediments were described as clays and sands of alternating brown and blue colors, indicating interfingered oxidized and reduced materials, respectively. Squires et al. (1992) described the Central Boise Lacustrine sediments as sand, silt, and clay units bearing lacustrine features (e.g., oolites, fine grain sizes). Sediments underlying an area of west Boise were described as deep lacustrine sands and alluvial lake margin sands. Wells in this area encountered 500 feet of nearly horizontal medium- to coarse-grained sands interbedded with silts, sands, and clays, underlain by 500 to 1,000 feet of fine-grained sand layers within thick layers of clay and silt. Seismic data indicated a westerly dip in the lower section of 3 to 7 degrees and 2 to 3 degrees in the upper materials. Finally, Squires et al. (1992) interpreted lake margin sediments containing sands, gravels, and occasional silty zones in the area underlying northeast Boise. The sediments were interpreted as lake margin sediments on the basis of the well-sorted

nature of the sand layers, interbedded fluvial deposits, and their stratigraphic location with respect to adjacent geologic outcroppings of the Boise Foothills.

Wood and Anderson (1981) first suggested that the Glenns Ferry sediments rest on a geological unconformity within the Idaho Group. The lower sediments dip basinward approximately 4 to 7 degrees. The buried unconformity lies 350 to 400 feet beneath central and east Boise and 400 to 500 feet deep in west Boise (Squires et al., 1992). Additional fluvial deposits have been noted within lacustrine sequences (Squires and Wood, 2001), indicating multiple episodes of rising and lowering lake levels.

Sequences of interbedded sand, silt, and clay, such as the upper portion of the Glenns Ferry Formation of the upper Idaho Group in the Nampa–Caldwell area, are the major water-producing aquifers in a large part of Canyon County (Anderson and Wood, 1981).

3.5. Water Chemistry

Despite regional geologic complexity, geochemical analyses conducted as part of the TVHP (Hutchings and Petrich, 2002a) show predictable relationships between ground water chemistry and the unique depositional environments of the principal aquifers. The analyses indicated (1) a strong relationship between concentrations of dissolved constituents and depositionally-defined aquifer units, (2) apparent geochemical evolution along the valley axis, and (3) a general east-to-west increase of ground water residence times.

Geochemical evolution of Treasure Valley ground water appears to be influenced by a solution of both carbonate and silicate minerals. Ground water near the northeastern basin margin has experienced little chemical interaction with aquifer minerals; ground water beyond the northeastern basin margin has experienced substantial interaction with aquifer minerals.

Concentrations of major ions and other dissolved constituents vary consistently with depth among aquifer zones. Specific conductance (and by inference, concentrations of total dissolved solids) is often greater in shallow alluvial aquifers than in some deeper zones. This finding indicates that water in these deeper zones did not enter the ground water regime through the carbon-rich sediments found in Treasure Valley soils.

Residence times of Treasure Valley ground water generally increase with depth and with distance along a regional east-to-west trending flow path (Hutchings and Petrich, 2002a; Hutchings and Petrich, 2002b). Residence times range from years to hundreds of years in shallow aquifers and thousands to tens of thousands of years in deeper, regional aquifers.

Residence times in the shallow system are bracketed, in part, based on tritium concentrations remaining from nuclear testing during the 1950s and 1960s. Tritium is present in shallow aquifers, such as those underlying the New York Canal (Hutchings and Petrich, 2002b). Tritium is virtually non-existent in deeper, regional ground waters, except where well construction has allowed inter-aquifer mixing. This finding indicates that ground water in deeper aquifers entered the flow regime prior to atmospheric nuclear testing during the 1950s and 1960s.

The youngest waters in the deeper, regional flow system entered the subsurface a few thousand years ago and are found along the eastern and northeastern boundary of the basin, adjacent to the Boise Foothills. The oldest waters in the regional flow system entered the subsurface between 20,000 and 40,000 years ago and are now found in the western reaches of the basin near the Snake River. Ground water in the deep deltaic aquifers beneath Boise entered the subsurface between 10,000 and 20,000 years ago.

From the ground water chemistry analyses it becomes clear that contemporary seepage from surface water in the central portion of the valley and/or irrigation water is not the primary source of recharge for most deeper, regional aquifers. Fractured granite aquifers of the Idaho Batholith, surface water in the far eastern portion of the valley, and tributary sedimentary aquifers (underflow) are the most likely sources of recharge to the regional flow system. A conceptual model consisting of (1) recharge in alluvial sediments in southeast Boise and at the base of the mountain front north of Boise, (2) movement of ground water from the recharge areas into the deeper Boise area fluvio-lacustrine aquifers, and (3) movement of ground water from the Boise area aquifers into regional deep-lake aquifers of Nampa and Caldwell is consistent with these chemistry data.

3.6. Ground Water Flow Systems

Ground water for municipal, industrial, rural domestic, and irrigation uses in the Treasure Valley is drawn from Snake River Group and Idaho Group aquifers. Many domestic wells draw water from shallow aquifers, such as those in the Snake River Group deposits. Larger production wells (for municipal and agricultural uses) generally draw water from the deeper Idaho Group sediments. Flow systems providing water to these wells can be markedly different. Distinguishing between shallow and regional ground water flow systems is important for understanding ground water flow characteristics and managing ground water resources.

Local flow systems in shallow aquifers are recharged by infiltration associated with precipitation, irrigation, and channel (e.g., streams or canals) losses. These local flow systems often discharge to local drains or streams. The time from recharge to discharge in shallow flow systems probably ranges from days to hundreds of years. In contrast, regional ground water flow systems extend much deeper than local flow

systems. The Treasure Valley regional flow system begins with downward movement in coarse-grained alluvial fan sediments in the eastern portion of the valley. Some water also enters the regional flow system as underflow from the Boise Foothills in the northeastern part of the valley. The regional flow system is thought to discharge primarily to the Boise and Snake Rivers in the western and southwestern parts of the valley. Residence times (Section 3.5) for some of the water in the regional flow system were estimated to be greater than 20,000 years (Hutchings and Petrich, 2002a).

3.7. Hydraulic Properties[5]

Numerous hydraulic parameter value estimates have been made for Treasure Valley aquifers. Most parameter estimates have been made on the basis of single-well tests. Water production wells are frequently pumped to estimate well yield and specific capacity. Very approximate estimates of transmissivity can sometimes be obtained with specific capacity data (Driscoll, 1986). Permeability estimates have also been made under laboratory conditions at some locations in conjunction with landfill construction (e.g., Seaman's Gulch, Clay Butte, and Pickles Butte). In addition, a few large-scale, multiple-well tests have been conducted in the Treasure Valley.

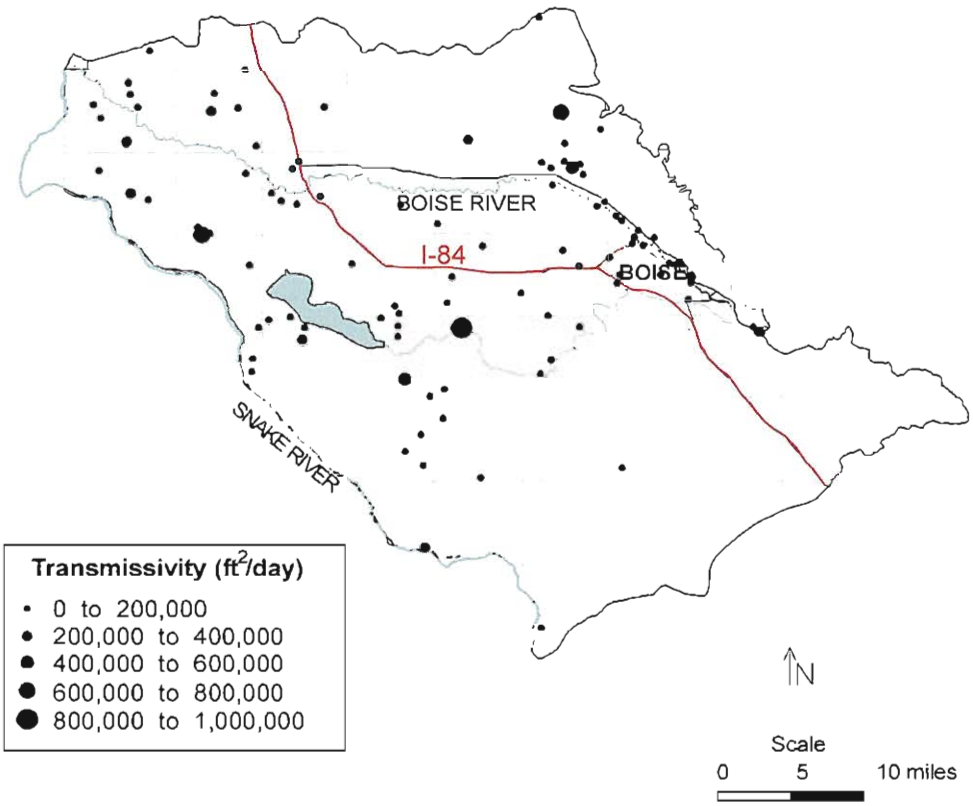
Specific capacity data obtained from well drillers' reports were used to develop plots of aquifer transmissivity values. These plots, however, should only be viewed on a qualitative basis because of a high degree of uncertainty associated with these data. The uncertainty is high because of variability in test duration, pumping rate, well efficiency, differences in well construction (e.g., different lengths of open intervals), degree of aquifer penetration, and measurement accuracy.

Well pump test data for 197 wells within the valley formed the basis for the specific capacity plots. The specific capacity data were compiled from drillers' report information contained in the IDWR Well_Log database[6]. Specific capacity data were divided into two depth zone categories: a zone from 0 to 300 feet below ground surface and a zone greater than 300 feet depth below ground surface. The data were divided into zones on the basis of open interval depths for wells as listed in the well drillers' reports. Aquifer thickness values were (1) entered in Well_Log on the basis of lithology indicated in the drillers' log or (2) assumed to be the thickness between the water level in the well and the well bottom.

A transmissivity map for the 0 to 300-foot zone (Figure 3-5) suggests that the bulk of transmissivity values calculated for shallow aquifers in the Treasure Valley are less than 200,000 ft^2/day. Isolated areas with comparatively high transmissivity values

[5] Data for this section were compiled and plotted by Rick Carlson, formerly with IWRRI.
[6] The Well_Log data base is being developed and maintained by IDWR with data from well drillers' reports.

(> 600,000 ft^2/day) were noted northeast and southeast of Lake Lowell and just north of the Boise River near Eagle. These high transmissivity values correlate with areas underlain by both gravel and basalt.

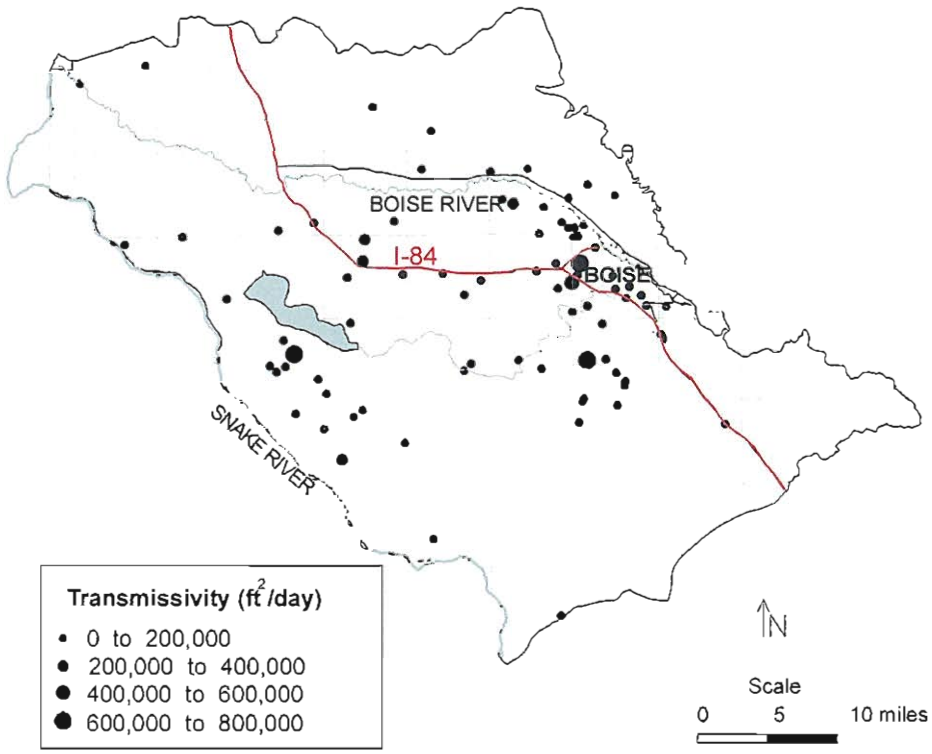


(Based on specific capacity data for wells with screened interval beginning at less than 300 feet below land surface)

Figure 3-5: Transmissivity estimates for wells completed between 0 and 300 feet below ground surface.

The map for the greater-than-300-foot zone (Figure 3-6) suggests that transmissivity values are comparatively greater at depth. The majority of calculated transmissivity values for deep aquifers across the Treasure Valley ranged between 200,000 and 400,000 ft^2/day. Isolated areas of higher transmissivity (600,000 to 800,000 ft^2/day) were apparent beneath west Boise, about 5 miles south of Boise, and 2 miles south of

Lake Lowell. These areas of high transmissivity are believed to correlate with deep aquifers containing zones of coarser-grained sediments[7].



(Based on specific capacity data for wells with screened interval beginning at greater than 300 feet below land surface)

Figure 3-6: Transmissivity estimates for wells completed below 300 feet below ground surface.

In addition, aquifer parameter estimates were compiled from various single- and multi-well aquifer test results. The source of these data includes various reports prepared by public agencies and private consultants. Test locations are shown in Figure 3-7. A table of values is provided in Appendix B. Estimated hydraulic conductivity values ranged from 2.49×10^{3} to 1.0×10^{5} ft/day.

[7] These conclusions may be skewed because (1) low-producing wells may not have been completed, and therefore are not included here, and (2) most of the wells used for aquifer tests are designed for production, and therefore are completed in the most productive zones.

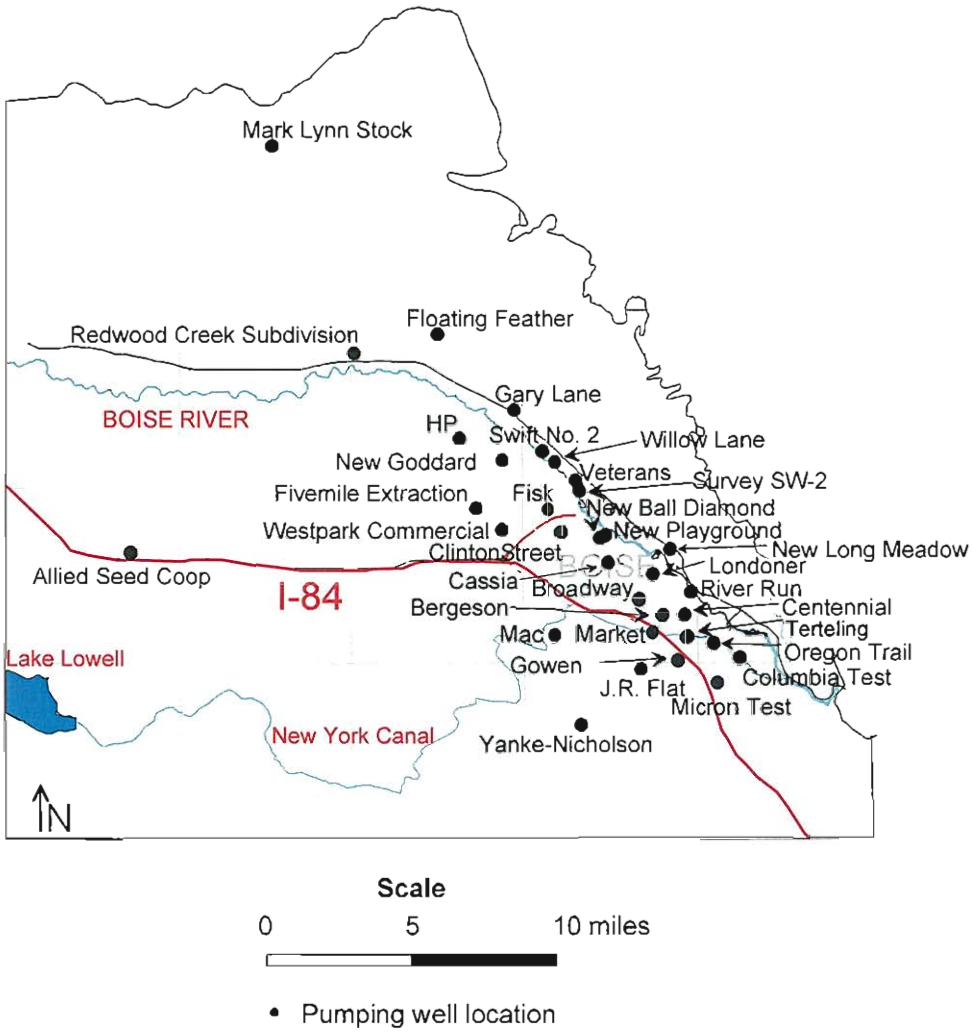


Figure 3-7: Locations of selected single and multiple well aquifer tests.

3.8. Geothermal System

The "cold water" aquifer system contained in the Snake River and Idaho Groups is underlain by a low-temperature geothermal[8] aquifer system. Temperatures of the low-temperature geothermal water range from 85° to 175°F along the Boise Front[9] (Petrich, 2003). The geothermal system provides heating for numerous Boise buildings and residences. In some areas, apparent upwelling from the geothermal system appears to influence potable non-geothermal ground water chemistry, evidenced by elevated concentrations of fluoride and other constituents.

The geothermal water along the Boise Front is associated with the Miocene basalts and underlying rhyolite (Wood and Burnham, 1987, p.121). Geothermal water rises from fractured rhyolite along the northwest-trending fault zone that marks the northeastern boundary of the Snake River Plain. A conceptual geothermal water circulation loop was described by Wood and Burnham (Wood and Burnham, 1987, p.121; Wood and Low, 1988, p.32-33), in which meteoric water from surrounding highlands circulates through deep fractures in the Idaho Batholith. The extent of the rhyolite aquifer into the valley is unknown. The rhyolite is present along the northern and southern margins of the WSRP, but no wells in the central part of the valley have extended into rhyolite (S. Wood, pers. comm., 1996). Potentiometric surface maps based on the 2002 mass measurements in geothermal wells suggest a westerly or southwesterly hydraulic gradient in the Boise Front area (Petrich, 2003).

It is important to differentiate between geothermal water and water that is greater than 85°F found in deeper Idaho Group sediments. Geothermal water from the rhyolite aquifers generally contains greater concentrations of sodium, bicarbonate, sulfate, chloride, fluoride, silica, arsenic, boron, and lithium than the overlying non-geothermal systems (Wood and Low, 1988, p.32). Upper aquifers, even if containing warm water, generally have higher concentrations of calcium and magnesium than the geothermal system. Squires and Wood (1989) note that ground water taken from Tenmile Ridge wells exhibits warm temperatures (70° to 88° F), but does not contain the high fluoride content associated with geothermal water on the north side of the Boise Valley. This lack of chemical similarity suggests that, with the exception of the fault zone area along the Boise Foothills, (1) the hydraulic connection between aquifers in the Idaho Group sediments and the geothermal rhyolite aquifers is limited, or (2) the volume of cold water entering the Idaho Group aquifers is much larger than the volume of geothermal water entering the Idaho Group aquifers.

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[8] "Low-temperature geothermal water" is defined by Idaho Code (I.C.§ 42-233) as ground water with a temperature greater than 85°F but less than 212°F.

[9] Boise Front describes the portion of the Idaho Batholith that forms the northeastern boundary of the lower Boise River basin.

Limited hydraulic interaction between the geothermal rhyolite aquifers and the non-geothermal aquifers in the Idaho Group is attributed to low permeabilities of the materials separating the aquifer zones. Miocene basalt and tuffaceous sediments overlying the rhyolite geothermal aquifer have low permeability because of clay alteration and minerals filling the fractures (Squires and Wood, 1989, S. Wood, pers. comm., 1997)S. Wood, pers. comm., 1997). Low permeability mudstone (which may be more than several hundred feet thick) at the base of the Idaho Group sediments further restricts the vertical permeability and hydraulic connection. However, elevated fluoride and temperature in some non-geothermal aquifers (along the Boise Front and in an area southwest of Nampa) indicates that some upwelling does occur.

4. DEDICATED TVHP MONITORING WELLS

Four multi-completion monitoring wells were constructed as a part of the TVHP (Figure 4-1). The purpose of the wells was to provide water level and chemistry data at different depths and locations within the aquifer system. A summary of screened intervals for the multiple-completion wells is provided in Table 4-1. Appendix A provides construction details and stratigraphic data for each of the wells. Geophysical data for wells TVHP #1, TVHP #2, and TVHP #4 are also provided in Appendix A.

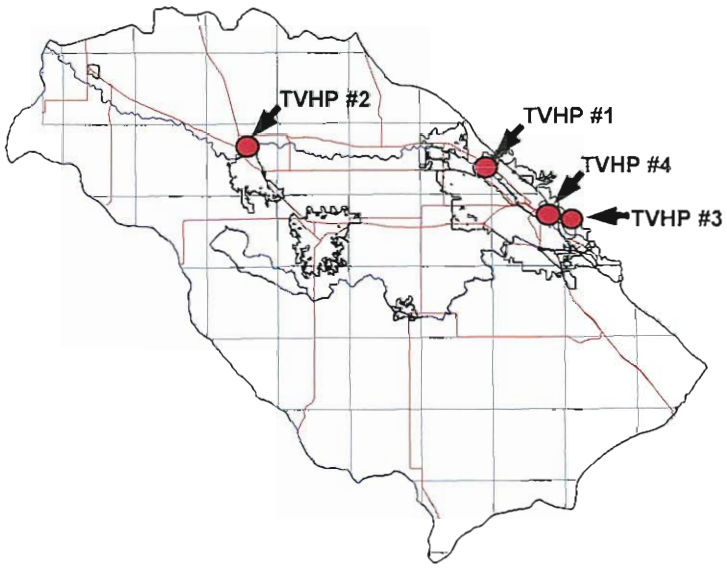


Figure 4-1: TVHP monitoring well locations.

Monitoring well TVHP #1 was drilled and constructed by United Water Idaho, Inc. (UWID) during December 1996. The well was drilled as a deep exploratory test well, and was originally drilled to evaluate potential aquifer units that might be developed for municipal water supply (Dittus and Squires, 1998). The borehole was drilled to a depth of 1,050 feet below ground surface but was subsequently backfilled to 357 feet. Four piezometers were then installed, with completion depths ranging from 170 to 340 feet. Water quality analyses from these piezometers showed the aquifers were not suitable for use as a municipal supply. UWI donated the well to the TVHP for use as a long-term monitoring well, and IDWR purchased an access easement to the well from a private landowner. Water levels (Figure 4-2) indicate an upward hydraulic gradient and apparent influences of nearby withdrawals and/or recharge.

Well Name	Piezometer	Screened Intervals – Depth below ground surface (feet)
TVHP #1 (Near Eagle)	Zone 1	300-310, 330-340
	Zone 2	270-290
	Zone 3	210-220, 240-250
	Zone 4	130-140, 150-170
TVHP #2 (Caldwell)	Zone 1	912-922, 932-942
	Zone 2	679-689, 699-709
	Zone 3	516-536
	Zone 4	376-396
	Zone 5	238-248
	Zone 6	182-192
	Zone 7	142-152
	Zone 8	110-120
TVHP #3 (Quarry View Park)	1	600-700
	2	813-848
TVHP #4 (Municipal Park)	1	35-55
	2	190-210
	3	300-320
	4	450-470
	5	710-730

Table 4-1: Construction details for TVHP monitoring wells.

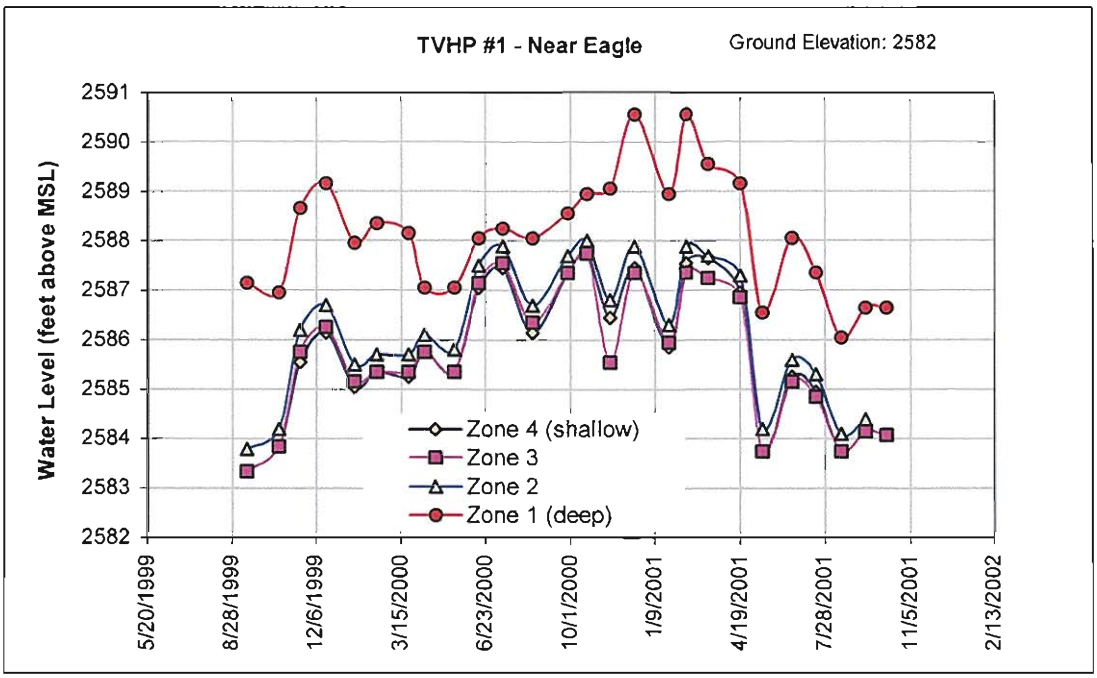


Figure 4-2: Hydrograph for TVHP #1.

Monitoring well TVHP #2 was constructed within the city of Caldwell during 1999. As with TVHP #1, this borehole was drilled for the purpose of seeking an additional source of municipal water. The city of Caldwell and IDWR agreed to share the cost of completing the borehole as a multi-level monitoring well (with in-kind technical support by UWID). Completed with eight piezometers, this well nest has completion depths ranging from 120 to 942 feet. Hydraulic head measurements (Figure 4-3) indicated a strong upward gradient between 725 feet and shallower zones and a moderate upward gradient from 550 feet to shallower zones. The vertical head differences ranged from 35 to 41 feet (upward gradient) between 11/30/99 and 6/20/01, with an average difference of 37 feet. The four uppermost completions (between 122 and 270 feet depth) are relatively consistent, indicating the possibility of a high degree of hydraulic connection between these zones. There appears to be a slight downward gradient from 725 to 1,010 feet. All completions above and including 550 feet show influences of seasonal withdrawals (i.e., summer declines).

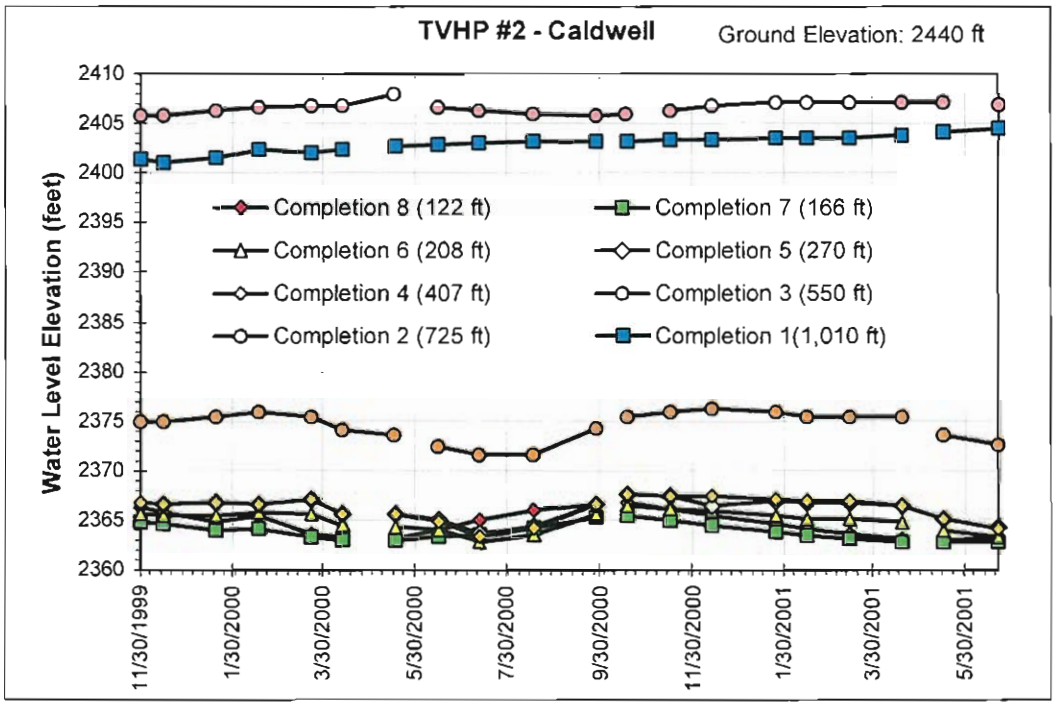


Figure 4-3: Hydrograph for TVHP #2.

Monitoring well TVHP #3 was completed in June 2001. Originally drilled in 1983, the well was used to irrigate the nearby Quarry View Park. The deepest completion produced geothermal water. Production ceased in 1988 to reduce geothermal water use (Scanlan, 2001). The well was then converted to a dual-level monitoring well by the city of Boise and IDWR as part of the TVHP. Water levels in the Quarry View well

were virtually identical between September 2001 and October 2003 (Figure 4-4), indicating close hydraulic connection between screened intervals. Decreased summer water levels indicate nearby irrigation influences.

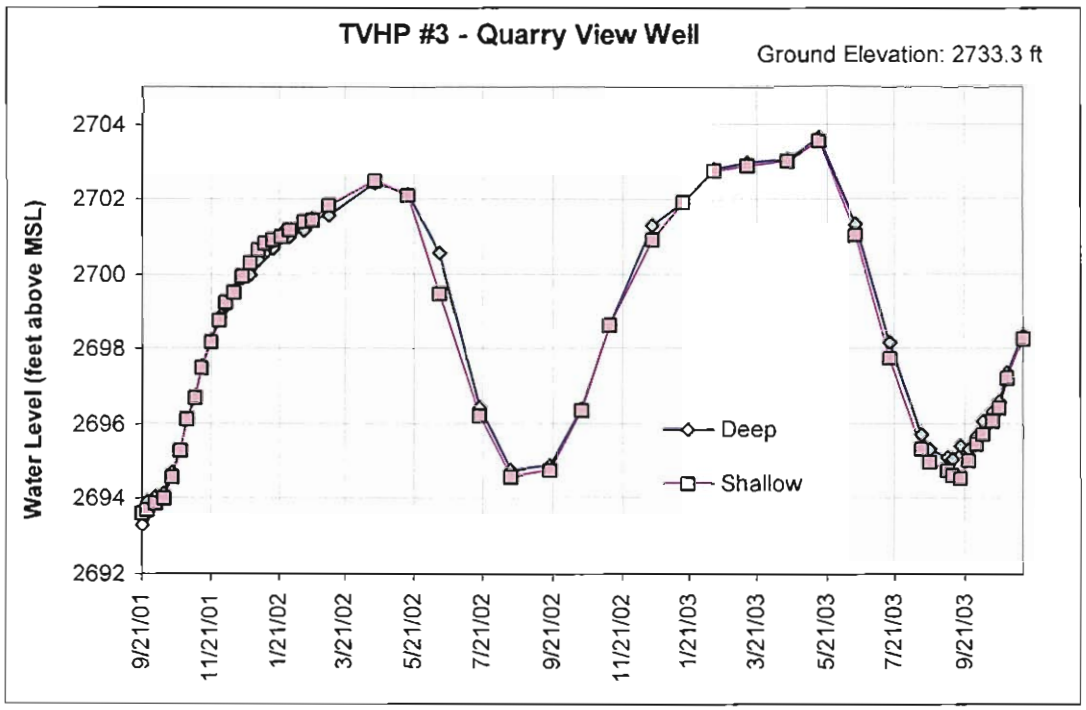
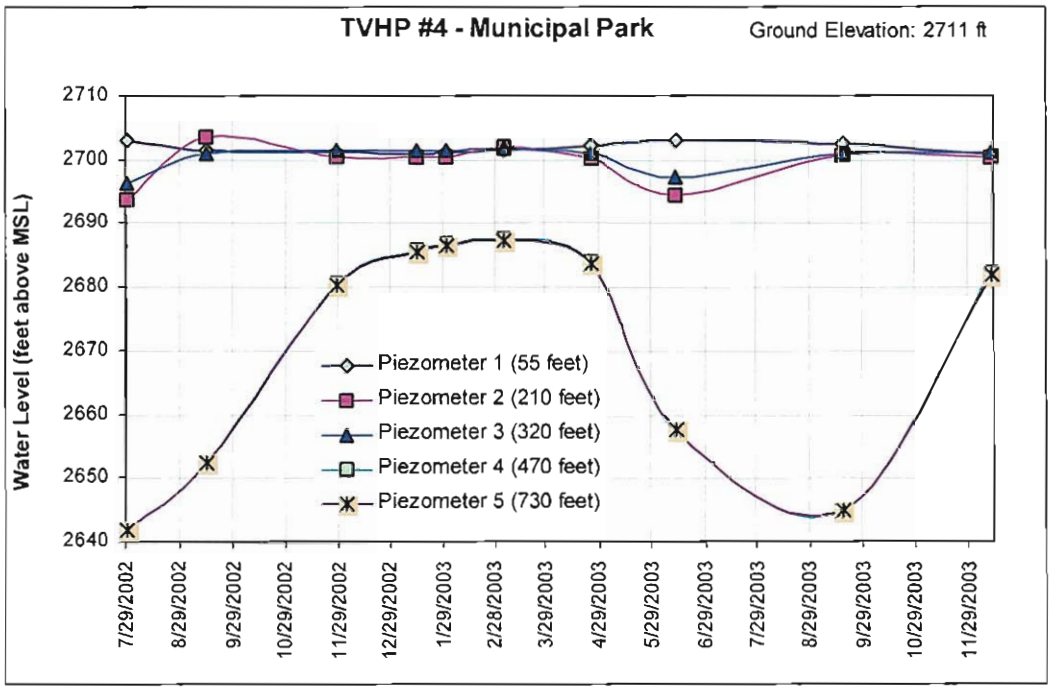


Figure 4-4: Hydrograph for TVHP #3.

Monitoring Well TVHP #4 was completed in July 2002. Located in the southeast corner of Boise's Municipal Park, this well was constructed as a multi-completion monitoring well in an area of downward hydraulic gradients. Initially drilled to a depth of 800 feet, this well includes five piezometers ranging in depth from 55 to 730 feet. Water levels in this well (Figure 4-5) indicate similar water levels in the upper three completions and lower water levels in the lowest two completions, confirming a downward hydraulic gradient. Water level differences in the Boise Municipal Park monitoring well ranged from about 15 to 61 feet between 7/29/02 and 4/24/03 (downward gradient). Decreased water levels in the deepest completions during summer months reflect nearby municipal and irrigation withdrawals. Several municipal wells are located near monitoring well TVHP #4, with peak usage of these wells occurring during the summer months; some are not used at all during the winter and spring months (R. Dittus, pers. comm., 2003).



Piezometers 4 and 5 indicate virtually the same water level elevations.

Figure 4-5: Hydrograph for TVHP #4.

5. GROUND WATER LEVELS

5.1. Introduction

Water level measurements conducted as part of the TVHP include seven mass ground water level measurements in approximately 300 wells and monthly ground water level measurements in approximately 70 wells. This section describes and presents results from these measurements.

5.2. Mass Ground Water Level Measurements

A "mass measurement" consists of a series of ground water level measurements taken within a short period of time (in this case, one to two weeks). The purpose of a mass ground water level measurement is to define a *potentiometric surface* at a point in time. A potentiometric surface represents the levels to which water rises in wells over a given area. The water table is the potentiometric surface of an unconfined aquifer. There may be more than one potentiometric surface for a given area if the hydraulic head[10] varies significantly with depth. A contour map describing a potentiometric surface is used for evaluating ground water flow directions and hydraulic gradients.

Mass ground water level measurements were conducted as part of the TVHP in the spring and fall of 1996, 1998, 2000, and fall 2001. Water levels throughout the Treasure Valley were measured within a one- to two-week time period during each mass measurement. This section describes the selection of mass measurement wells and presents potentiometric surface maps created with the mass measurement data.

The U.S. Geological Survey (USGS) selected wells for the mass measurements and performed the water level measurements. The USGS selected wells by:

1. Identifying candidate wells from the USGS Ground Water Site Inventory (GWSI) database.
2. Categorizing candidate wells on the basis of open intervals in shallow, deep, and geothermal aquifers.
3. Choosing wells that are spatially and vertically distributed throughout the Treasure Valley (where possible) in the non-geothermal aquifers. The shallow aquifer was targeted for about 60% of the measurements.

The numbers of wells included in the mass measurements are shown in Table 5-1. Additional wells were included for use in developing potentiometric surfaces if they were measured at approximately the same time as

[10] Hydraulic head consists of elevation head and pressure head; the hydraulic head for a given aquifer zone is indicated by the water level in a well screened in the aquifer zone.

the mass measurement. The open interval of each well was categorized by depth on the basis of ground water flow model layers ((see Petrich, 2004a, for more information)

Table 5-2). Wells with screen openings in layers 3 and 4 are grouped together in the subsequent potentiometric surface maps because of the relatively small number of wells in each zone.

Mass Measurement	Number of Wells	Measuring Entity
Spring 1996	343	USGS
Fall 1996	342	USGS
Spring 1998	383	USGS
Fall 1998	372	USGS
Spring 2000	392	USGS
Fall 2000	390	Kleinfelder, Inc.
Fall 2001	341	Kleinfelder, Inc.

Table 5-1: Numbers of wells measured during each of four mass water level measurements.

Layer	Thickness (feet)	Depth below Potentiometric Surface (feet)
Layer 1	200	0-200
Layer 2	200	200-400
Layer 3	400	400-800
Layer 4	400	800-1200

(see Petrich, 2004a, for more information)

Table 5-2: Model layer thicknesses.

Well construction details for the mass measurement wells are provided in Appendix D. The information includes:

1. Well codes indicating whether the well was used only as a mass measurement well or also for monthly well measurements
2. Well use (e.g., municipal, domestic, irrigation, industrial, etc.)
3. Upper and lower screen opening elevations (provides a basis for associating water level data with model layers)
4. Total screen length
5. Aquifer penetration depth (depth of standing water in well)

The aquifer penetration depth is provided because even deep wells may only penetrate a short distance into an aquifer. Lack of well depth data indicates that there is no drillers' log available for the well[11].

5.2.1. Data Collection

Water level measurements during 1996-2000 were collected by the USGS; Kleinfelder, Inc., collected water levels in fall 2000 and 2001. Pre-measurement tasks included contacting owners for permission to measure wells, preparing field maps, forms, and other necessary equipment, and assembling a field crew. Measurement tasks included visiting well sites, measuring and recording water levels, and updating well inventory information. Post-measurement tasks included entering measurement and inventory data into USGS GWSI database and publishing measurements in USGS annual water data reports.

5.2.2. Potentiometric Surface Maps

Potentiometric surface contour maps based on kriged interpolations for the mass measurements conducted in spring and fall of 1996, 1998, and 2000, and fall 2001 (for shallow, intermediate, and deep zones) are provided in Appendix E. Monitoring wells with open intervals in the layer of interest are shown with gray dots. Three examples of potentiometric surface plots are shown in Figure 5-1 through Figure 5-3. The following sections describe some of these figures.

There are several observations that can be made from the potentiometric surface maps presented in the previous sections and in Appendix E. In general, contour maps drawn from mass measurement data indicate ground water flow from the eastern part of the valley toward the west, except for the area south of Boise, where ground water flow is to the south or southwest. Potentiometric surface contours in the southeastern portion and parts of the northern part of the study area are uncertain because of the paucity of data in these areas.

[11] A few wells were used for water level measurements despite the lack of well construction or lithologic information because they were located in areas of few or no other observation alternatives.

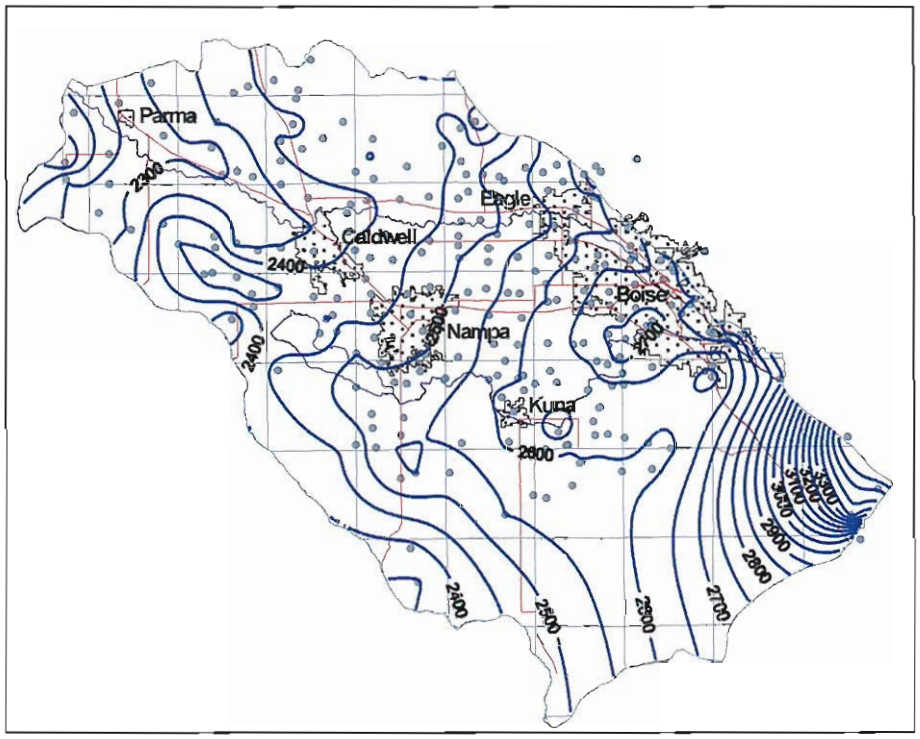


Figure 5-1: Potentiometric surface, spring 1996, shallow zone (240 wells).

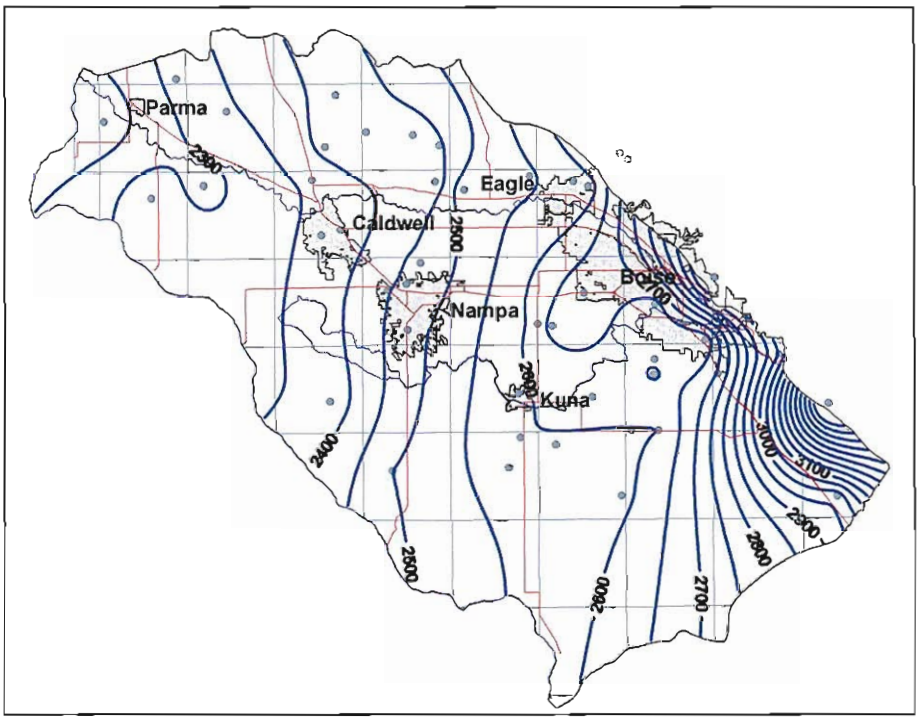


Figure 5-2: Potentiometric surface, spring 1996, intermediate zone (49 wells).

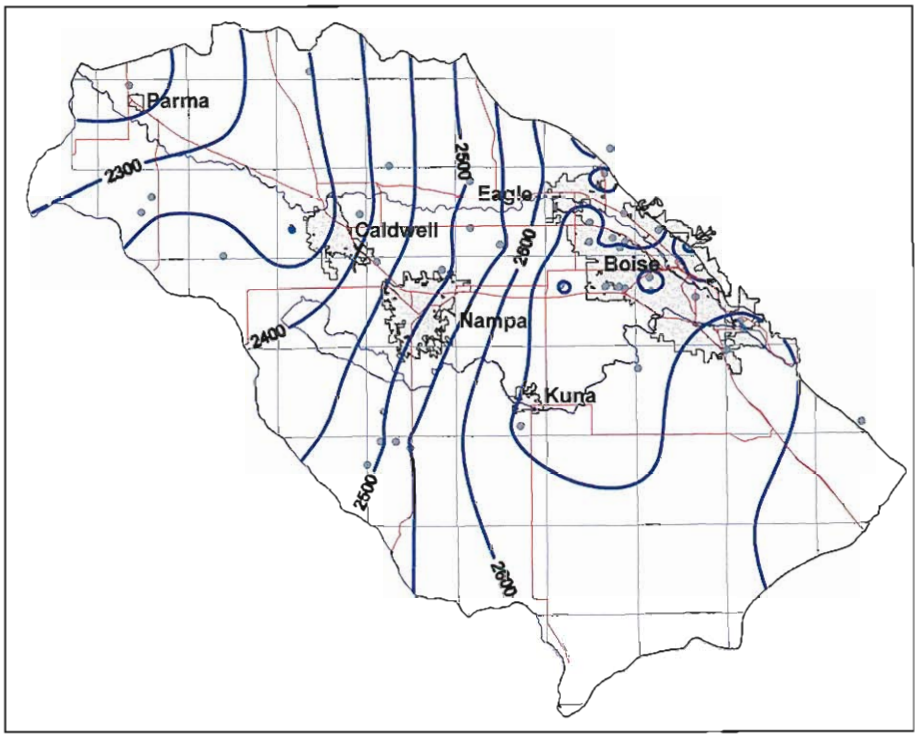


Figure 5-3: Potentiometric surface, spring 1996, deep zone (45 wells).

Additional specific observations include the following:

1. Potentiometric contours from deeper aquifer zones indicate ground water movement in a westerly direction.
2. Potentiometric surface contours in maps indicate ground water mounding in the vicinity of the New York and Mora Canals, presumably from canal leakage (Berenbrock, 1999; Carlson and Petrich, 1998) and infiltration from irrigated fields.
3. Ground water mounding appears in the area northwest of Lake Lowell.
4. Ground water mounding appears to form a ground water divide between the Boise and Snake Rivers along the New York and Mora Canals, and extending northwest from Lake Lowell. North of these canals ground water flows toward the Boise River, south of these canals hydraulic gradients indicate ground water flow toward the Snake River. The effects of ground water mounding underneath the New York Canal are evident in both the potentiometric surfaces based on shallow and deeper wells, although water from the New York Canal is not reaching these lower zones (Hutchings and Petrich, 2002b).
5. The potentiometric surface maps indicate ground water movement from the Boise Foothills in a west-southwest direction toward the Boise River.

5.2.3. Seasonal Water Level Changes

Seasonal water level changes occur in the Treasure Valley in response to ground water withdrawals, surface irrigation, and canal leakage. Figure 5-4 illustrates seasonal water level changes between spring and fall 1996. The map was prepared by subtracting fall potentiometric surface in the shallow zone from that of the spring potentiometric surface in the shallow zone. The map indicates general ground water level increases (in the uppermost aquifer zone) in the central portion of the valley south of the Boise River. These rises were attributed to infiltration associated with summer irrigation. Ground water declines are indicated in the southwestern portion of the valley, though these declines appear to be associated with select wells and may not necessarily reflect regional trends.

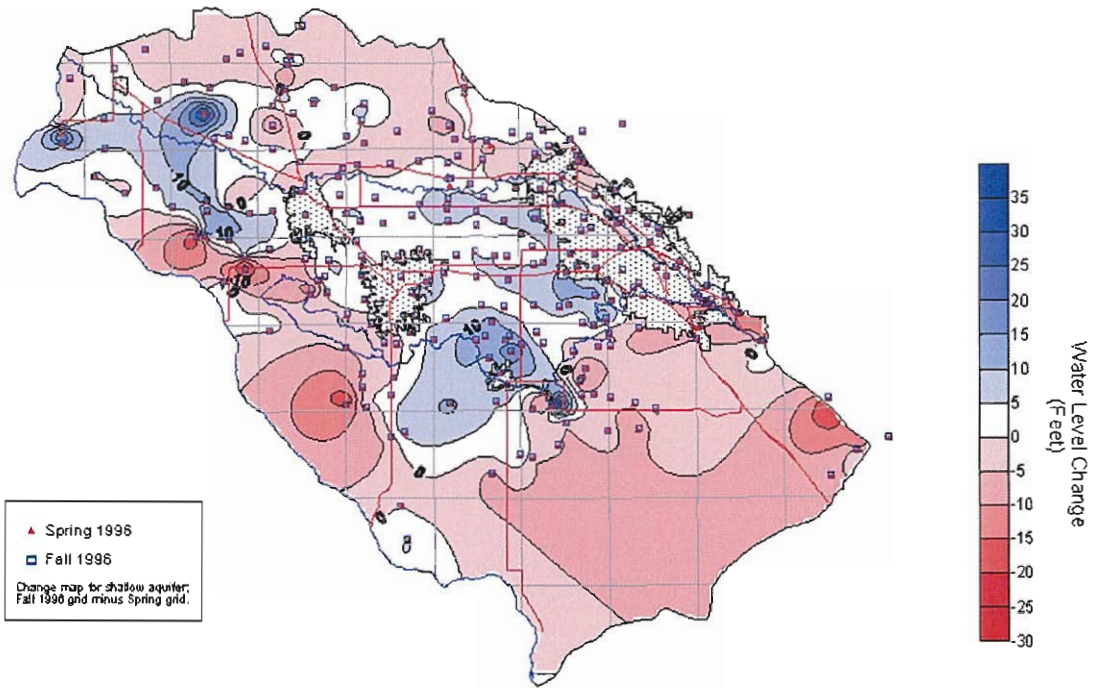


Figure 5-4: Spring and fall 1996 change map.

The reliability of the water level change map is limited by the reliability of the spring and fall water level interpolations. The interpolations, and comparisons based on interpolations, may contain substantial error, especially in areas containing few data points (such as areas along the periphery of the project area).

5.3. Periodic Ground Water Level Monitoring

Monthly, quarterly, or semi-annual ground water level measurements were made in a variety of Treasure Valley wells. The monitoring network and monitoring results are described in the following sections.

5.3.1. Well Network Description

The TVHP monitoring well network consisted of approximately 72 wells[12]. The purpose of the periodic measurements was to provide a basis for (1) evaluating seasonal fluctuations in water levels and (2) establishing long-term water level trends. The wells were measured on a monthly basis from 1996 through 2001, and measured on a quarterly basis thereafter. The locations of the monthly monitoring wells are shown in Figure 5-5. Well construction details for these wells are provided in Appendix D.

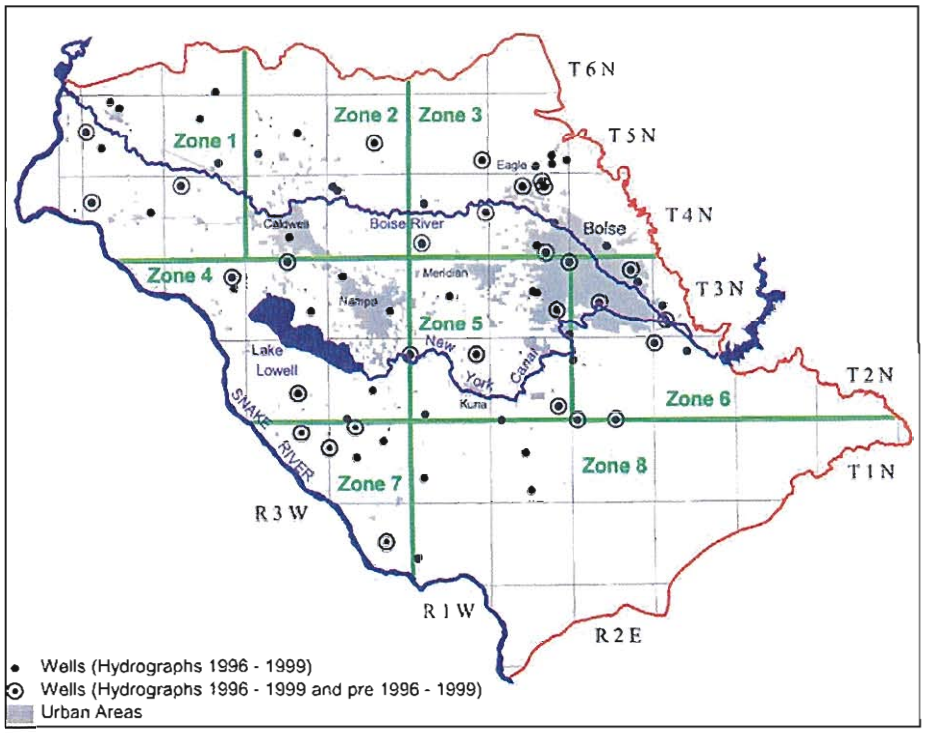


Figure 5-5: Locations of hydrograph wells

[12] These wells were also included in the mass measurements described in Section 5.2.

Thirty of the TVHP monitoring wells have been monitored cooperatively by the IDWR and the USGS since the 1950s. Water levels in these wells (referred to as "co-op wells") were measured primarily on a semi-annual basis, although a few of the wells were measured more frequently. The measurement frequency in these wells was increased to a monthly basis in 1996 as part of the TVHP.

Forty-two wells were added to the monthly measurement program in 1996. The 42 monitoring wells were selected from 305 wells measured in the spring 1996 mass water-level measurement. Criteria for selecting the additional monitoring wells included

1. Spatial distribution throughout project area
2. Available drillers' report
3. Reasonably detailed lithologic log
4. Discrete open interval, preferably corresponding with specific aquifer depths
5. Access to well by USGS, IDWR, or other personnel for conducting measurements

5.3.2. Hydrographs

Water level measurements from these wells were used to construct well hydrographs. Hydrographs from the TVHP monthly monitoring wells for April 1996 through December 2002 are presented in Appendix F. These hydrographs are organized by area for convenience (Figure 5-5). Hydrographs from wells with a longer sampling record (long-term "co-op" wells) are also presented in Appendix F.

Hydrograph data indicate that (1) water levels in many parts of the valley appear to be relatively stable, but water level declines have occurred in some areas; (2) long term water level increases have occurred in some areas; and (3) most wells fluctuate on a seasonal basis. The seasonal variations can be caused by pumping, recharge, or both.

In general, water levels in many parts of the valley appear to be relatively stable from year to year. Some of the stability reflects shallow water levels in the central and western parts of the valley that are being controlled by topography (e.g., the elevations of canals and drains). There are, however, a number of wells that have experienced increasing or decreasing water levels (Table 5-3). Of the 32 wells with long-term data records, approximately 13 showed water level decreases and 5 showed increases (the rest were relatively stable)[13]. Of the 71 wells with short-term records (which includes all of the wells with long-term records), approximately 24 showed some amount of

[13] The number of wells showing water level increases or decreases is somewhat subjective.

water level decrease and 8 showed increases. The greatest declines have occurred in the area south of Lake Lowell (declines of about 65 feet) and southeast Boise (declines of 30 feet). Water levels in several intermediate and deep wells have declined in areas 3 and 5 (Figure 5-5 and Appendix F), which represent the central portion of the basin (west Boise, Eagle, Meridian, and Kuna).

The wells showing water level increases or decreases (Table 5-3) may or may not reflect regional conditions. For example, increased withdrawals from an extraction well used for monitoring (or a nearby pumping well) may cause an apparent local decline that does not reflect regional water levels. A field survey of select wells (Figure 5-6) was conducted during August 1999 to determine the possible cause of the water level changes. Each well was visited and any obvious changes in land use that may have contributed to the observed water level changes were noted. Appendix G contains hydrographs for these wells, including a brief description of what may have contributed to the observed water level changes. In most cases, wells displaying decreasing trends are located in areas that appeared to be undergoing transitions from flood irrigated farmland to residential development. It is unclear whether observed drawdowns in these areas reflect local equilibria required for increased withdrawals or regional ground water level declines. Additional monitoring is recommended in these areas using non-pumping wells.

	Area (see Figure 3-7)	Total Number of Wells in Area	Number of Wells with Increasing Water Level (categorized by total well depth below ground surface)			Number of Wells with Decreasing Water Level (categorized by total well depth below ground surface)		
			0-200'	200-400'	>400'	0-200'	200-400'	>400'
Long-Term Data Record (> 7 years)	1&2	4		1		1		
	3	9				3	3	1
	4	3				1		
	5	5				1	1	2
	6	6			2	1		
	7 & 8	5			2			
Total number of wells		32		1	4	6	4	3
Short-Term Data Record (~7 years)	1	10				1		
	2	6			1	2		
	3	15				5	1	3
	4	9		1	1	3		
	5	11				3	4	
	6	10		2	2		1	
	7	5			1			1
	8	5						
Total number of wells		71		3	5	14	6	4

Table 5-3: Approximate number of monitoring wells with increasing or decreasing water levels.

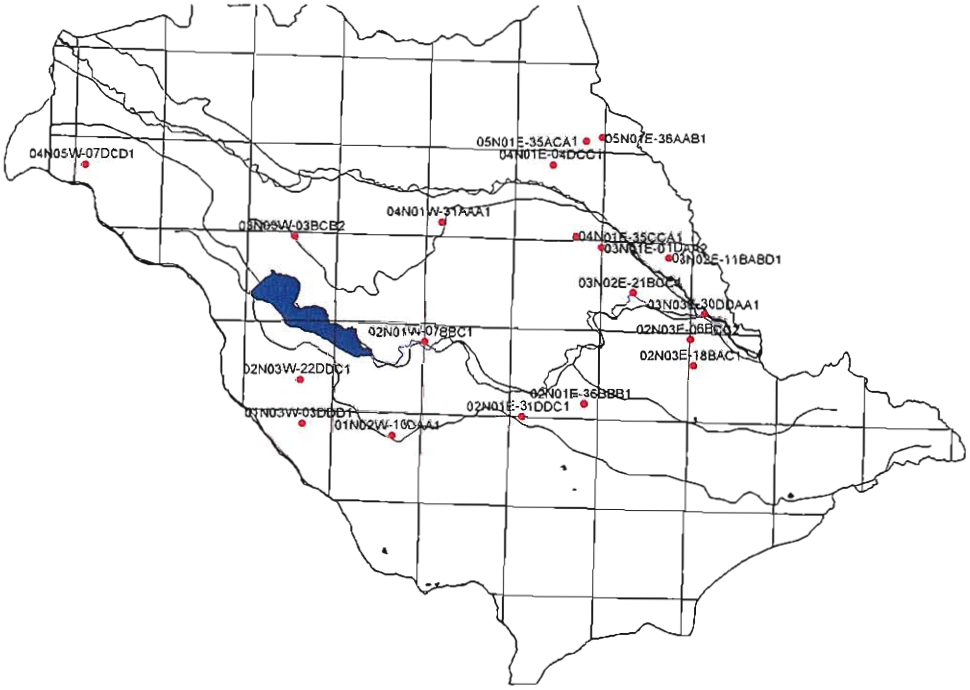


Figure 5-6: Locations of wells showing substantial water level changes.

6. AQUIFER INFLOWS AND OUTFLOWS

6.1. Introduction

An annual water budget was prepared for the Treasure Valley aquifer system for the calendar year 1996 (Urban and Petrich, 1998). The water budget provides an estimate of the current balance between total aquifer withdrawals and discharge, aquifer recharge, and changes in aquifer storage. Specific objectives for this water budget were to (1) define major water budget components, (2) estimate inflows and outflows for the Treasure Valley aquifer systems, (3) describe, where possible, the spatial characteristics of inflows and outflows, (4) create GIS coverages of the water budget data, and (5) create input files (e.g., recharge, withdrawals and ET) for the Treasure Valley ground water flow model. A revised 1996 water budget was completed more recently (Urban, 2004) and also includes a water budget for the year 2000.

6.2. 1996 Water Budget

Inflows to the Treasure Valley aquifer system include (1) seepage from canals and irrigated fields, (2) seepage from rivers and streams, (3) seepage from Lake Lowell, (4) underflow, (5) infiltration of precipitation and surface water, and (6) seepage from rural domestic septic systems. Outflows include (1) municipal withdrawals, (2) industrial withdrawals, (3) irrigation withdrawals, (4) rural domestic withdrawals, (5) stock withdrawals, (6) discharge to canals, drains, and rivers, and (7) evapotranspiration.

Total inflow (Table 6-1) into the Treasure Valley aquifer system was estimated to be 1,035,000 acre-feet (af) in 1996, while total outflow was estimated to be 999,000 af. The net difference shows an apparent increase in aquifer storage of 36,000 af. This difference is less than 4% of the total recharge or discharge and is well within the estimated margin of error of individual component estimates.

The largest source of estimated ground water recharge was seepage from the canal system, followed by seepage from flood irrigation and precipitation. The aggregate discharge to the Boise and Snake Rivers (through canals, drains, or direct discharge) is far greater than all withdrawals combined. On a valley-wide basis, the volume of annual ground water withdrawals represents approximately 20% of the total 1996 ground water recharge (Table 6-1).

Sources of Recharge and Discharge	Estimated Recharge/Discharge for 1996	
Recharge[1]	**acre-feet**	**Percent of Total**
Canal Seepage	637,000	61
Seepage from Rivers and Streams	16,000	1
Seepage from Lake Lowell	19,000	2
Underflow	8,000	1
Flood Irrigation and Precipitation[2]	302,000	30
Recharge by Other Land Uses[3]	48,000	4
Rural Domestic Septic Systems	5,000	<1
Total Recharge[1]	1,035,000	
Discharge		
Domestic and Industrial Withdrawals	66,000	6
Municipal Irrigation	10,000	1
Self-Supplied Industrial	21,000	2
Agricultural Irrigation	72,000	7
Rural Domestic Withdrawals	27,000	2
Stock Watering	3,000	<1
Discharge to Rivers and Drains	800,000	81
Total Discharge	999,000	
Net Difference[4]	+36,000	

1. See text for explanations; values shown in this table are rounded to the nearest 1,000 acre-feet.
2. Includes recharge from precipitation and irrigation on flood-irrigated lands only.
3. Includes recharge from precipitation by land use; does not include flood-irrigated land.
4. Because of the error associated with the individual water budget components, a positive net difference does not necessarily indicate a positive change in aquifer storage.

Table 6-1: Summary of recharge and discharge estimates contained in the 1996 water budget.

Primary ground water withdrawal and recharge areas do not necessarily coincide throughout the valley. The primary recharge areas are those with extensive canals and/or flood irrigation, while the greatest withdrawals occur in areas that are not flood irrigated. For example, agricultural irrigation withdrawals (non-supplemental) are concentrated in areas where surface water irrigation is unavailable, and municipal withdrawals are concentrated near the urban areas of Boise, Nampa, Caldwell, and Meridian. As a result, withdrawals may exceed recharge in local areas within the Treasure Valley, resulting in local water level declines. Water level increases were noted in areas where recharge appears greater than local withdrawals.

The aggregate nature of the water budget masks the differences between inflows to and outflows from individual aquifer zones. Much of the inflow may only recharge shallow aquifers; recharge to deeper zones depends on local vertical hydraulic gradients and aquifer material properties. Recharge to deeper zones is estimated to be a small portion of the total aquifer inflows (Petrich, 2004a).

The aggregate nature of the water budget also masks the temporal characteristics of ground water recharge, withdrawals, and natural discharge. Infiltration from the

surface water distribution system and irrigation occurs primarily in the summer. The actual aquifer recharge from irrigation activities lags the initial infiltration, thus water levels may be rising months after irrigation has ceased. Municipal withdrawals also vary throughout the year but are generally greatest during the summer irrigation season.

Several general conclusions were drawn from this 1996 water budget:

1. The largest components of aquifer recharge in the Treasure Valley are seepage from the canal system and infiltration associated with irrigated agriculture.
2. Discharge to rivers, drains, and canals is the largest source of discharge from the Treasure Valley aquifer system.
3. Overall, aggregate aquifer recharge to the Treasure Valley aquifer system appears to be in dynamic equilibrium with the aggregate aquifer discharge. The net difference between estimated recharge and discharge is well within the error range of the large water budget components and is therefore negligible.
4. Recharge to shallow Treasure Valley aquifers is influenced significantly by land use (by the location of irrigation activities).

7. TREASURE VALLEY GROUND WATER FLOW CHARACTERISTICS

This section presents a summary of ground water flow in the Treasure Valley based on the descriptions of aquifer characteristics (Section 3, page 13), water level measurements (Section 5, page 36), and inflows and outflows (Section 6, page 46). This summary represents a "conceptual model" of ground water flow in the basin that was the basis for a series of aquifer simulations (Petrich, 2004a; 2004b).

The Treasure Valley aquifer system is comprised of a complex series of interbedded, tilted, faulted, and eroded sediments extending to depths of over 6,000 feet in the deepest parts of the basin (Wood and Clemens, in press). The valley contains shallow, local flow systems (with ground water residence times ranging from years to hundreds of years) and a deep, regional flow system (with residence times ranging from hundreds to tens of thousands of years). Few water wells extend beyond a depth of about 1,200 feet.

The Treasure Valley sedimentary section reflects a history of lacustrine, deltaic, fluvial, and alluvial deposition (see Section 3.3). In general, basin sedimentary deposits grade from coarser, more permeable sediments near the Boise Front to finer, less permeable sediments at the distal end of the basin. At the basin scale, sediments also grade finer with depth. Highly permeable deposits associated with deltaic and/or fluvial deposition are often sandwiched between lacustrine deposits of lower permeability.

Ground water flow in the Treasure Valley is controlled by aquifer characteristics and hydraulic gradient. Aquifer characteristics influencing ground water flow include grain size, sorting, stratigraphic layering, sedimentary layer dip, sediment grain cementation, and the degree of fracturing (in basalt aquifers). Additional controls on the movement of ground water are attributed to structural processes, including faulting throughout the basin and along the basin margin. A series of southeast-northwest trending faults dissect the valley, with stratigraphic offsets of several hundred feet or more. Analyses of aquifer test data from southeast Boise (West and Osiensky, 1999) indicate negative boundary conditions associated with faults in the southeast Boise area. Artesian conditions just north of the Boise River in the vicinity of monitoring well TVHP #1 may be created in part by restricted flow across the Eagle–West Boise Fault Zone (Figure 3-2). Ground water chemistry data (Hutchings and Petrich, 2002a) indicate different ground water chemistry north of the fault zone compared to the area south of the fault zone, suggesting restricted flow across the fault zone. Basin downwarping and an associated downslope trend in sediment deposition contribute to steeply dipping sedimentary deposits that may cause deeper aquifer units to pinch out at depth (Wood, 1997a). Based on seismic imaging and outcrop mapping, aquifer sediments of various fault blocks are dipping at angles ranging from zero to approximately 12 degrees (Wood, 1997a).

Fractures within shallow Pleistocene basalts or along upper and lower surfaces of individual basalt flows can contribute to ground water movement. For instance, basalt fractures and course-grained sediments underlying the basalt may greatly contribute to transmitting leakage from the New York Canal (and other surface water channels) into shallow aquifers.

An erosional unconformity associated with changing lake levels in Pliocene Lake Idaho truncates down-dipping units near the basin margin near Boise (Squires and Wood, 2001; Squires et al., 1992; Wood, 1997a). The unconformity separates lacustrine and deltaic sediments (tilted in the Boise area) from overlying lacustrine/deltaic sediments. Coarse-grained sediments associated with the erosional unconformity (Squires et al., 1992; Wood, 1997a) appear to serve as a manifold for deeper, regional ground water migrating horizontally into the basin from alluvial fan sediments in the eastern portion of the basin (corroborated by E. Squires, pers. comm., 2002).

Potentiometric surface contours indicate ground water movement in a westerly to southwesterly direction, depending on depth and location (Section 5.2.2, page 38). Potentiometric surface contours in shallow aquifer zones reflect surface hydrologic conditions, such as mounding under the New York and Mora Canals (e.g., Figure 5-1) or discharge to the Boise River. The mounding in the vicinity of the New York Canal represents a local ground water divide, with shallow ground water north of the canal flowing toward the Boise River and shallow ground water south of the canal flowing toward the Snake River. Potentiometric surface contours from shallow aquifers show ground water flow toward and discharge to the Boise River in mid- to lower reaches. Potentiometric surface contours in deeper zones indicate a more uniform westerly flow direction (Section 5.2.2, page 38). Downward hydraulic gradients are indicated along the Boise Foothills, the eastern part of the study area (see TVHP #4 well in Figure 4-5), and in the vicinity of the New York and Mora Canals. Upward gradients are evident in the central and western portions of the valley (see TVHP #2 hydrographs in Figure 4-3) and in the vicinity of the Boise River.

Individual hydrographs (Section 5.3 and Appendix F) indicate relatively stable water levels in many areas, although water level declines have occurred in a number of wells. Wells in two areas, southeast Boise (e.g., well 03N03E-30DDAA1) and south of Lake Lowell (e.g., well 03N04W-11ADA1), have experienced declines of approximately 30 feet and 65 feet, respectively. Water levels in these areas appear to have stabilized in recent years.

Additional ground water level declines were observed (Appendix F and Table 5-3) in areas 3 (northwest Boise and Eagle, Figure 5-5) and 5 (southwest Boise, Meridian, and Kuna). Most of the long-term declines in these wells have been less than 10 feet. Reasons for the declines may include increased withdrawals from the measured wells

(very few of the monitoring wells are dedicated to monitoring alone), increased nearby withdrawals, and/or changes in local infiltration rates (Appendix G). Further investigation of these apparent declines is warranted to determine if they reflect regional or local conditions. Additional monitoring wells would also be warranted in these areas of apparent declines.

A number of shallow monitoring wells indicated water level decreases (Table 5-3). Shallow wells may be especially sensitive to changes in local surface water irrigation patterns in areas where the water table is not in direct hydraulic connection with surface channels. Ground water level changes are less likely in shallow wells in areas where the water table is controlled by topography (by virtue of drains and canals).

Seasonal water level fluctuations are evident in many Treasure Valley wells. The fluctuations generally are a response to seasonal increases in withdrawals (e.g., summer irrigation withdrawals) or increases in recharge associated with surface water irrigation.

The largest component of recharge to shallow aquifers is seepage from the canal system and infiltration associated with irrigated agriculture (Urban, 2004; Urban and Petrich, 1998). Water enters shallow aquifers as infiltration from canals, irrigated areas, and other water bodies (e.g., Lake Lowell), and possibly from upper reaches of the Boise River (e.g., Barber Dam to Capitol Street Bridge) during high flows. Infiltration from surface channels occurs if and when (1) water is available and (2) hydraulic heads in the channel (or lake) are higher than the surrounding aquifer heads. Additional recharge sources include mountain front recharge, underflow from the granitic Idaho Batholith and tributary sedimentary aquifers, and direct precipitation.

Shallow aquifer levels increased by as much as 100 feet in some areas in response to the initiation of large-scale flood irrigation in the late 1800s and early 1900s. Shallow ground water levels rose to and remained at (or near) ground surface in many areas (at least seasonally), discharging to drains and other surface channels.

Shallow and intermediate aquifers are separated from deeper zones by interbedded silt and clay layers in many parts of the valley. While individual clay layers are not necessarily areally extensive, multiple clay layers in aggregate form effective barriers to vertical ground water movement.

Recharge to the deeper aquifers begins as downward flow through coarse-grained alluvial fan sediments in the eastern portion of the basin and as underflow at basin margins. Ground water is then thought to flow horizontally into the basin via more permeable sediments (e.g., coarse-grained sediments of the geological unconformity overlying Chalk Hills sediments), intersecting the alluvial fan sediments.

This is illustrated in water chemistry data collected from shallow aquifers near the New York Canal. Water in the canal, as in upper portions of the Boise River, has relatively low specific conductance (and by inference, total dissolved solids). In shallow aquifers underlying the canal, specific conductance was found to increase with depth, corresponding with canal water that has infiltrated through soil horizons. In contrast, water in deeper sand units separated from upper zones by multiple clay layers has lower specific conductance than water in overlying horizons (Hutchings and Petrich, 2002a; Hutchings and Petrich, 2002b). This finding indicates that water in at least some deeper aquifers originates at the basin margins and does not enter the ground water regime through the carbon-rich sediments found in Treasure Valley soils.

Residence times of Treasure Valley ground water were generally found to increase with depth and distance along a regional east-to-west-trending flow path (Hutchings and Petrich, 2002a). Residence time estimates ranged from thousands to tens of thousands of years. The youngest waters entered the subsurface a few thousand years ago and were found along the northeastern boundary of the basin, adjacent to the Boise Foothills. The oldest waters entered the subsurface between 20,000 and 40,000 years ago and were found in the western reaches of the basin near the Snake River. Ground water in the deep deltaic aquifers beneath Boise entered the subsurface between 10,000 and 20,000 years ago.

Comparisons between measured water chemistry constituents and established models of geochemical processes (Hutchings and Petrich, 2002a) show that (1) ground water near the northeastern basin margin has experienced little interaction with aquifer minerals, and (2) ground water beyond the northeastern basin margin has experienced substantial interaction with aquifer minerals. Geochemical evolution of Treasure Valley ground water appears to be influenced by solution of both carbonate and silicate minerals.

Ground water discharge to rivers, drains, and canals represents the dominant form of discharge from the Treasure Valley aquifer system (Urban and Petrich, 1998). The primary form of natural discharge from the deeper aquifers is thought to be regional upwelling in the southern and western portions of the basin, with ultimate discharge to the Boise River and/or Snake River. Rates of discharge from the deeper aquifers in the western portions of the valley are unknown but are probably low because of the thick accumulation of lacustrine clays separating these aquifers from ground surface.

Relatively long residence times in the regional flow system (over 20,000 years) implies that (1) regional aquifers are not very transmissive, (2) recharge rates to the deeper regional aquifers are very limited, and/or (3) regional aquifers are discharge-limited. Although there are abundant silt and clay layers with low hydraulic conductivity, productive sand layers are present throughout central portions of the valley; these sand zones are tapped by many irrigation and municipal wells. Recharge to the deeper,

regional system is limited but has generally been sufficient for current rates of withdrawal. Thick lacustrine clays at the distal end of the valley likely inhibit upward (discharge) flow, limiting the amount of water that can flow through the system.

In summary, the Treasure Valley aquifer system consists of shallow aquifers containing local ground water flow systems and a deeper, regional ground water flow system. Recharge to the shallow system consists largely of infiltration from irrigated fields and canals. Primary discharge is to the Boise and Snake Rivers and other streams and to drains discharging into these channels. The deeper, regional flow system consists of (1) recharge in alluvial sediments in southeast Boise and at the base of the mountain front north of Boise, (2) movement of ground water from the recharge areas into the deeper Boise area fluvio-lacustrine aquifers, and (3) movement of ground water from the Boise area aquifers into regional lacustrine/deltaic aquifers in the central and western portions of the valley.

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Appendix A. CONVERSION FACTORS

Volume

1 cubic foot of water = 7.4805 gallons = 62.37 pounds of water

1 acre-foot (af) = enough water to cover 1 acre of land 1 foot deep

1 acre-foot (af) = 43,560 cubic feet

1 acre-foot (af) = 325,850 gallons

1 million gallons = 3.0689 acre-feet

Flow Rates

1 cubic foot per second (cfs) = 448.83 gallons per minute (gpm) = 26,930 gallons per hour

1 cubic foot per second (cfs) = 646,635 gallons per day = 1.935 acre-feet per day

1 cubic foot per second (cfs) for 30 days = 59.502 acre-feet

1 cubic foot per second (cfs) for 1 year = 723.94 acre-feet

1 cubic meter per second (cms) = 25.31 cubic feet per second

1 cubic meter per second (cms) = 15,850 gallons per minute

1 million gallons per day (mgd) = 1,120.147 acre-feet per year

1 miner's inch = 9 gallons per minute

1 miner's inch = 0.02 cubic feet per second

Hydraulic Conductivity

1 gallon per day per foot^2 (gal/day/ft^2) = 0.134 foot/day = 0.0408 meters/day

Economic

$0.10 per 1,000 gallons = $32.59 per acre-foot

Appendix B. AQUIFER TEST DATA

This appendix contains selected aquifer test data (compiled by Rick Carlson, formerly with the Idaho Water Resources Research Institute). References for the aquifer test data are listed beginning on page 81.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANSMISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC CONDUCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
New Playground Well	3N2E9DC	260	111 - 260	m	1145	pumping well	early	13,200	150	88	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	A step test was completed
New Playground Well	3N2E9DC	260	111 - 260	m	1145	pumping well	late	16,000	150	107	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	
New Playground Well	3N2E9DC	260	111 - 260	m	1145	obs. well 1 (80ft)	early	12,300	150	82	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	
New Playground Well	3N2E9DC	260	111 - 260	m	1145	obs. well 1 (80ft)	late	18,300	150	122	8E-04	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	
New Playground Well	3N2E9DC	260	111 - 260	m	1145	obs. well 2 (1700ft)	early	***	150		***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	
New Playground Well	3N2E9DC	260	111 - 260	m	1145	obs. well 2 (1700ft)	late	23,000	150	153	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	T for this well is suspect.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
New Playground Well	3N2E9DC	260	111 - 260	m	1145	obs. well 3 (2000ft)	early	***	150	***	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	
New Playground Well	3N2E9DC	260	111 - 260	m	1145	obs. well 3 (2000ft)	late	***	150	***	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	med. Sand	2/13/92	1	
New Ball Diamond Well	3N2E9DD	435	186-396	m	1200	obs. well 1	early	58,000	150	387	***	31.0	constant rate pump test, Jacobs Semi-log Drawdown Method	24	med. Sand	3/2/92	2	
New Ball Diamond Well	3N2E9DD	435	186-396	m	1200	obs. well 1	late	13,000	150	87	7E-04	31.0	constant rate pump test, Jacobs Semi-log Drawdown Method	24	med. Sand	3/2/92	2	
New Ball Diamond Well	3N2E9DD	435	186-396	m	1200	obs. well 2	early	***	150	***	8E-04	31.0	constant rate pump test, Jacobs Semi-log Drawdown Method	24	med. Sand	3/2/92	2	High, late, T values suggest hydraulic boundaries
New Ball Diamond Well	3N2E9DD	435	186-396	m	1200	obs. well 2	late	13,000	150	87	***	31.0	constant rate pump test, Jacobs Semi-log Drawdown Method	24	med. Sand	3/2/92	2	

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
New Ball Diamond Well	3N2E9DD	435	186-396	m	1200	obs. well 3	early	***	150	***	3E-04	31.0	constant rate pump test, Jacobs Semi-log Drawdown Method	24	med. Sand	3/2/92	2	
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	pumping well	early	11,986	160	***	***	10.3	constant rate pump test, Jacobs Semi-log Drawdown Method	720	fine sand to course sand	3/26/91	3	Early T believed to be affected by casing storage.
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	pumping well	late	143,749	160	898	***	10.3	constant rate pump test, Jacobs Semi-log Drawdown Method	720	fine sand to course sand	3/26/91	3	
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	obs. well 1 (900ft)	late	83,350	160	521	0.019	10.3	constant rate pump test, Chow Semi-log Time Drawdown Method	720	fine sand to course sand	3/26/91	3	
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	obs. well 2 (1300ft)	early	553,418	160	3459	0.02	10.3	constant rate pump test, Chow Semi-log Time Drawdown Method	720	fine sand to course sand	3/26/91	3	High T from gravity drainage effects
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	obs. well 4 (2500ft)	early	681,132	160	4257	0.005	10.3	constant rate pump test, Chow Semi-log Time Drawdown Method	720	fine sand to course sand	3/26/91	3	High T from gravity drainage effects

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft²)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	obs. well 4 (2500ft)	late	219,720	160	1373	0.017	10.3	constant rate pump test, Chow Semi-log Time Drawdown Method	720	fine sand to course sand	3/26/91	3	
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	obs. well 5 (3700ft)	early	315,339	160	1971	0.017	10.3	constant rate pump test, Chow Semi-log Time Drawdown Method	720	fine sand to course sand	3/26/91	3	
Floating Feather Hills Well	4N1E3CCC	415	215-265, 375-385	m	743	obs. well 5 (3700ft)	late	287,490	160	1797	0.006	10.3	constant rate pump test, Chow Semi-log Time Drawdown Method	720	fine sand to course sand	3/26/91	3	
Broadway Well	3N2E22DD	532	250-524	m	2975	pumping well	no		225	***	***	66.0	constant rate pump test, Jacobs Semi-log Drawdown Method	6	sand	7/20/72	4	
Redwood Creek Subdivision Well No. 1	4N1E7BD	415	298-313, 361 - 401	m	2100	pumping well	no	55,000	200	275	***	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8.5	course sand to gravel	4/7/94	5	Artesian - static water level is 5 feet above ground surface.
Redwood Creek Subdivision Well No. 1	4N1E7BD	415	298-313, 361 - 401	m	2100	obs. well 1 (2600ft)	no	154,000	200	770	2E-04	24.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8.5	course sand to gravel	4/7/94	5	

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Willow Lane Well Field	4N2E32BCB	90	unkn own	m	1400	yes	no	274,000	90	3044	0.02	23.0	constant rate pump test, Jacobs Semi-log Drawdown Method	72	course sand to gravel	9/14/62	6	9 observation wells were monitored.
Veterans Well	4N2E32DDC	275	150-275	m	800	pumping well	yes	***	125	***	***	12.3	constant rate pump test, Jacobs Semi-log Drawdown Method	94	course sand to gravel	5/10/96	7	Unclear if time drawdown measurements were recorded from observation wells.
Veterans Well	4N2E32DDC	275	150-277	m	800	obs. well	late	10,036	125	80	***	12.3	constant rate pump test, Jacobs Semi-log Drawdown Method	94	course sand to gravel	5/10/96	7	Unclear if time drawdown measurements were recorded from observation wells.
Gary Lane Well	4N2E24DBA	837	742-837	m	600	pumping well	yes	***	100	***	***	7.8	constant rate pump test, Jacobs Semi-log Drawdown Method	34	course sand to gravel	3/23/96	8	Unclear if time drawdown measurements were recorded from observation wells.
Gary Lane Well	4N2E24DBA	837	742-837	m	600	obs. well	late	3,955	100	40	***	7.8	constant rate pump test, Jacobs Semi-log Drawdown Method	34	course sand to gravel	3/23/96	8	Unclear if time drawdown measurements were recorded from observation wells.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft²)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Fisk Well	3N2E6DDC1	850	569-589, 604-624, 639-660, 705-715	m	1500	pumping well	no	39,554	145	273	***	68.2	constant rate pump test, Jacobs Semi-log Drawdown Method	7	sand?	1/28/92	9	Aquifer parameters determined from pumping well
Market Well	3N2E35DAD1	944	460-470, 495-515, 600-610, 695-705, 725-735, 760-775, 804-814, 830-840, 892-902	s	1,500	no	no	40,000	440	91	***	40.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	sand?	5/28/91	10	Aquifer parameters determined from pumping well
HP Well	4N1E27ADC 1	700	598. 5-685	s	1,400	no	early	29,600	87	340	***	19.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	sand?	5/17/91	11	
HP Well	4N1E27ADC1	700	598. 5-685	s	1,400	no	late	12,300	87	141	***	19.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	sand?	5/17/92	11	Low, late, T values suggest hydraulic barriers.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
New Goddard Well	4N1E36BAC	551	475-545	s	1,714	yes	late	22,000	70	314	***	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	8	sand	2/28/91	12	Low, late, T values suggest hydraulic barriers.
Columbia Test Well	3N3E32CD D1	802	560-575, 628-638, 711-731	s	22	no	early	5,000	150	33	***	3.0	step-rate pump test, Jacobs Semi-log Drawdown Method	4	fine sand	10/5/90	13	Estimated long term yields less than 200gpm.
Columbia Test Well	3N3E32CD D1	802	560-575, 628-638, 711-731	s	40	no	middle	1,100	150	7	***	3.3	step-rate pump test, Jacobs Semi-log Drawdown Method	4	fine sand	10/5/90	13	
Columbia Test Well	3N3E32CD D1	802	560-575, 628-638, 711-731	s	88	no	late	500	150	3	***	2.1	step-rate pump test, Jacobs Semi-log Drawdown Method	4	fine sand	10/5/90	13	Low, late, T values suggest hydraulic barriers.
Cassia Well	3N2E16DAA1	590	215-241, 285-321, 357-367, 390-400	s	850	no	early	50,000	150	333	***	29.0	constant rate pump test, Jacobs Semi-log Drawdown Method	5.7	unknow n	5/29/90	14	T values may have decreased with longer pump test.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Cassia Well	3N2E16DAA1	590	215-241, 285-321, 357-367, 390-400	s	850	no	late	40,000	150	267	***	29.0	constant rate pump test, Jacobs Semi-log Drawdown Method	5.7	unknown	5/29/90	14	T values may have decreased with longer pump test.
Bergeson Well	3N2E26DAB 1	852	?	m	1200	pumping well	early	60,000	385	156	***	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12	?	2/13/90	16	S.C. Determined from step-rate pump test.
Bergeson Well	3N2E26DAB 1	852	?	m	1200	pumping well	late	25,000	385	65	***	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12	?	2/13/90	16	S.C. Determined from step-rate pump test.
Bergeson Well	3N2E26DAB 1	852	?	m	1200	obs. well 1	early	150,000	385	390	0.005	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12	?	2/13/90	16	Storativity value is suspect.
Bergeson Well	3N2E26DAB 1	852	?	m	1200	obs. well 1	late	60,000	385	156	0.005	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12	?	2/13/90	16	Storativity value is suspect.
Bergeson Well	3N2E26DAB 1	852	?	m	1200	obs. well 2	no	40,000	385	104	4E-04	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12	?	2/13/90	16	

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Bergeson Well	3N2E26DAB 1	852	?	m	1200	obs. well 3	no	40,000	385	104	2E-04	15.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12	?	2/13/90	16	
Clinton Street Well	3N2E8CBB1	485	?	s	1500	pumping well	late	13,000			***	18.9	constant rate pump test, Jacobs Semi-log Drawdown Method	9	?	2/8/91	17	Short term S.C averaged 27 gpm/ft.
Yanke-Nicholson North Well	2N2E17AAD 1	880	537-692, 697-860	s	1500	pumping well	no	29,000	320	91	***	30.0	constant rate pump test, Jacobs Semi-log Drawdown Method	120	sand, clay, gravel	11/16/90	18	S.C. is suspect because of discrepancies in static water level.
J.R. Flat Test Well	2N2E2BBC2	567		s	725	pumping well	early	8,500					constant rate pump test, Jacobs Semi-log Drawdown Method	0.3		7/28/89	19	
J.R. Flat Test Well	2N2E2BBC2	567		s	815	pumping well	late	25,000					constant rate pump test, Jacobs Semi-log Drawdown Method	6		7/28/89	19	
New Long Meadow Well	3N2E?13BC B1	415	123-401	m	1775	pumping well	early	62,000	278	223	***	32.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/14/89	20	Pumping well was determined to have high efficiency.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
New Long Meadow Well	3N2E?13BC B2	415	123-401	m	1775	pumping well	late	31,000	278	112	***	32.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/14/89	20	Pumping well was determined to have high efficiency.
New Long Meadow Well	3N2E?13BC B3	415	123-401	m	1175	obs. well 2	no	43,000	278	155	***	32.0	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/14/89	20	Pumping well was determined to have high efficiency.
Swift No. 2 Well	4N2E30DC2			m	2200	pumping well	early	100,000			***	32	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/11/89	21	
Swift No. 2 Well	4N2E30DC2			m	2200	pumping well	middle	30,000			***	32	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/11/89	21	
Swift No. 2 Well	4N2E30DC2			m	2200	pumping well	late	15,000			***	32	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/11/89	21	
Swift No. 2 Well	4N2E30DC2			m	2200	obs. well	early	100,000			0.001	32	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/11/89	21	

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Swift No. 2 Well	4N2E30DC2			m	2200	obs. well	middle	35,000			0.001	32	constant rate pump test, Jacobs Semi-log Drawdown Method	12		3/11/89	21	
Londoner Well	3N2E?23BA A1	?1200		s	55	pumping well	early-deep zone (810-875)	8,500	65	131	***	***	step rate pump test, Jacobs Semi-log Drawdown Method	6		9/8/88	22	Late, low T values likely due to aquifer thinning.
Londoner Well	3N2E?23BA A1	?1200		s	140	pumping well	late-deep zone (810-875)	2,500	65	38	***	***	step rate pump test, Jacobs Semi-log Drawdown Method	6		9/8/88	22	Late, low T values likely due to aquifer thinning.
Londoner Well	3N2E?23BAA 1	?1200		s	35	pumping well	early-inter-medi-ate zone (650-750)	5,000	100	50	***	***	step rate pump test, Jacobs Semi-log Drawdown Method	4.5		9/2/88	22	Low amount of drawdown likely due to upper zone leakage.
Londoner Well	3N2E?23BAA 1	?1200		s	135	pumping well	late-inter-medi-ate zone (650-750)	5,000	100	50	***	***	step rate pump test, Jacobs Semi-log Drawdown Method	4.5		9/2/88	22	Low amount of drawdown likely due to upper zone leakage.
Londoner Well	3N2E?23BAA 1	?1200		s	82	pumping well	early-upper zone (220-550)	10,000	330	30	***	***	step rate pump test, Jacobs Semi-log Drawdown Method	4		8/19/88	22	

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
River Run Well	3N2E24DB D2	485	198-480	m	1880	pumping well	early	50,000			***		step rate pump test, Jacobs Semi-log Drawdown Method	11		3/11/88	23	Third step of test was used as constant rate pump test (9.5 hours).
River Run Well	3N2E24DB D2	485	198-480	m	1880	pumping well	middle	25,000			***		step rate pump test, Jacobs Semi-log Drawdown Method	11		3/11/88	23	Third step of test was used as constant rate pump test (9.5 hours).
River Run Well	3N2E24DB D2	485	198-480	m	1880	pumping well	late	5,000			***		step rate pump test, Jacobs Semi-log Drawdown Method	11		3/11/88	23	Third step of test was used as constant rate pump test (9.5 hours).
River Run Well	3N2E24DB D2	485	198-480	m	1880	obs. well 1 (100ft)	no	10,000			0.03		step rate pump test, Jacobs Semi-log Drawdown Method	11		3/11/88	23	Third step of test was used as constant rate pump test (9.5 hours).
River Run Well	3N2E24DB D2	485	198-480	m	1880	obs. well 2 (Logger well)	no	7,500			5E-05		step rate pump test, Jacobs Semi-log Drawdown Method	11		3/11/88	23	Third step of test was used as constant rate pump test (9.5 hours).
River Run Well	3N2E24DB D2	485	198-480	M	1880	obs, well 3 (Long Meadow Well)	no	6,000			3E-05		step rate pump test, Jacobs Semi-log Drawdown Method	11		3/11/88	23	Third step of test was used as constant rate pump test (9.5 hours).

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Hidden Hollow Landfill EW-2		58	32-52	m	45	pumping well	no	5,400	18	300	***	10.1	constant rate pump-bailer test, Neuman Method	2.5	fine sand to course sand	4/24/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-2		58	32-53	m	45	obs. well1(10ft)	no	10,900	17	641	0.05	10.1	constant rate pump-bailer test, Nueman Method	2.5	fine sand to course sand	4/24/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-2		58	32-54	m	45	obs. well 2 (160ft)	no	24,400	22	1,109	0.1	10.1	constant rate pump-bailer test, Nueman Method	2.5	fine sand to course sand	4/24/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-3		98	50-70	m	45	pumping well	no	4,300	22	195	***	8.2	constant rate pump-bailer test, Nueman Method	2	fine sand to course sand	4/22/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-3		98	50-71	m	45	obs. well 1 (9ft)	no	10,700	22	486	0.04	8.2	constant rate pump-bailer test, Nueman Method	2	fine sand to course sand	4/22/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-3		98	50-72	m	45	obs. well 2 (136ft)	no	19,300	21	919	0.1	8.2	constant rate pump-bailer test, Nueman Method	2	fine sand to course sand	4/22/97	25	Pumping rate is based on an average of variable pumping rates.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Hidden Hollow Landfill EW-4		78	51-71	m	45	pumping well	no	2,100	20	105	***	4.7	constant rate pump-bailer test, Nueman Method	1	fine sand to course sand	4/28/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-4		78	51-72	m	45	obs. well 1 (12ft)	no	4,200	21	200	0.06	4.7	constant rate pump-bailer test, Nueman Method	1	fine sand to course sand	4/28/97	25	Pumping rate is based on an average of variable pumping rates.
Hidden Hollow Landfill EW-4		78	51-73	m	45	obs. well 2 (80)	no	21,000	22	955	0.002	4.7	constant rate pump-bailer test, Nueman Method	1	fine sand to course sand	4/28/97	25	Pumping rate is based on an average of variable pumping rates.
Allied Seed Coop MW-1	3N2W	21.5	5.0-20.0	s	6	pumping well	no	1,491	11.5	130	***	3.8	constant rate pump test, Jacobs Semi-log Drawdown Method	1	fine sand	7/16/91	26	Short duration pump test with recovery data.
Mark Lynn Stock Water Well	5N1W	429	165-300	m	172	pumping well	no	77,000	135	570	***	***	water level recovery test, Jacobs Semi-log Drawdown Method	120	sand and gravel	10/17/94	27	Domestic pump was pumping intermittently during test.
Mark Lynn Stock Water Well	5N1W	429	165-300	m	172	obs. well (275ft)	no	108,000	135	800	0.01	***	water level recovery test, Jacobs Semi-log Drawdown Method	120	sand and gravel	10/17/95	27	Domestic pump was pumping intermittently during test.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Westpark Commercial Center Well 9		45	25-45	m	?	pumping well	no	143,100	30	4,770	0.03	***	***	10	gravel	9/1988	28	Several monitoring wells are located at the site.
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	pumping well	late	86,730	23	3,771	0.115	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 1 (125)	early	696,388	23	30,278	0.009	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 1 (125)	late	111,751	23	4,859	0.185	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 2 (157)	early	404,668	23	17,594	0.006	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 2 (157)	late	123,644	23	5376	0.053	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 3 (168))	late	169,870	23	7386	0.027	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 4 (335)	early	***	23	***	***	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
N. Fivemile Extraction Well FMEW-2		67	12.0-65.0	m	82	obs. well 4 (335)	late	165,981	23	7217	0.079	1.5	constant rate pump test, Jacobs Semi-log Drawdown Method	24	gravel	11/16/95	29	Some fluctuation in Q was noted. Specific capacity value is likely attributed to 10% well efficiency.
Caldwell Geothermal Well 1				m	1000	obs. well	no	10,472	23	455	2E-04	38.5	water level recovery test, Theis Drawdown Test Method	3.9	?	8/23/89	30	5 aquifer test periods were completed
Oregon Trail Well	3N3E	838				pumping well		9,000	800	11	***		constant rate pump test, Theis Drawdown Test Method	720		1/13/92	31	
Terteling Production Well	3N2E	642	342-632			obs. well		31,000	300	103	2E-04		constant rate pump test, Theis Drawdown Test Method	720		1/13/92		
Centennial Production Well	3N2E	416				obs. well		31,000	800	39	2E-04		water level recovery test, Theis Drawdown Test Method	720		1/13/92	31	Observation well for Oregon Trail 30 day pump test

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
Gowen Production Well	2N2E	702	375-507			obs. well		45,000	125	360	0.001		water level recovery test, Theis Drawdown Test Method	720		1/13/92	31	Observation well for Oregon Trail 30 day pump test
Micron Test Well	2N3E	855	629-845			obs. well		480,000	215	2,233	0.002		water level recovery test, Theis Drawdown Test Method	720		1/13/92	31	Observation well for Oregon Trail 30 day pump test
Columbia Test Well	3N3E	802				obs. well		30,000	800	38	0.003		water level recovery test, Theis Drawdown Test Method				31	Observation well for Oregon Trail 30 day pump test
Canyon Co Drainage District No. 4	5N4W28CC1				1030						0.025					6/53	32	
Pioneer Irrigation District	4N3W25DA1				1550					5,000	0.004					10/53	32	
Pioneer Irrigation District	4N3W3BB1				2110					23,000	0.23					11/53	32	

COMMENTS						
REFERENCE	32	32	32	32	32	32
START DATE	10/53	10/53	2/53	11/53	9/53	3/51
LITHOLOGY						
DURATION (hours)						
METHOD						
SPECIFIC CAPACITY(gpm/ft)						
STORATIVITY	0.006	0.0006	0.0001	0.003	0.004	
HYDRAULIC COND-UCTIVITY (gpd/ft^2)	25,000		5,900	3,700	18,000	300
Assumed Aquifer Thickness (ft)						
TRANS-MISSIVITY (gpd/ft)						
MULTIPLE TIMES						
MULTIPLE WELLS						
PUMPING RATE (gpm)	2,175	1,480	1,830	1,060	2,900	480
Multiple or Single Well?						
COMPLETION INTERVAL(FT)						
DEPTH OF PUMPING WELL (FT)						
LOCATION	3N3W11DA1	3N2W8CC1	3N2W9DD4	3N1W7BB1	2N1W7BC4	4N1W13DC1
PUMPING WELL NAME	Pioneer Irrigation District	Pioneer Irrigation District	Amal-gamated Sugar	Pioneer Irrigation District	US Bureau of Reclamation	State Fish Hatchery

PUMPING WELL NAME	LOCATION	DEPTH OF PUMPING WELL (FT)	COMPLETION INTERVAL(FT)	Multiple or Single Well?	PUMPING RATE (gpm)	MULTIPLE WELLS	MULTIPLE TIMES	TRANS-MISSIVITY (gpd/ft)	Assumed Aquifer Thickness (ft)	HYDRAULIC COND-UCTIVITY (gpd/ft^2)	STORATIVITY	SPECIFIC CAPACITY(gpm/ft)	METHOD	DURATION (hours)	LITHOLOGY	START DATE	REFERENCE	COMMENTS
State Fish Hatchery	4N1W13DC2				600					660	0.001					3/51	32	
US Bureau of Reclamation	3N1E5AB1				125					900	0.001					11/53	32	
US Bureau of Reclamation	3N1E5AB1				600					2,400	0.006					11/53	32	
M.S. Ayres	3N1E36AD2				980					1,500	0.00007					9/53	32	
Ada Co Drainage District No. 2	3N2E25BB1				1,380					2,500	0.43					11/53	32	

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Appendix C. CONSTRUCTION DETAILS FOR DEDICATED, MULTI-LEVEL PIEZOMETERS

*** Construction diagrams for TVHP monitoring wells provided under separate cover. ***

Appendix D. CONSTRUCTION AND MEASUREMENT DETAILS FOR MASS MEASUREMENT WELLS

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
01N 01E 03CCC1	432644116195401	43.44556	-116.3317	2782	I	27-288	288	X	X	X	X	X	X	X
01N 01E 05CCD1	432641116221201	43.44473	-116.37	2817	I	279-440	440	X	X	X		X	X	
01N 01E 12DAA1	432613116162901	43.43695	-116.2747	2860	U	232-312	322	X	X					
01N 01E 16ACC1	432525116203301	43.42361	-116.3425	2820	H	38-386	386	X	X	X	X	X	X	X
01N 01E 19ADB1	432442116223901	43.41167	-116.3775	2880	I	18-440	440	X	X	X	X	X	X	X
01N 01E 25DBA1	432336116164601	43.39333	-116.2794	2849	I	36-530	530	X						
01N 01E 33AAD1	432301116200401	43.38361	-116.3344	2865	I	19-618	618			X	X	X	X	X
01N 01W 01BDB1	432717116242501	43.45472	-116.4069	2800	I	183-325	401			X		X	X	X
01N 01W 02ADC1	432707116250501	43.45195	-116.4181	2850	I	245-455	455	X						
01N 01W 07BCC1	432618116304401	43.43834	-116.5122	2820	I	14-408	408			X	X	X	X	
01N 01W 07CAB1	432613116302601	43.43695	-116.5072	2780	I	12-461	461	X						
01N 01W 07DBB1	432613116300901	43.4375	-116.5028	2800	I	18-591	591		X					
01N 01W 15DAA1	432520116260401	43.42222	-116.4344	2890	I	293-541	541	X						
01N 01W 18CCC1	432500116303901	43.41667	-116.5108	2730	H	484-520	520			X	X	X	X	X
01N 01W 22DDD1	432407116260001	43.40195	-116.4333	2888	I	345-502	502			X	X	X	X	
01N 01W 24AAA1	432452116234201	43.41445	-116.395	2880	I	20-366	366	X	X	X	X	X		
01N 01W 27ADD1	432344116255901	43.39556	-116.4331	2904	U/I	18-365	500	X	X	X	X	X	X	X
01N 01W 30AAD1	432351116293701	43.3975	-116.4936	2740	I	21-415	415			X	X	X	X	X
01N 02E 04BBA1	432729116134201	43.45806	-116.2283	3005	I/M	488-615	625	X	X	X				
01N 02E 06BAA1	432732116155501	43.45889	-116.2653	2910	I/U	448-510	535	X	X	X	X	X	X	X
01N 02E 08ADA2	432620116140102	43.43889	-116.2336	2930	H	375-400	400	X	X	X	X	X	X	
01N 02W 04DDC1	432645116343001	43.44584	-116.575	2700	I	450-685	685	X	X	X	X	X	X	X
01N 02W	432708116353901	43.45222	-116.5942	2675	I	415-720	720	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
05ADD1														
01N 02W 06ADD1	432709116365101	43.4525	-116.6142	2728	I	596-720	720	X	X	X		X	X	X
01N 02W 09DDD2	432554116342101	43.43167	-116.5725	2665	H	-	252	X	X	X	X	X	X	X
01N 02W 10DAA1	432613116331001	43.43695	-116.5528	2660	H	19-150	150	X	X	X	X	X	X	X
01N 02W 17DDA1	432510116353301	43.41945	-116.5925	2718	I	370-565	565	X	X	X	X			
01N 02W 35CDB1	432232116330401	43.37555	-116.5511	2600	H	35-213	213			X	X	X	X	X
01N 03W 02CCB1	432652116401701	43.44778	-116.6714	2730	H	500-1000	1000			X	X	X	X	X
01N 03W 03DDD1	432646116402101	43.44611	-116.6725	2715	H	331-731	731	X	X	X	X	X	X	X
01N 03W 06DDC1	432640116440701	43.44445	-116.7353	2240	H	416-560	560	X	X	X	X	X	X	X
01N 03W 13AAA1	432548116375701	43.43	-116.6325	2688	I	220-607	607	X	X	X	X	X	X	X
01N 03W 25AAA1	432403116375601	43.40083	-116.6322	2740	H	599-710	710			X	X	X	X	X
01N 04E 13CCCB1	432500115560301	43.41667	-115.9342	3530	H	38-110	110	X	X					
01N 04E 28CAC1	432326115591601	43.39167	-115.9889	3360	N	500-752	763	X	X			X	X	X
01N 05E 17BAB1	432539115532201	43.4275	-115.8894	3660	U	53-68	82	X	X					
01S 01W 05BAC1	432209116282501	43.36916	-116.4736	2738	I	9-370	370			X	X	X	X	X
01S 01W 19AAB1	431944116294401	43.32889	-116.4956	2615	I	225-383	388			X	X	X	X	
01S 01W 29CBC1	431816116292801	43.30444	-116.4911	2575	I	200-282	295			X	X	X	X	
01S 01W 29CBD1	431816116291401	43.30444	-116.4872	2590	I	259-279	300			X	X	X	X	
01S 01W 30AAB1	431848116295001	43.31333	-116.4972	2543	H	299-400	400			X	X	X	X	
01S 01W 30BAB1	431851116301101	43.31417	-116.5031	2512	H	198-300	300		X	X	X	X	X	X
01S 02W 03DBC1	432147116333601	43.36305	-116.56	2410	H	32-44	44	X	X	X				
01S 02W 08DCD1	432040116354701	43.34444	-116.5964	2350	H	120-170	180			X	X	X	X	X
01S 02W 13ABBC1	432031116311201	43.34194	-116.52	2530	H	137-183	183			X	X	X	X	

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
01S 02W 13ABBC2	432031116311202	43.34194	-116.52	2530	H	18-300	300			X	X	X	X	X
01S 02W 14CCC2	431948116330001	43.33	-116.55	2395	H	-	235	X	X	X	X	X	X	X
01S 02W 15ABA1	432037116332101	43.34361	-116.5558	2450	H	220-420	420			X	X	X	X	X
01S 02W 24CBA1	431917116313301	43.32139	-116.5258	2490	I	127-190	190		X	X	X	X	X	X
01S 04E 03ADB1	432202115573001	43.36722	-115.9583	3375	U	-	530	X	X	X	X	X	X	X
02N 01E 01BCBC1	433230116173301	43.54167	-116.2925	2739	H	-	145	X	X	X	X	X	X	
02N 01E 02BACB1	433242116182601	43.545	-116.3072	2729	I	169-184	184	X	X	X	X	X	X	X
02N 01E 05CBDC1	433220116222001	43.53583	-116.3708	2735	H	236-242	242	X	X	X				
02N 01E 07CBBC1	433124116233501	43.52361	-116.3917	2670	H/I	135-145	145	X	X	X	X	X	X	
02N 01E 08ACC1	433129116214401	43.52472	-116.3622	2728	H	254-260	260	X	X	X	X	X	X	
02N 01E 12CDB1	433127116170101	43.52083	-116.2867	2885	H	-	290	X	X	X	X	X	X	
02N 01E 15ABA1	433101116191301	43.51694	-116.3203	2766	H	240-243	243	X	X	X	X			
02N 01E 22DCA1	432931116190701	43.49194	-116.3186	2836	I	360-440	444	X	X					
02N 01E 23BAD1	432959116181601	43.49972	-116.3045	2910	I	332-382	386	X	X	X	X			
02N 01E 26BBC1	432911116184601	43.48639	-116.3128	2840	H	298-300	300	X	X	X	X	X	X	
02N 01E 29BDB1	432915116222001	43.48417	-116.3678	2730	H	19-215	215			X	X	X	X	X
02N 01E 29DCA1	432834116213801	43.47611	-116.3606	2742	H	19-130	130	X	X	X	X	X	X	
02N 01E 31DDC1	432734116223901	43.45945	-116.3775	2748	H	225-248	248	X	X	X	X	X	X	X
02N 01E 33CAC1	432748116205201	43.46333	-116.3478	2758	H	16-224	224	X	X	X	X	X	X	X
02N 01E 33CCA2	432746116210202	43.46278	-116.3506	2752	H	-	0	X	X					
02N 01E 35BBC1	432822116183801	43.47278	-116.3106	2825	I	230-340	340	X	X	X	X	X	X	X
02N 01E 36BBB1	432825116173501	43.47361	-116.2931	2867	S/U	300-305	305	X	X	X	X	X	X	X
02N 01W	433246116255401	43.54611	-116.4317	2658	H	100-104	104	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
02BBA1														
02N 01W 03ABB1	433246116262701	43.54611	-116.4408	2650	H	299-306	306	X	X	X	X	X	X	X
02N 01W 07AAB1	433155116294401	43.53194	-116.4956	2570	H	30-126	126			X		X	X	X
02N 01W 07BBC1	433145116304301	43.52917	-116.5119	2548	H	98-102	103	X	X	X	X	X	X	X
02N 01W 08BBBA1	433155116292501	43.53194	-116.4903	2570	H	33-94	94			X	X	X	X	X
02N 01W 09ADA1	433140116271401	43.52778	-116.4539	2600	H	-	37	X	X	X	X	X	X	X
02N 01W 09ADA2	433140116271402	43.52778	-116.4539	2600	U	192-197	197			X	X		X	X
02N 01W 10ABB1	433155116263101	43.53194	-116.4419	2640	H	128-130	130	X	X	X	X	X	X	X
02N 01W 11ADA1	433143116245101	43.52861	-116.4142	2685	I	64-130	190	X	X	X	X	X	X	X
02N 01W 12BAA1	433154116242601	43.53167	-116.4072	2675	H	93-95	95	X	X	X	X	X	X	X
02N 01W 13BAB1	433102116242301	43.51722	-116.4064	2683	H	-	96	X	X	X	X	X	X	X
02N 01W 15ADC1	433038116261201	43.51056	-116.4367	2675	H	95-96	96	X	X					
02N 01W 23ACC1	432946116251401	43.49611	-116.4206	2691	H	-	110	X	X	X	X	X	X	
02N 01W 27BCC1	432853116270901	43.48139	-116.4525	2689	H	400-410	410	X	X	X	X	X	X	X
02N 01W 29DCC1	432828116285001	43.47445	-116.4806	2670	H	242-250	250			X	X	X	X	X
02N 01W 32CBB1	432757116292601	43.46584	-116.4906	2685	I	150-234	240	X	X	X	X	X	X	X
02N 01W 35BDC1	432800116253901	43.46667	-116.4275	2790	I	155-210	218	X	X	X	X	X	X	X
02N 02E 01BAB1	433244116095501	43.54556	-116.1653	2921	P	375-507	702			X	X	X		
02N 02E 02BBC1	433235116112801	43.54306	-116.1911	2915	U	114-805	805	X	X					
02N 02E 02BBC2	433233116113201	43.5425	-116.1922	2911	P/P	435-500	567						X	X
02N 02E 04CAA1	433216116132201	43.53778	-116.2228	2887	I	-	0					X	X	X
02N 02E 04CBA1	433218116134201	43.53833	-116.2283	2884	I	300-400	555					X	X	
02N 02E 04CBB1	433218116135301	43.53889	-116.2319	2880	H/S	332-353	353	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
02N 02E 06CCC1	433157116162301	43.5325	-116.2731	2768	H	-	0		X	X	X	X	X	X
02N 02E 06CCC2	433200116162001	43.53333	-116.2722	2770	H	185-195	195	X	X					
02N 02E 07CBC1	433119116161601	43.52195	-116.2711	2920	H	448-460	460	X	X	X	X	X	X	X
02N 02E 08AAD1	433144116135801	43.52889	-116.2328	2873	I	362-640	640	X	X					
02N 02E 12AAC1	433143116092001	43.52833	-116.1531	3035	H	417-503	503	X	X	X	X			
02N 02E 17AAD1	433050116140301	43.51389	-116.2342	3139	I	537-860	880	X	X					
02N 02E 21BAB1	433007116133501	43.50195	-116.2264	3142	I/H	523-800	800	X	X					
02N 02E 22BBB1	IDWR-S2000-01	43.50195	-116.2083	3175	P	691-912	930			X		X	X	X
02N 02E 31BCA1	432812116161401	43.47	-116.2706	2920	H	294-395	401	X	X	X	X	X	X	
02N 02E 32DBA1	432753116141901	43.46472	-116.2386	2985	I	492-559	564	X	X					
02N 02E 34CCD1	432732116123401	43.45889	-116.2094	3040	H	484-504	504	X	X	X	X	X	X	X
02N 02W 02CACC1	433211116324401	43.53639	-116.5456	2550	H	20-73	73	X	X	X	X	X	X	X
02N 02W 05ABA1	433243116355401	43.545	-116.5981	2555	H	178-180	180	X	X	X	X	X	X	X
02N 02W 07CBC1	433116116375501	43.52111	-116.6319	2555	H	-	122	X	X	X	X	X	X	X
02N 02W 09ACC1	433132116345001	43.52555	-116.5806	2602	P	178-194	194	X	X	X	X	X	X	
02N 02W 10CAA2	433128116335001	43.52444	-116.5639	2575	H	178-183	183	X	X	X	X	X	X	X
02N 02W 12ADCD1	433129116305301	43.52472	-116.5147	2570	H	-	76			X	X	X	X	X
02N 02W 20CBB1	432942116364101	43.495	-116.6114	2563	P/H	155-177	177	X	X	X	X	X	X	X
02N 02W 22CCA1	432928116340601	43.49111	-116.5683	2640	H	205-207	208	X	X	X	X	X	X	X
02N 02W 28DDD1	432826116342001	43.47389	-116.5722	2610	H	99-135	135	X	X					
02N 02W 29BCC1	432852116363601	43.48111	-116.61	2621	I	176-255	255	X	X	X	X	X	X	X
02N 02W 31CBA1	432801116374401	43.46695	-116.6289	2705	I	697-920	920	X	X	X	X	X	X	X
02N 02W	432743116362101	43.46194	-116.6058	2700	H	225-240	240	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
32CDB1														
02N 03E 02CDD1	433157116035201	43.5325	-116.0644	3180	H	78-470	470	X	X					
02N 03E 06AAB1	433246116081701	43.54389	-116.1339	2960	I	475-1001	1001	X	X					
02N 03E 06BCC2	433221116090702	43.53917	-116.1519	3015	H/P	335-460	460	X	X	X	X	X	X	X
02N 03E 06DCA1	433202116082001	43.53389	-116.1389	3065	U	609-845	855	X	X	X	X	X	X	X
02N 03E 07BAC1	IDWR-S2000-03	43.52806	-116.1461	3064	O	553-580	580			X	X	X	X	X
02N 03E 07CDA1	433112116084501	43.52	-116.1458	3058	U/H	-	549			X	X	X	X	X
02N 03E 07DBB1	433137116084301	43.52333	-116.1431	3059	Z	551-561	561			X	X	X	X	X
02N 03E 07DBB2	433137116084601	43.52306	-116.1497	3059	Z	801-811	811			X	X	X	X	X
02N 03E 09BAA2	433150116061802	43.53056	-116.105	3140	U/H	499-522	522			X	X	X	X	X
02N 03E 09BCA2	433139116063402	43.5275	-116.1094	3135	H	599-620	620				X	X	X	X
02N 03E 11ACC1	433132116034701	43.52555	-116.0631	2838	P/R	40-100	100	X	X	X	X	X	X	X
02N 03E 18BAC1	433050116085001	43.51389	-116.1472	3070	H	605-635	642	X	X	X	X			
02N 03W 06DBA1	433217116441301	43.53806	-116.7369	2600	H	239-247	247	X	X	X	X	X	X	X
02N 03W 13BCB1	433044116390601	43.51222	-116.6517	2445	I	211-310	310			X	X	X	X	X
02N 03W 22DDC1	432919116403701	43.48861	-116.6769	2750	I	400-603	603	X	X	X	X	X	X	X
02N 03W 36DAD1	432753116375701	43.46472	-116.6325	2785	H	364-523	523	X	X					
02N 04E 29ADB1	432900115595301	43.48333	-115.9981	3680	H	20-217	227	X	X					
02N 04E 34BCB1	432805115582301	43.46806	-115.9731	3700	I	135-260	260	X	X					X
02N 04W 13ACD1	433035116452401	0	0	2315	H	97-205	205			X	X	X	X	
02N 04W 25CAD1	432840116460101	43.47778	-116.7669	2260	H	99-121	121			X		X	X	
02S 01E 23ADD1	431402116173701	43.23389	-116.2936	3155	U/I	615-816	816					X	X	X
03N 01E 01DAA1	IDWR-S2000-04	43.62666	-116.2744	2690	U/I	40-417	420	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
03N 01E 01DAA2	433736116162802	43.62667	-116.2744	2690	I	265-420	420	X	X	X	X	X	X	X
03N 01E 06BBAB1	433801116232401	43.63361	-116.39	2590	H	63-64	64	X	X	X	X	X	X	X
03N 01E 06DDD1	433716116223001	43.62111	-116.375	2606	H	81-83	83	X	X	X	X	X	X	X
03N 01E 08DCDC1	433619116214001	43.60528	-116.3611	2650	H	-	67	X	X	X	X	X	X	X
03N 01E 10BDA1	433651116192501	43.61417	-116.3236	2650	H	99-100	100	X	X	X	X	X	X	X
03N 01E 12BCD1	433646116172101	43.61278	-116.2892	2690	I	77-87	87	X	X	X	X	X	X	X
03N 01E 13BDB1	433558116171701	43.59945	-116.2881	2735	H	91-97	97	X	X	X	X	X	X	X
03N 01E 14AAC2	433605116174602	43.60139	-116.2961	2726	U	-	1000	X	X			X	X	X
03N 01E 14AAC3	433605116174603	43.60139	-116.2961	2726	P	318-920	952	X		X		X		
03N 01E 15AAD1	433607116185201	43.60194	-116.3144	2709	H	146-151	154	X	X	X	X	X	X	X
03N 01E 15ADD1	433554116184901	43.59833	-116.3136	2701	P	479-565	565	X	X	X	X	X	X	X
03N 01E 15CBD1	433544116194601	43.59555	-116.3294	2680	H	85-90	90	X	X	X	X	X	X	X
03N 01E 15CDA1	433537116192501	43.59361	-116.3236	2706	P	301-335	335	X	X	X	X	X	X	X
03N 01E 16BCA1	433605116210001	43.60139	-116.35	2660	T/I	792-877	902	X			X	X	X	X
03N 01E 17ACA1	433601116213701	43.60028	-116.3603	2650	H	61-66	66		X		X			X
03N 01E 17BBB1	433613116222301	43.60361	-116.3731	2620	H	100-105	105	X	X	X	X	X	X	X
03N 01E 23DDD1	433433116173801	43.57583	-116.2939	2725	Z/U	25-443	446	X	X	X	X	X	X	X
03N 01E 24ADA1	433512116162501	43.58667	-116.2736	2750	H	-	144	X	X	X	X	X	X	X
03N 01E 25BCB1	433417116172701	43.57139	-116.2908	2751	H	103-109	117	X	X	X	X	X	X	X
03N 01E 27CDDB1	433347116193101	43.56306	-116.3253	2717	H	113-118	118	X	X	X	X	X	X	X
03N 01E 28DCDD2	433341116202102	43.56139	-116.3392	2695	H	117-122	125	X	X	X	X	X	X	X
03N 01E 30DDD1	433347116222501	43.56306	-116.3736	2667	H	84-132	132	X	X	X	X	X	X	
03N 01E	433309116192401	43.5525	-116.3233	2718	P	169-403	425	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
34CAA1														
03N 01E 36DDB1	433256116163301	43.54889	-116.2758	2810	I	46-152	152	X	X	X	X	X	X	X
03N 01W 03AAAA1	433800116255901	43.63334	-116.4331	2555	H	145-155	156			X	X	X	X	X
03N 01W 03DADD1	433724116255801	43.62333	-116.4328	2560	H	70-72	72			X	X	X	X	X
03N 01W 06CBBB1	433736116304201	43.62666	-116.5117	2495	H	173-175	175			X	X	X	X	X
03N 01W 06DDDC1	433712116294001	43.62	-116.4944	2510	H	69-74	80			X	X	X	X	X
03N 01W 08BDAC1	433648116285001	43.61333	-116.4806	2520	H	140-160	160	X	X	X	X	X	X	
03N 01W 09AACB1	433701116272201	43.61694	-116.4561	2539	H	94-102	102	X	X	X	X	X	X	
03N 01W 11BDCC1	433645116253801	43.6125	-116.4272	2572	H	145-150	150	X	X	X	X	X	X	X
03N 01W 12CBBB1	433646116244101	43.61194	-116.4114	2595	I	-	36	X	X	X	X	X	X	X
03N 01W 16DDD1	433528116271101	43.59111	-116.453	2677	H	183-190	190	X	X	X	X	X	X	X
03N 01W 18DAC1	433545116295201	43.59583	-116.4978	2635	H	237-240	240	X	X	X	X	X	X	X
03N 01W 21DBCA1	433450116274001	43.58055	-116.4611	2620	H	193-295	295			X	X	X	X	X
03N 01W 24BBDA1	433517116243101	43.58805	-116.4086	2612	H	55-60	60	X	X	X	X	X	X	X
03N 01W 25DAD1	433354116233501	43.565	-116.3931	2712	H/S	327-330	330	X	X	X	X	X	X	X
03N 01W 26DDDC1	433342116245201	43.56166	-116.4144	2700	H	202-213	213	X	X	X	X	X	X	X
03N 01W 27CDCB1	433346116264901	43.56278	-116.4469	2645	H	-	200	X	X	X	X	X	X	
03N 01W 31DDA1	433302116294101	43.55	-116.4944	2542	H	31-67	67	X	X	X	X	X	X	X
03N 02E 03BAAD2	433757116121101	43.6325	-116.2031	2712	I	72-77	78	X	X	X	X	X	X	X
03N 02E 04DAB1	433729116125701	43.62472	-116.2158	2675	I	-	50	X	X	X	X	X	X	X
03N 02E 06DDC1	433713116152101	43.62028	-116.2558	2708	P	568-850	850	X	X	X		X	X	X
03N 02E 06DDD1	433710116151501	43.61945	-116.2539	2712	C	94-98	98	X	X	X	X	X	X	X
03N 02E 06DDD2	433711116151501	43.61972	-116.2542	2712	C	124-136	137	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
03N 02E 07DAAC1	433637116151901	43.61028	-116.2553	2715	I	456-471	471	X	X	X	X	X	X	X
03N 02E 11BABD1	433705116110601	43.61806	-116.185	2743	U	781-1220	1220	X	X	X	X	X	X	X
03N 02E 11DDD1	433619116103001	43.60528	-116.175	2718	H	-	68	X	X	X	X	X	X	X
03N 02E 13BABA1	433614116095801	43.60389	-116.1661	2730	I	-	0	X	X	X	X	X	X	X
03N 02E 14ACB2	433559116105201	43.59972	-116.1811	2710	I	35-55	55	X	X	X	X	X	X	X
03N 02E 15BDB2	433557116122201	43.59917	-116.2061	2700	H/I	78-84	84	X	X	X	X	X	X	X
03N 02E 15DDDD1	433527116113401	43.59083	-116.1928	2719	U/P	-	165	X	X	X	X			
03N 02E 17CAD2	IDWR-S2000-05	43.59444	-116.2447	2727	P	399-612	650	X			X	X	X	X
03N 02E 18DAA1	433549116151301	43.59694	-116.2536	2720	I	78-80	80	X	X	X	X	X	X	X
03N 02E 19BAA2	433522116155502	43.58944	-116.2653	2765	P	468-519	525	X		X	X	X	X	
03N 02E 20DBD1	433446116141801	43.57944	-116.2383	2793	U	-	106	X	X	X	X	X	X	
03N 02E 21BCC1	433502116135201	43.58389	-116.2311	2751	D/U	-	58	X	X	X	X	X	X	X
03N 02E 23BAA1	433517116110101	43.58805	-116.1836	2720	U	-	1200					X	X	X
03N 02E 23DDBC2	433439116103501	43.5775	-116.1764	2742	I	292-362	425	X	X					
03N 02E 25AAC1	433420116091901	43.57222	-116.1553	2758	H	63-68	70	X	X	X	X	X	X	X
03N 02E 25BDA1	IDWR-S2000-06	43.57028	-116.1631	2759	I	39-65	75					X	X	X
03N 02E 25CAA1	IDWR-S2000-07	43.56778	-116.1628	2788	P	-	416					X	X	X
03N 02E 25CACC1	433353116100001	43.56472	-116.1667	2800	U	32-42	43			X	X	X	X	
03N 02E 25CBCA1	433358116101301	43.56611	-116.1703	2755	U	-	0			X	X	X	X	X
03N 02E 25CDBA1	433351116095701	43.56417	-116.1658	2815	U	37-51	51			X	X	X	X	X
03N 02E 25CDBB1	433351116100201	43.56417	-116.1672	2813	U	35-47	47			X	X	X	X	X
03N 02E 26DBA1	IDWR-S2000-08	43.5675	-116.1778	2800	P	355-644	663					X	X	X
03N 02E	433353116115201	43.56472	-116.1978	2871	P/P	365-455	455	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	Spring	2000 Fall	2001 Fall
27DBD1														
03N 02E 28BDB1	433417116133001	43.57139	-116.225	2830	N	275-280	280	X	X	X	X	X	X	
03N 02E 30CAC1	433359116160301	43.56667	-116.2681	2765	H	100-103	103	X	X	X	X	X	X	X
03N 02E 30DDB1	433350116152201	43.56389	-116.2561	2785	H	-	212			X	X	X	X	X
03N 02E 31AAC1	433332116152301	43.55889	-116.2564	2682	H	136-143	143			X	X	X	X	X
03N 02E 35BAB1	433334116110601	43.55944	-116.185	2892	P	-	944							X
03N 02E 36ABC1	433328116094201	43.55833	-116.1611	2890	P	342-642	642					X	X	X
03N 02E 36CDD1	IDWR303824	43.5475	-116.1633	2930	I	517-566	570	X	X					
03N 02W 03DAA1	433735116331101	43.62639	-116.5531	2470	H	229-234	234	X	X	X	X	X	X	X
03N 02W 04ADD1	433741116342201	43.62806	-116.5728	2460	H	310-314	319	X	X	X	X	X	X	X
03N 02W 06ACD1	433737116370701	43.62694	-116.6186	2441	I	80-87	87	X	X	X	X	X	X	X
03N 02W 06DCC1	433714116371901	43.62055	-116.6219	2430	P	380-510	550	X	X	X	X	X	X	X
03N 02W 08BCCC1	433645116364001	43.6125	-116.6111	2445	C	-	94	X	X	X	X	X	X	X
03N 02W 09DDDD1	433620116342101	43.60555	-116.5725	2470	U/N	58-289	292	X	X					
03N 02W 10ACC1	433645116334301	43.6125	-116.562	2460	I/D	84-138	138	X	X	X	X			
03N 02W 12BBB1	433708116315401	43.61889	-116.5317	2488	H	58-60	61	X	X	X	X	X	X	X
03N 02W 14DBA1	433552116321501	43.59778	-116.5375	2540	P	400-605	700	X	X	X	X	X	X	X
03N 02W 15DCDA1	433532116332901	43.59222	-116.5581	2485	I/D	114-131	131	X	X	X				
03N 02W 17ACDB1	433558116355401	43.59944	-116.5983	2460	U	123-300	300	X	X	X	X	X	X	
03N 02W 17CCB2	433537116364301	43.59361	-116.6119	2450	H	73-76	104	X	X	X	X	X	X	
03N 02W 24BAD2	433516116312701	43.58694	-116.5231	2544	H	-	71	X	X	X	X	X	X	X
03N 02W 26BAA1	433433116323001	43.57583	-116.5417	2505	H	34-83	83	X	X	X	X	X	X	X
03N 02W 29BCD1	433410116362601	43.56944	-116.6072	2467	H	-	116	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
03N 02W 31BCC1	433317116375401	43.55416	-116.6314	2590	I	152-172	172	X	X	X	X	X	X	X
03N 02W 34BBCB1	433335116341501	43.55972	-116.5708	2490	I	165-200	210	X	X	X	X	X	X	X
03N 02W 35DBAC1	433311116321901	43.55305	-116.5386	2503	I/H	67-117	117	X	X	X	X	X	X	X
03N 03E 07CBAC1	433636116090201	43.61	-116.1506	3160	U	129-290	290	X	X					
03N 03E 19DBD1	433449116082001	43.58028	-116.1389	2800	H	75-80	80	X	X	X	X	X	X	X
03N 03E 29ADD2	433408116065202	43.56889	-116.1144	2810	P	81-101	106	X	X	X	X	X	X	X
03N 03E 29CCDA2	433343116074301	43.56194	-116.1286	2820	H	140-100	100			X	X	X	X	X
03N 03E 30BCBD1	433413116090401	43.57028	-116.1508	2762	H	-	48	X	X	X	X	X	X	X
03N 03E 30DAAD2	433406116080101	43.56694	-116.1333	2750	P/I	-	60	X	X	X	X	X	X	X
03N 03E 30DDAA1	433351116380301	43.56417	-116.1342	2800	U	246-940	940	X	X	X	X	X	X	X
03N 03E 31BDD1	IDWR-S2000-09	43.55361	-116.1444	2945	P	527-818	838					X	X	X
03N 03E 31CAA1	433313116083901	43.55416	-116.1444	2945	P	-	0					X	X	
03N 03E 32BBA1	433337116075001	43.56028	-116.1306	2823	U/C	232-260	280	X	X	X	X	X	X	X
03N 03E 32CDD1	433247116072601	43.54639	-116.1239	2965	Z/Z	560-731	802	X	X	X	X	X	X	X
03N 03E 33DAA1	433310116054201	43.55278	-116.095	2862	H	120-127	127	X	X	X	X	X	X	X
03N 03W 03BCB2	433745116412501	43.62917	-116.6903	2429	U	22-94	95		X	X	X	X	X	X
03N 03W 06DDC1	433710116441101	43.61944	-116.7361	2560	I	131-137	255	X	X	X	X	X	X	X
03N 03W 09BAB1	433704116421901	43.61777	-116.7053	2500	H	98-122	122		X	X	X	X	X	X
03N 03W 10CBA3	433636116411901	43.61	-116.6886	2560	T/I	70-300	300	X	X					
03N 03W 11DAC1	433630116392401	43.60833	-116.6567	2441	I/D	-	90	X	X	X	X			
03N 03W 14CDA1	433531116394601	43.59194	-116.6628	2480	H	69-79	80	X	X					
03N 03W 23BBC1	433517116401801	43.58805	-116.6717	2540	U/I	118-190	250	X	X	X	X	X	X	X
03N 03W	433433116392701	43.57583	-116.6575	2490	I	50-80	97	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
23DCD1														
03N 03W 27ABB1	433427116405001	43.57417	-116.6805	2450	I	119-122	122	X	X	X	X	X	X	X
03N 03W 31ADA1	433321116435601	43.55583	-116.7322	2630	H	159-260	260			X	X	X	X	
03N 04W 03AAD1	433746116473101	43.62944	-116.7919	2487	P	70-75	78	X	X	X	X	X	X	
03N 04W 05AAB1	433755116500901	43.63194	-116.8358	2618	I	140-325	325	X	X					
03N 04W 07ABA1	433703116513001	43.6175	-116.8583	2462	I	208-503	503			X	X	X	X	X
03N 04W 11ADA1	433646116461801	43.61278	-116.7717	2497	U	94-175	175	X	X	X	X	X	X	X
03N 04W 12AAD2	433655116451001	43.61528	-116.7528	2492	H	233-270	270			X	X	X	X	X
03N 04W 13BBC1	433601116461001	43.60028	-116.7694	2535	H	205-295	295	X	X	X	X	X		
03N 04W 15DCC1	433517116475501	43.58805	-116.7986	2378	H	79-80	80	X	X	X	X	X	X	X
03N 05W 03ADA1	433740116544201	43.62778	-116.9117	2285	C	40-55	55			X	X	X	X	
03N 05W 03DBD1	433723116550201	43.62305	-116.9172	2250	P	456-533	533			X	X	X	X	X
03N 05W 11DAD1	433627116532701	43.6075	-116.8908	2280	H/S	85-86	86			X	X	X	X	X
04N 01E 03DAD1	434243116185001	43.71194	-116.3139	2700	U	100-140	250	X	X	X	X	X	X	X
04N 01E 04BCCD1	434250116210401	43.71389	-116.3511	2600	H	387-465	470	X	X	X	X	X	X	X
04N 01E 04DCC1	IDWR347115	43.70694	-116.3428	2632	U	276-285	285	X	X	X	X			
04N 01E 05CBBD1	434245116221701	43.7125	-116.3714	2590	H	-	30	X	X	X	X	X	X	X
04N 01E 10ACB2	434206116192001	43.70167	-116.3222	2636	H	289-308	308	X	X		X	X	X	X
04N 01E 11BAA1	434216116183501	43.705	-116.3039	2800	H	290-300	335	X	X	X	X	X	X	X
04N 01E 11BBB1	434223116183901	43.70639	-116.3108	2690	H	120-203	203	X	X	X	X	X	X	X
04N 01E 13BDDB1	434109116170701	43.68583	-116.2853	2620	H	70-78	78					X	X	X
04N 01E 14CCB1	434048116184401	43.68	-116.3122	2582	U	300-340	357					X	X	X
04N 01E 14CCB2	434048116184402	43.68	-116.3122	2582	U	270-290	295					X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
04N 01E 14CCB3	434048116184403	43.68	-116.3122	2582	U	210-250	250					X	X	X
04N 01E 14CCB4	434048116184404	43.68	-116.3122	2582	U	130-170	177					X	X	X
04N 01E 15BADC1	434121116192901	43.68917	-116.3247	2575	P	1-18	103						X	X
04N 01E 16AAA1	434129116200301	43.69139	-116.3342	2565	H/S	87-88	88	X	X	X	X	X	X	
04N 01E 17CDDD1	434042116215001	43.67833	-116.3639	2546	H	-	115	X	X	X	X	X	X	X
04N 01E 21DCCC1	433948116203401	43.66333	-116.3428	2605	H	99-104	106	X	X	X	X	X	X	X
04N 01E 21DDDC1	433950116200401	43.66389	-116.3344	2630	U	93-102	102	X	X	X	X	X	X	X
04N 01E 23DAC1	433957116173601	43.66833	-116.2961	2698	P	327-403	403	X	X	X	X			
04N 01E 24BCA1	434020116171901	43.67222	-116.2886	2602	H	50-70	71	X	X	X	X			
04N 01E 26CDD1	433856116181501	43.64889	-116.3042	2660	H	96-105	105	X	X	X	X	X	X	X
04N 01E 27AADA1	433939116184801	43.66084	-116.3133	2613	U/U	620-868	892	X	X	X	X	X	X	X
04N 01E 29CCCD1	433856116221601	43.64889	-116.3711	2605	H	84-89	90	X	X	X	X	X	X	X
04N 01E 33AADC1	433843116200701	43.64528	-116.3353	2637	H	96-101	103	X	X	X	X	X	X	X
04N 01E 34ACB1	433838116192301	43.64389	-116.3231	2643	H	145-150	160							X
04N 01E 34ACBC1	433837116192301	43.64361	-116.3231	2644	H	476-481	481		X	X	X	X	X	X
04N 01E 34CAD1	433819116192501	43.6375	-116.3247	2650	P	671-752	755	X	X					
04N 01E 35CCA1	433813116183201	43.63695	-116.3089	2660	D/I	90-108	109	X	X	X	X	X	X	X
04N 01E 35DAA1	433822116174101	43.63945	-116.2947	2675	H	175-205	205	X	X	X	X	X	X	X
04N 01E 36BAC1	433843116171601	43.645	-116.2875	2673	U	760-1005	1005	X	X	X	X			
04N 01E 36BAC2	433842116171601	43.645	-116.2875	2673	P	474-545	551	X		X		X	X	X
04N 01W 01CAA1	434244116241101	43.71222	-116.4031	2552	H	239-260	260	X	X	X	X	X	X	X
04N 01W 03CDDA1	434228116263401	43.70778	-116.4428	2502	H	51-57	57	X	X	X	X	X	X	X
04N 01W	434243116284501	43.71194	-116.4792	2520	H	132-142	142	X	X	X	X	X	X	

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
05DBD1														
04N 01W 07AAAD1	434219116293401	43.70528	-116.4928	2465	H	162-172	172	X	X	X	X	X	X	X
04N 01W 07DAAA1	434156116293301	43.69889	-116.4925	2465	U/P	420-440	440	X	X	X	X	X	X	X
04N 01W 13AACC1	434106116240301	43.68861	-116.3972	2525	I	240-320	332	X	X	X	X	X	X	X
04N 01W 13DDB1	434048116235101	43.68	-116.3975	2525	I	-	130	X	X	X	X	X		
04N 01W 16CAAA1	434104116274701	43.68444	-116.4631	2482	H	150-152	160	X	X					
04N 01W 17BBDB1	434124116292101	43.69	-116.4892	2470	H	140-149	149		X	X	X	X	X	X
04N 01W 17BBDC1	434120116292101	43.68889	-116.4892	2468	H	381-424	424	X	X	X	X	X	X	X
04N 01W 17CBDB1	434059116292101	43.68306	-116.4892	2465	H	113-118	118	X						
04N 01W 19DADA1	434007116293501	43.66861	-116.4931	2495	H	161-170	170	X	X	X	X	X	X	
04N 01W 22DBB1	434013116262801	43.67028	-116.4411	2545	H	80-93	93	X	X	X	X	X	X	
04N 01W 23ACCC2	434013116252201	43.67028	-116.4228	2560	H	150-155	155			X	X	X	X	X
04N 01W 24ACAB1	434026116235601	43.67389	-116.3989	2570	H	109-120	120			X	X	X	X	X
04N 01W 24ACAB3	434025116235901	43.67361	-116.3997	2570	Q	300-313	313			X	X	X	X	
04N 01W 24BCAC1	434020116243401	43.67222	-116.4094	2575	H	230-235	235			X	X	X	X	X
04N 01W 28ADD1	433923116271001	43.65639	-116.4528	2535	H	72-80	80	X	X	X	X	X	X	X
04N 01W 30ABBC1	433942116300901	43.66167	-116.5025	2500	H	230-237	237			X	X	X	X	X
04N 01W 30ADAA2	433934116293602	43.65917	-116.493	2505	H	89-99	99	X	X		X	X	X	X
04N 01W 31AAA1	433852116293401	43.64778	-116.4928	2508	I	455-462	462	X	X	X	X	X	X	X
04N 01W 32BBBC1	433849116293201	43.64695	-116.4922	2510	H	60-65	65	X	X	X	X	X	X	X
04N 01W 33ADAD1	433835116271201	43.64306	-116.4533	2530	H	67-77	77	X	X	X	X	X	X	X
04N 01W 33CBB1	433828116281701	43.64111	-116.4714	2525	H	-	400	X	X					
04N 01W 35AAA1	433852116244801	43.64778	-116.4133	2571	H/U	-	44	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
04N 02E 09CCD2	434131116134201	43.69194	-116.2283	3200	H	-	0							X
04N 02E 17CABC1	434103116143601	43.68278	-116.2467	3020	H	110-525	525					X	X	X
04N 02E 19ABB1	434035116154401	43.67639	-116.2622	2680	H	-	98	X	X	X	X	X	X	X
04N 02E 21DACA1	434003116125701	43.6675	-116.2158	2890	A	644-880	880	X	X					
04N 02E 25DCBB1	433901116093901	43.65139	-116.1614	3490	H	339-340	340	X	X					
04N 02E 29ACA1	433930116141901	43.65833	-116.2386	2670	H	43-48	85							X
04N 02E 29ACC1	433921116143401	43.65583	-116.2428	2663	I	-	45	X	X	X	X	X	X	X
04N 02E 29ACDB1	433925116141901	43.65694	-116.2386	2670	I/A	-	1195	X	X	X	X	X	X	X
04N 02E 30ACAC1	433929116153701	43.65778	-116.2594	2630	I	-	0	X	X					
04N 02E 30ACDB1	433928116153801	43.6575	-116.2597	2630	H	-	41	X	X	X	X	X	X	X
04N 02E 31AAB2	433850116151701	43.64722	-116.2547	2630	H	-	60	X	X	X	X	X	X	X
04N 02E 31ACAB1	433838116153601	43.64389	-116.26	2632	U	-	0	X	X					
04N 02E 33ACAC1	433836116132701	43.64333	-116.2194	2695	I/H	47-52	53	X	X	X	X	X	X	X
04N 02E 34CAAC1	433821116121701	43.63917	-116.2047	2728	H/I	69-100	100	X	X	X	X	X	X	X
04N 02E 35CBBA1	433824116112501	43.63972	-116.1894	2850	U	737-771	781	X	X					
04N 02W 01AADA1	434310116304501	43.71944	-116.5125	2480	H	-	0			X	X	X	X	X
04N 02W 01ADAA3	434301116304401	43.71695	-116.5122	2480	H	74-84	84			X	X	X	X	X
04N 02W 01DCDD1	434225116310301	43.70694	-116.5175	2450	H	530-675	675			X	X	X	X	X
04N 02W 02DDD1	434226116315701	43.70722	-116.5325	2445	H	31-50	50	X	X	X	X	X	X	X
04N 02W 05ABB1	434314116360401	43.72055	-116.6011	2497	P	-	475	X	X					
04N 02W 06CDD1	434228116372701	43.70778	-116.6242	2404	P	404-420	420	X	X	X	X	X	X	X
04N 02W 07AAC1	434214116365901	43.70389	-116.6164	2395	H	40-42	42	X	X	X	X	X	X	X
04N 02W	434200116353201	43.7	-116.5922	2407	H	60-80	80		X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
08ADD1														
04N 02W 10BBCB1	434217116341801	43.70472	-116.5717	2420	H	128-133	133	X	X	X	X	X	X	X
04N 02W 21CBB1	434014116353201	43.67056	-116.5922	2432	H	79-90	90	X	X	X	X	X	X	X
04N 02W 22DCD1	433948116333201	43.66333	-116.5589	2458	H	237-262	262			X	X	X	X	
04N 02W 24CCC1	433951116315401	43.66417	-116.5317	2479	I	53-77	77	X	X	X	X	X	X	X
04N 02W 26CAD1	433910116323301	43.65278	-116.5425	2472	I	140-152	152	X	X	X	X			
04N 02W 31AAA1	433852116364501	43.64778	-116.6125	2438	H	-	150	X	X	X	X	X	X	X
04N 02W 33ABC1	433844116345401	43.64556	-116.5817	2455	I	123-148	148	X	X	X	X			
04N 02W 36CCC1	433757116320101	43.63472	-116.5317	2480	H	106-108	108			X	X	X	X	X
04N 03W 01CBBA1	434248116385901	43.71333	-116.6497	2420	H	213-218	218			X	X	X	X	X
04N 03W 02ADDD1	434249116390901	43.71361	-116.6525	2430	H	97-135	135			X	X	X	X	X
04N 03W 04DCB1	434233116420201	43.70917	-116.7006	2430	H/I	259-293	296	X	X	X	X	X	X	X
04N 03W 04DDCD1	434224116414401	43.70667	-116.6956	2465	H	199-227	227	X	X	X	X	X	X	X
04N 03W 06AAA1	434312116435501	43.72	-116.7319	2372	I	31-160	160	X	X	X	X	X	X	X
04N 03W 12ACDD1	434200116381701	43.7	-116.6381	2387	U/I	10-35	40	X	X	X	X	X	X	X
04N 03W 13BAA1	434128116383601	43.69111	-116.6433	2370	S	181-185	185	X	X	X	X	X	X	X
04N 03W 15ADC1	434105116402701	43.68472	-116.6742	2440	U	875-1010	1010					X	X	X
04N 03W 15ADC2	434105116402702	43.68472	-116.6742	2440	U	579-725	725					X	X	X
04N 03W 15ADC3	434105116402703	43.68472	-116.6742	2440	U	430-550	550					X	X	X
04N 03W 15ADC4	434105116402704	43.68472	-116.6742	2440	U	270-407	407					X	X	X
04N 03W 15ADC5	434105116402705	43.68472	-116.6742	2440	U	208-270	270					X	X	X
04N 03W 15ADC6	434105116402706	43.68472	-116.6742	2440	U	166-208	208					X	X	X
04N 03W 15ADC7	434105116402707	43.68472	-116.6742	2440	U	122-166	166					X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
04N 03W 15ADC8	434105116402708	43.68472	-116.6742	2440	U	110-120	122					X	X	X
04N 03W 16DDDC1	434038116413801	43.67722	-116.6939	2348	U/I	57-75	80	X	X	X	X	X	X	X
04N 03W 24ACB1	434024116382901	43.67334	-116.6414	2412	H	-	92	X	X	X	X	X	X	X
04N 03W 25DAA3	433919116375701	43.65528	-116.6325	2424	U	62-68	80	X	X	X	X			
04N 03W 26ABCC1	433935116394301	43.65973	-116.6619	2412	P	286-503	515	X	X					
04N 03W 27AACD1	433934116403201	43.65945	-116.6756	2380	P	175-320	330	X	X	X	X	X	X	X
04N 03W 27CBAD1	433915116411701	43.65417	-116.6881	2380	I	76-97	97	X	X	X	X	X	X	X
04N 03W 28ADDD1	433921116413501	43.65583	-116.6931	2378	P	150-200	395	X	X	X	X	X	X	X
04N 03W 30ADA1	433935116441001	43.65806	-116.7322	2353	H	160-192	192	X	X	X	X	X	X	X
04N 03W 31CBA2	433825116445702	43.64028	-116.7492	2467	H	-	0			X	X	X	X	X
04N 03W 33DADC1	433815116413801	43.6375	-116.6939	2440	H	348-357	357			X	X	X	X	X
04N 04W 04CDC1	434225116493101	43.70694	-116.8253	2285	H/S	387-420	420	X	X	X	X	X	X	X
04N 04W 05CAC1	434234116504601	43.70945	-116.8461	2280	H	168-224	224		X	X	X	X	X	X
04N 04W 08BB1	IDWR297941	43.70383	-116.8492	2280	H	210-230	230	X						
04N 04W 08CDCC1	434128116504401	43.69111	-116.8456	2350	H	58-70	70			X	X	X	X	X
04N 04W 10CDAB1	434138116481201	43.69389	-116.8033	2300	H/S	97-116	116			X	X	X	X	X
04N 04W 15ACCB2	434108116480402	43.68555	-116.8011	2304	H	68-74	74			X	X	X	X	
04N 04W 15ACCB3	434107116480501	43.68528	-116.8014	2304	H	215-220	220	X		X		X	X	X
04N 04W 21CAA1	434008116492001	43.66889	-116.8222	2440	H	35-36	36	X	X	X		X	X	X
04N 04W 21CAA2	432835116492501	43.66945	-116.8225	2420	H	35-36	36	X	X	X		X	X	
04N 04W 22DDD1	433945116473201	43.6625	-116.7922	2353	I	72-132	137	X	X	X				
04N 04W 25BDD3	433919116454903	43.65528	-116.7636	2368	I/U	138-175	175	X	X	X	X			
04N 04W	433929116491501	43.65806	-116.8208	2470	H/S	54-56	56	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Surface Elevation	Use	Open Interval	Well Depth	Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
28ACB1														
04N 04W 30BBB1	433942116520101	43.66167	-116.8669	2461	U/H	76-85	85	X		X	X	X	X	X
04N 04W 30BBB2	433941116521301	43.66139	-116.8703	2480	H	34-71	71	X	X	X	X	X	X	X
04N 04W 33CDC2	433800116493001	43.63334	-116.825	2525	U/I	50-63	72	X	X	X	X	X	X	X
04N 04W 36DB1	IDWR297845-X	43.63867	-116.7695	2494	H	564-586	586	X						
04N 05W 07DCD1	434132116584001	43.69222	-116.9778	2292	I	64-131	131	X	X	X	X	X	X	X
04N 05W 10CDD1	434128116551601	43.69111	-116.9211	2423	H/S	287-306	306	X	X	X	X	X	X	X
04N 05W 14CCC2	434040116543502	43.67778	-116.9097	2424	P	500-910	910	X	X	X				
04N 05W 14DAD1	434053116532901	43.68139	-116.8914	2421	H	56-65	65	X	X	X	X	X	X	X
04N 05W 21AAB2	434033116560501	43.67583	-116.9347	2440	H	178-220	220	X	X	X	X	X	X	X
04N 05W 23BCC1	434009116543701	43.66917	-116.9103	2465	P	285-515	525	X	X					
04N 05W 23CBB1	434006116543701	43.66833	-116.9103	2467	H	68-80	80			X	X	X	X	
04N 06W 02DDA1	434234117004501	43.70945	-117.0125	2420	H	123-280	280			X	X	X	X	X
04N 06W 11DCA1	434138117010101	43.69389	-117.0169	2240	H/S	30-31	31			X	X	X	X	X
04N 06W 12CAC1	434141117002001	43.69473	-117.0056	2275	H	83-123	123			X	X	X	X	X
05N 01E 26CDDC1	434409116182101	43.73583	-116.3058	2715	H	-	61	X	X	X	X	X	X	X
05N 01E 26DCD1	434412116175801	43.73972	-116.2992	2750	H/I	633-688	688	X	X	X	X	X	X	X
05N 01E 29DCA1	434415116213401	43.7375	-116.3594	2740	H/S	244-246	247	X	X	X	X	X	X	X
05N 01E 31ACA1	434349116224101	43.73028	-116.3781	2655	H	90-99	99	X	X	X	X	X	X	
05N 01E 33CCCD1	434316116210501	43.72111	-116.3514	2632	H	168-190	190	X	X	X	X	X	X	X
05N 01E 34DBB1	434341116192001	43.72805	-116.3222	2680	I	-	175	X	X	X	X	X	X	X
05N 01E 35ACA1	434350116175701	43.73056	-116.2992	2720	S	-	0	X	X	X	X	X	X	X
05N 01E 36AAB1	434404116164001	43.73444	-116.2778	2780	I	144-230	230	X	X	X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
05N 01W 09CAD1	434700116274501	43.78333	-116.4625	2688	H/I	390-450	450			X	X	X	X	X
05N 01W 09CCD2	434650116280802	43.78056	-116.4689	2680	I	285-415	425	X	X		X	X	X	X
05N 01W 16CAB1	434615116275801	43.77083	-116.4656	2715	H	492-628	628			X	X	X	X	
05N 01W 17BCA1	434628116292101	43.77444	-116.4892	2630	H/I	222-237	237	X	X	X	X	X	X	
05N 01W 29CBA1	434433116291601	43.74167	-116.4889	2630	I	272-332	332	X	X	X	X	X	X	X
05N 01W 32ACC1	434344116285401	43.72889	-116.4817	2595	H	-	280	X	X	X	X	X	X	X
05N 01W 33ACD1	434344116273301	43.72889	-116.4592	2590	H	106-108	108	X	X	X	X	X	X	
05N 01W 33CBDA1	434336116280301	43.72667	-116.4675	2560	H	185-188	188			X	X	X	X	X
05N 01W 34DBAD1	434335116261501	43.72639	-116.4375	2585	H	-	74	X	X	X	X	X	X	X
05N 01W 35CCC1	434321116255301	43.7225	-116.4314	2582	I	44-84	84	X	X	X	X	X	X	X
05N 01W 36ABB1	434406116240801	43.735	-116.4022	2618	H/I	204-208	208	X	X	X	X	X	X	X
05N 02E 29BCC1	434433116150401	43.7425	-116.2511	2990	H	14-68	68	X	X					
05N 02E 31CAB1	434341116160201	43.72806	-116.2672	2815	I	48-254	254	X	X					
05N 02W 19CBA1	434525116373601	43.75694	-116.6267	2482	U	254-260	261	X	X	X	X	X	X	X
05N 02W 19CBA2	434525116373602	43.75694	-116.6267	2482	H	-	0		X	X	X	X	X	X
05N 02W 20BBA1	434551116362801	43.76417	-116.6078	2500	S	71-114	117	X	X	X	X	X	X	X
05N 02W 22CAD1	434514116334501	43.75389	-116.5625	2605	I	279-403	450	X	X	X	X	X	X	X
05N 02W 24DAB1	434525116305101	43.75694	-116.5142	2595	S	280-320	330	X	X	X	X	X	X	
05N 02W 25BCD1	434436116313601	43.74333	-116.5267	2632	I	-	448	X	X					
05N 02W 27DCC1	434413116334201	43.73695	-116.5617	2565	H	213-218	218	X	X	X	X	X	X	X
05N 02W 29BBC2	434452116364101	43.74778	-116.6114	2505	H	164-180	180	X	X	X	X	X	X	X
05N 02W 31BBC1	434356116375201	43.73222	-116.6311	2472	H	102-132	133	X	X	X	X	X	X	
05N 02W	434331116362501	43.72528	-116.6069	2500	H	230-233	233	X	X	X	X	X	X	

Well Name	Site ID	Well Latitude	Well Longitude	Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
32CBD1														
05N 03W 02CCD1	434738116400501	43.79389	-116.6681	2560	H	380-384	386	X	X	X	X	X	X	X
05N 03W 04BCB1	434815116423901	43.80416	-116.7108	2460	H	140-143	143	X	X	X	X	X	X	
05N 03W 08DDC1	434646116425401	43.77917	-116.7153	2450	H	197-203	203	X	X	X	X	X	X	X
05N 03W 12CCA1	434652116385201	43.78111	-116.6478	2560	H	60-314	314	X	X	X	X	X	X	X
05N 03W 15DDC1	434554116403101	43.765	-116.6753	2495	H/S	147-152	152	X	X	X	X	X	X	X
05N 03W 19AAD1	434545116435701	43.7625	-116.7325	2440	H	131-143	143	X	X	X	X	X	X	X
05N 03W 21CAD1	434517116421101	43.75472	-116.703	2480	H	177-200	200	X	X	X	X	X	X	X
05N 03W 23BC1	IDWR297637	43.75923	-116.6693	2500	H	345-352	352		X					
05N 03W 27CAA1	434432116405801	43.74222	-116.6828	2450	H	236-287	287	X	X					
05N 03W 30ADD1	434430116435601	43.74306	-116.7322	2475	H	158-180	180	X	X	X	X	X	X	X
05N 04W 08BCC1	434716116505401	43.78667	-116.8519	2430	H	196-202	202	X	X	X	X	X	X	X
05N 04W 09DCA1	434651116490501	43.78083	-116.8181	2460	H	274-279	281	X	X	X	X	X	X	X
05N 04W 16ABA1	434640116490301	43.77778	-116.8175	2430	H	261-333	333	X	X	X	X	X	X	
05N 04W 20DADD1	434510116495501	43.75278	-116.8319	2350	H	99-102	102		X	X	X	X	X	X
05N 04W 21CABB2	434522116493201	43.75611	-116.8256	2350	H	180-203	203	X		X	X	X	X	X
05N 04W 24ABA1	434543116453301	43.76194	-116.7592	2510	I	264-415	448	X	X	X	X	X	X	X
05N 04W 34BCB1	434346116484101	43.72945	-116.8114	2300	H/S	115-190	190	X	X	X	X	X	X	X
05N 04W 35BBB1	434359116472801	43.73306	-116.7911	2330	H	74-75	75	X	X	X	X	X	X	X
05N 04W 36BCC1	434339116461201	43.7275	-116.77	2345	I	135-146	146	X	X	X	X	X	X	X
05N 05W 04BCC1	434759116570201	43.79972	-116.9506	2285	S/I	45-46	46	X	X	X	X	X	X	X
05N 05W 04DCD1	434733116561501	43.7925	-116.9375	2281	P	245-477	505	X	X	X	X	X	X	X
05N 05W 09BDB1	434714116564201	43.7875	-116.9444	2225	U/P	245-440	450			X	X	X	X	X

Well Name	Site ID	Well Latitude	Well Longitude	Elevation	Use	Open Interval	Well Depth	1996 Spring	1996 Fall	1998 Spring	1998 Fall	2000 Spring	2000 Fall	2001 Fall
05N 05W 10BBCB1	434724116555001	43.79	-116.9305	2275	H	100-122	123			X	X	X	X	X
05N 05W 13CBC1	434605116532601	43.76805	-116.8906	2311	U/I	39-142	142	X	X	X	X	X	X	X
05N 05W 18CAC1	434603116590901	43.7675	-116.9858	2225	H	-	250	X	X	X	X	X	X	X
05N 05W 20CCD1	434459116575001	43.74972	-116.9639	2255	H	36-37	37	X	X	X	X	X	X	X
05N 05W 27DDBC1	434411116545301	43.73639	-116.9147	2260	H	60-61	61			X	X	X	X	X
05N 05W 29CDDA1	434409116574101	43.73583	-116.9614	2375	H	199-222	222			X	X	X	X	X
05N 05W 32AAAA1	434402116570501	43.73389	-116.9514	2378	I	210-380	385			X	X	X	X	X
05N 05W 32CDC1	434313116574901	43.72028	-116.9636	2312	H/S	57-58	58	X	X	X	X	X	X	X
05N 05W 33ACCC1	434349116562401	43.7275	-116.9408	2380	I	198-348	368			X	X	X	X	
05N 06W 01CDD1	434735117000801	43.79306	-117.0022	2200	S	40-47	47			X	X	X	X	X
05N 06W 11AAD1	434725117004101	43.79028	-117.0114	2195	H	76-82	82	X	X	X	X	X	X	X
05N 06W 26CAA1	434430117012301	43.74167	-117.0231	2210	U/H	-	34	X	X	X	X	X	X	X
05N 06W 35CAC1	434310117011201	43.725	-117.0217	2275	H	42-43	43	X	X	X	X	X	X	X
06N 03W 22CBB1	435032116412801	43.84222	-116.6911	2570	H	-	235	X	X	X	X	X	X	X
06N 03W 30DCC1	434920116442701	43.82222	-116.7408	2440	H	206-216	216	X	X	X	X	X	X	X
06N 03W 33CBA1	434845116422901	43.8125	-116.7081	2480	H	-	152	X	X	X	X	X	X	
06N 04W 28CDC1	434922116493301	43.82278	-116.8258	2630	I	369-705	705	X	X					
06N 04W 34DDB1	434835116474301	43.80972	-116.7953	2480	H	144-147	147	X	X	X	X	X	X	X
06N 04W 35ADC1	433858116463401	43.81611	-116.7761	2620	H	352-362	362	X	X	X	X	X	X	X
06N 05W 30CDC1	434920116591701	43.82222	-116.9881	2335	H	60-62	62			X	X	X	X	X
06N 05W 35BAC1	434910116542701	43.81944	-116.9075	2520	H	298-322	322	X	X	X	X	X	X	X
06N 05W 36CDB1	434836116531201	43.81	-116.8867	2500	I	308-385	385	X	X	X	X	X	X	X
SUMMARY: Number of Wells								**343**	**343**	**383**	**372**	**392**	**390**	**341**

Appendix E. POTENTIOMETRIC SURFACE MAPS

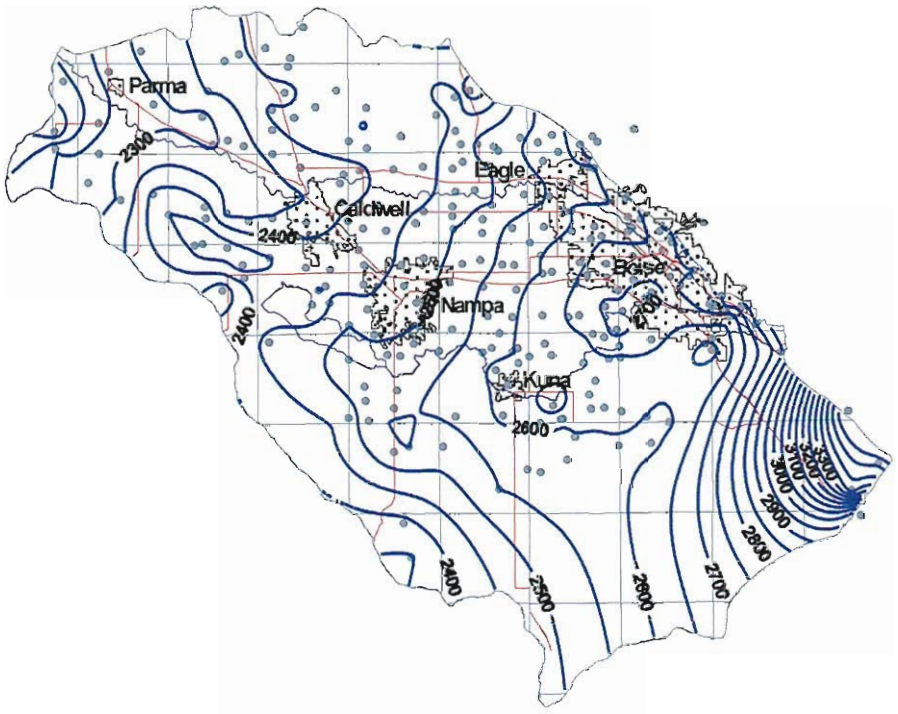


Figure E-1: Spring 1996, shallow zone (240 wells).

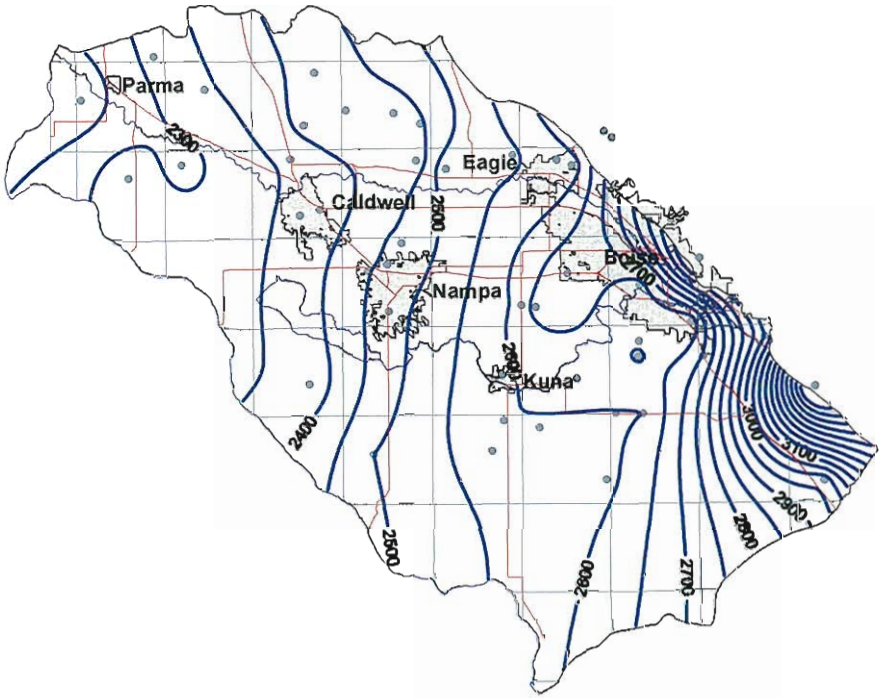


Figure E-2: Spring 1996, intermediate zone (49 wells).

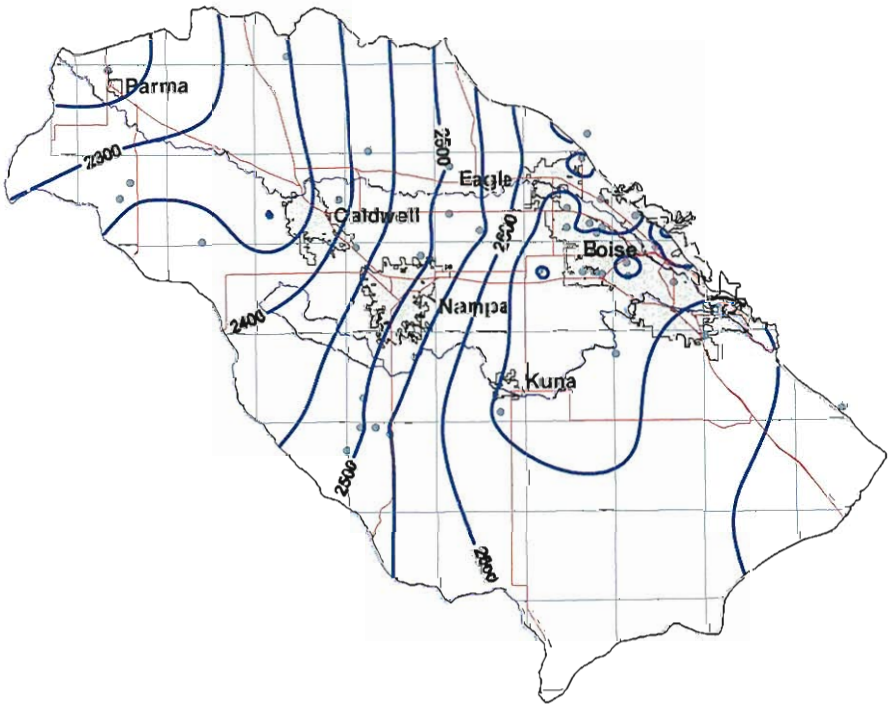


Figure E-3: Spring 1996, deep zone (45 wells).

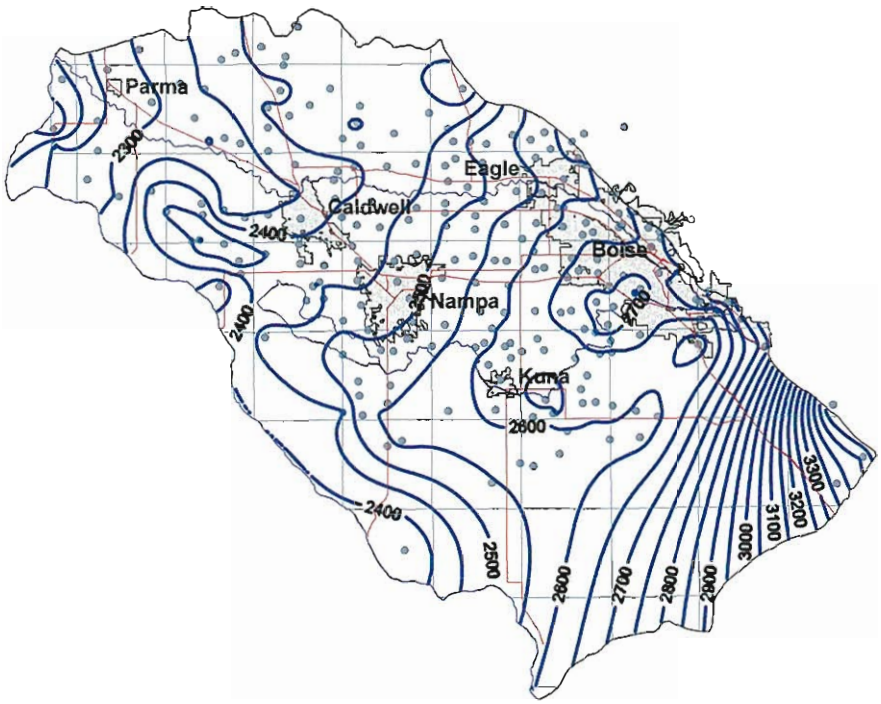


Figure E-4: Fall 1996, shallow zone (235 wells).

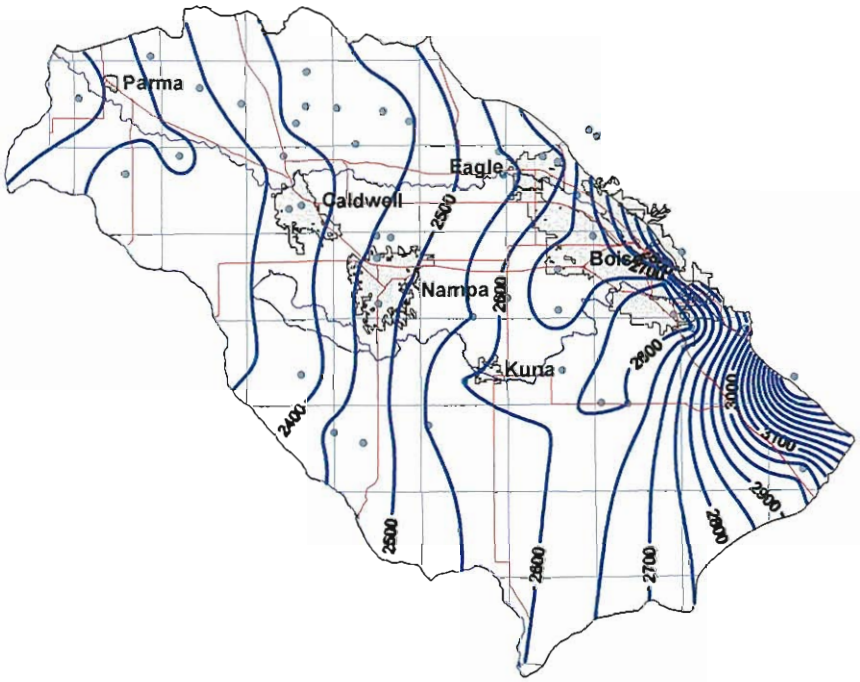


Figure E-5: Fall 1996, intermediate zone (49 wells).

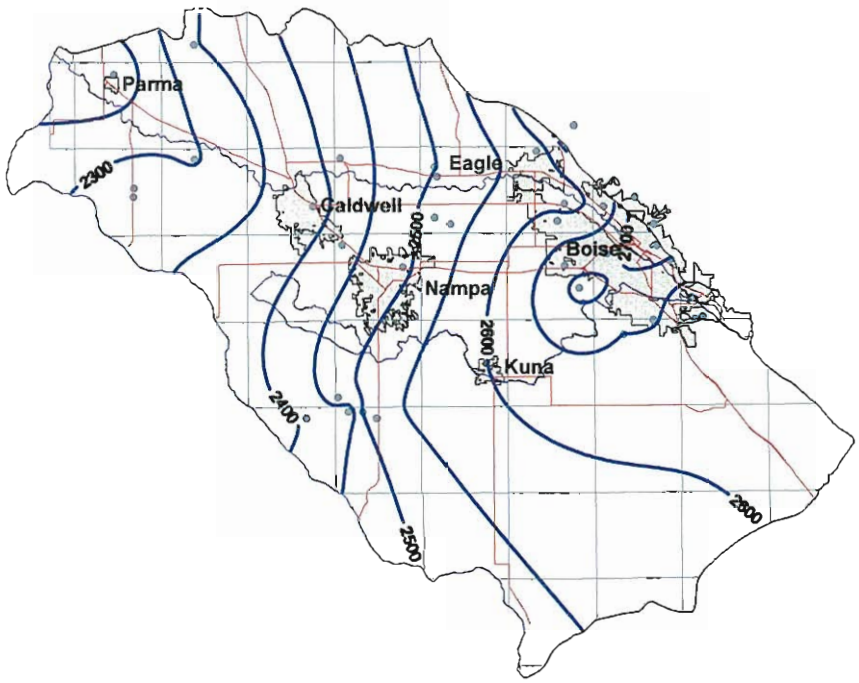


Figure E-6: Fall 1996, deep zone (35 wells).

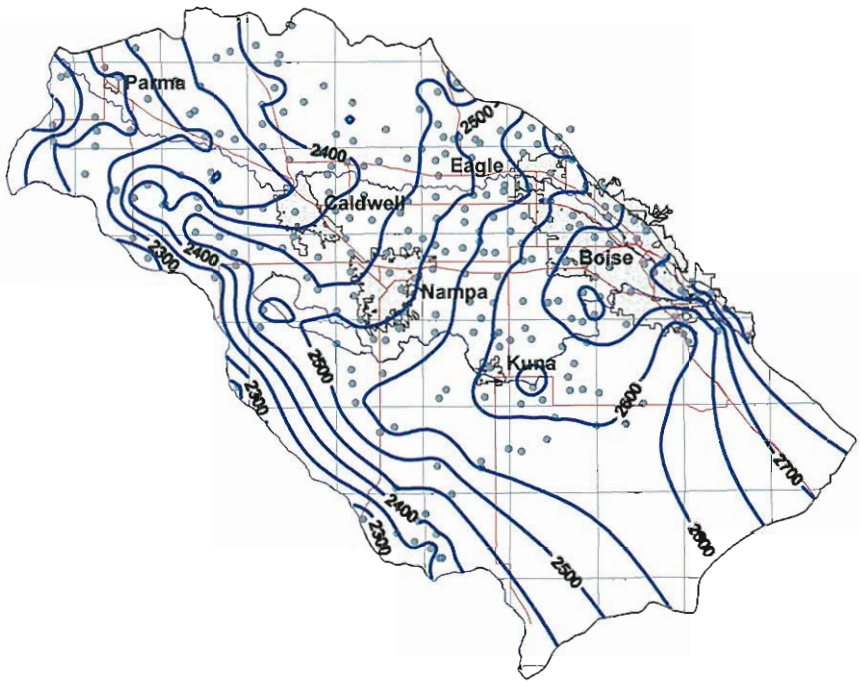


Figure E-7: Spring 1998, shallow zone (259 wells).

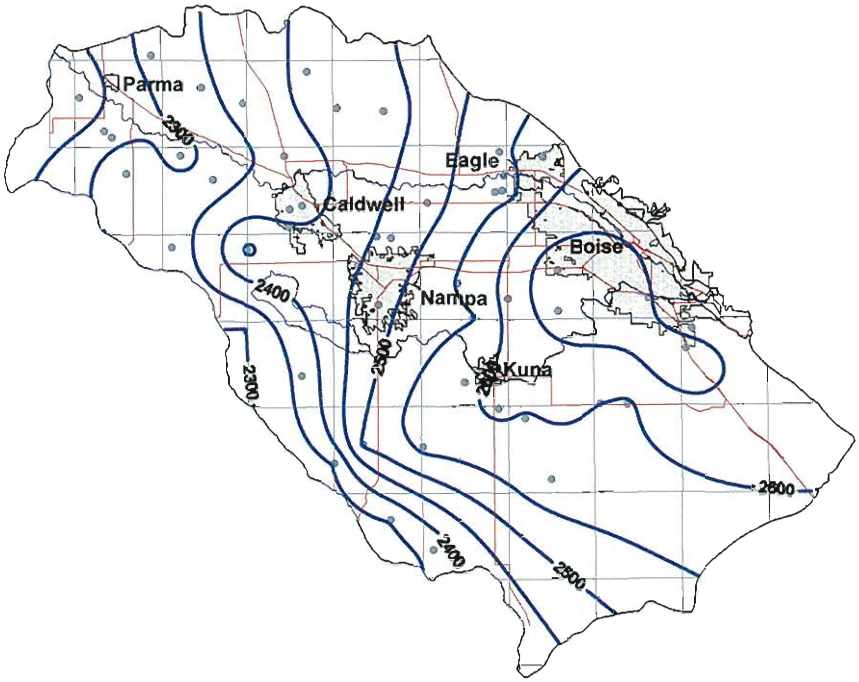


Figure E-8: Spring 1998, intermediate zone (50 wells).

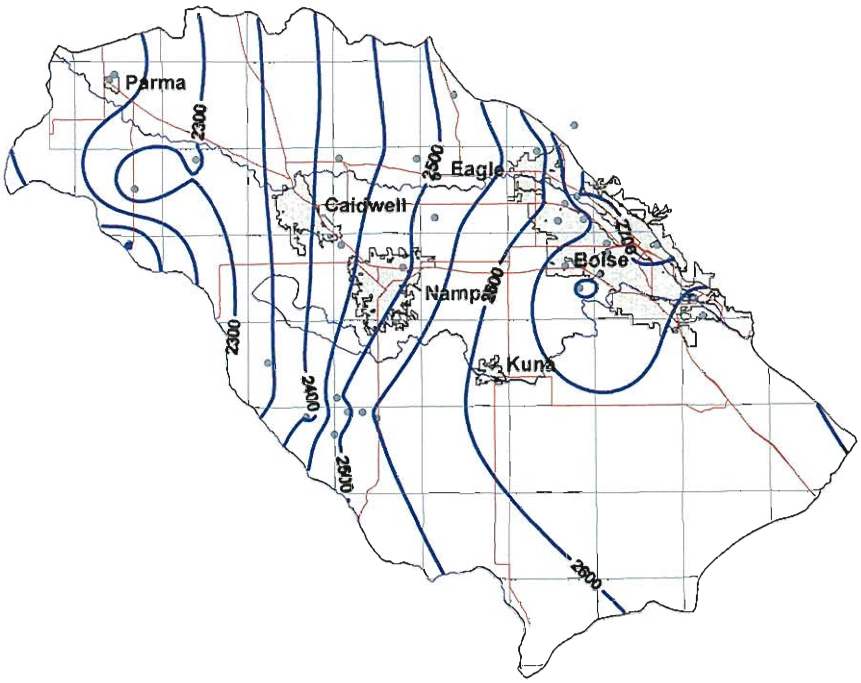


Figure E-9: Spring 1998, deep zone (38 wells).

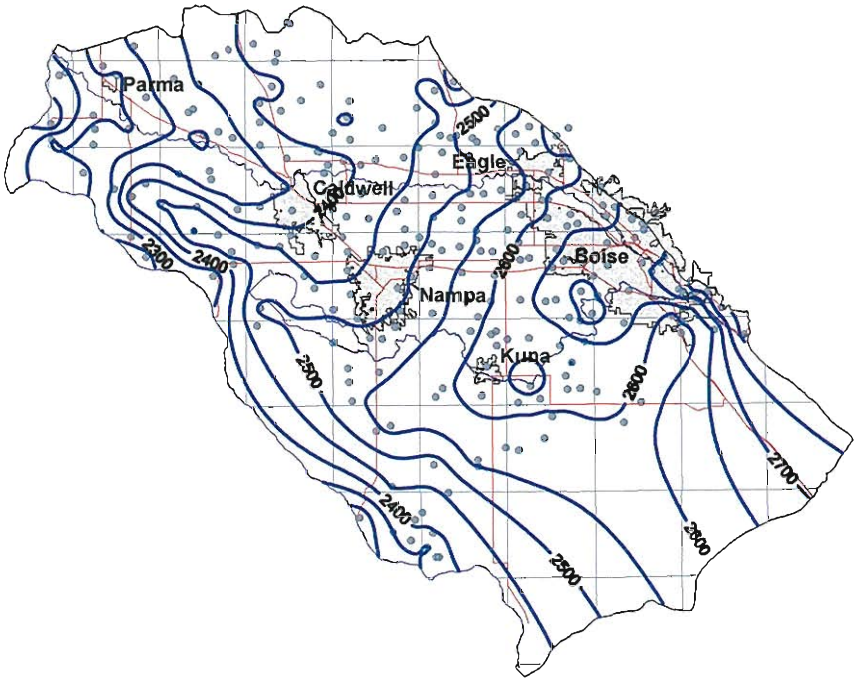


Figure E-10: Fall 1998, shallow zone (245 wells).

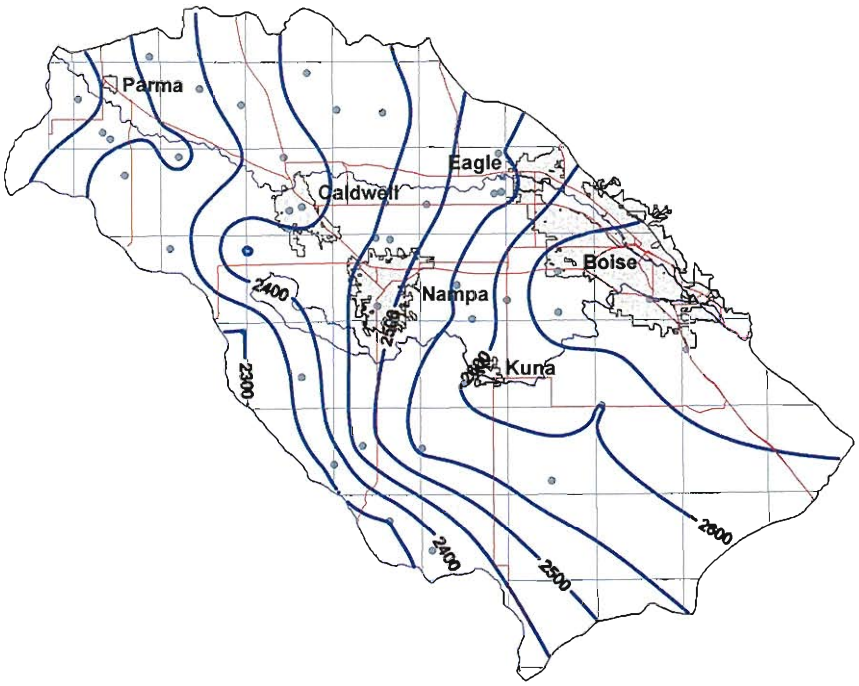


Figure E-11: Fall 1998, intermediate zone (44 wells).

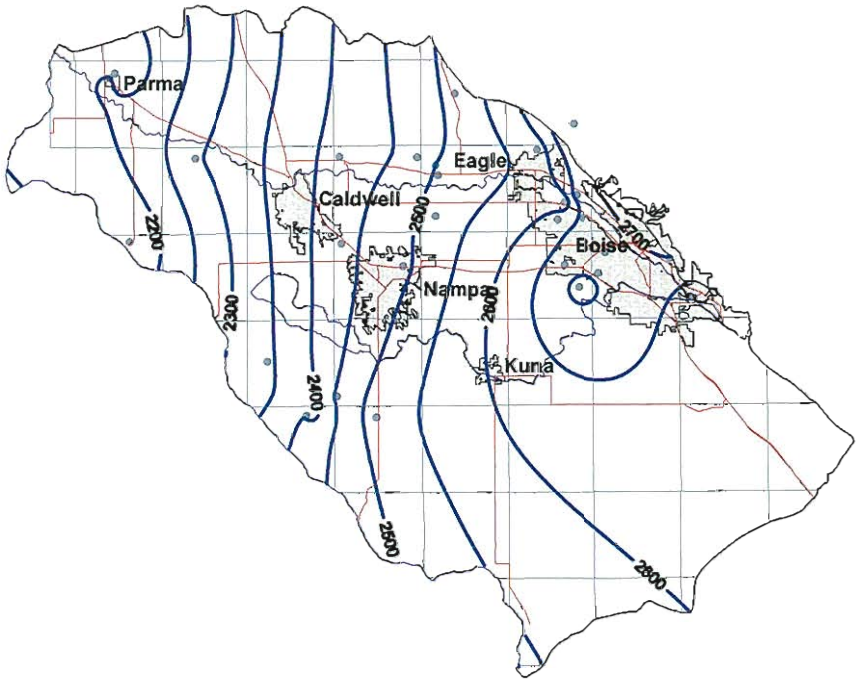


Figure E-12: Fall 1998, deep zone (29 wells).

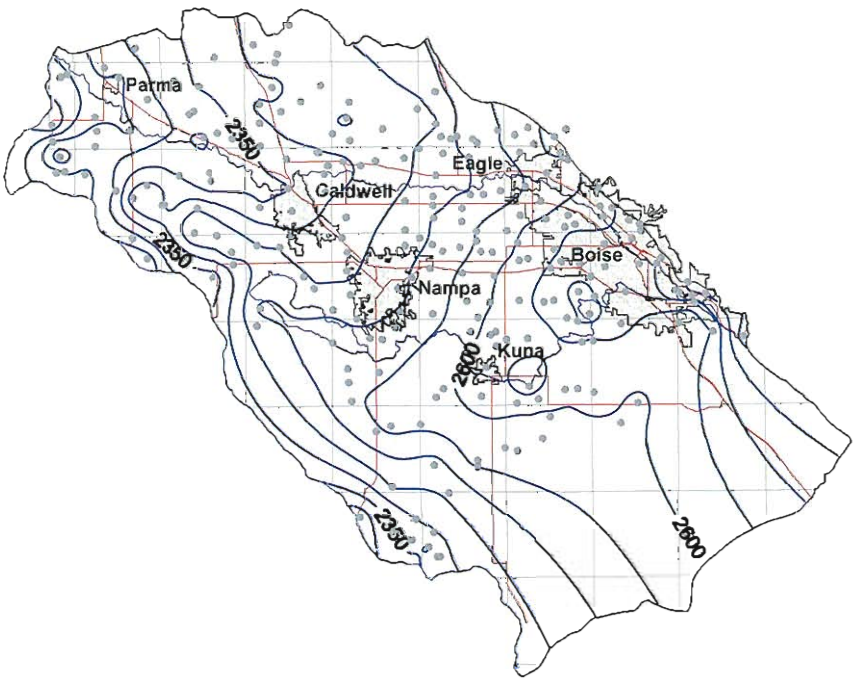


Figure E-13: Spring 2000, shallow zone (238 wells).

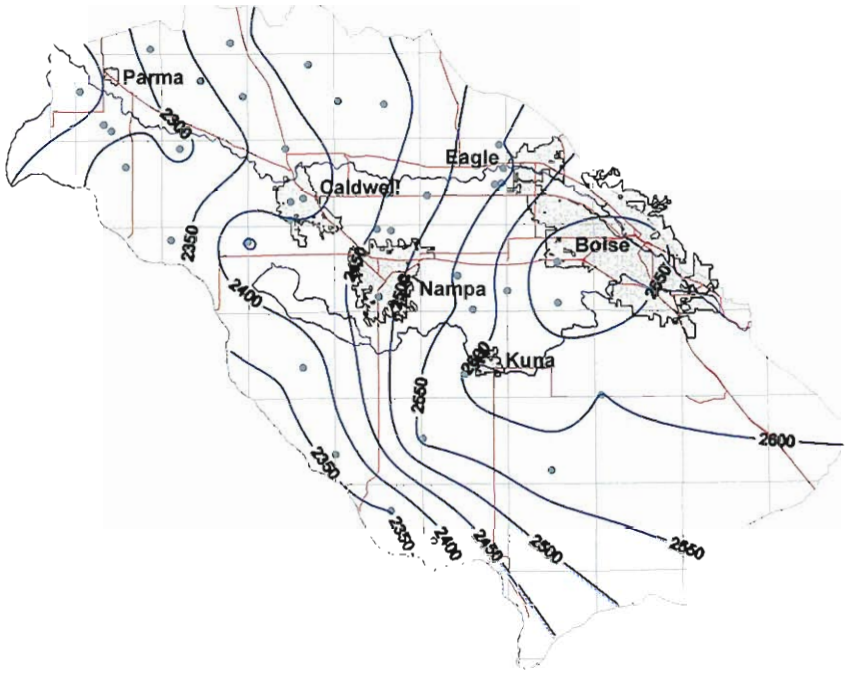


Figure E-14: Spring 2000, intermediate zone (42 wells).

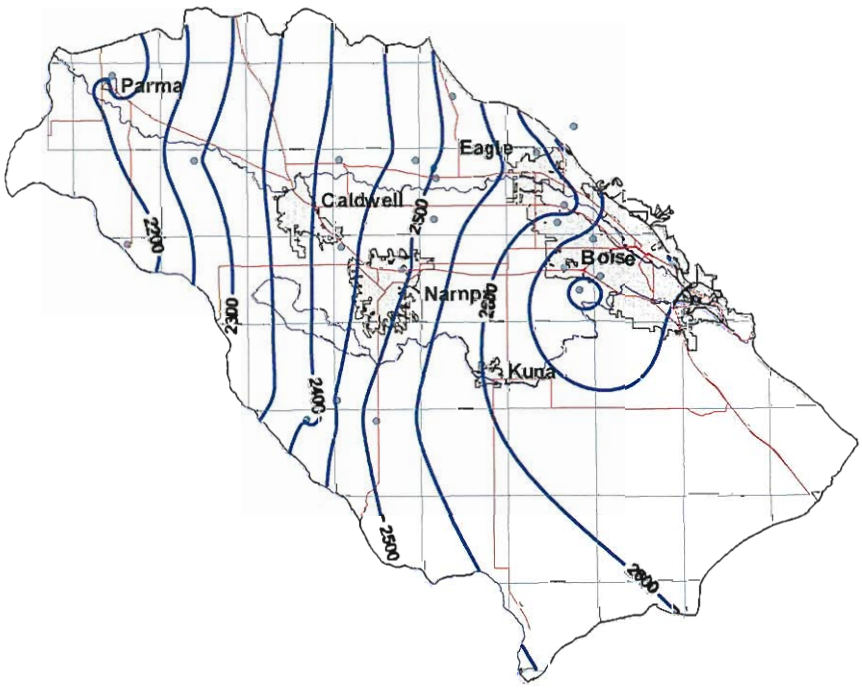


Figure E-15: Spring 2000, deep zone (27 wells).

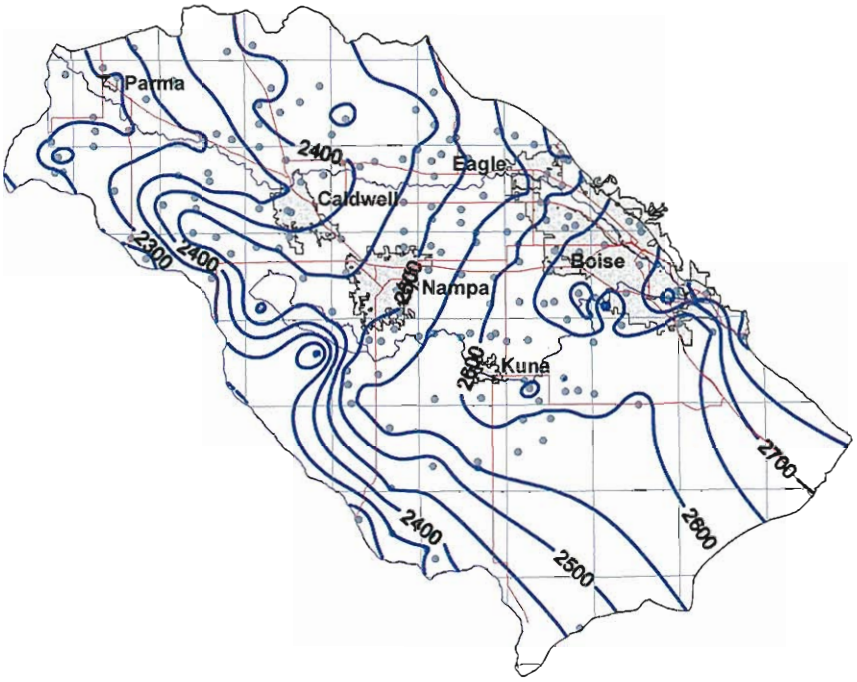


Figure E-16: Fall 2000, shallow zone (16 wells).

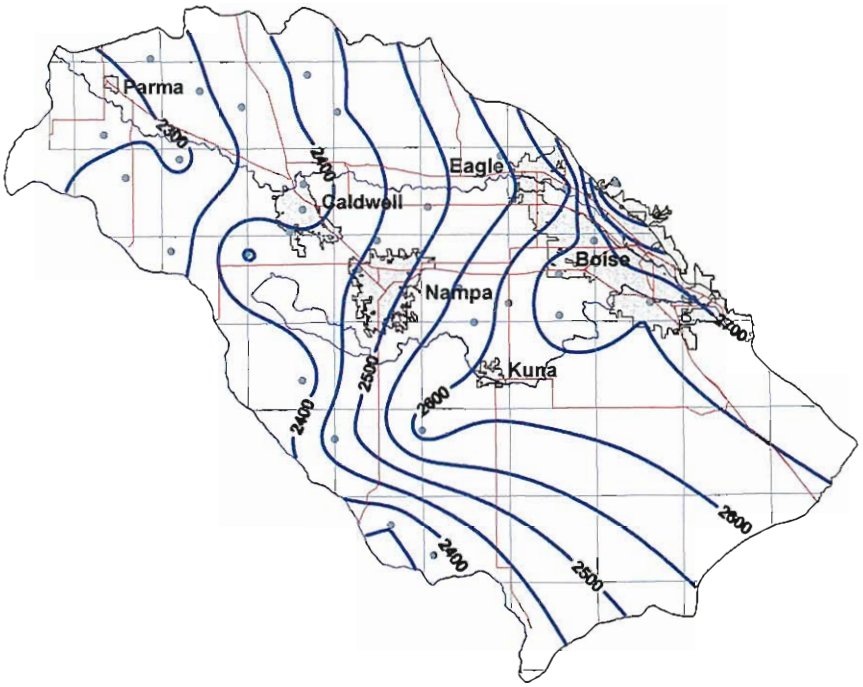


Figure E-17: Fall 2000, intermediate zone (34 wells).

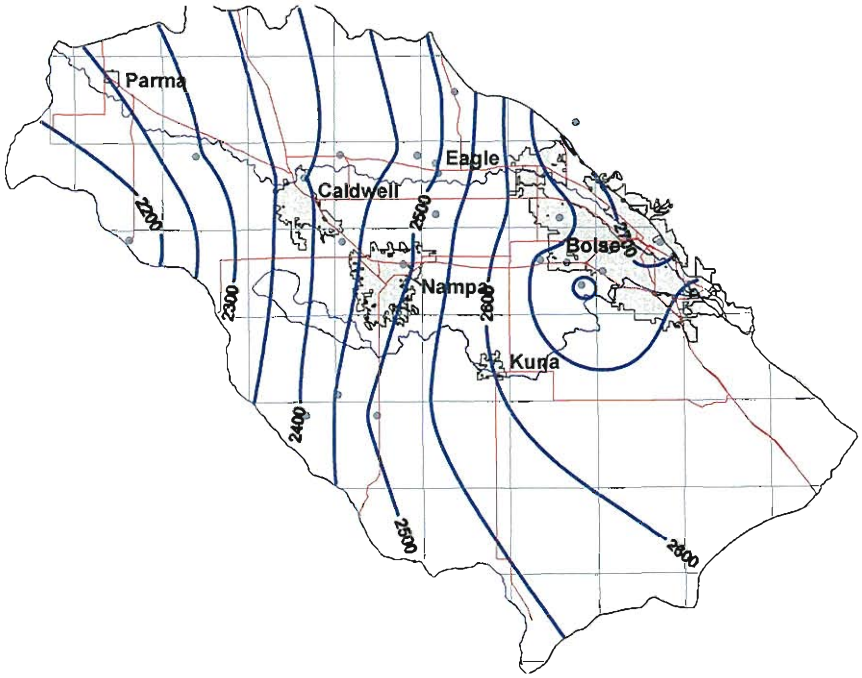


Figure E-18: Fall 2000, deep zone (26 wells).

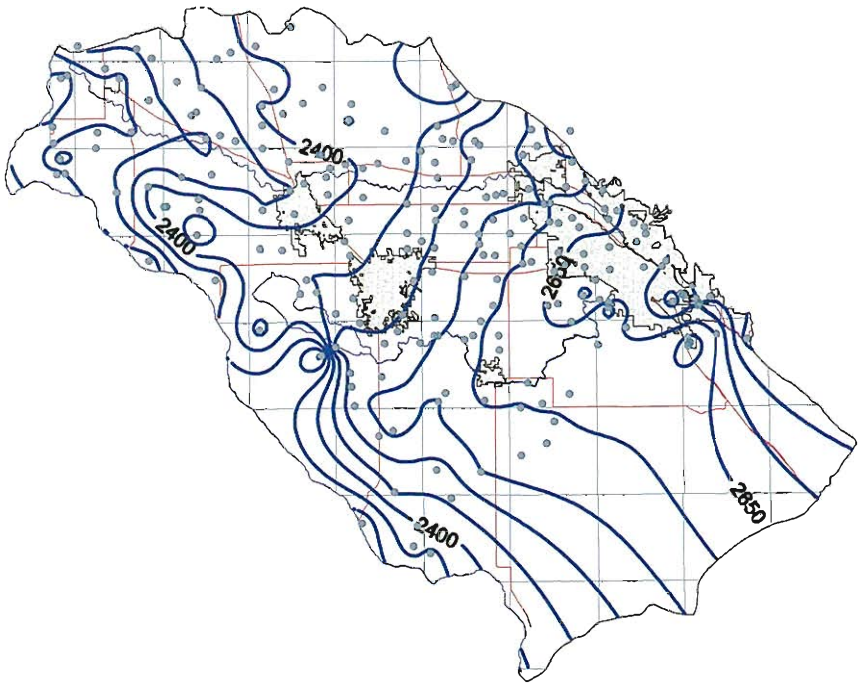


Figure E-19: Fall 2001, shallow zone (212 wells).

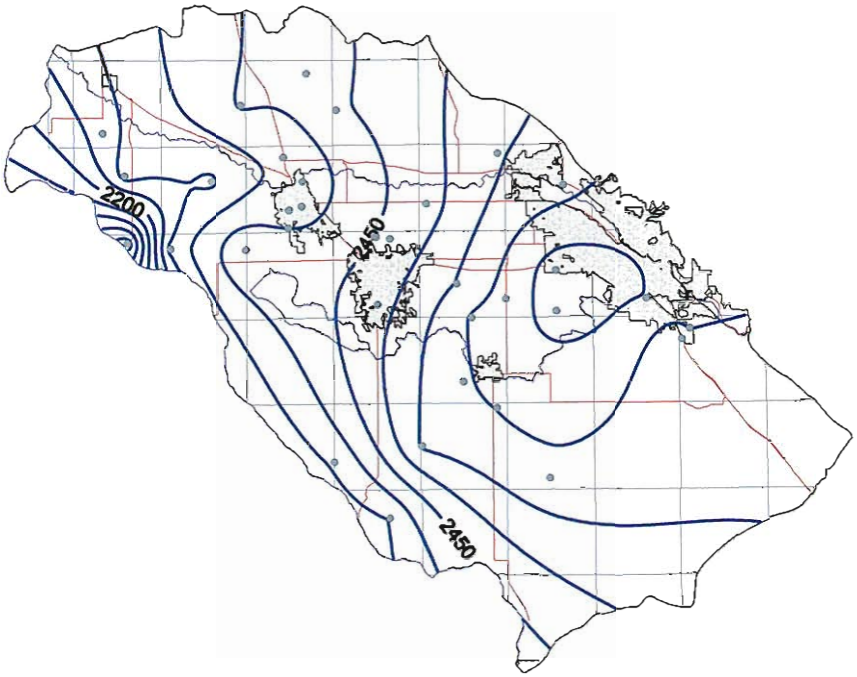


Figure E-20: Fall 2001, intermediate zone (35 wells).

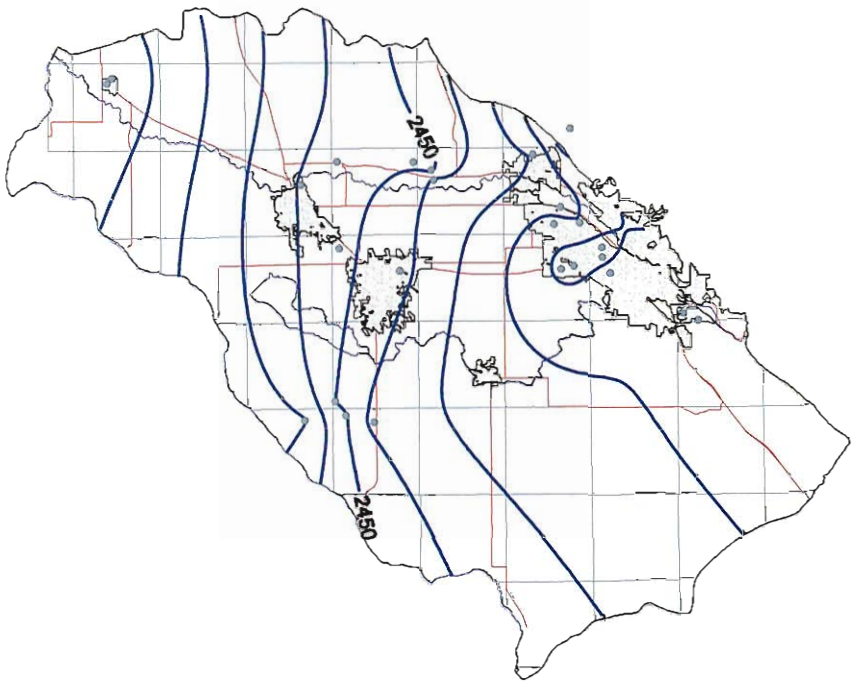
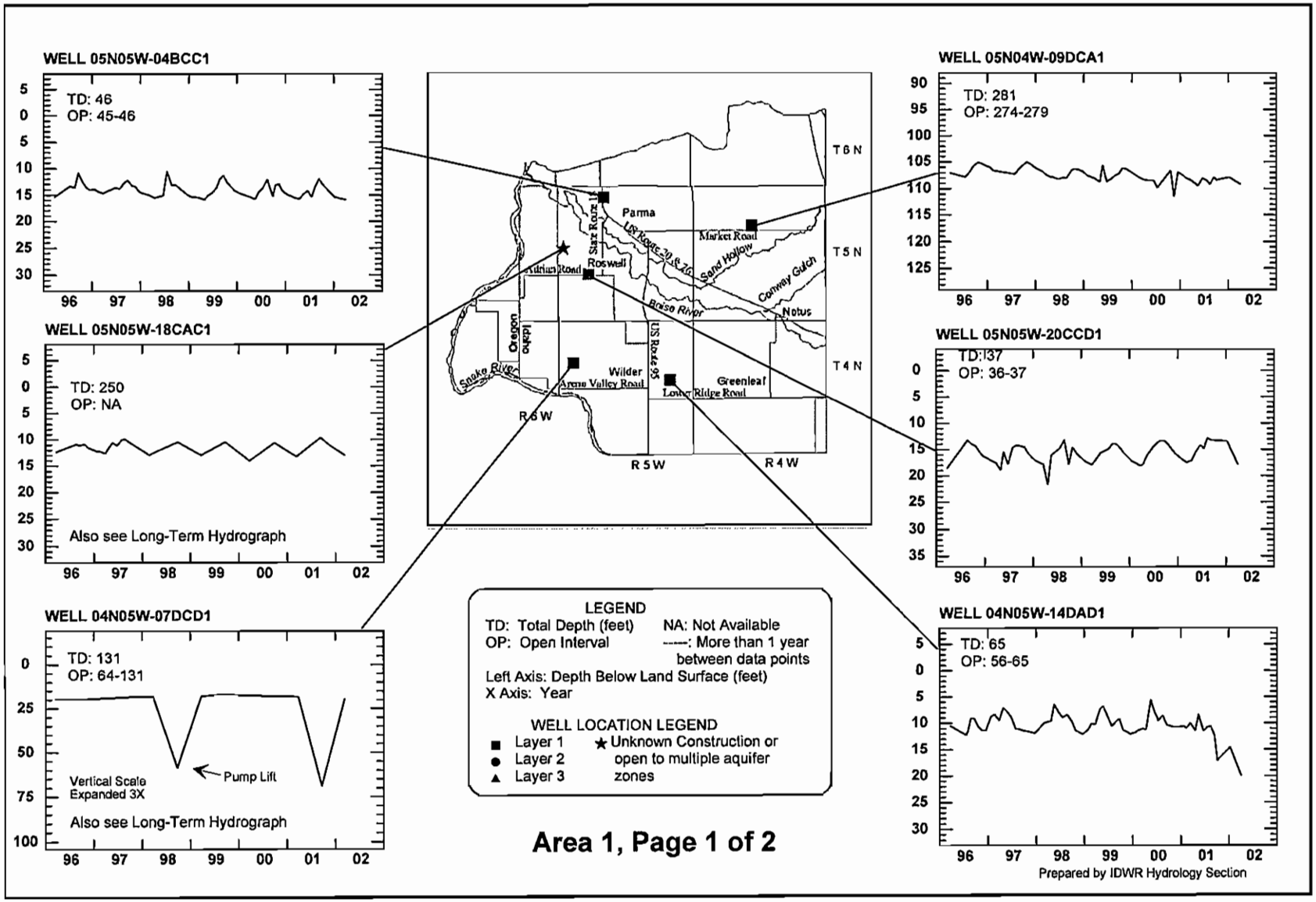
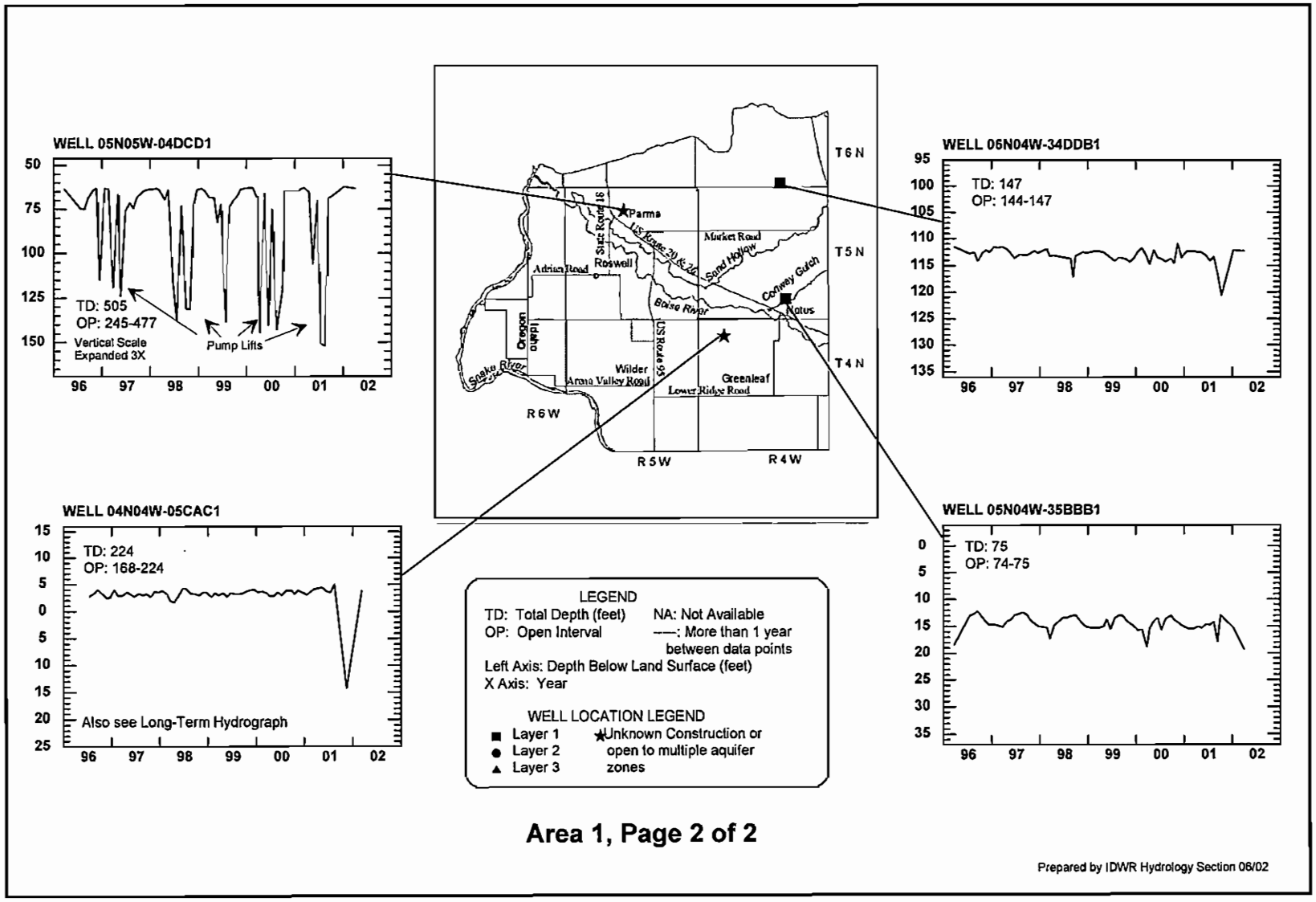


Figure E-21: Fall 2001, deep zone (27 wells).

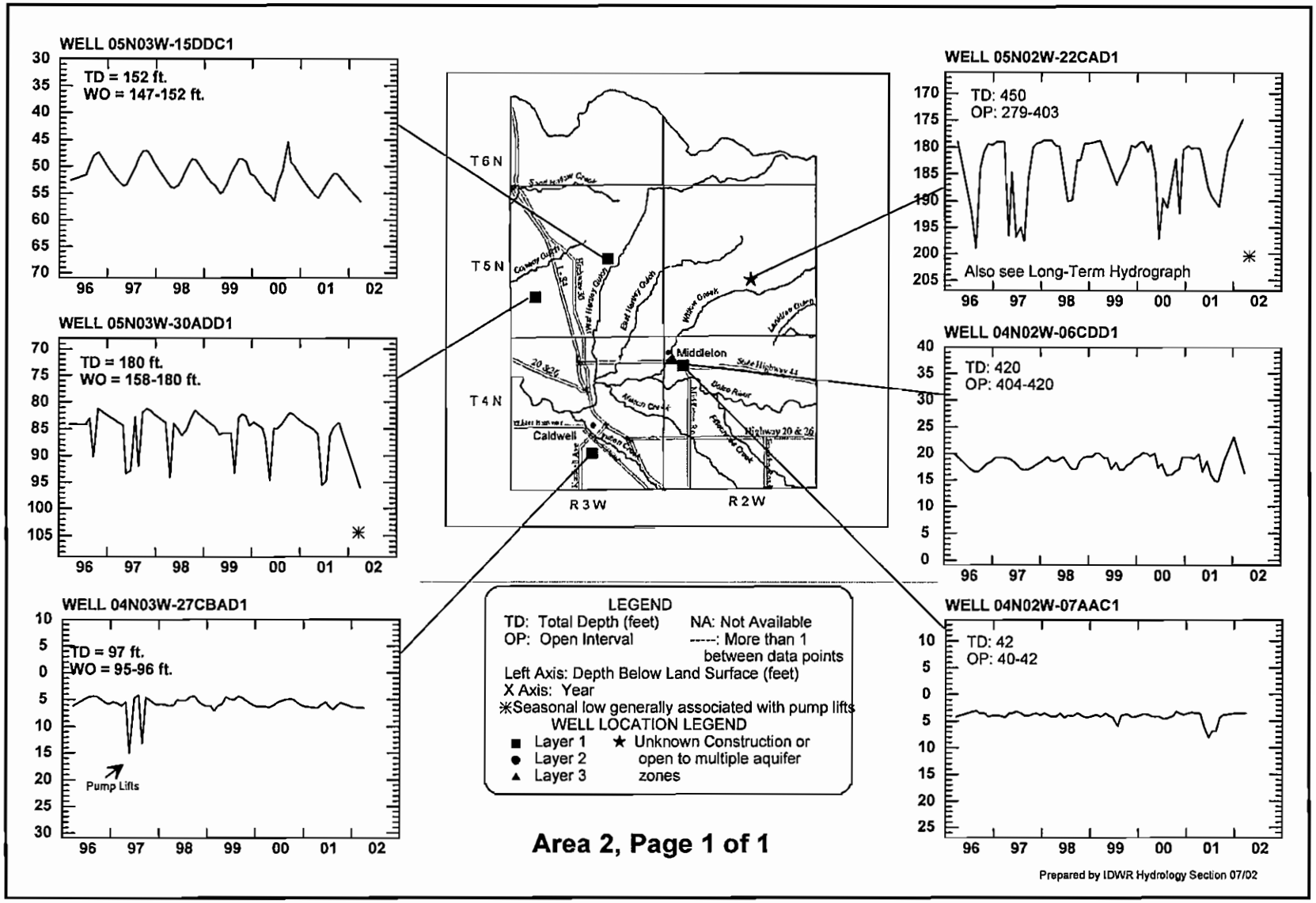
Appendix F. HYDROGRAPHS

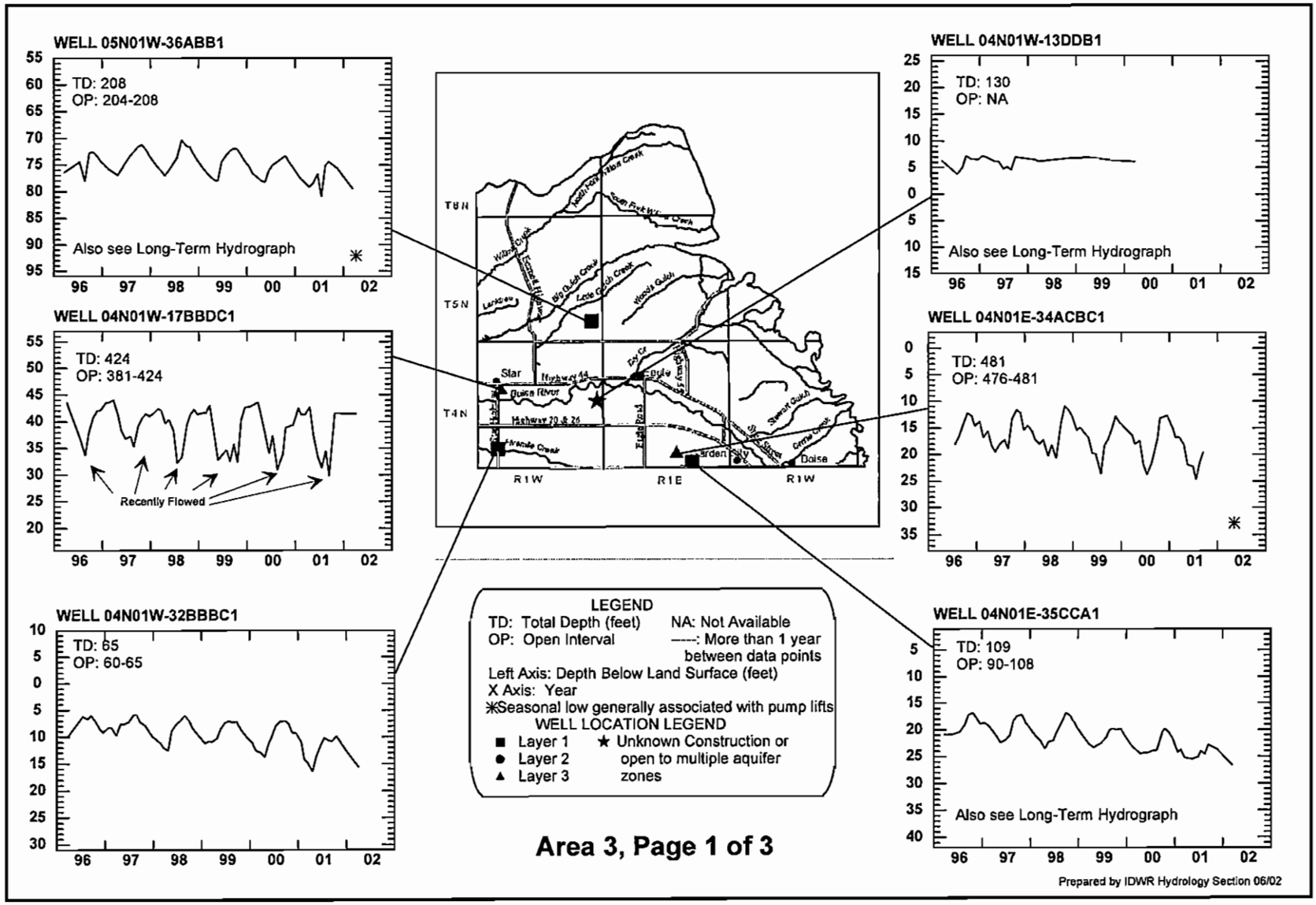

WELL 05N05W-04BCC1
TD: 46
OP: 45-46
WELL 05N05W-18CAC1
TD: 250
OP: NA
Also see Long-Term Hydrograph
WELL 04N05W-07DCD1
TD: 131
OP: 64-131
Vertical Scale Expanded 3X
Pump Lift
Also see Long-Term Hydrograph
WELL 05N04W-09DCA1
TD: 281
OP: 274-279
WELL 05N05W-20CCD1
TD:137
OP: 36-37
WELL 04N05W-14DAD1
TD: 65
OP: 56-65
96 97 98 99 00 01 02
Parma
Roswell
Market Road
Sand Hollow
Conway Gulch
Notus
Wilder
Greenleaf
Lower Ridge Road
Arena Valley Road
Snake River
Oregon
Idaho
Boise River
T6N
T5N
T4N
R6W
R5W
R4W
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
Unknown Construction or open to multiple aquifer zones
Area 1, Page 1 of 2
Prepared by IDWR Hydrology Section

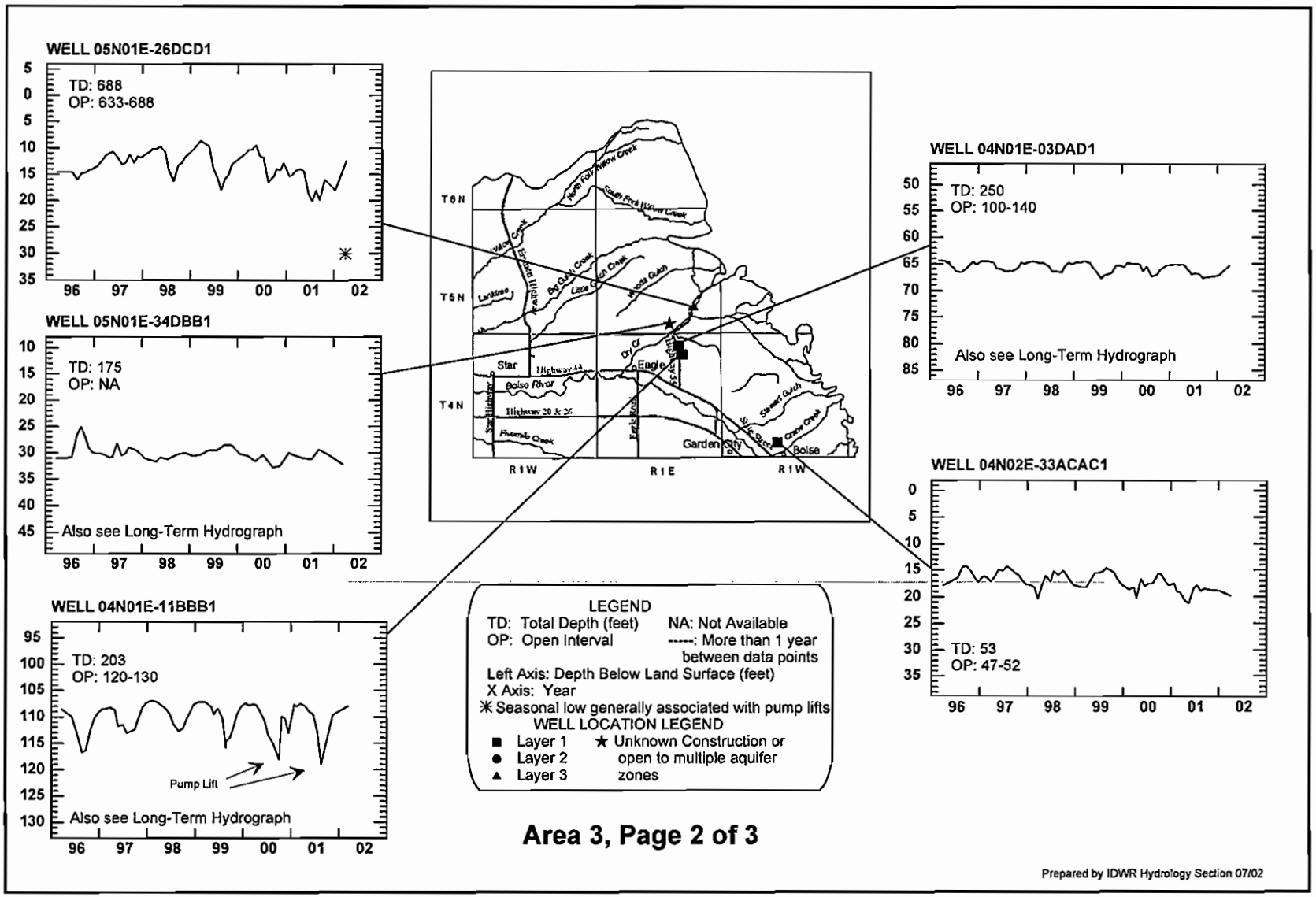


Area 1, Page 2 of 2

Prepared by IDWR Hydrology Section 06/02

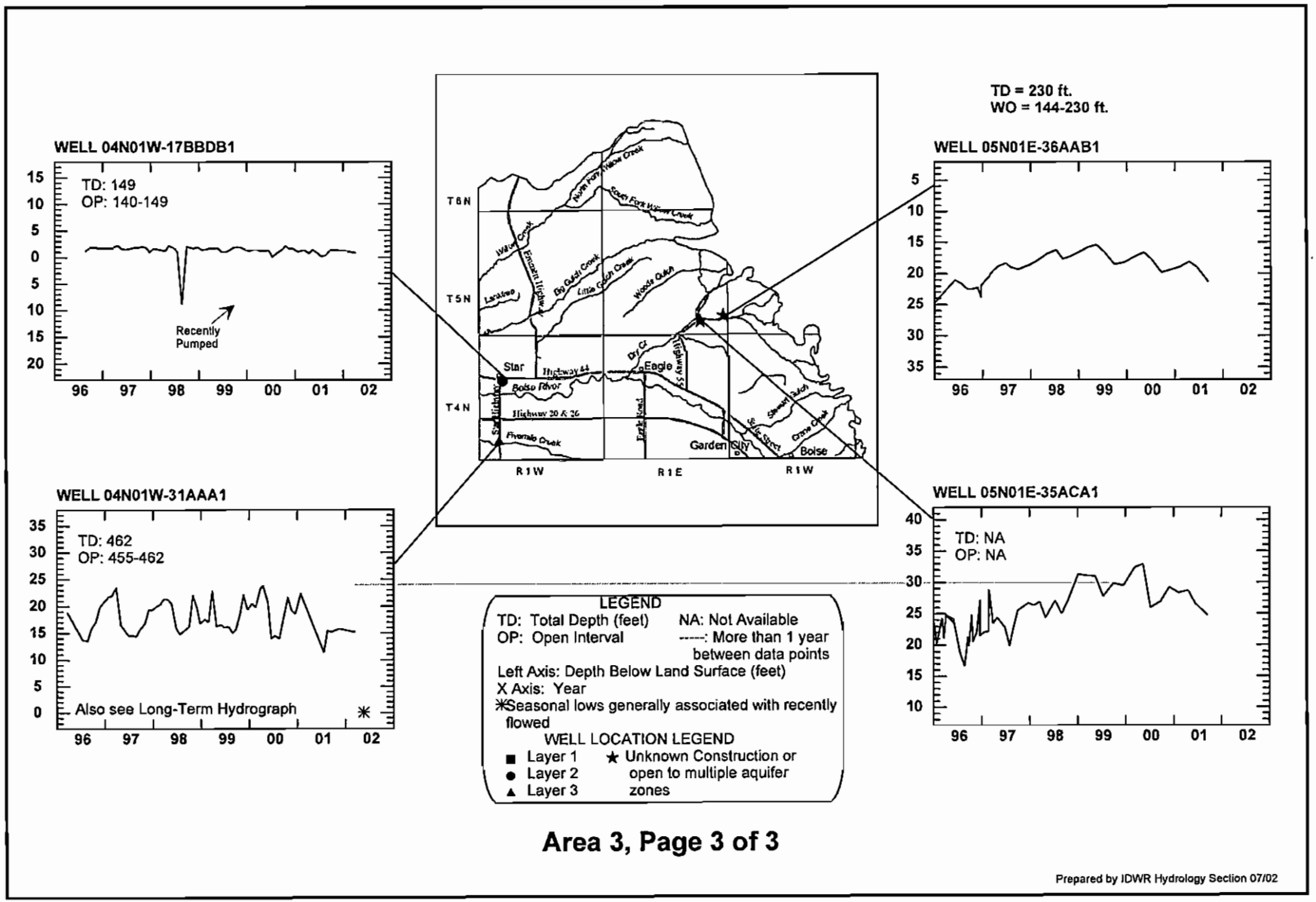

WELL 05N03W-15DDC1
TD = 152 ft.
WO = 147-152 ft.
WELL 05N03W-30ADD1
TD = 180 ft.
WO = 158-180 ft.
WELL 04N03W-27CBAD1
TD = 97 ft.
WO = 95-96 ft.
Pump Lifts
T6N
T5N
T4N
R3W
R2W
Middleton
Caldwell
WELL 05N02W-22CAD1
TD: 450
OP: 279-403
Also see Long-Term Hydrograph
WELL 04N02W-06CDD1
TD: 420
OP: 404-420
WELL 04N02W-07AAC1
TD: 42
OP: 40-42
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
✳Seasonal low generally associated with pump lifts
WELL LOCATION LEGEND
■ Layer 1
● Layer 2
▲ Layer 3
★ Unknown Construction or open to multiple aquifer zones
Area 2, Page 1 of 1
Prepared by IDWR Hydrology Section 07/02


WELL 05N01W-36ABB1
TD: 208
OP: 204-208
Also see Long-Term Hydrograph
WELL 04N01W-17BBDC1
TD: 424
OP: 381-424
Recently Flowed
WELL 04N01W-32BBBC1
TD: 65
OP: 60-65
WELL 04N01W-13DDB1
TD: 130
OP: NA
Also see Long-Term Hydrograph
WELL 04N01E-34ACBC1
TD: 481
OP: 476-481
WELL 04N01E-35CCA1
TD: 109
OP: 90-108
Also see Long-Term Hydrograph
T8N
T5N
T4N
R1W
R1E
R1W
Star
Eagle
Boise
Garden City
Dixie River
Highway 44
Highway 20 & 26
Eagle Road
Five Mile Creek
Ten Mile Creek
Stewart Gulch
Central Drain
Lake Lowell
Lake Fork Creek
Big Gulch Creek
Little Gulch Creek
Woods Gulch
Larkin
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
*Seasonal low generally associated with pump lifts
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
★ Unknown Construction or open to multiple aquifer zones
Area 3, Page 1 of 3
Prepared by IDWR Hydrology Section 06/02



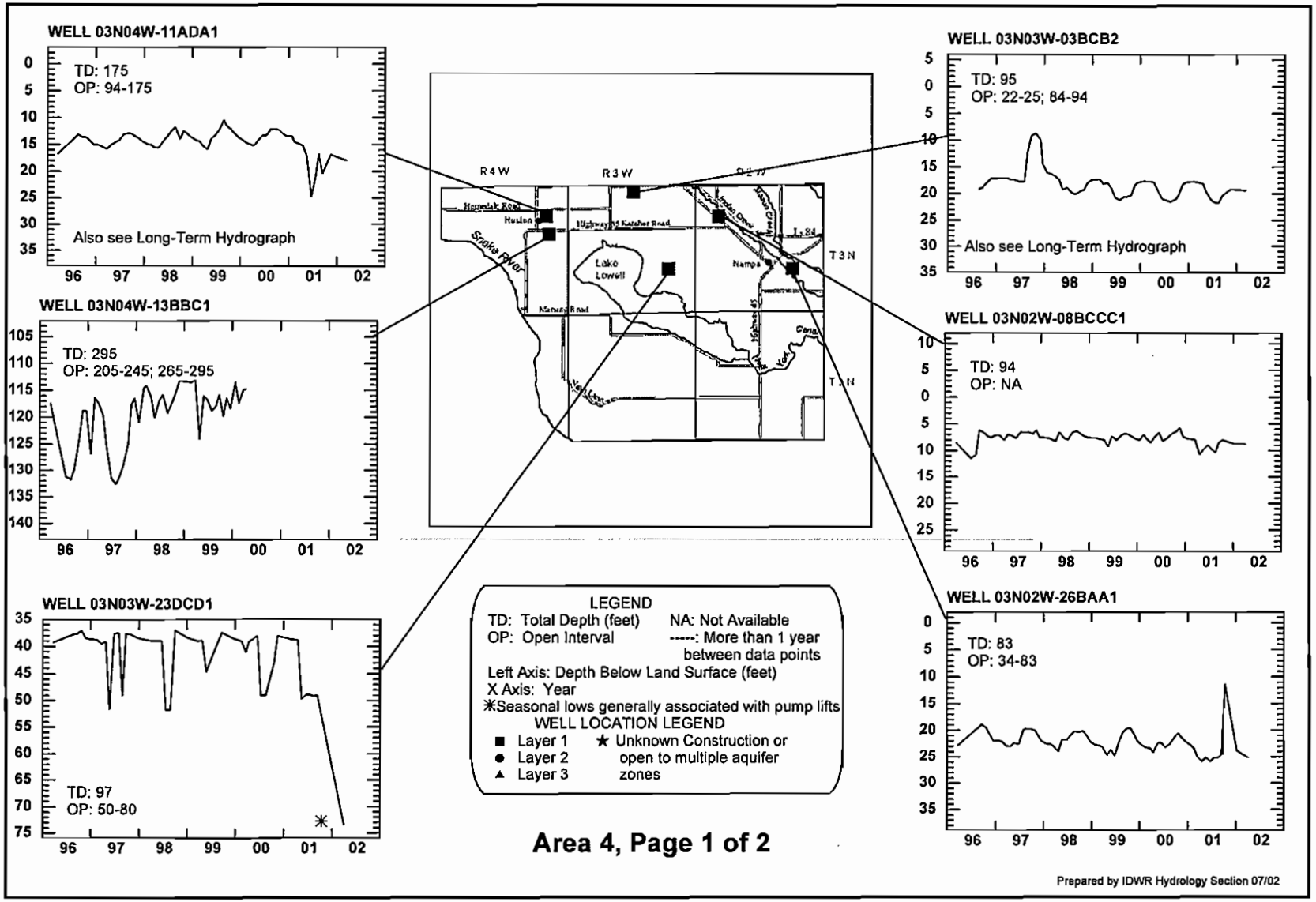
Area 3, Page 2 of 3

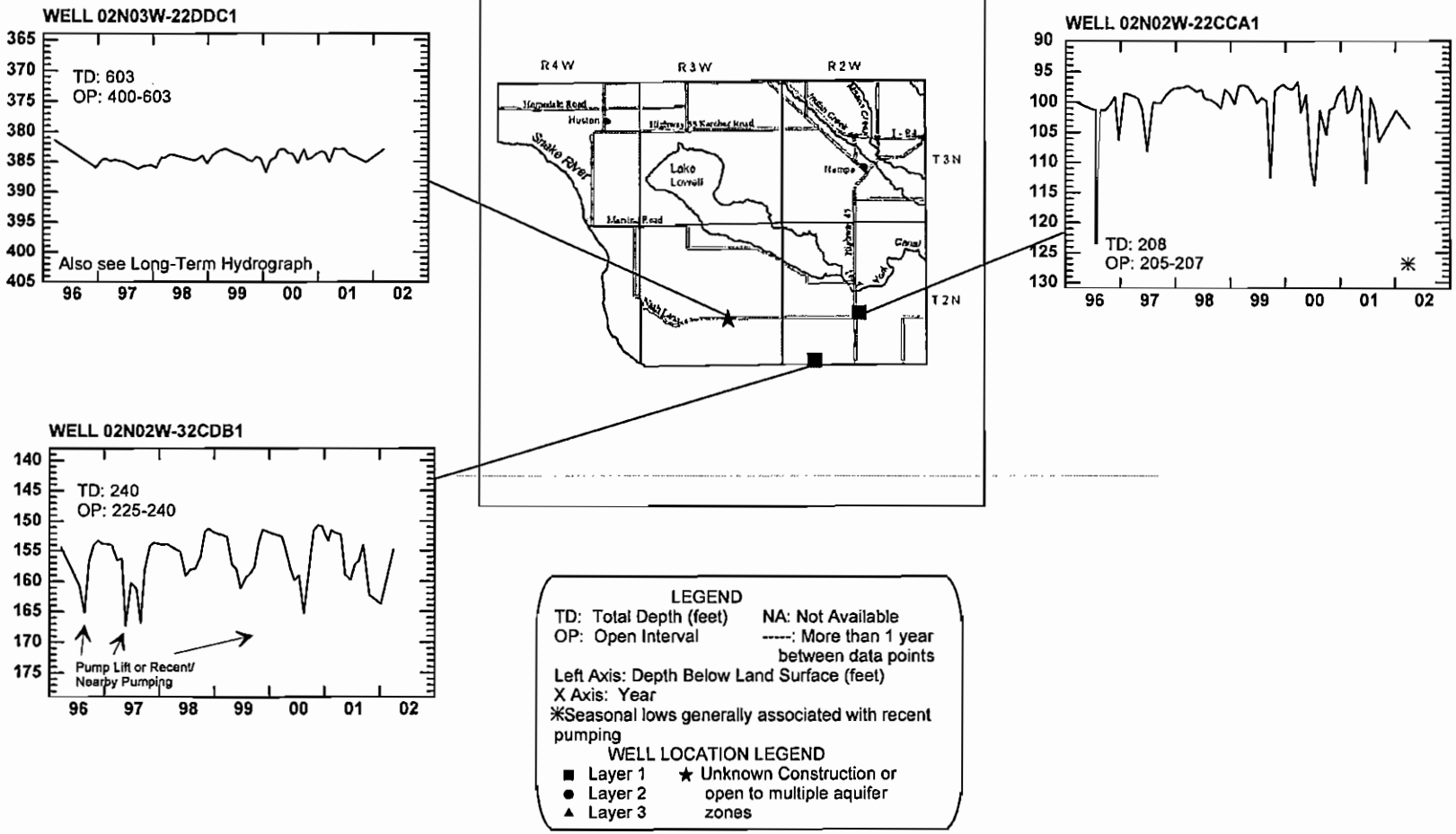
Prepared by IDWR Hydrology Section 07/02



Area 3, Page 3 of 3

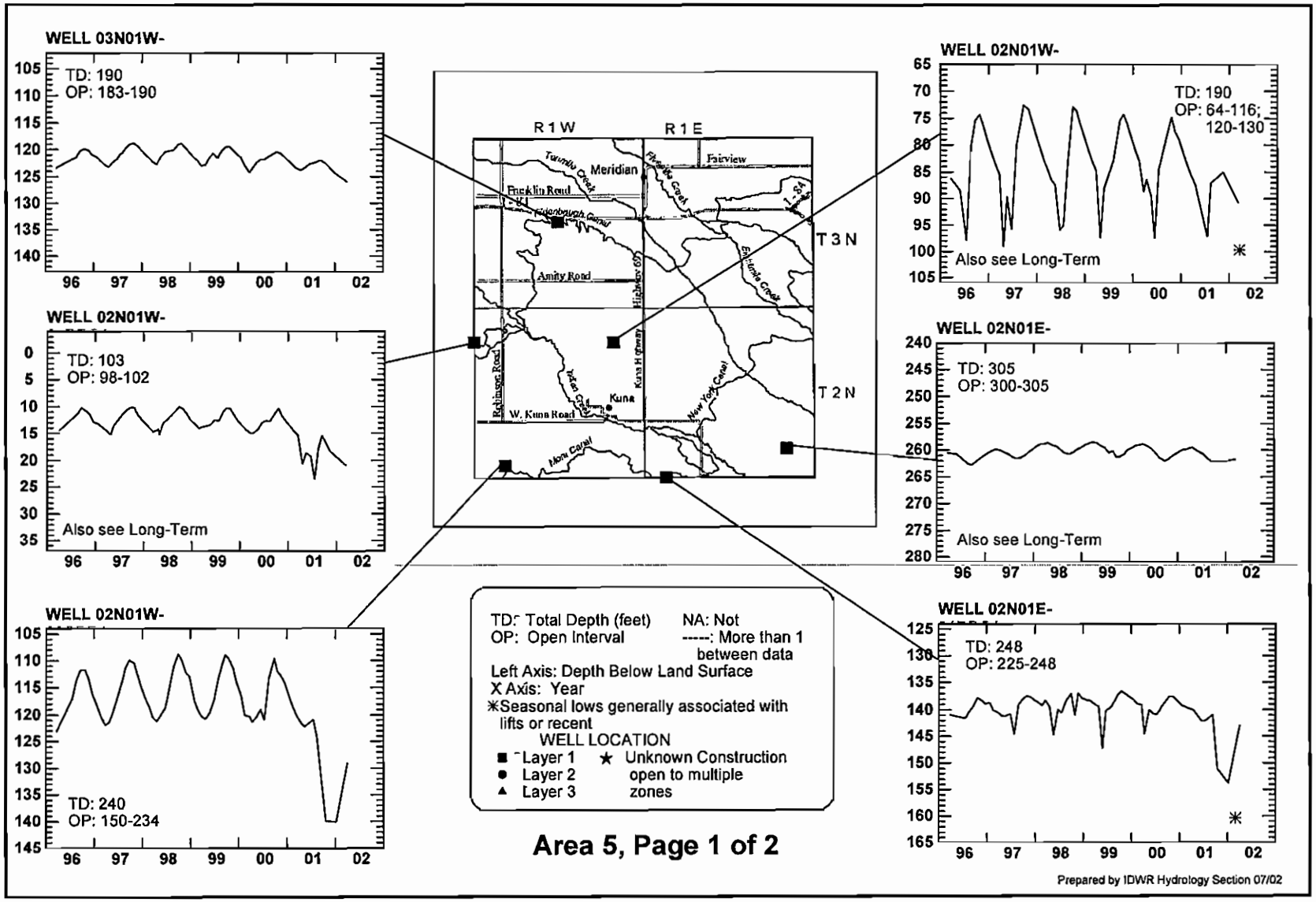
Prepared by IDWR Hydrology Section 07/02

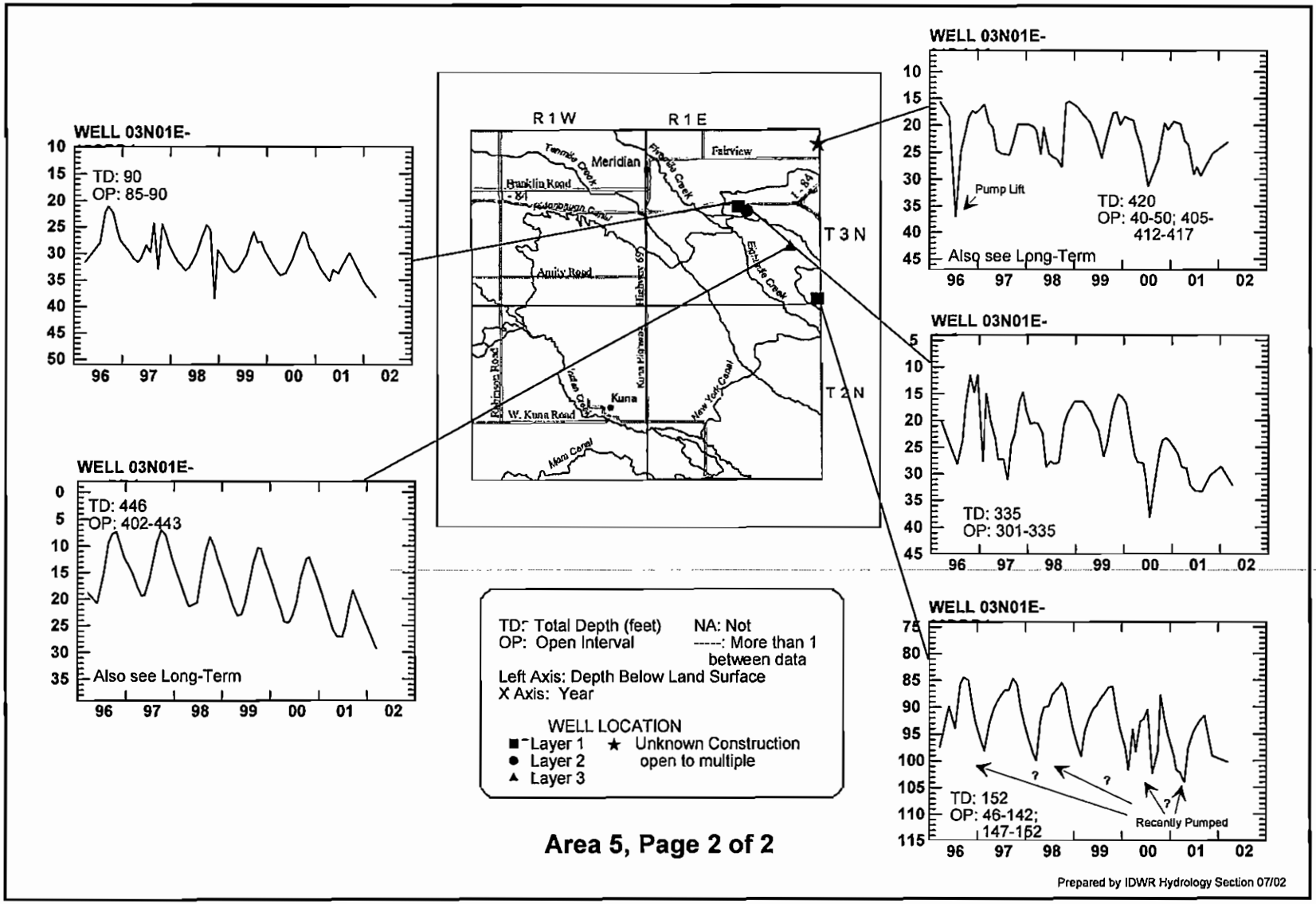

WELL 03N04W-11ADA1
TD: 175
OP: 94-175
Also see Long-Term Hydrograph
WELL 03N04W-13BBC1
TD: 295
OP: 205-245; 265-295
WELL 03N03W-23DCD1
TD: 97
OP: 50-80
WELL 03N03W-03BCB2
TD: 95
OP: 22-25; 84-94
Also see Long-Term Hydrograph
WELL 03N02W-08BCCC1
TD: 94
OP: NA
WELL 03N02W-26BAA1
TD: 83
OP: 34-83
R4W
R3W
T3N
T2N
Lake Lowell
Nampa
Huston
Snake River
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
*Seasonal lows generally associated with pump lifts
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
★ Unknown Construction or open to multiple aquifer zones
Area 4, Page 1 of 2
Prepared by IDWR Hydrology Section 07/02

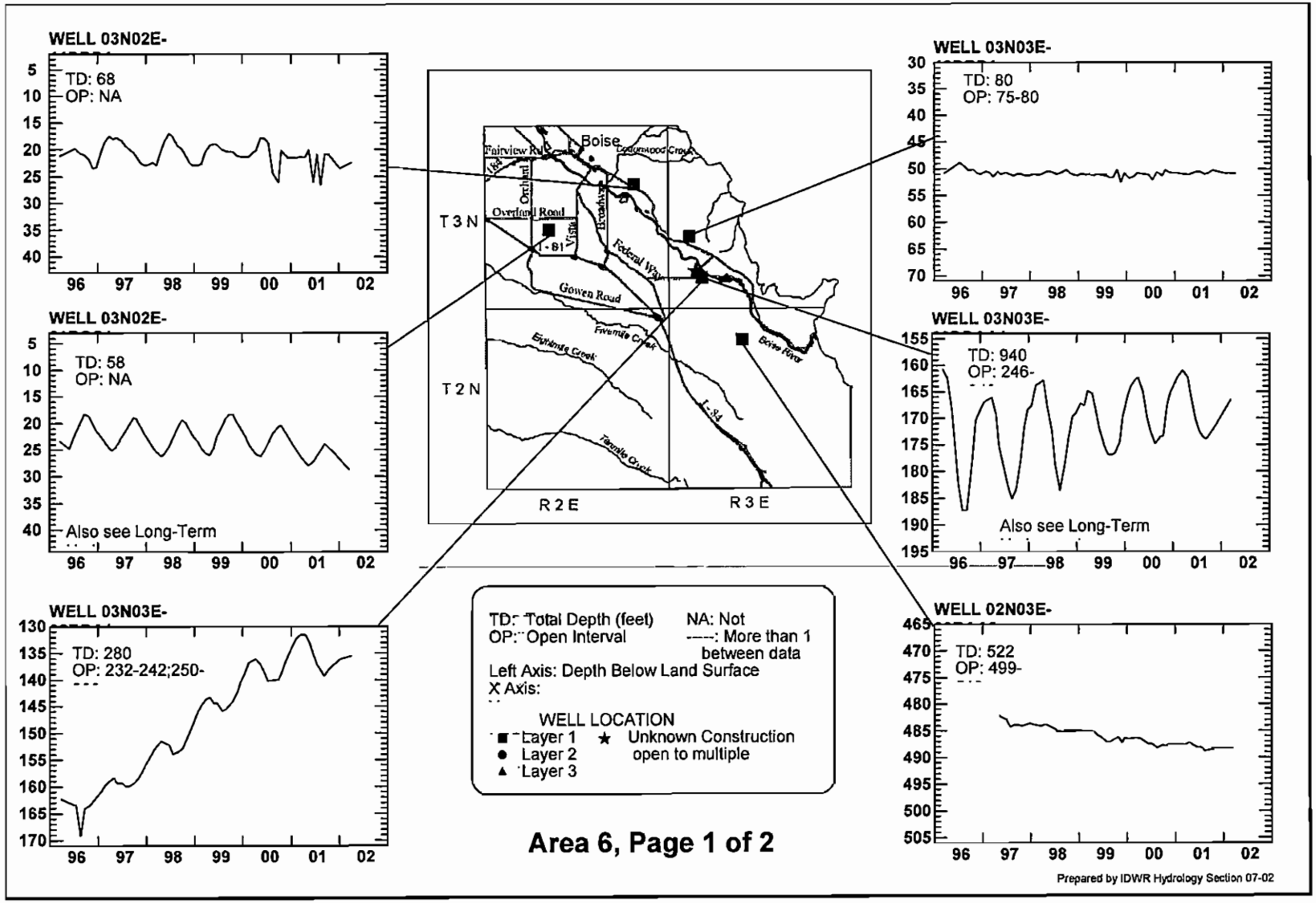


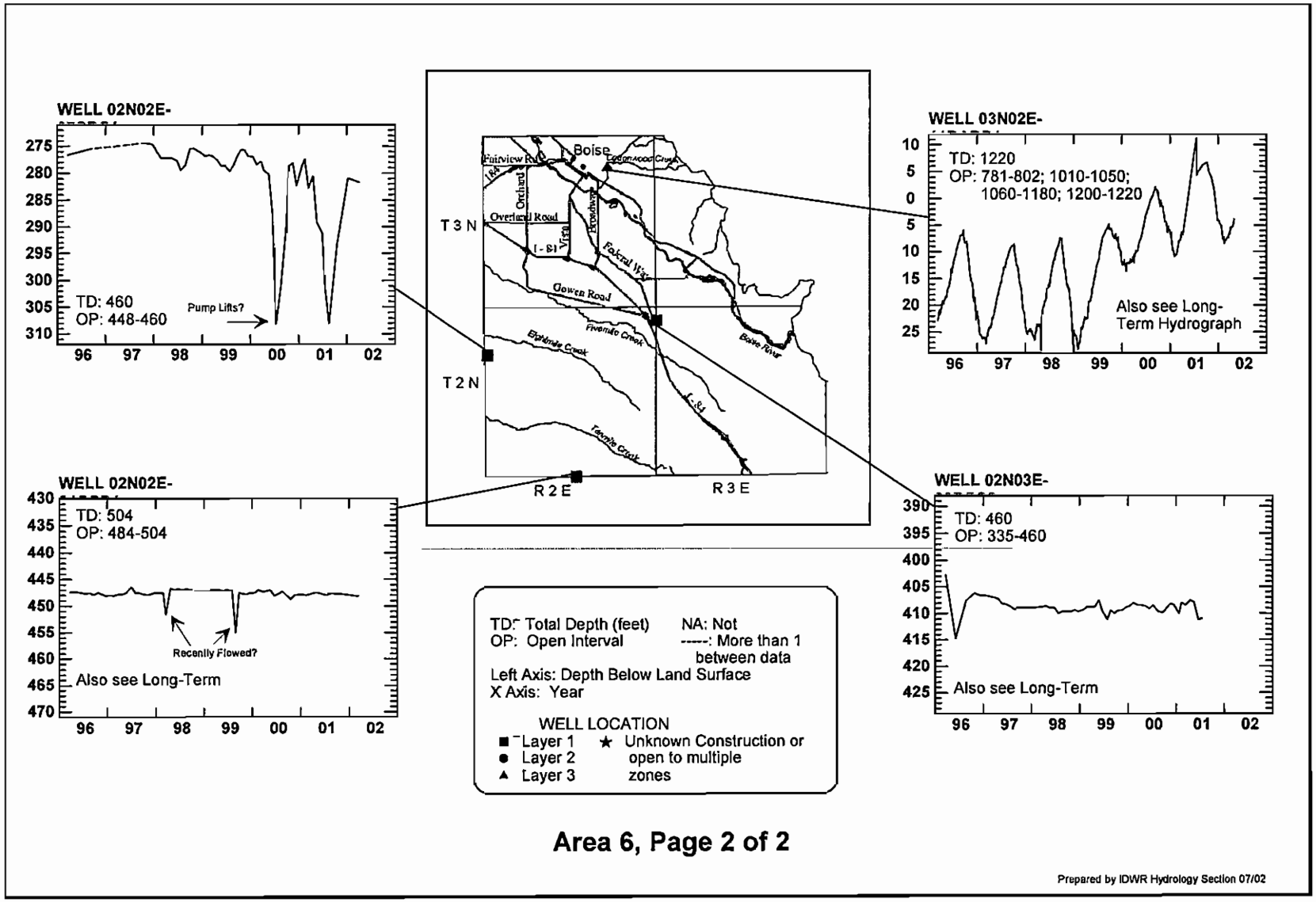
Area 4, Page 2 of 2

Prepared by IDWR Hydrology Section 07/02


WELL 03N01W-
TD: 190
OP: 183-190
WELL 02N01W-
TD: 103
OP: 98-102
Also see Long-Term
WELL 02N01W-
TD: 240
OP: 150-234
R 1 W
R 1 E
Meridian
Fairview
Franklin Road
Amity Road
Eagle Creek
Kuna
W. Kuna Road
New York Canal
T 3 N
T 2 N
WELL 02N01W-
TD: 190
OP: 64-116; 120-130
Also see Long-Term
WELL 02N01E-
TD: 305
OP: 300-305
Also see Long-Term
WELL 02N01E-
TD: 248
OP: 225-248
TD: Total Depth (feet)
OP: Open Interval
NA: Not
-----: More than 1 between data
Left Axis: Depth Below Land Surface
X Axis: Year
*Seasonal lows generally associated with lifts or recent
WELL LOCATION
Layer 1
Layer 2
Layer 3
Unknown Construction open to multiple zones
Area 5, Page 1 of 2
Prepared by IDWR Hydrology Section 07/02

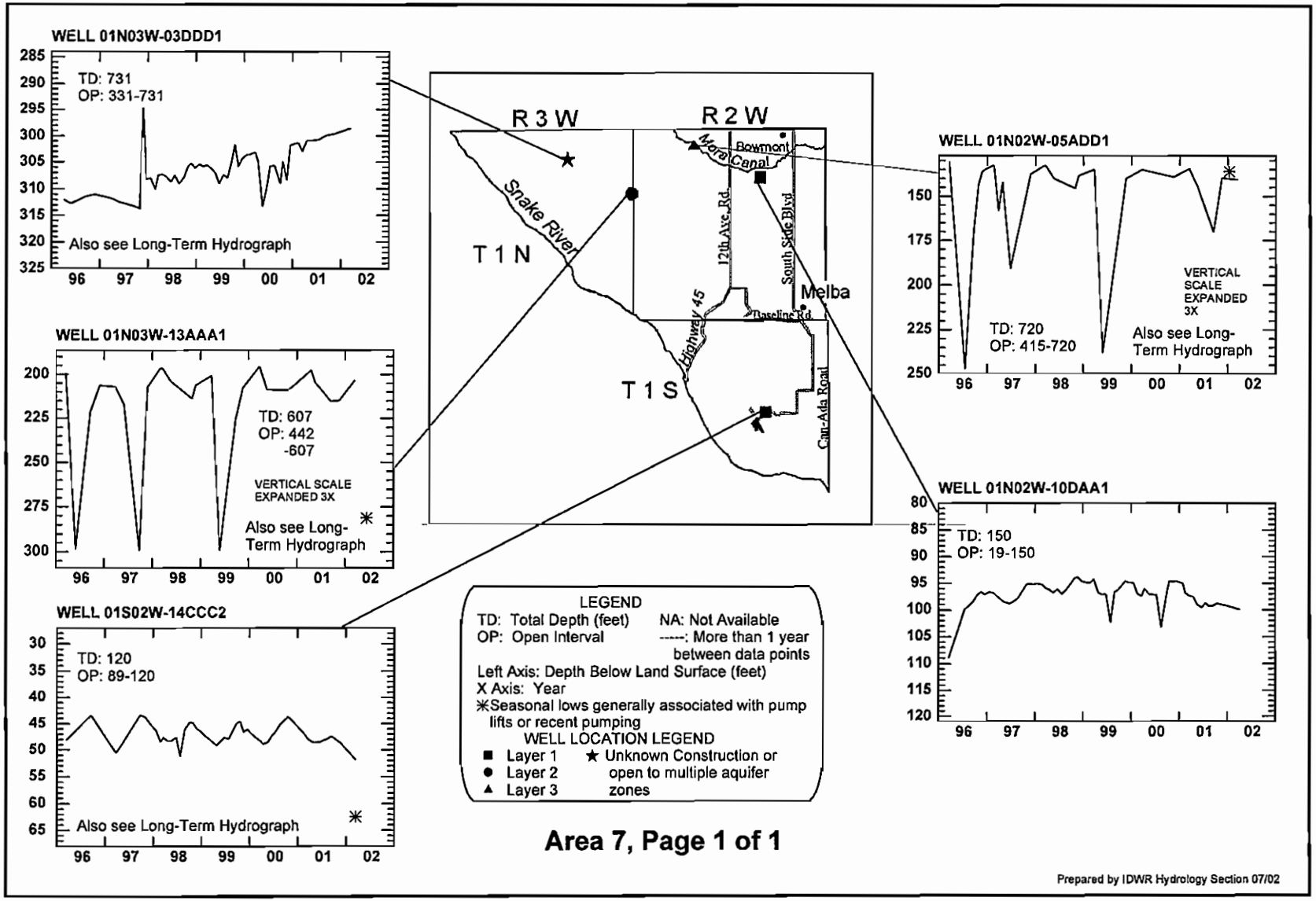

WELL 03N01E-
TD: 90
OP: 85-90
WELL 03N01E-
TD: 446
OP: 402-443
Also see Long-Term
R 1 W
R 1 E
T 3 N
T 2 N
Meridian
Fairview
Franklin Road
Ustick Road
W. Kuna Road
Kuna
Robinson Road
Kuna Highway
New York Canal
Mora Canal
Eagle Creek
WELL 03N01E-
Pump Lift
TD: 420
OP: 40-50; 405-412-417
Also see Long-Term
WELL 03N01E-
TD: 335
OP: 301-335
WELL 03N01E-
TD: 152
OP: 46-142; 147-152
Recently Pumped
TD: Total Depth (feet)
OP: Open Interval
NA: Not
-----: More than 1 between data
Left Axis: Depth Below Land Surface
X Axis: Year
WELL LOCATION
Layer 1
Layer 2
Layer 3
Unknown Construction open to multiple
Area 5, Page 2 of 2
Prepared by IDWR Hydrology Section 07/02


WELL 03N02E-
TD: 68
OP: NA
WELL 03N02E-
TD: 58
OP: NA
Also see Long-Term
WELL 03N03E-
TD: 280
OP: 232-242;250-
WELL 03N03E-
TD: 80
OP: 75-80
WELL 03N03E-
TD: 940
OP: 246-
Also see Long-Term
WELL 02N03E-
TD: 522
OP: 499-
96 97 98 99 00 01 02
Boise
Fairview Rd
Cottonwood Creek
Overland Road
Broadway
Federal Way
Gowen Road
Eighmile Creek
Fivemile Creek
Boise River
Tenmile Creek
I-84
T3N
T2N
R2E
R3E
TD: Total Depth (feet)
OP: Open Interval
NA: Not
----: More than 1 between data
Left Axis: Depth Below Land Surface
X Axis:
WELL LOCATION
Layer 1
Layer 2
Layer 3
Unknown Construction
open to multiple
Area 6, Page 1 of 2
Prepared by IDWR Hydrology Section 07-02



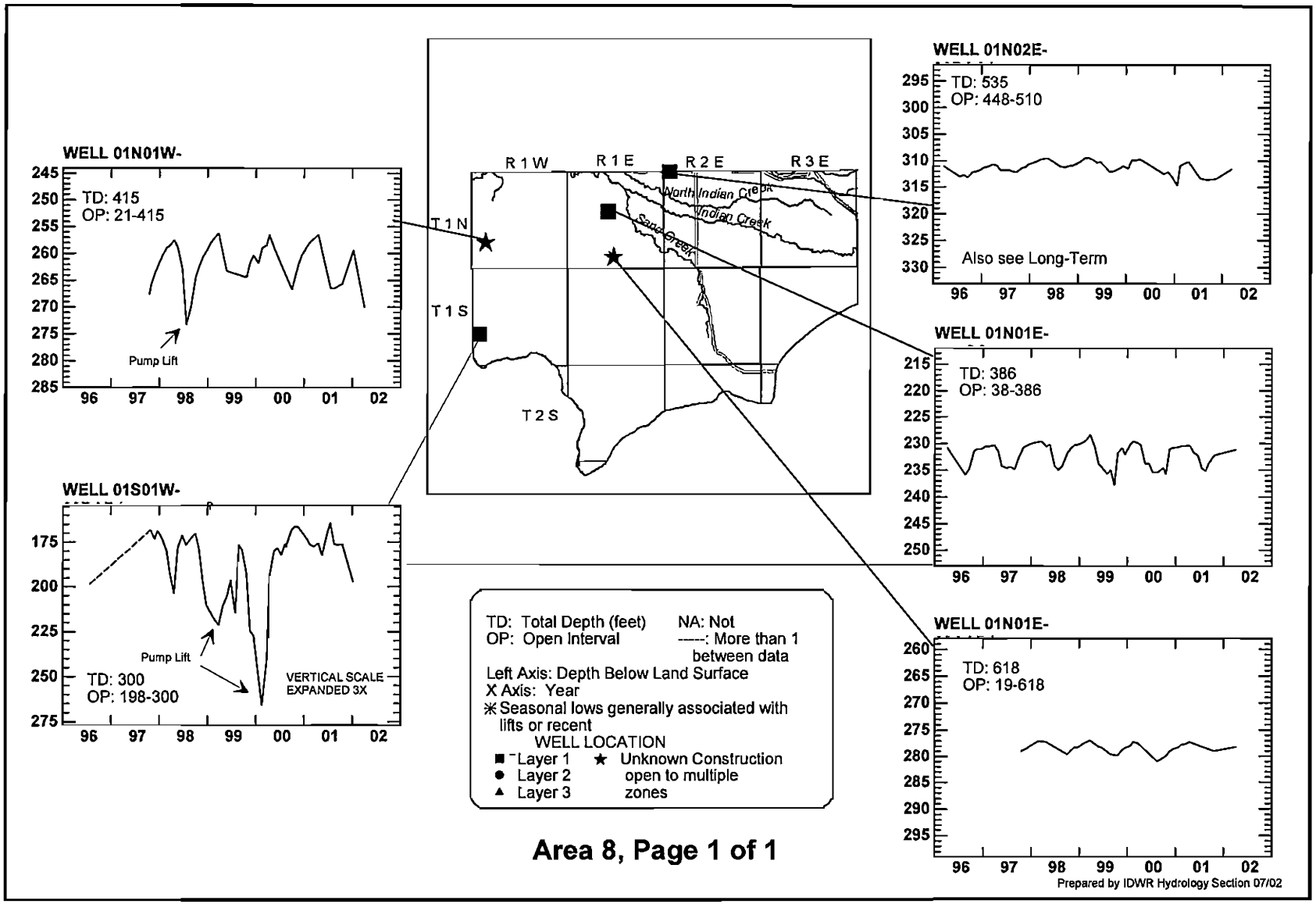
Area 6, Page 2 of 2

Prepared by IDWR Hydrology Section 07/02

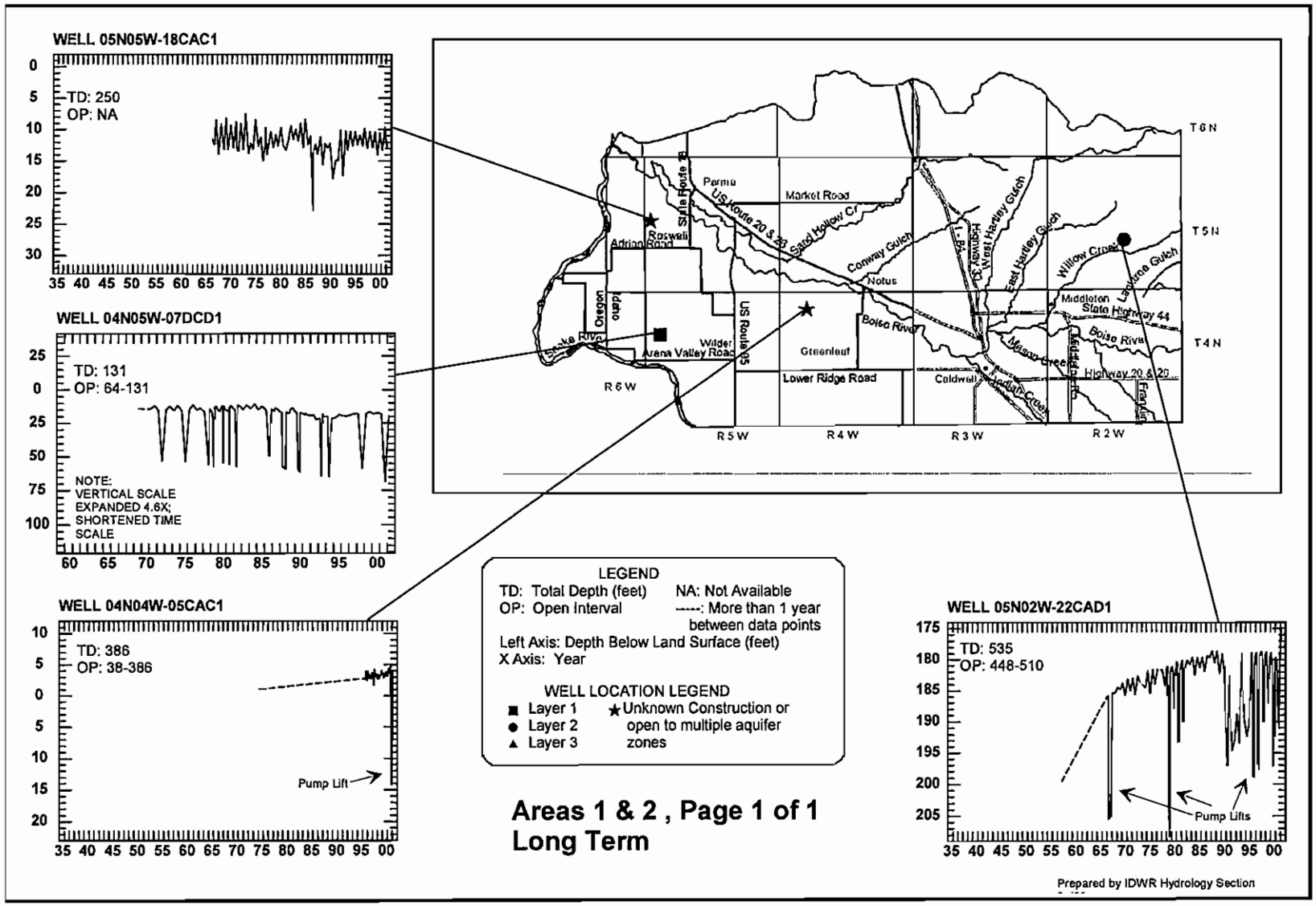


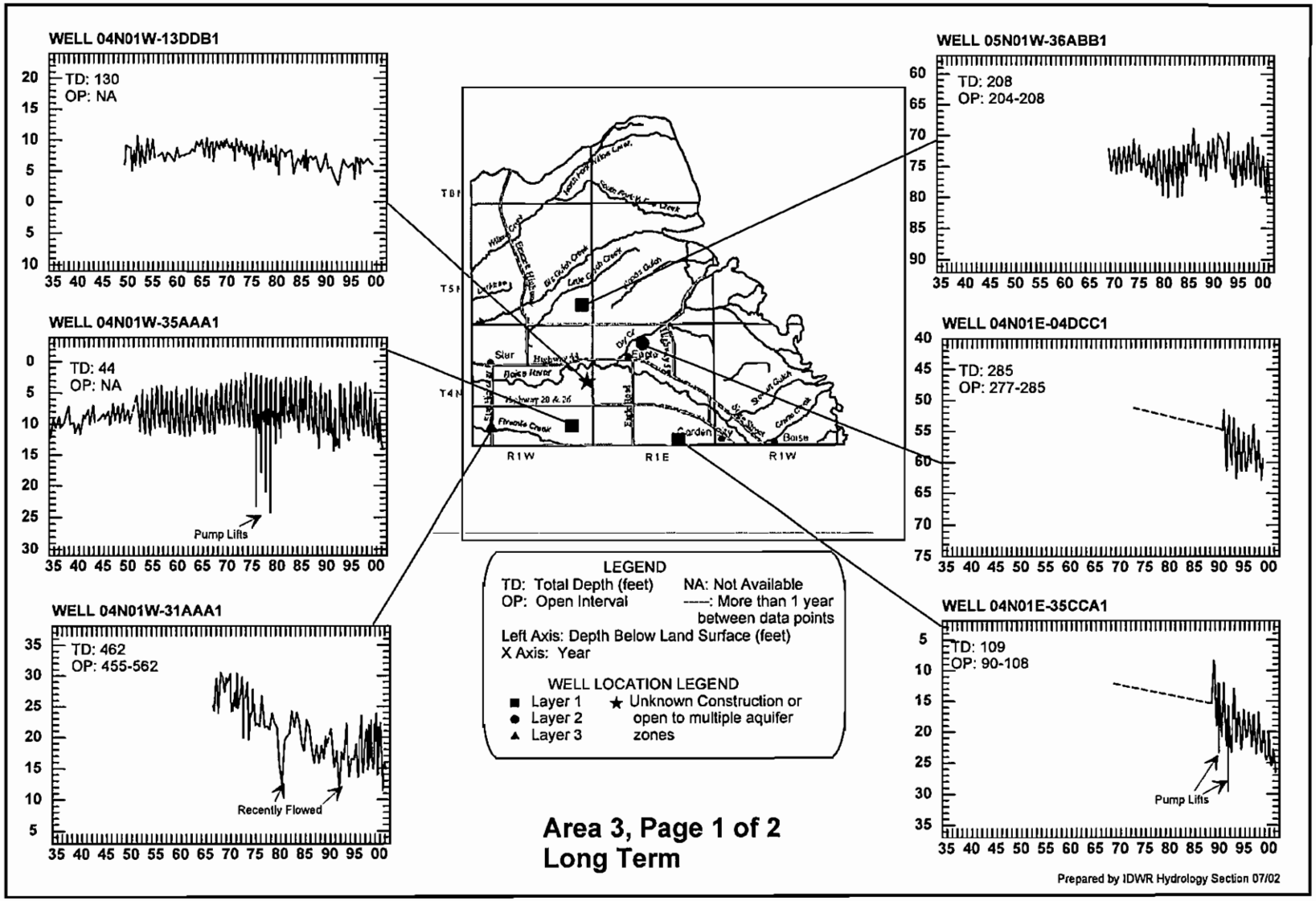
Area 7, Page 1 of 1

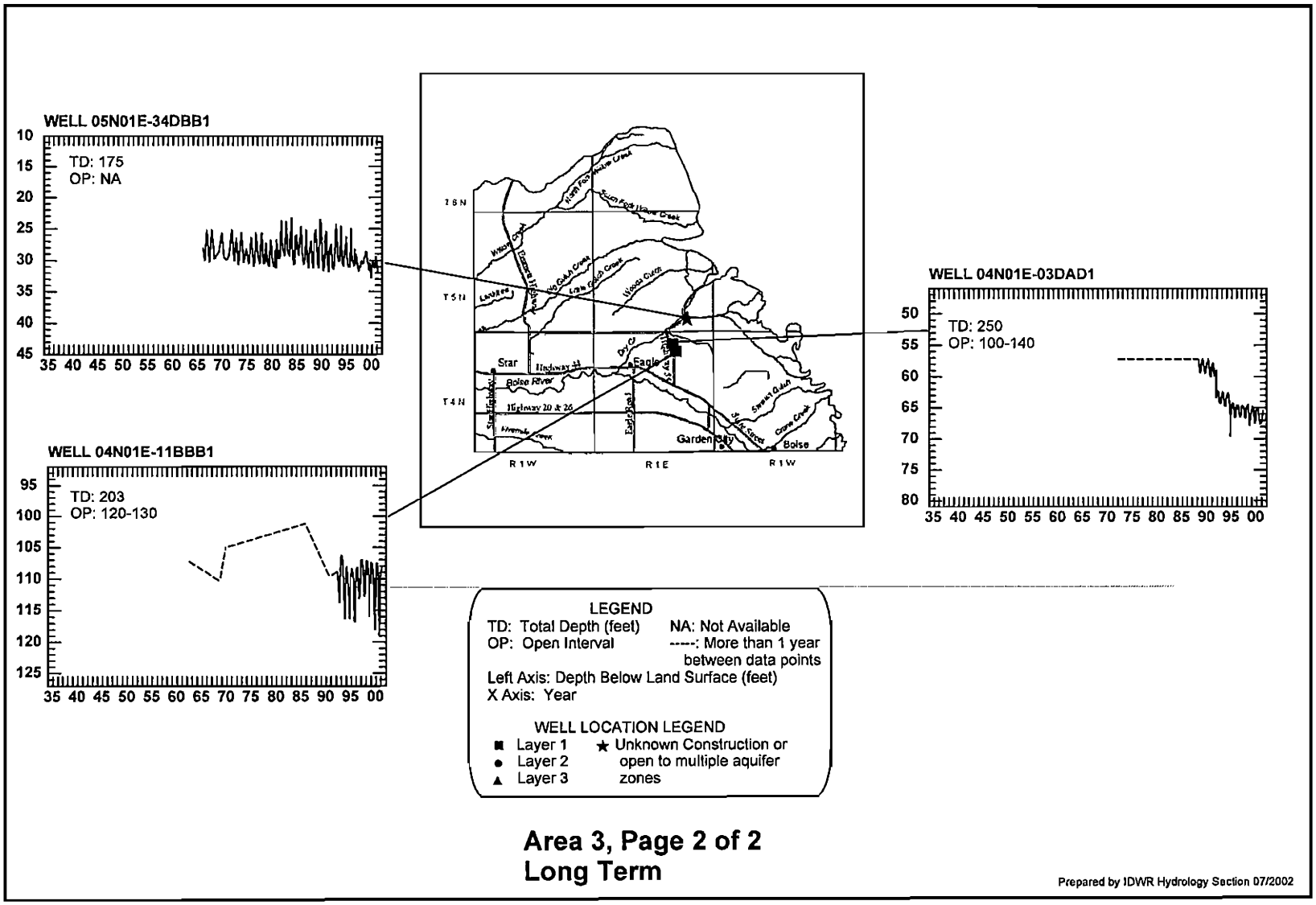
Prepared by IDWR Hydrology Section 07/02



Area 8, Page 1 of 1

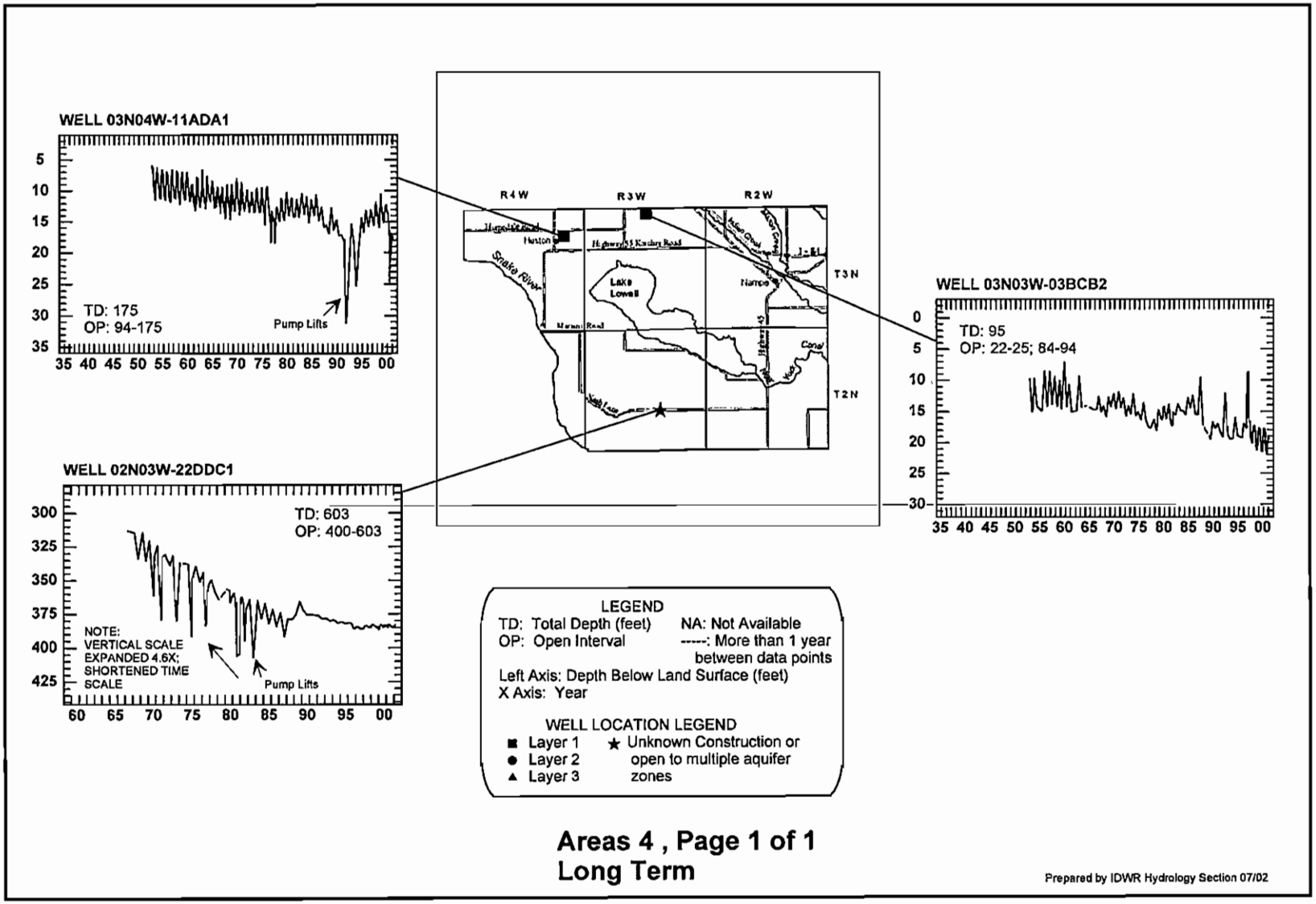

WELL 05N05W-18CAC1
TD: 250
OP: NA
WELL 04N05W-07DCD1
TD: 131
OP: 64-131
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
WELL 04N04W-05CAC1
TD: 386
OP: 38-386
Pump Lift
Perma
Market Road
Roswell
Adrian Road
Notus
Conway Gulch
Sand Hollow Cr
East Hartley Gulch
West Hartley Gulch
Willow Creek
Middleton
State Highway 44
Boise River
Greenleaf
Wilder
Arena Valley Road
Lower Ridge Road
Caldwell
Highway 20 & 26
Mason Creek
Indian Creek
Oregon
Idaho
Snake River
US Route 95
T6N
T5N
T4N
R6W
R5W
R4W
R3W
R2W
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
Unknown Construction or open to multiple aquifer zones
Areas 1 & 2 , Page 1 of 1
Long Term
WELL 05N02W-22CAD1
TD: 535
OP: 448-510
Pump Lifts
Prepared by IDWR Hydrology Section

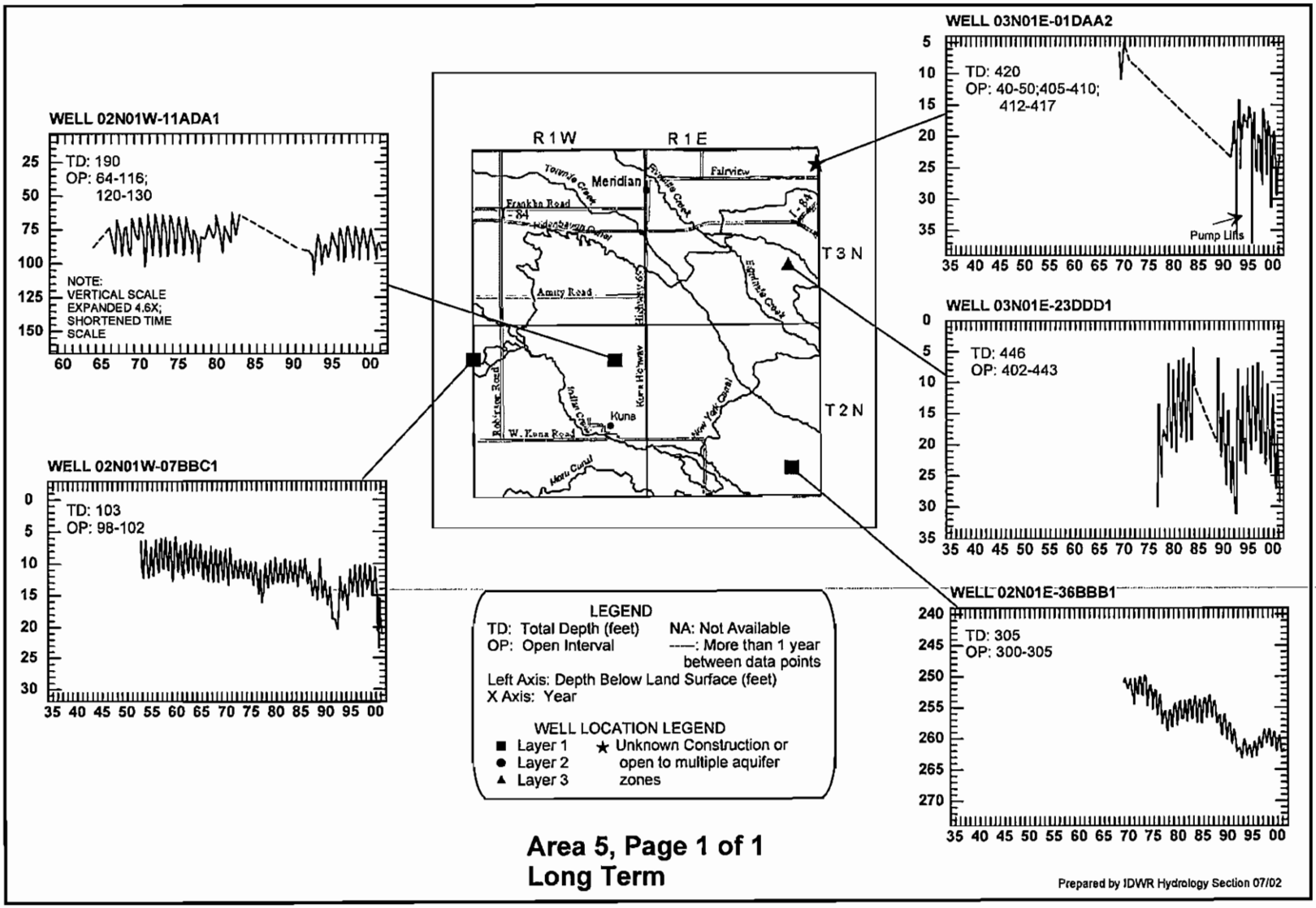

WELL 04N01W-13DDB1
TD: 130
OP: NA
WELL 04N01W-35AAA1
TD: 44
OP: NA
Pump Lifts
WELL 04N01W-31AAA1
TD: 462
OP: 455-562
Recently Flowed
WELL 05N01W-36ABB1
TD: 208
OP: 204-208
WELL 04N01E-04DCC1
TD: 285
OP: 277-285
WELL 04N01E-35CCA1
TD: 109
OP: 90-108
Pump Lifts
R1W
R1E
R1W
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
Unknown Construction or open to multiple aquifer zones
Area 3, Page 1 of 2
Long Term
Prepared by IDWR Hydrology Section 07/02



Area 3, Page 2 of 2
Long Term

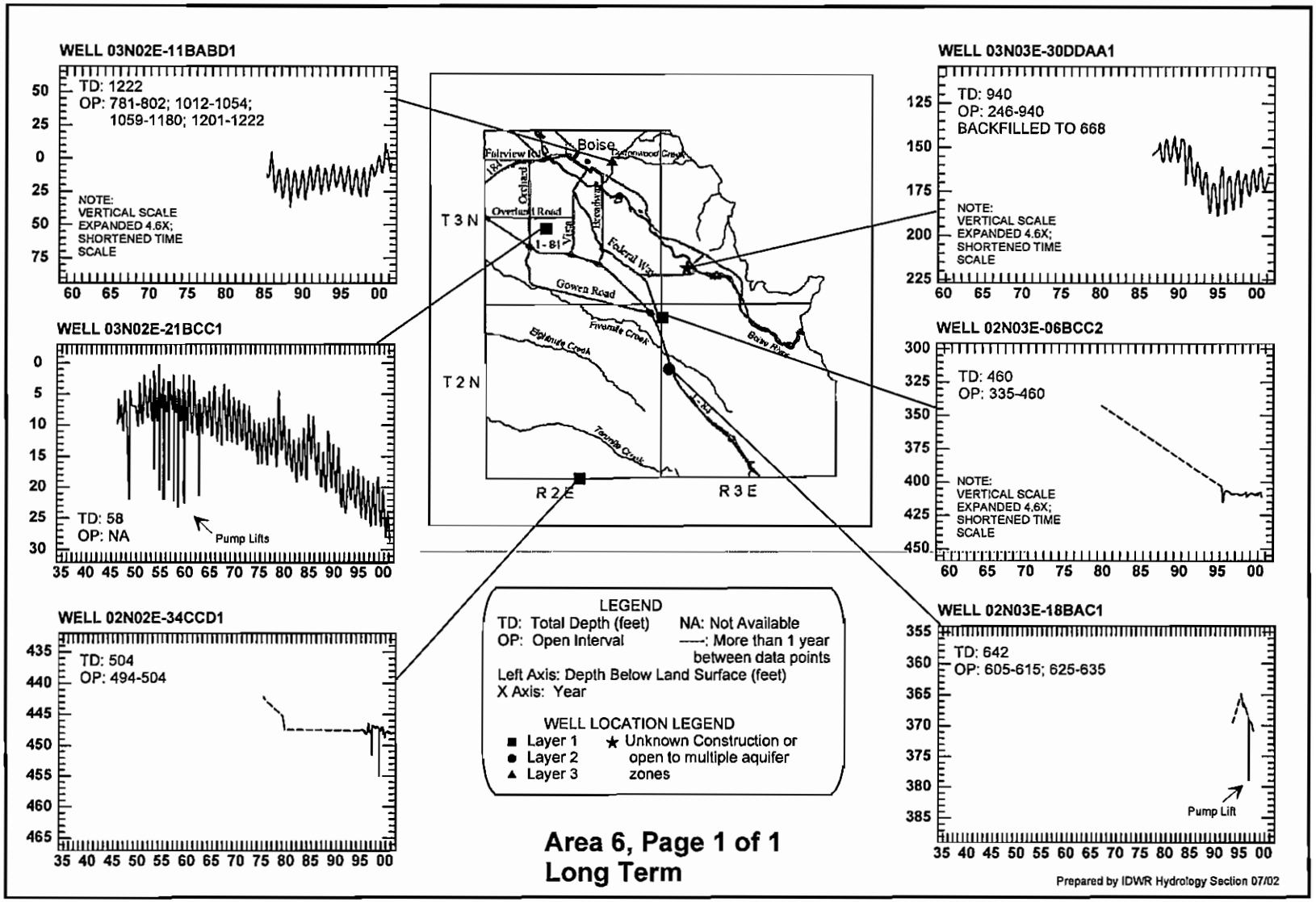
Prepared by IDWR Hydrology Section 07/2002

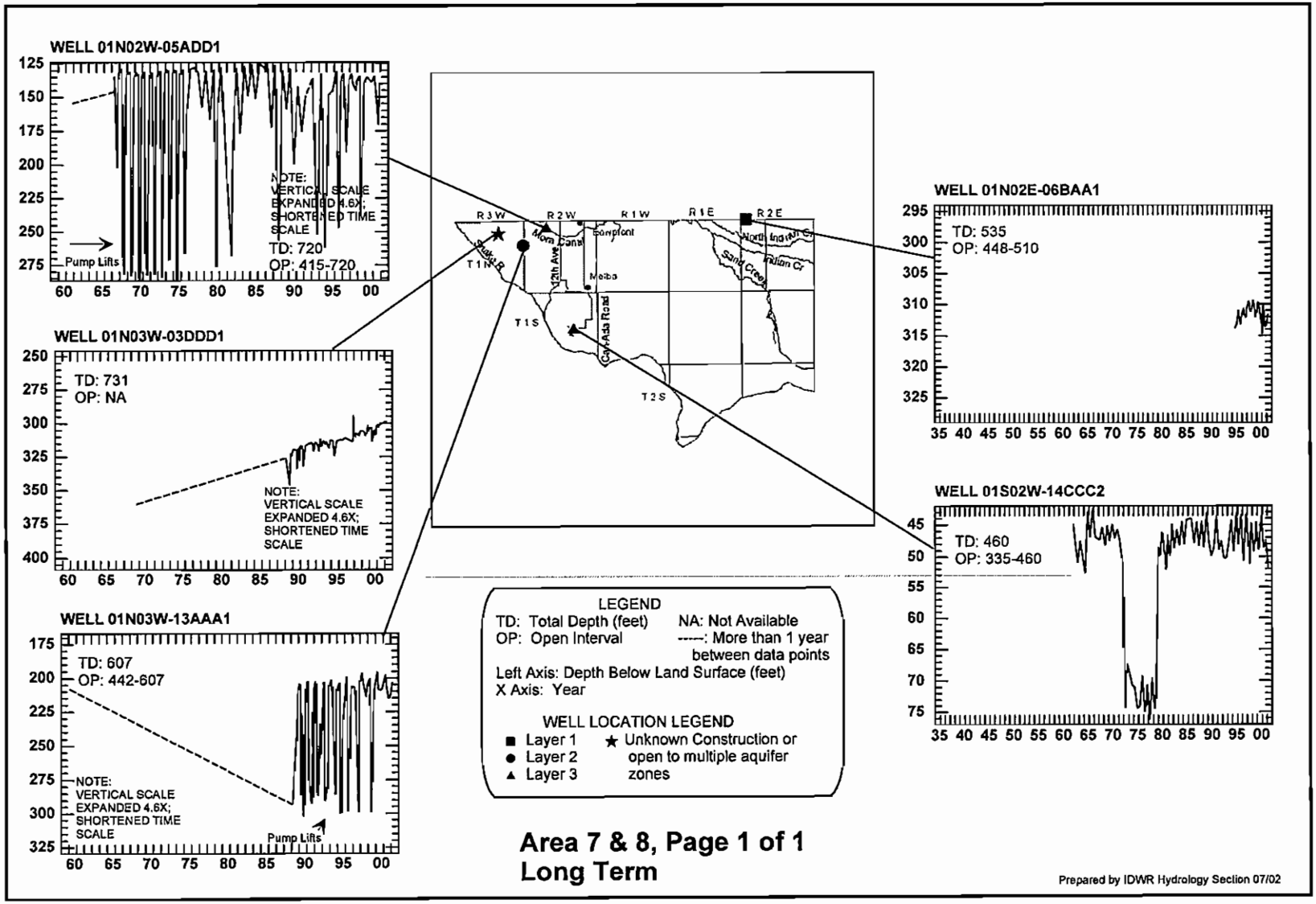

WELL 03N04W-11ADA1
TD: 175
OP: 94-175
Pump Lifts
5
10
15
20
25
30
35
35 40 45 50 55 60 65 70 75 80 85 90 95 00
R4W
R3W
R2W
T3N
T2N
Snake River
Lake Lowell
Nampa
Canal
WELL 02N03W-22DDC1
TD: 603
OP: 400-603
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
Pump Lifts
300
325
350
375
400
425
60 65 70 75 80 85 90 95 00
WELL 03N03W-03BCB2
TD: 95
OP: 22-25; 84-94
0
5
10
15
20
25
30
35 40 45 50 55 60 65 70 75 80 85 90 95 00
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
Unknown Construction or open to multiple aquifer zones
Areas 4 , Page 1 of 1
Long Term
Prepared by IDWR Hydrology Section 07/02



Area 5, Page 1 of 1
Long Term

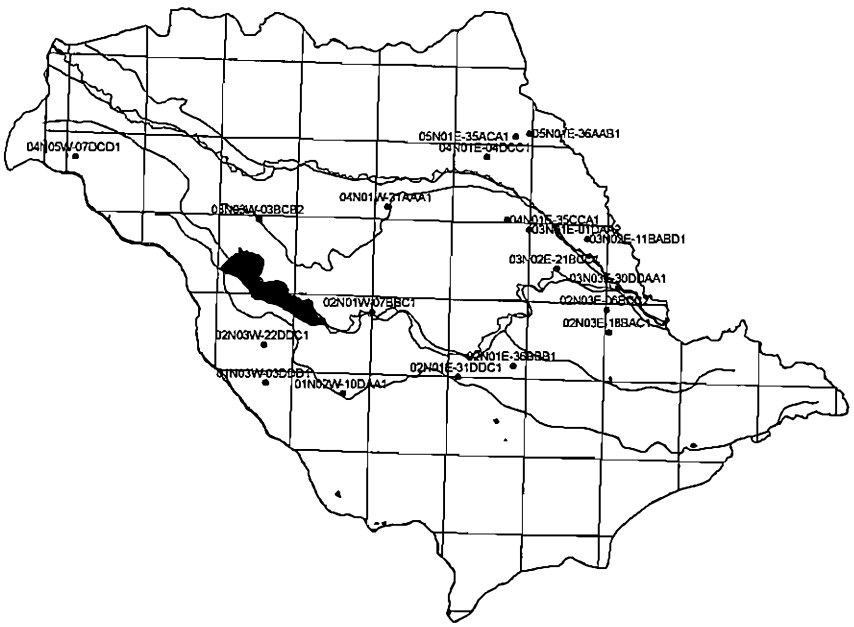
Prepared by IDWR Hydrology Section 07/02


WELL 03N02E-11BABD1
TD: 1222
OP: 781-802; 1012-1054;
1059-1180; 1201-1222
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
WELL 03N02E-21BCC1
TD: 58
OP: NA
Pump Lifts
WELL 02N02E-34CCD1
TD: 504
OP: 494-504
WELL 03N03E-30DDAA1
TD: 940
OP: 246-940
BACKFILLED TO 668
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
WELL 02N03E-06BCC2
TD: 460
OP: 335-460
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
WELL 02N03E-18BAC1
TD: 642
OP: 605-615; 625-635
Pump Lift
Boise
Fairview Rd
Overland Road
Gowen Road
Federal Way
Broadway
Orchard
Vista
I-84
Eighteenth Creek
Fivemile Creek
Boise River
Tenmile Creek
T3N
T2N
R2E
R3E
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
WELL LOCATION LEGEND
■ Layer 1
● Layer 2
▲ Layer 3
★ Unknown Construction or open to multiple aquifer zones
Area 6, Page 1 of 1
Long Term
Prepared by IDWR Hydrology Section 07/02

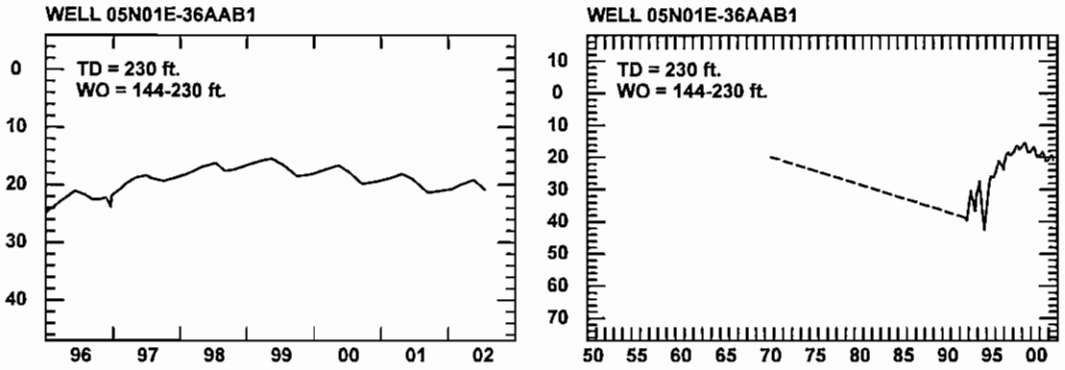

WELL 01N02W-05ADD1
125
150
175
200
225
250
275
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
TD: 720
OP: 415-720
Pump Lifts
60 65 70 75 80 85 90 95 00
WELL 01N03W-03DDD1
250
275
300
325
350
375
400
TD: 731
OP: NA
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
60 65 70 75 80 85 90 95 00
WELL 01N03W-13AAA1
175
200
225
250
275
300
325
TD: 607
OP: 442-607
NOTE:
VERTICAL SCALE
EXPANDED 4.6X;
SHORTENED TIME
SCALE
Pump Lifts
60 65 70 75 80 85 90 95 00
R3W
R2W
R1W
R1E
R2E
T1N
T1S
T2S
Boise R.
Meridian
Eagle
Star
Middleton
Nampa
Caldwell
Homedale
Parma
Greenleard
Notus
Wilder
Melba
Ada Co.
Canyon Co.
Owyhee Co.
Payette Co.
Gem Prairie
Sand Creek
Indian Cr.
North Indian Cr.
Morris Canal
12th Ave
Cole/Ada Road
WELL 01N02E-06BAA1
295
300
305
310
315
320
325
TD: 535
OP: 448-510
35 40 45 50 55 60 65 70 75 80 85 90 95 00
WELL 01S02W-14CCC2
45
50
55
60
65
70
75
TD: 460
OP: 335-460
35 40 45 50 55 60 65 70 75 80 85 90 95 00
LEGEND
TD: Total Depth (feet)
NA: Not Available
OP: Open Interval
-----: More than 1 year between data points
Left Axis: Depth Below Land Surface (feet)
X Axis: Year
WELL LOCATION LEGEND
Layer 1
Layer 2
Layer 3
Unknown Construction or open to multiple aquifer zones
Area 7 & 8, Page 1 of 1
Long Term
Prepared by IDWR Hydrology Section 07/02

Appendix G. SELECTED HYDROGRAPHS SHOWING CHANGES

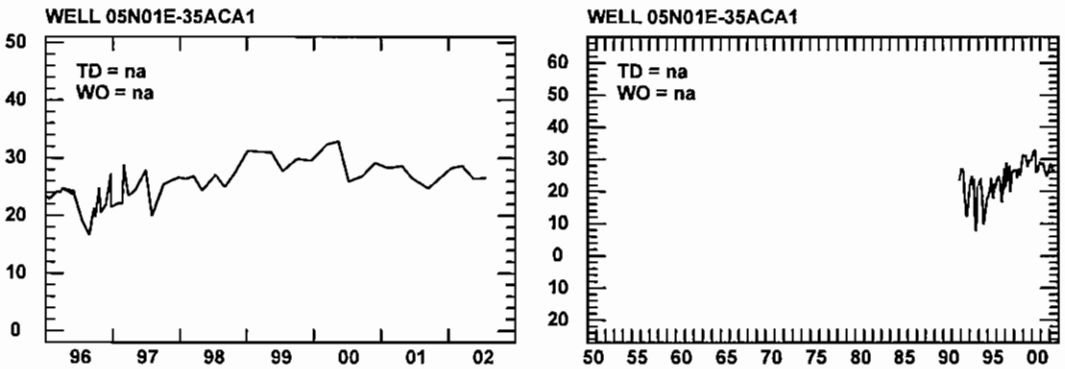
This section repeats selected hydrographs that were shown in the previous appendices, but the discussion regarding water level has changed. Locations of the hydrographs included in this appendix are shown below.



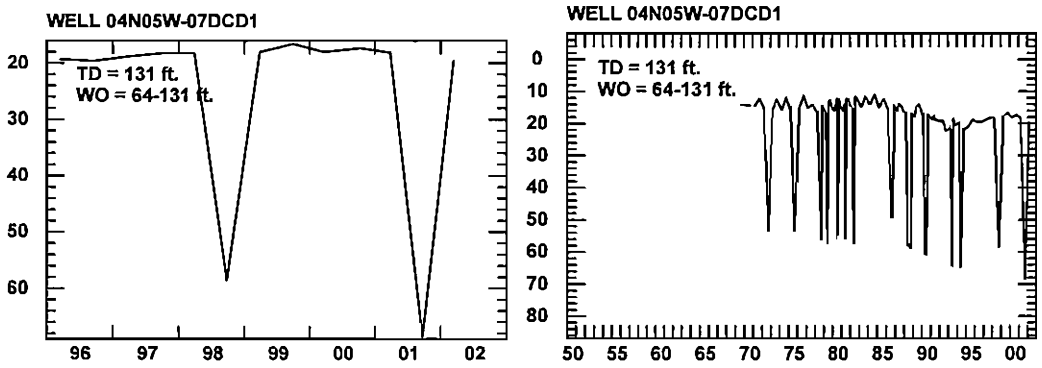
Location of Wells



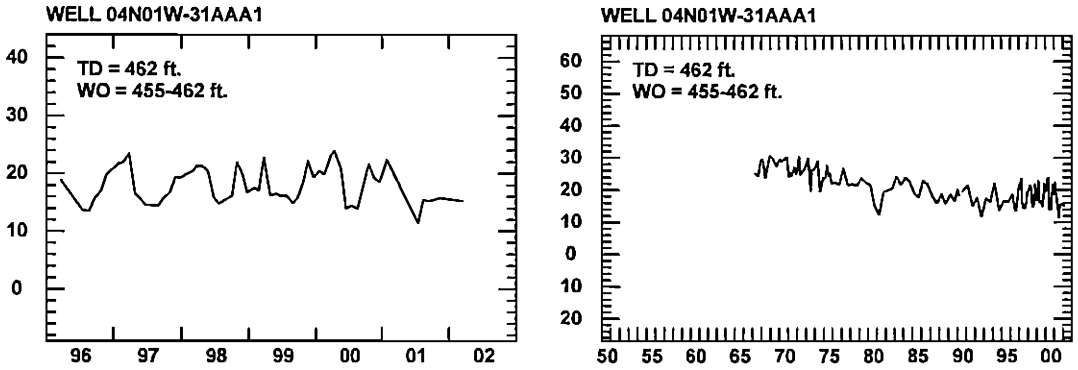
NORTHEAST OF EAGLE, Jeker geothermal well. Per Ken Neely, the increasing shut-in pressures are a result of decreasing production within the geothermal aquifer during the period between 1995 and 1999.



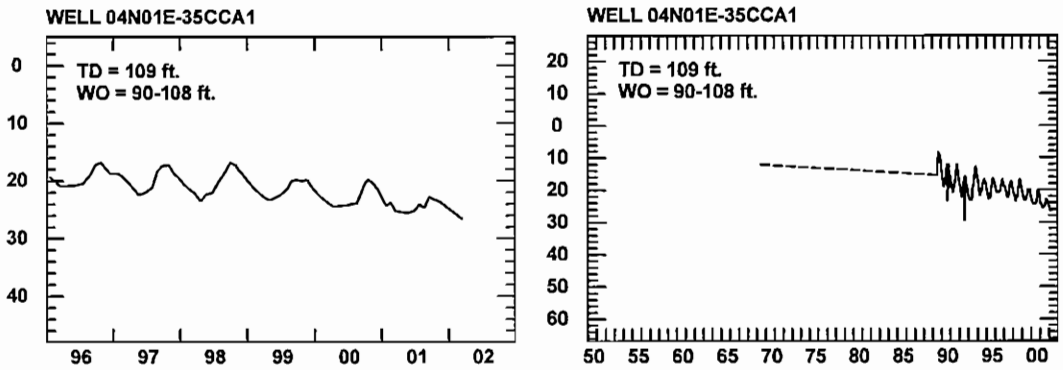
NORTHEAST OF EAGLE (no well log available). Geothermal well showed rises in the shut-in pressuring during the period 1994-1999. From 2000 to present, slight declines have been shown.



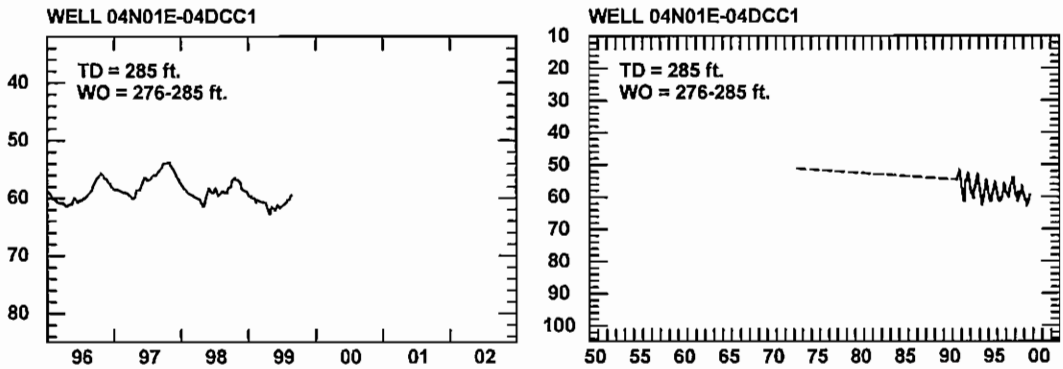
NORTHWEST OF NOTUS, NORTH OF GREENLEAF. Decline from 1985 to 1993–1994, which coincides with below normal precipitation. Increases from 1995 to present coincide with increased precipitation. Hydrograph curves prior to 1985 generally correspond with the precipitation curve.



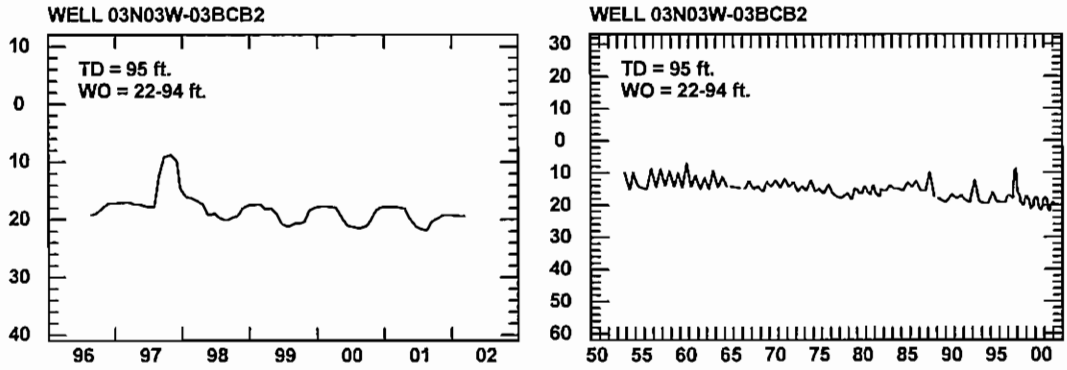
SOUTH OF STAR. Flowing well, apparent decrease in pressure from early 1970s to 1990. Water levels from 1990 to 1998 appear stable to increasing. Well is 5 miles down gradient from Meridian, 2 miles north of I-84 corridor. Land use change map does not indicate major decrease in irrigated lands, but some changes have occurred locally. Water levels may have come to equilibrium. Five-foot decline over past 3 years beginning in 1999 may indicate a renewed period of decline.



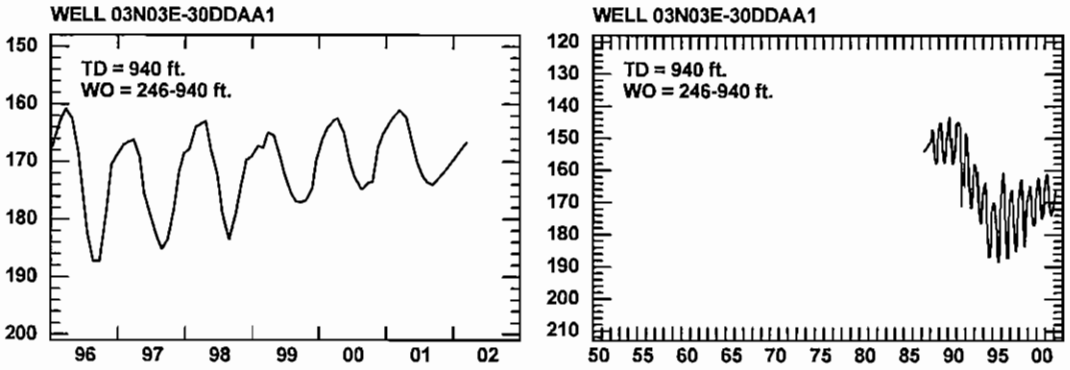
WEST OF GARDEN CITY, 3 miles. Vicinity of Ustick & Five Mile Road. Suburban development since late 1980s or early 1990s. Formerly irrigated farmlands. Leveled off 1996–1998. Has been declining since 1998.



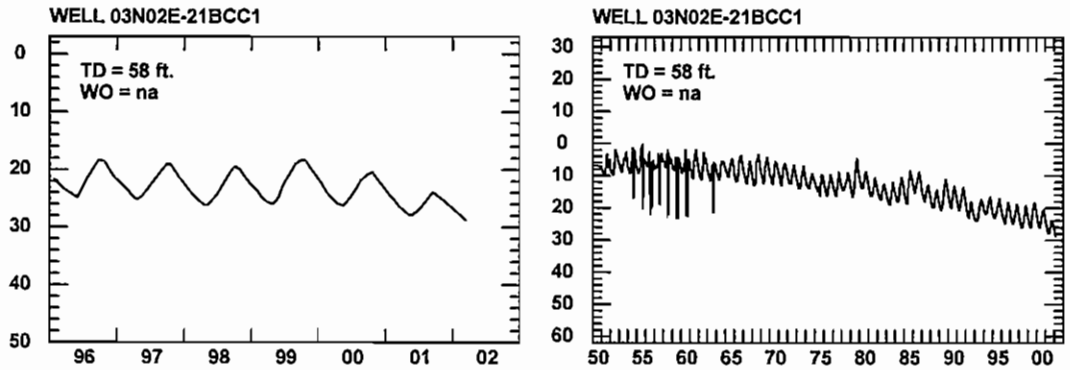
NORTH OF EAGLE. Suburban development since late 1980s to present. Formerly irrigated farmland. Slight declines continue.



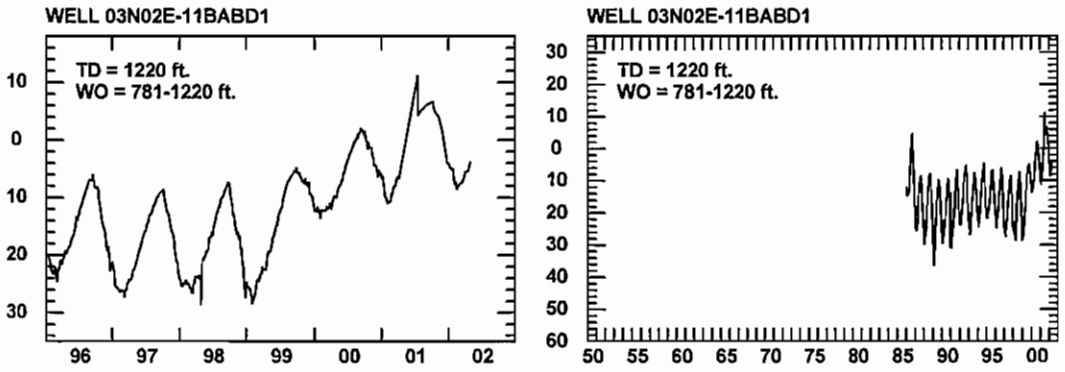
Field visit shows current high density housing construction surrounded by flood-irrigated lands and older residential tracts. Long-term decline probably resulting from gradual increase in housing throughout this area.



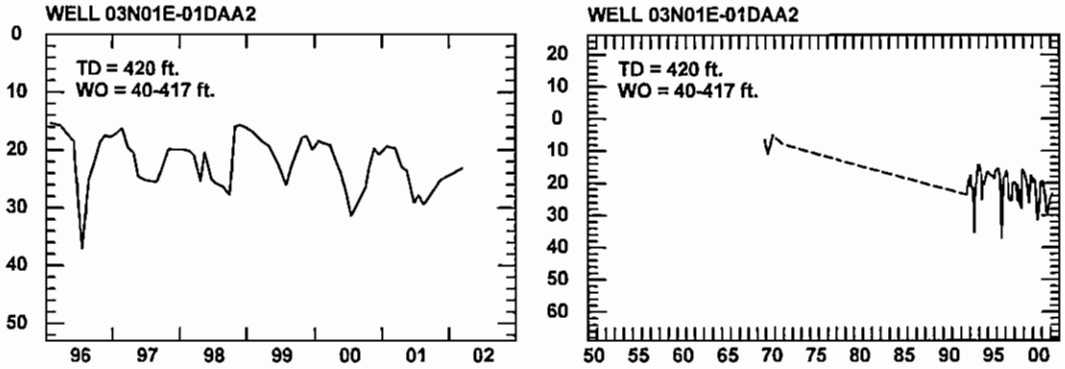
EAST BOISE TEST WELL. Water levels are indicative of the declining water levels and subsequent increasing trends since 1999 in the southeast Boise area surrounding the Micron facility.



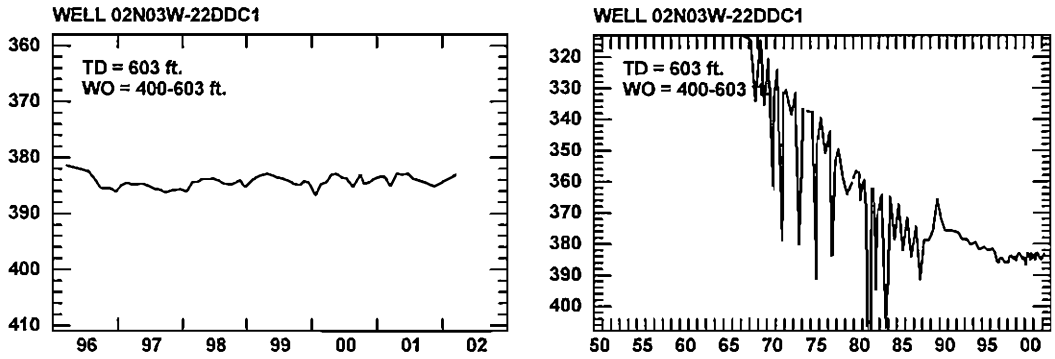
BOISE, NEAR HILLCREST GOLF COURSE. The golf course was built around 1962; the neighborhood looks to be 1945+ era. Water level increased until 1955, when a steady decline of 1-2' per year began and has continued. Also, New York Canal is within 1 mile south of the site but has been lined since approx 1907 (D. Dyke, pers. comm.). Decline may be result of nearby (?) residential well use.



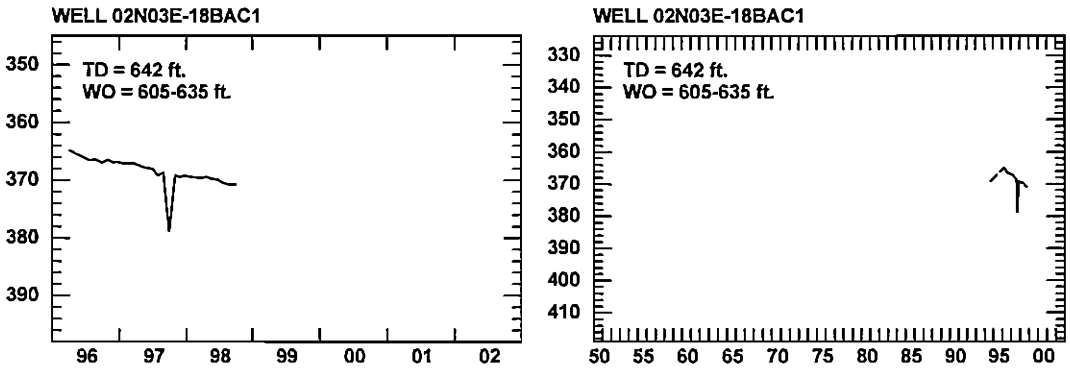
BLM GEOTHERMAL WELL. Declines in pressures correspond to other wells in the geothermal aquifer. Declines appear to have stabilized through the aquifer. Increasing water levels since 1999 may be influenced by the injection of spent geothermal water from the Boise City geothermal system. Injection began in 1999.



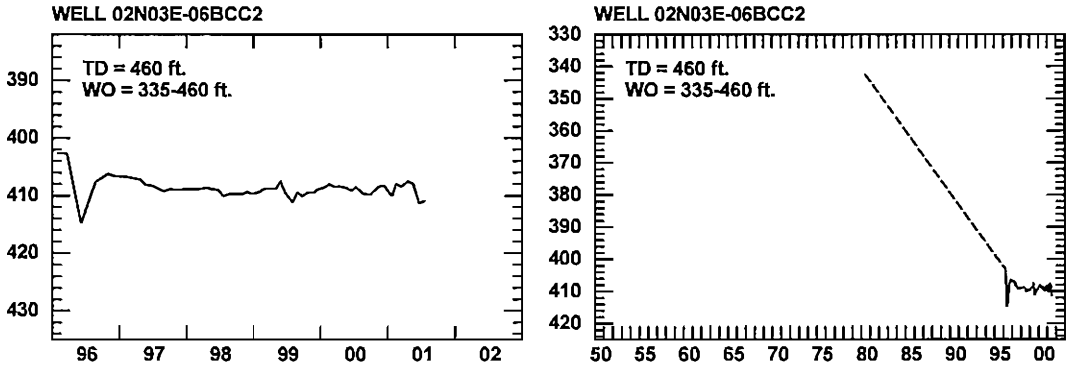
EAST OF MERIDIAN, NORTH OF FAIRVIEW. Reduction in flood irrigation combined with increased urbanization is most likely cause of water level decline.



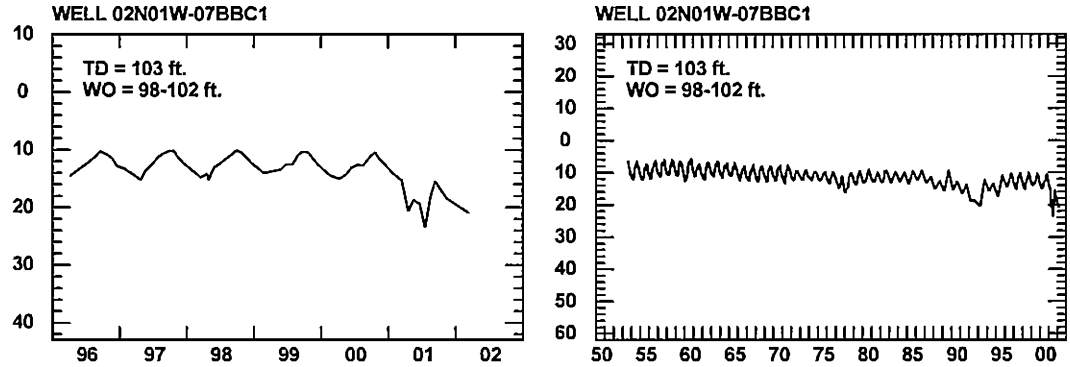
SOUTH OF LAKE LOWELL. Sprinkle irrigated farmland; mostly with ground water (per land use mapping). Fallow land to north and west, no flood irrigation available. Decline from mid-1960s to mid-1990s probably resulting from steady ground water over use coupled with low recharge rates. Water levels stabilized since mid-1990s.



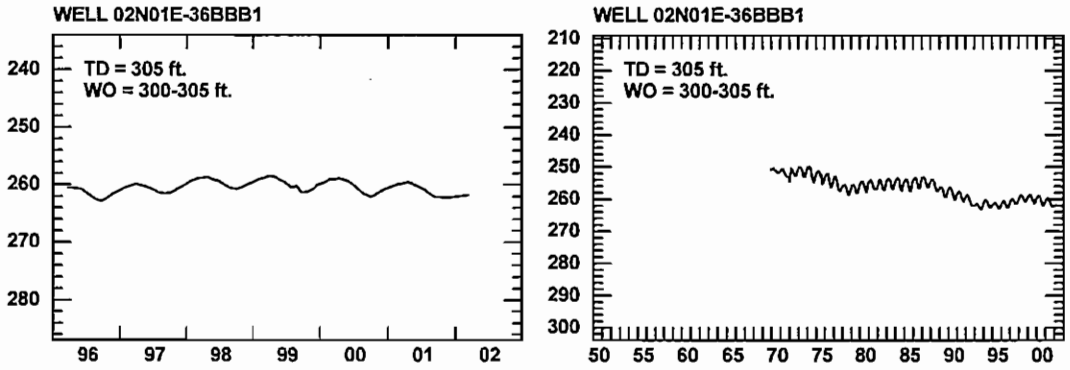
SOUTH OF BOISE, SOUTH OF FIVE MILE CREEK. Knox well, located on hill near Micron. Limited data, and no new data since 1998. Declines possibly resulting from increased water use in Micron vicinity or use at the well site itself.



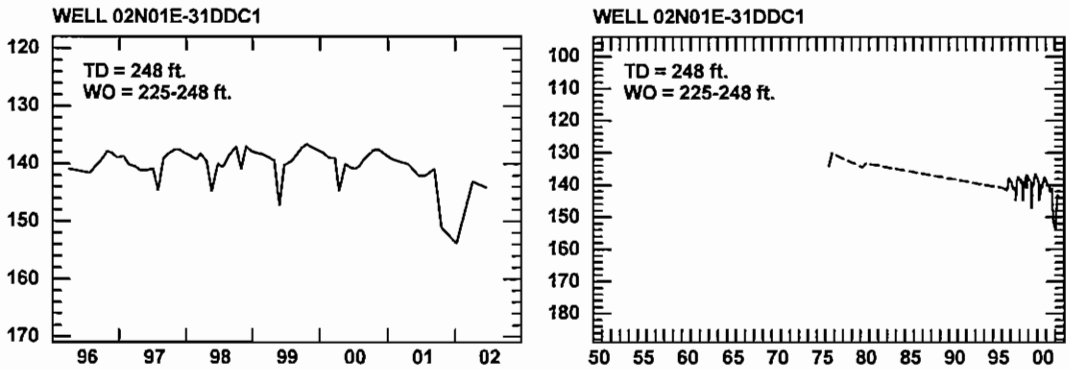
GOWEN ROAD & FEDERAL WAY, KOA well. Located near SE Boise GWMA. Major declines have been observed throughout this area. This decline probably resulted from major increase in water use in the Micron vicinity. Water levels have stabilized since 1996.



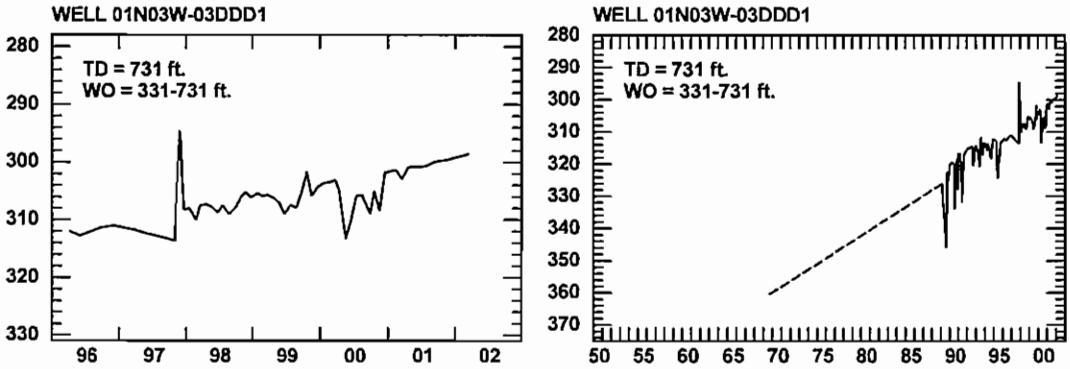
NORTHWEST OF KUNA, WEST OF ROBINSON ROAD. This section is mostly flood-irrigated farmland with houses along the perimeter. Age of houses range from pre-1940 to present. Gradual decline of water level probably result of gradual increase in residential construction. Sharp declines in 1990 and 2001, probably drought related.



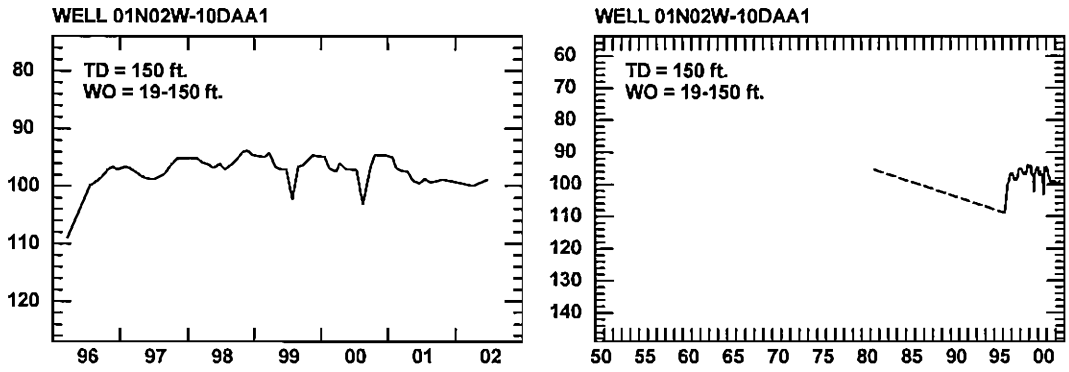
EAST OF KUNA 6 MILES, SOUTH OF NEW YORK CANAL. General long-term decline, punctuated by period of recovery that coincide with years of above normal precipitation.



SOUTHEAST OF KUNA. Fairly stable from 1996 through 2000. Data are too limited to determine cause of declines prior to 1996.



NEAR SNAKE RIVER, WEST OF MORA CANAL. Unclear reason for sharp increase in water level. Several injection wells (total depths approximately 100-150') are used for disposal of field runoff nearby.



NORTH OF MELBA, NEXT TO MORA CANAL. Short record of data. Relative to 1980 USGS measurement, current water levels have not changed substantially. Continued increases may be due to above average precipitation during mid- to late-1990s. Recent levels appear to reflect drier-than-normal conditions.

Costs associated with this publication are available from the Idaho Department of Water Resources in accordance with Section 60-202, *Idaho Code*. IDWR-21000-20-03/2004.

33E

APPENDIX C
MONITORING WELL DIAGRAMS

FOR THE REPORT

CHARACTERIZATION OF GROUND WATER FLOW IN THE LOWER BOISE RIVER BASIN

prepared for and in cooperation with the

Idaho Department of Water Resources
1301 North Orchard
Boise, Idaho 83706-2237

FINAL DRAFT: 3/12/2004
JUNE 2003

IDAHO WATER RESOURCES RESEARCH INSTITUTE
RESEARCH REPORT

IWRRI-2003-09

Appendix C: Construction Details for Dedicated, Multi-Level Piezometers

This section provides well construction diagrams for the four dedicated monitoring wells constructed in conjunction with the Treasure Valley Hydrologic Project.

Diagram for TVHP #1 taken from United Water Idaho report "Hydrogeology, Geochemistry, and Well Construction of the Treasure Valley Hydrologic Project Monitoring Well #1, Ada County, Idaho (Dittus, Allred and Squires, 1999). Diagram for TVHP #2 provided by Ed Squires, Hydrologic, Inc. Diagram for TVHP #3 provided by Terry Scanlan, Scanlan Engineering. Diagram for TVHP #4 created by Scott Urban, IDWR.

Treasure Valley Hydrologic Project Monitoring Well #1

Comparison of Water Chemistry in Piezometer Completion Zones

(Analyses in mg/l unless note otherwise.)

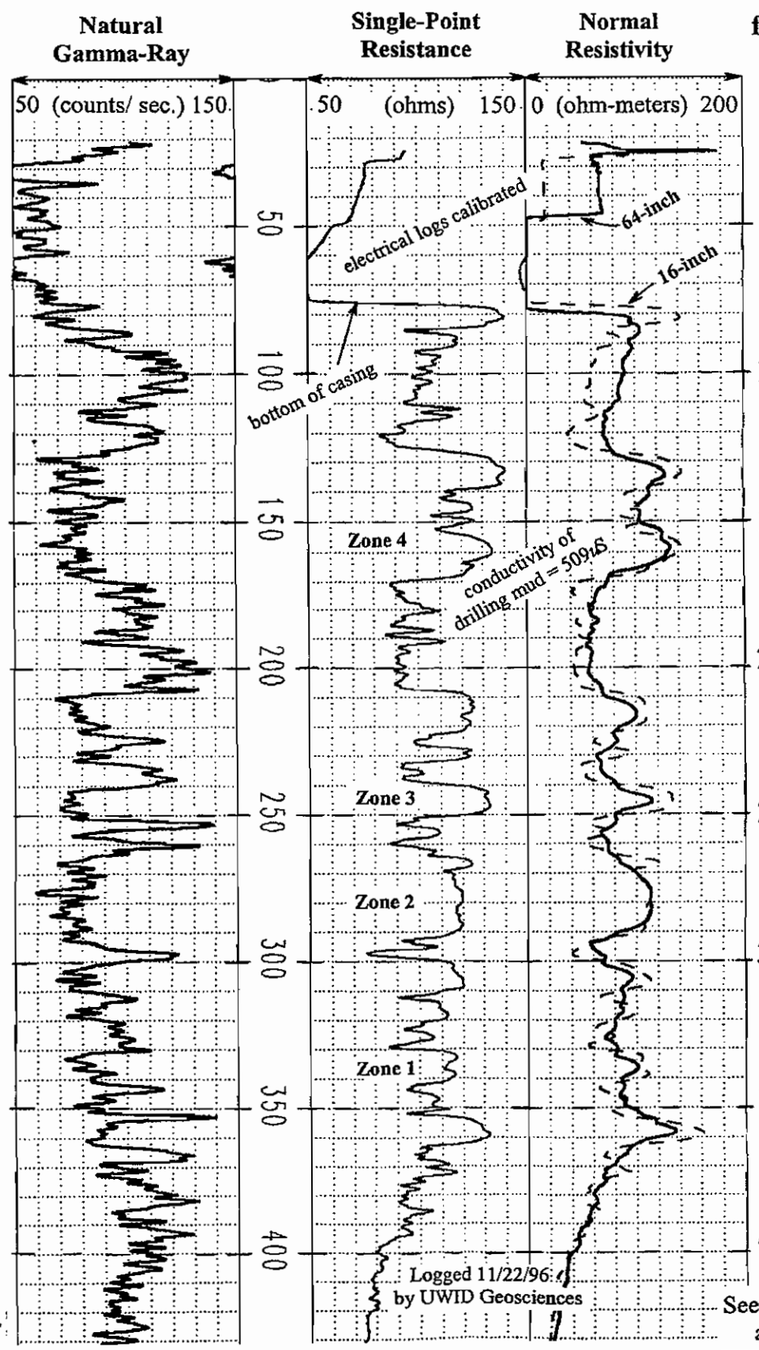
Constituent	Zone 4		Zone 3		Zone 2		Zone 1	
screen setting (ft below ground)	130-140 ft. 150-170 ft.		210-220 ft. 240-250 ft.		270-290 ft.		300-310 ft. 330-340 ft.	
Laboratory X: Alchem Y: Analytical	X	Y	X	Y	X	Y	X	Y
Date sampled	12/13/96		12/13/96		12/13/96		12/13/96	
Chloride	3.20	3	2.63	3	1.73	2	2.05	2
Fluoride (direct)	0.33	0.45	0.37	0.5	0.26	0.46	0.34	0.57
Nitrate (N)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.13	0.16
Sodium	24.9	24.2	20.3	19.4	15.2	14.2	17.5	15.8
Sulfate	10.2	11	22.5	22	11.4	12	14.4	14
Sulfide	<0.05	0.19	<0.05	0.16	<0.05	0.45	<0.05	0.07
Calcium	37.5	33.3	39.0	35.1	28.1	25.8	28.9	29.2
Potassium	2.17	1.64	2.55	2.06	2.07	1.63	2.00	1.58
Magnesium	4.16	3.62	7.22	6.55	3.94	3.70	4.54	4.58
Iron-total	0.05	<0.05	0.65	0.50	0.05	<0.05	0.06	<0.05
Iron-dissolved *	0.01	<0.05	0.57	0.45	0.01	<0.05	0.02	<0.05
Manganese-total	0.01	<0.05	0.06	0.05	0.04	<0.05	0.03	<0.05
Manganese -dissolved *	0.01	<0.05	0.05	0.05	0.04	<0.05	0.03	<0.05
Silica	28.7	30.6	31.5	32.9	31.6	34.1	32.5	29.9
Alkalinity	139.0	143	132.0	138	101.0	103	112.0	114
Conductivity - lab (uS)	299	294	313	305	224	207	260	255
Conductivity - field (uS)	262		273		213		247	
Corrosivity (Langelier)	-0.33	-0.7	-0.35	-0.8	-0.54	-0.8	-0.87	-1.1
Hardness	111.0	108	129.0	125	86.4	93.7	90.9	99.9
Phosphorus (total)	0.05	0.08	0.04	0.06	0.03	0.07	0.04	0.07
Total dissolved solids	248.0	188	173.0	200	188.0	164	218.0	182
pH - lab (standard units)	7.70	8.0	7.65	7.9	7.70	8.1	7.30	7.6
pH – field (standard units)	7.36		7.18		7.42		7.03	
Temperature	54.8 °F		56.6 °F		58.0 °F		58.4 °F	

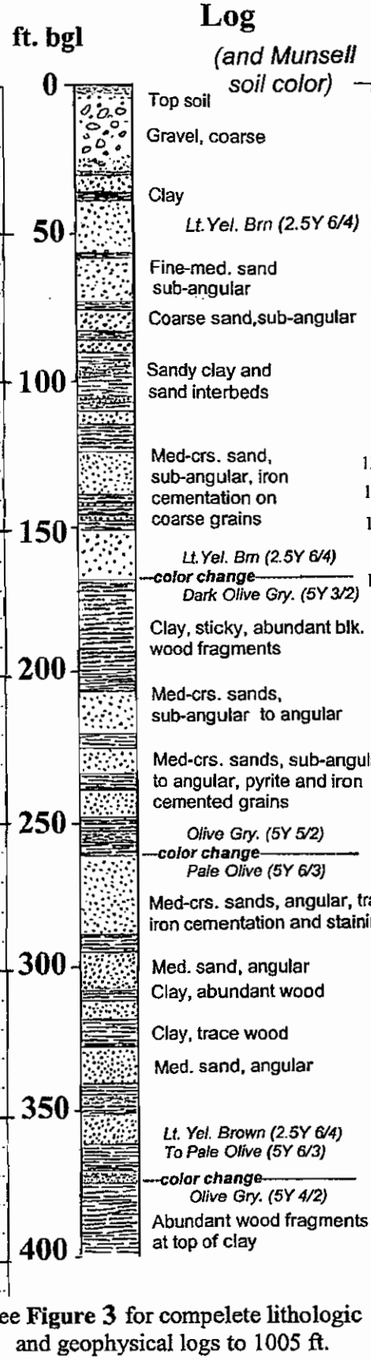
* Samples for dissolved Iron and Manganese were filtered in the field

Location: NW ¼, SW ¼, SW ¼, Section 14, T4N, R1E, B.M., Ada County, Idaho
Well design by United Water Idaho Geosciences
Well completed 12/5/96 by Stevens & Sons Well Drilling, Boise, ID.

Figure 2. Composite diagram showing well construction, lithologic log, geophysics and water chemistry at various depths.

Geophysical Logs





Lithologic Log

(and Munsell soil color)

Top soil

Gravel, coarse

Clay
Lt.Yel. Brn (2.5Y 6/4)

Fine-med. sand sub-angular

Coarse sand,sub-angular

Sandy clay and sand interbeds

Med-crs. sand, sub-angular, iron cementation on coarse grains

Lt.Yel. Brn (2.5Y 6/4)
color change
Dark Olive Gry. (5Y 3/2)

Clay, sticky, abundant blk. wood fragments

Med-crs. sands, sub-angular to angular

Med-crs. sands, sub-angular to angular, pyrite and iron cemented grains

Olive Gry. (5Y 5/2)
color change
Pale Olive (5Y 6/3)

Med-crs. sands, angular, trace iron cementation and staining

Med. sand, angular
Clay, abundant wood

Clay, trace wood

Med. sand, angular

Lt. Yel. Brown (2.5Y 6/4)
To Pale Olive (5Y 6/3)
color change
Olive Gry. (5Y 4/2)

Abundant wood fragments at top of clay

See **Figure 3** for compelete lithologic and geophysical logs to 1005 ft.

Monitoring Well Construction

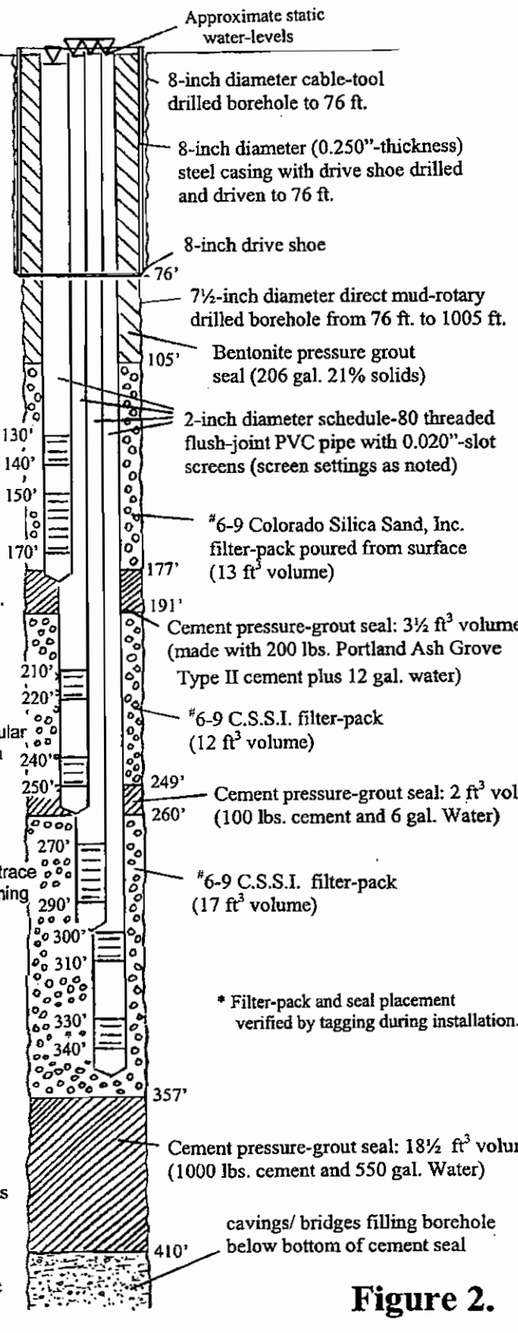


Figure 2.

Treasure Valley Hydrologic Project #2 Monitoring Well

11/2/1999

Well Construction

Depth (ft. bgl)

0 — 100 — 200 — 300 — 400 — 500 — 600 — 700 — 800 — 900 — 1000

- 12-inch diameter X .375-inch wall steel well casing
- 22-inch drilled hole to 84-feet
- 3/8-inch washed granitic pea-gravel
- #8-#16 sieve "Bird Seed" brand graded silica filter sand
- "Johnson" schedule 80 2-inch, flush-joint PVC "V-wire" 20-slot, well screen
- 12-inch diameter reverse-rotary drilled hole
- 3/8-to-5/8-inch bentonite chips from the "Teague" pits at Adrian, Oregon
- "Johnson" schedule 80 2-inch, flush-joint PVC pipe
- 3/8-inch washed granitic pea-gravel
- #8-#16 sieve "Bird Seed" brand graded silica filter sand
- 3/8-to-5/8-inch bentonite chips from the "Teague" pits at Adrian, Oregon
- cavings
- total depth =1010 ft.

Zone 8 · Zone 7 · Zone 6 · Zone 5 · Zone 4 · Zone 3 · Zone 2 · Zone 1

Vertical Scale: 1" = 100'
Horizontal Scale: .1" = 1"

Lithology

0 — 100 — 200 — 300 — 400 — 500 — 600 — 700 — 800 — 900 — 1000

- *highly fractured basalt*
- *caved river gravels and slabby basalt*
- *unconsolidated river terrace gravels*
- *"sticky" clay*
- *interbedded medium sands and "sticky" cohesive clays*
- *interbedded sequences of "sticky" clay and fine-to-medium sands*
- oxidized sediments (pale yellow-to-tan) — 450 — reduced sediments (greenish gray-to-dark-gray)
- *fine micaceous sand*
- *top of cemented mudstone section*
- *siltstone*
- *"sticky" clay*
- *medium-to-coarse sands*
- *wood*
- *massive indurated mudstone with thin lenses of fine-to-medium sands*
- *wood*
- *very fine sand*
- *shell fragments/wood*

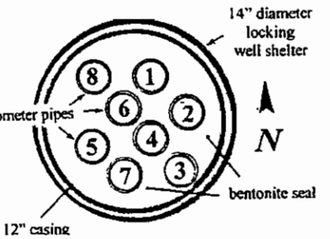
Geophysics

Caliper: 0 inches 20
64" Resistivity: 0 ohm-meters 200
16" Resistivity: 0 ohm-meters 200
H2O Temperature: 65 Degrees F 75
NaturalGammaRay: 0 counts/sec 150
PointResistance: 100 ohms 300

- *bottom of basalt*
- *bottom of 12-inch casing*

BHT=71.5°F

Wellhead Configuration



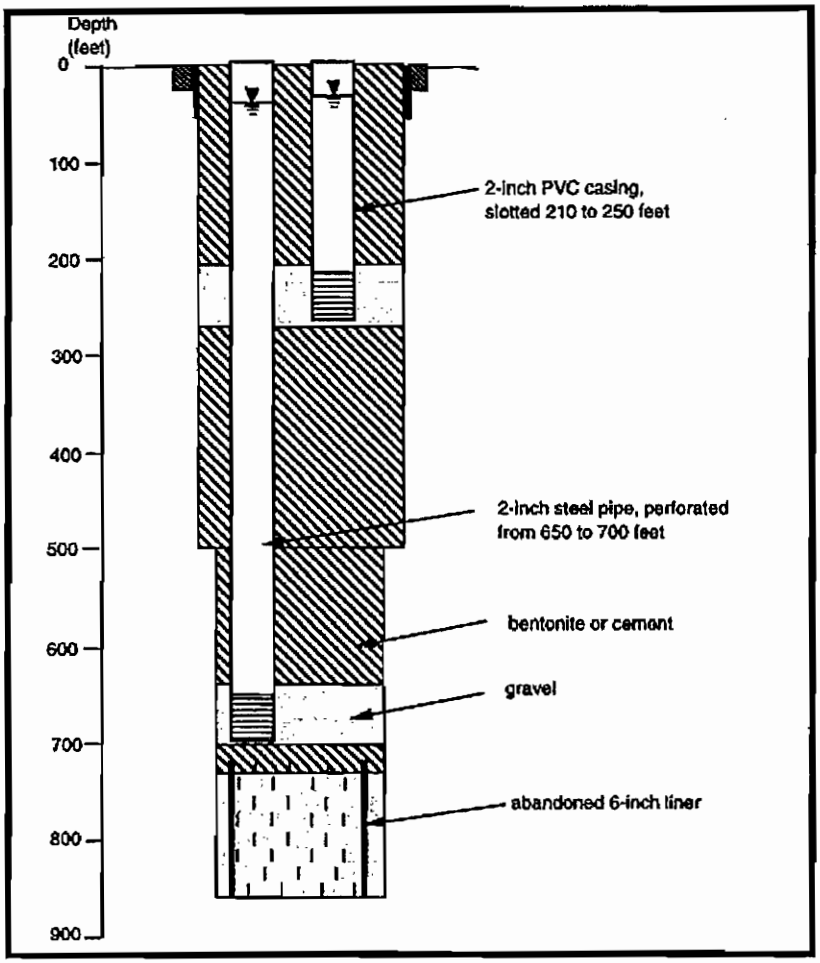
Water Chemistry

Parameter (mg/l)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
Alkalinity			73.2	80.6	61.8	75.2	359.0	
Ammonia as N			0.33	0.04	0.04	0.06	0.03	
Calcium			18.4	9.84	10.7	18.9	62.3	
Chloride			2.44	2.80	3.06	9.31	13.5	
Corrosivity			-0.25	-0.65	-0.85	-0.3	0.15	
Fluoride			0.57	0.15	0.44	0.43	0.43	
Hardness			58.9	30.5	31.9	60.9	199.0	
Iron			<0.01	<0.01	<0.01	<0.01	<0.01	
Iron (diss.)			<0.01	<0.01	<0.01	<0.01	<0.01	
Magnesium			6.73	1.38	1.51	3.23	10.4	
Manganese (diss)			0.05	<0.01	<0.01	<0.01	<0.01	
Nitrate as N			<0.10	0.16	0.27	0.49	0.23	
Potassium			1.38	1.45	1.55	2.63	3.83	
Silica			22.3	24.6	23.0	29.7	36.8	
Sodium			23.3	7.14	8.16	20.3	90.0	
Sulfate			7.07	1.39	0.19	3.27	7.15	
Total Dissolved Solids	9@167	6@170	4@132	6@173	2@156	<@139	<@158	
Total Phosphorus as P			0.030	0.037	0.056	0.033	0.817	
Field pH			8.38	8.17	8.04	8.08	7.88	8.15
Field Conductance uS	232	236	183	169	175	148	727	650
Field Temperature °F	@ 65	@ 65	66.0	64	64.5	63	61.5	60.8
Odor	1@5	1@5	1@5	0@	0@	0@	0@	0@
Gas (visible)			0@	0@	0@	0@	0@	0@
Water level (ft. bmp)		40.62	36.38	67.27	54.55	71.66	74.26	74.45
VOC's				N/D	N/D	N/D	N/D	N/D

Geophysical logs run in an open, water filled borehole on 10/1/99

ES/BC
11-99

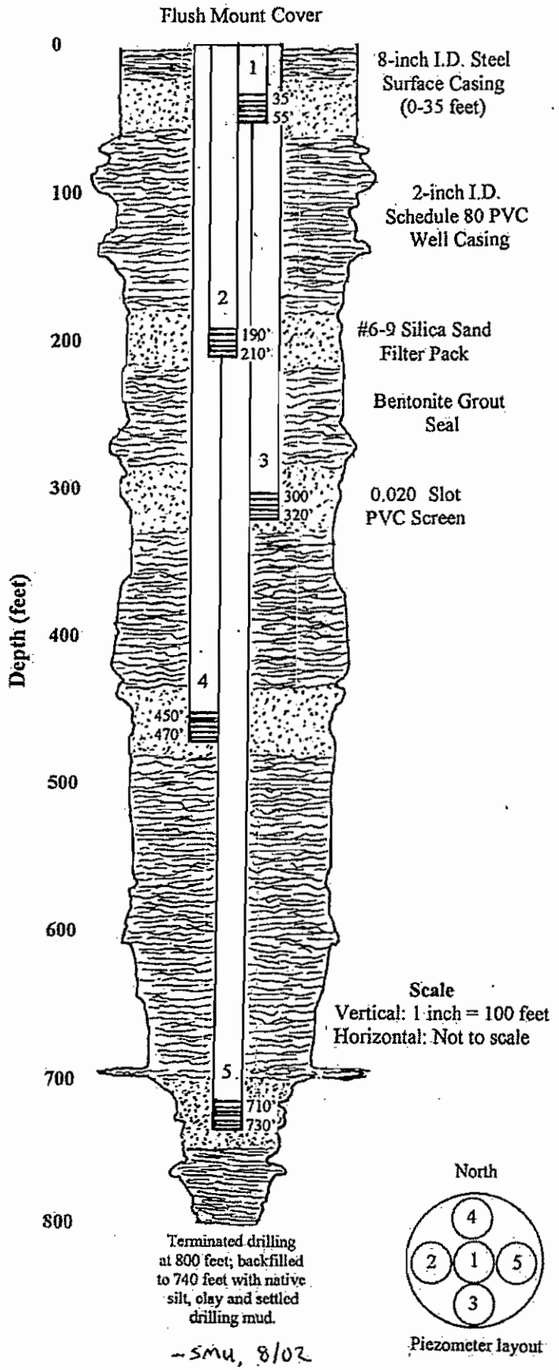
Drilling Contractor: Riverside, Inc. - Jeff "Newt" Hash & Justin Cleaver driller's
Geophysical Logging: United Water Idaho, Inc. - Roger Dittus and Ed Squires operators
Well Design and Geotechnical: Ed Squires, Hydro Logic, & Brian Cavanagh, BSU
Construction Oversight: Boise State University, Geosciences - Brian Cavanagh,
Project Management: Hal Anderson, IDWR & Ben Weymouth/Gordon Law, City of Caldwell



TVHP #3 – Quarry View Park
(diagram by T. Scanlan, Scanlan Engineering)

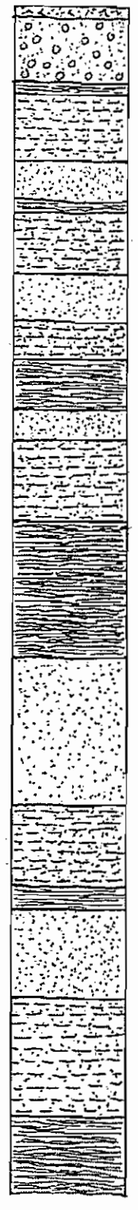
Municipal Park Monitoring Well (TVHP #4)

Well Construction Details



Lithologic Log

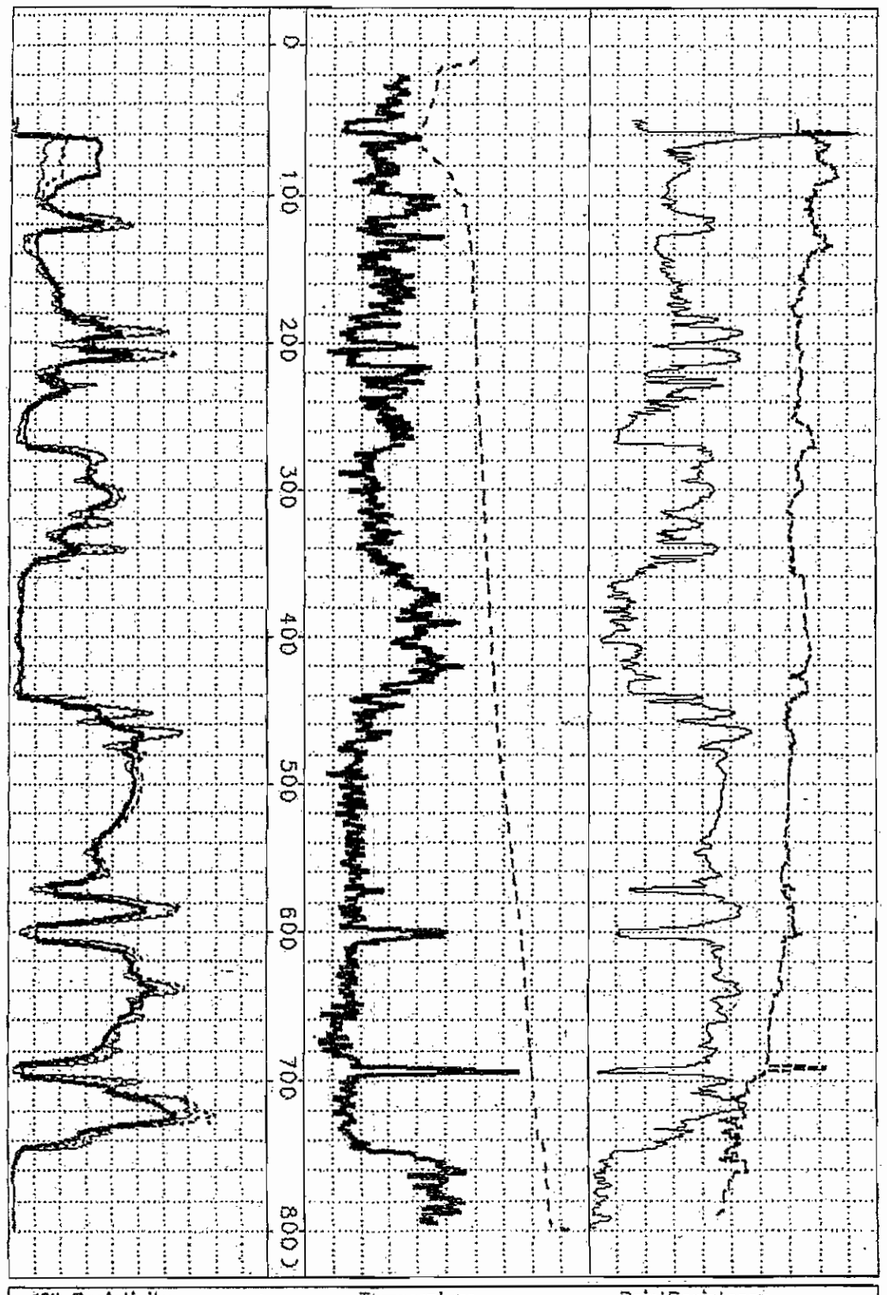
0 – 8	Topsoil/fill/sand and gravel; grayish brown (2.5Y 5/2)
8 – 55	Sand with gravel; light brownish gray (2.5Y 6/2); Possibly cemented at 37 - 38 feet, then >H_20
55 – 60	V. fine sand (yellowish-brown, 10YR 5/4) interbedded with clay (dark gray, 5Y 4/4). "Brown clay" in driller's report
60 – 105	Fine to coarse sand with clay; gray (5Y 6/1); Fast drilling (60 feet/hour)
105 – 130	Fine to coarse sand; light olive-gray (5Y 6/2)
130 – 140	Clay; v. dark gray (10YR 3/1); some wood fragments;
140 – 180	Sandy clay, fine to medium; greenish-gray (5GY 5/1)
180 – 215	Sand, interbedded fine to coarse; olive-gray (5Y 5/2)
215 – 240	Sandy clay; v. dark gray (5Y 3/1 – 4/1)
240 – 270	Clay; v. dark gray (5Y 4/1)
270 – 295	Sand, fine to coarse; olive-gray (5Y 5/2)
295 – 345	Sand, fine to coarse, interbedded with clay; dark gray (5Y 5/1) Fast drilling (averaging 90 feet/hour from 330 – 530 feet)
345 – 440	Clay; dark gray (10YR 4/1)
440 – 540	Sand, fine to coarse; dark gray (5Y 4/1)
540 – 595	Sand, fine to coarse, interbedded with some clay; dark gray (5Y 4/1); Slower drilling (30 feet/hour)
595 – 610	Clay/sandy clay; dark gray (5Y 4/1)
610 – 670	Sand, fine to coarse; dark gray (5Y 4/1) Slow drilling (35 feet/hour); Caliper log suggests evidence of bit wear.
670 – 750	Sand, sandy clay, possible sandstone/mudstone; dark gray (5Y 4/1); very slow drilling (less than 20 feet/hour)
750 – 800	Clay; dark gray (5Y 4/1)



Drilled by Stevens and Son Well Drilling, Inc.
- Started drilling 6/18/02; well completed on 7/29/02
- Cable tool rig 0-59 feet; mud rotary 59-800 feet

Geophysical logging by L. Pearson, Hydro Logic, Inc.
- Well logged on 6/27/02

Geophysical Logs



33F

Water Quality Data for Monitoring Well TVHP #4 Municipal Park

Addendum to the Report

Characterization of the Ground Water Flow in the Lower Boise River Basin
(Petrich and Urban, 2004)

Summary of Water Chemistry Data for TVHP #4, Municipal Park Monitoring Well

	MP-1	MP-2	MP-3	MP-4	MP-5
Well Data					
Well depth (feet to bottom of screen)	55	210	320	470	730
Elevation (feet, top of PVC casing)	2710.32	2710.26	2710.19	2710.15	2710.12
Laboratory Parameter					
Alkalinity (mg/L; as CaCO3)	39	66	122	74	86
Ammonia (mg/L)	<0.005	0.073	0.084	0.1	0.124
Arsenic (mg/L)	<0.005	<0.005	<0.005	0.013	0.014
Calcium (mg/L)	10	13.4	31	7.4	12.4
Carbonate alkalinity (mg/L; as CaCO3)	<1	<1	3	3	<1
Chloride (mg/L)	<2.00	<2.00	3.14	6.16	7.49
Fluoride (mg/L)	1.61	3.71	1.59	9.98	8.52
Hardness (mg/L;as CaCO3)	32	28	78	22	32
Iron (mg/L)	0.08	<0.01	0.06	0.06	0.28
Magnesium (mg/L)	1.9	0.3	0.5	0.1	0.2
Manganese (mg/L)	0.003	0.026	0.033	0.009	0.027
pH (pH units)	7.16	8.05	8.23	8.23	8.31
Potassium (mg/L)	0.5	0.7	1	0.7	1.2
Silica (mg/L; as SiO2)	0.6	12	10	7	3
Sodium (mg/L)	4.5	25	40	65	72
Sulfate (mg/L)	2.83	17.2	40.1	52	72.1
Sulfide (mg/L)	0.03	<0.01	0.01	<0.01	0.02
TDS (mg/L)	13	84	170	200	180
Carbon 14 Age (years BP)	NA	NA	1,470+/- 50	NA	12,720 +/- 70
Tritium Units	NA	NA	4.4 +/- 2.1	NA	<2
Field Parameters					
Conductivity (mS/cm)	0.07	0.15	0.29	0.29	0.34
Dissolved Oxygen (mg/L)	12.5	10.4	9.6	8.1	8
Average Purge Rate (gpm)	2.1	2.2	2.3	1.3	1.4
Gallons Purged	40	50	210	80	100
Salinity (%)	0	0	0	0	0
pH (pH units)	6	8.1	8.3	8.9	8.5
Temperature (Celsius)	12	15	17	18	19
Turbidity (NTU)	20	0	30	10	20
Hydrogen Sulfide Odor?	no	no	yes	yes	yes

NA = Not Analyzed
Water Quality parameters analyzed by Idaho Department of Health and Welfare
Carbon 14 and Tritium data from Geochron Laboratories, Cambridge, Mass.
Samples collected 1/30/2003

Laboratory Data Sheets
for
Monitoring Well TVHP #4

RECEIVED
MAY - 5 2003
Department of Water Resources

IDAHO DEPARTMENT OF HEALTH & WELFARE

DIRK KEMPTHORNE – Governor
KARL B. KURTZ – Director

BUREAU OF LABORATORIES
RICHARD F. HUDSON, Ph.D., Chief
2220 Old Penitentiary Road
Boise, ID 83712
PHONE 208-334-2235
FAX 208-334-2382

Attention: Scott Urban
Idaho Dept. of Water Resources
1301 N ORCHARD ST.
BOISE, ID 83706-

Date Collected: 1/30/2003
Time Collected: 1:00 PM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 416
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Matrix: Drinking Water
Sample ID: ~~TXHP-4 Well~~ MP-1
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Alkalinity (as CaCO3)	SM 2320 B	39	mg/L	2/3/2003	ordeb
Ammonia as N	EPA 350.1	<0.005	mg/L	2/11/2003	rousselled
Arsenic	EPA 200.9	<0.005	mg/L	2/12/2003	stranskyj
Calcium	EPA 200.7	10.0	mg/L	2/13/2003	stranskyj
Carbonate alkalinity (as CaCO3)	EPA 310.1	<1	mg/L	2/3/2003	ordeb
Chloride	EPA 300.0	<2.00	mg/L	2/12/2003	ordeb
Fluoride	EPA 300.0	1.61	mg/L	2/6/2003	ordeb
Hardness (as CaCO3)	EPA 130.2	32	mg/L	2/10/2003	ordeb
Iron	EPA 200.7	0.08	mg/L	2/13/2003	stranskyj
Magnesium	EPA 200.7	1.9	mg/L	2/13/2003	stranskyj
Manganese	EPA 200.7	0.003	mg/L	2/13/2003	stranskyj
pH	EPA 150.1	7.16	pH Units	1/31/2003	bartlettl
Potassium	SM 3111B	0.5	mg/L	2/5/2003	stranskyj
Silica (as SiO2)	EPA 370.1	0.6	mg/L	2/27/2003	ordeb
Sodium	SM 3111B	4.5	mg/L	2/5/2003	stranskyj

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

Laboratory Supervisor

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Lab Sample ID Number
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(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Matrix: Drinking Water
Sample ID: ~~TXHP 4 Well~~ MP-1
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Sulfate	EPA 300.0	2.83	mg/L	2/12/2003	ordeb
Sulfide	EPA 376.2	0.03	mg/L	2/6/2003	ordeb
Total Dissolved Solids	EPA 160.1	13	mg/L	2/4/2003	mathewss

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

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Date Collected: 1/30/2003
Time Collected: 1:30 PM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 417
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-2

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Alkalinity (as CaCO3)	SM 2320 B	66	mg/L	2/3/2003	ordeb
Ammonia as N	EPA 350.1	0.073	mg/L	2/11/2003	rousselled
Arsenic	EPA 200.9	<0.005	mg/L	2/12/2003	stranskyj
Calcium	EPA 200.7	13.4	mg/L	2/13/2003	stranskyj
Carbonate alkalinity (as CaCO3)	EPA 310.1	<1	mg/L	2/3/2003	ordeb
Chloride	EPA 300.0	<2.00	mg/L	2/12/2003	ordeb
Fluoride	EPA 300.0	3.71	mg/L	2/6/2003	ordeb
Hardness (as CaCO3)	EPA 130.2	28	mg/L	2/10/2003	ordeb
Iron	EPA 200.7	<0.01	mg/L	2/13/2003	stranskyj
Magnesium	EPA 200.7	0.3	mg/L	2/13/2003	stranskyj
Manganese	EPA 200.7	0.026	mg/L	2/13/2003	stranskyj
pH	EPA 150.1	8.05	pH Units	1/31/2003	bartlettl
Potassium	SM 3111B	0.7	mg/L	2/5/2003	stranskyj
Silica (as SiO2)	EPA 370.1	12	mg/L	2/27/2003	ordeb
Sodium	SM 3111B	25	mg/L	2/5/2003	stranskyj

Reported: Wednesday, April 30, 2003

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BOISE, ID 83706-

Date Collected: 1/30/2003
Time Collected: 1:30 PM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 417
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-2

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Sulfate	EPA 300.0	17.2	mg/L	2/12/2003	ordeb
Sulfide	EPA 376.2	<0.01	mg/L	2/6/2003	ordeb
Total Dissolved Solids	EPA 160.1	84	mg/L	2/4/2003	mathewss

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

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FAX 208-334-2382

Attention: Scott Urban
Idaho Dept. of Water Resources
1301 N ORCHARD ST.
BOISE, ID 83706-

Date Collected: 1/30/2003
Time Collected: 2:50 PM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 418
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-3

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Alkalinity (as CaCO3)	SM 2320 B	122	mg/L	2/4/2003	ordeb
Ammonia as N	EPA 350.1	0.084	mg/L	2/11/2003	rousselled
Arsenic	EPA 200.9	<0.005	mg/L	2/12/2003	stranskyj
Calcium	EPA 200.7	31.0	mg/L	2/13/2003	stranskyj
Carbonate alkalinity (as CaCO3)	EPA 310.1	3	mg/L	2/4/2003	ordeb
Chloride	EPA 300.0	3.14	mg/L	2/12/2003	ordeb
Fluoride	EPA 300.0	1.59	mg/L	2/6/2003	ordeb
Hardness (as CaCO3)	EPA 130.2	78	mg/L	2/10/2003	ordeb
Iron	EPA 200.7	0.06	mg/L	2/13/2003	stranskyj
Magnesium	EPA 200.7	0.5	mg/L	2/13/2003	stranskyj
Manganese	EPA 200.7	0.033	mg/L	2/13/2003	stranskyj
pH	EPA 150.1	8.23	pH Units	1/31/2003	bartlettl
Potassium	SM 3111B	1.0	mg/L	2/5/2003	stranskyj
Silica (as SiO2)	EPA 370.1	10	mg/L	2/27/2003	ordeb
Sodium	SM 3111B	40	mg/L	2/5/2003	stranskyj

Laboratory Supervisor

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

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Date Collected: 1/30/2003
Time Collected: 2:50 PM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 418
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-3

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Sulfate	EPA 300.0	40.1	mg/L	2/12/2003	ordeb
Sulfide	EPA 376.2	0.01	mg/L	2/6/2003	ordeb
Total Dissolved Solids	EPA 160.1	170	mg/L	2/4/2003	mathewss

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

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Date Collected: 1/30/2003
Time Collected: 9:20 AM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 419
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-4

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Alkalinity (as CaCO3)	SM 2320 B	74	mg/L	2/4/2003	ordeb
Ammonia as N	EPA 350.1	0.100	mg/L	2/11/2003	rousselled
Arsenic	EPA 200.9	0.013	mg/L	2/12/2003	stranskyj
Calcium	EPA 200.7	7.4	mg/L	2/13/2003	stranskyj
Carbonate alkalinity (as CaCO3)	EPA 310.1	3	mg/L	2/4/2003	ordeb
Chloride	EPA 300.0	6.16	mg/L	2/12/2003	ordeb
Fluoride	EPA 300.0	9.98	mg/L	2/6/2003	ordeb
Hardness (as CaCO3)	EPA 130.2	22	mg/L	2/10/2003	ordeb
Iron	EPA 200.7	0.06	mg/L	2/13/2003	stranskyj
Magnesium	EPA 200.7	0.1	mg/L	2/13/2003	stranskyj
Manganese	EPA 200.7	0.009	mg/L	2/13/2003	stranskyj
pH	EPA 150.1	8.23	pH Units	1/31/2003	bartlettl
Potassium	SM 3111B	0.7	mg/L	2/5/2003	stranskyj
Silica (as SiO2)	EPA 370.1	7	mg/L	2/27/2003	ordeb
Sodium	SM 3111B	65	mg/L	2/5/2003	stranskyj

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

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Date Collected: 1/30/2003
Time Collected: 9:20 AM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 419
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-4

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Sulfate	EPA 300.0	52.0	mg/L	2/12/2003	ordeb
Sulfide	EPA 376.2	<0.01	mg/L	2/6/2003	ordeb
Total Dissolved Solids	EPA 160.1	200	mg/L	2/4/2003	mathewss

Reported: Wednesday, April 30, 2003

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BOISE, ID 83706-

Date Collected: 1/30/2003
Time Collected: 10:35 AM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 420
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-5

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Alkalinity (as CaCO3)	SM 2320 B	86	mg/L	2/4/2003	ordeb
Ammonia as N	EPA 350.1	0.124	mg/L	2/11/2003	rousselled
Arsenic	EPA 200.9	0.014	mg/L	2/12/2003	stranskyj
Calcium	EPA 200.7	12.4	mg/L	2/13/2003	stranskyj
Carbonate alkalinity (as CaCO3)	EPA 310.1	<1	mg/L	2/4/2003	ordeb
Chloride	EPA 300.0	7.49	mg/L	2/12/2003	ordeb
Fluoride	EPA 300.0	8.52	mg/L	2/6/2003	ordeb
Hardness (as CaCO3)	EPA 130.2	32	mg/L	2/10/2003	ordeb
Iron	EPA 200.7	0.28	mg/L	2/13/2003	stranskyj
Magnesium	EPA 200.7	0.2	mg/L	2/13/2003	stranskyj
Manganese	EPA 200.7	0.027	mg/L	2/13/2003	stranskyj
pH	EPA 150.1	8.31	pH Units	1/31/2003	bartlettl
Potassium	SM 3111B	1.2	mg/L	2/5/2003	stranskyj
Silica (as SiO2)	EPA 370.1	3	mg/L	2/27/2003	ordeb
Sodium	SM 3111B	72	mg/L	2/5/2003	stranskyj

Reported: Wednesday, April 30, 2003

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Date Collected: 1/30/2003
Time Collected: 10:35 AM
Date/Time Received: 1/31/2003 4:28:27 PM

Lab Sample ID Number
03 01 420
(Please refer to this number when contacting the lab)

IDWR / 2002 Monitoring
Site: Municipal Park
Collected By: Scott Urban
Sample ID: IDWR-MP-5

Matrix: Drinking Water
Type / Source:

Test	Method	Result	Units	Date Completed	Analyst
Sulfate	EPA 300.0	72.1	mg/L	2/12/2003	ordeb
Sulfide	EPA 376.2	0.02	mg/L	2/6/2003	ordeb
Total Dissolved Solids	EPA 160.1	180	mg/L	2/4/2003	mathewss

Reported: Wednesday, April 30, 2003

EPA Laboratory ID: ID00018

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JUN 10 2003
Department of Water Resources

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No.	**GX-30182-AMS**	Date Received:	03/13/2003
Your Reference:	Purchase Order 03-31	Date Reported:	05/30/2003
Submitted by:	Idaho Dept. of Water Resources *Attention: Scott Urban* 1301 North Orchard Street Boise, ID 83706		

Sample Name: **IDWR – MP3**

AGE = **1470 ± 50 ^{14}C years BP (^{13}C corrected)**
83.28 ± 0.55 % of the modern (1950) ^{14}C activity

Description: Sample of ground water

Pretreatment: The sample was rapidly transferred, by aspiration, to an evacuated flask and acidified to recover carbon dioxide from dissolved carbonates for the analysis. ^{13}C analysis was performed on a small portion of the same evolved gas.

The sample yielded very little carbon and analysis by accelerator mass spectrometry (AMS) was required.

Comments:

$\delta^{13}C_{PDB}$ = **-14.3 ‰**

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error is +/- 1 s as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.

The age is referenced to the year A.D. 1950.

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RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No.	**GX-30183-AMS**	Date Received:	03/13/2003
Your Reference:	Purchase Order 03-31	Date Reported:	05/30/2003
Submitted by:	Idaho Dept. of Water Resources Attention: Scott Urban 1301 North Orchard Street Boise, ID 83706		

Sample Name: **IDWR – MP5**

AGE = **12720 ± 70 ^{14}C years BP (^{13}C corrected)**
20.53 ± 0.18 % of the modern (1950) ^{14}C activity

Description: Sample of ground water

Pretreatment: The sample was rapidly transferred, by aspiration, to an evacuated flask and acidified to recover carbon dioxide from dissolved carbonates for the analysis. ^{13}C analysis was performed on a small portion of the same evolved gas.

The sample yielded very little carbon and analysis by accelerator mass spectrometry (AMS) was required.

Comments:

$\delta^{13}C_{PDB}$ = **-8.1 ‰**

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error is +/- 1 s as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.

The age is referenced to the year A.D. 1950.

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Idaho Dept. Water Resources
Attn. Scott Urban
1301 North Orchard
Boise, Idaho 83706

Date Received: 03/13/03

Date Reported: 04/18/03

Your Reference: Municipal Park Well

REPORT OF TRITIUM ANALYSES
Date of Analysis - 03/29/2003

Our Lab. No.	Your Sample Number	Tritium Units
T-7535	IDWR - MP3	4.4+/-2.1
T-7536	IDWR - MP5	<2

336

GROUND WATER RECHARGE AND FLOW IN THE REGIONAL TREASURE VALLEY AQUIFER SYSTEM

GEOCHEMISTRY AND ISOTOPE STUDY

Submitted to:

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1301 North Orchard Street
Boise, Idaho 83706

Submitted by:

The Idaho Water Resources Research Institute

UI – Boise Center
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IDAHO WATER RESOURCES RESEARCH INSTITUTE
RESEARCH REPORT IWRRI-2002-08

December 2002

University of Idaho

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- Scott Urban, Idaho Department of Water Resources
- Rich Nehl, Micron Corporation
- Liz Cody, City of Boise

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- U.S. Environmental Protection Agency
- U.S. Geological Survey
- United Water Idaho, Inc.
- Micron Technology, Inc.
- Hydro Logic, Inc.
- U.S. Bureau of Reclamation
- Boise Project Board of Control

Executive Summary

Ground water in a regional system of deep, confined aquifers is increasingly targeted for the Treasure Valley's growing municipal and industrial water needs. Additional development of these aquifers requires greater knowledge about ground water recharge and flow in the regional system. The purpose of this study was to (1) refine the conceptual model of regional ground water recharge and flow in the Treasure Valley using hydrochemical data, and (2) provide new information for estimating regional-scale hydraulic parameters. The study objectives were to:

- Describe hydrochemical characteristics of principal aquifers that comprise the regional ground water flow system.
- Assess likely sources of recharge.
- Examine patterns in dissolved ion concentrations and abundance of carbon isotopes along regional ground water flow paths.
- Determine whether known geochemical processes describe the observed patterns.
- Estimate residence times for regional ground waters.

Results from the study show distinctive relationships between ground water chemistry and the unique depositional environments of the principal aquifers. Specifically, the study found that:

- Tritium was non-existent in samples from deeper, regional ground water, except where poor well construction may have allowed inter-aquifer mixing. This finding indicates that ground water in deeper aquifers entered the flow regime prior to atmospheric nuclear testing during the 1950s and 1960s.
- Specific conductance (and by inference, total dissolved solids) is greatest in shallow alluvial aquifers and decreases with depth. This finding indicates that water in deeper aquifers did not enter the ground water regime through the carbon-rich sediments found in Treasure Valley soils.
- Concentrations of major ions and other dissolved constituents varied consistently with depth among aquifer zones. The high degree of consistency suggests that these hydrochemical data can be used to identify discrete aquifer zones in other areas of the basin.
- Comparisons between measured constituents and established models of geochemical processes showed that (1) ground water near the northeastern basin margin has experienced little interaction with aquifer minerals and (2) ground water beyond the northeastern basin margin has experienced substantial interaction with aquifer minerals. Geochemical evolution of Treasure Valley ground water appears to be influenced by solution of both carbonate and silicate minerals.
- Residence times of Treasure Valley ground water generally increase with depth and with distance along a regional east-to-west trending flow path. Residence

times range from thousands to tens of thousands of years. The youngest waters entered the subsurface a few thousand years ago and are found along the northeastern boundary of the basin, adjacent to the Boise foothills. The oldest waters entered the subsurface between 20,000 and 40,000 years ago and are found in the western reaches of the basin near the Snake River. Ground water in the deep deltaic aquifers beneath Boise was recharged between 10,000 and 20,000 years ago. The proximity of these paleo-ground waters to the mountain front recharge area suggests that there is little natural flow in these aquifers.

- Contemporary seepage from rivers and/or irrigation diversions is not the primary source of recharge for most deeper, regional aquifers. Paleo-river channels, fractured granite aquifers in the Idaho Batholith and tributary sedimentary aquifers are the most likely sources of recharge to the regional flow system.
- A strong relationship between concentrations of dissolved constituents and depositionally-defined aquifer units, observed geochemical patterns consistent with the apparent evolution of ground water geochemistry, and the general east-to-west increase of ground water residence times support a conceptual model of regional ground water flow consisting of (1) recharge in alluvial sediments in southeast Boise and at the base of the mountain front north of Boise, (2) movement of ground water from the recharge areas into the deeper Boise area fluvial-lacustrine aquifers, and (3) movement of ground water from the Boise area aquifers into regional deep-lake aquifers of Nampa and Caldwell.

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Abbreviations for Wells and Other Waters

Am	Amity production
BCW	Banner Creek wells
BC	Blacks Creek production
BFS	Boise Front springs
BR	Boise River
C15	Caldwell No. 15 production
C16	Caldwell No. 16 production
CM	Cassia monitoring
C1	Cassia No. 1 production
C2	Cassia No. 2 production
Ch	Christiansen domestic
Edg	Edgeview (Braddock) production
G1	Goddard No. 1 production
G2	Goddard No. 2 production
Gy	Guyer domestic
HP	Hewlett-Packard production
In	Inouye domestic
J	Johnson domestic
JR	JR Flat production
Kn	Knox domestic
Ku	Kuespert domestic
L	Lete domestic
MAC	MAC production
MH	Maple Hills
MSt	Market Street production
McN	McNabb domestic
M8t	Meridian No. 8 test
M15	Meridian No. 15 production
M19	Meridian No. 19 production
M19t	Meridian No. 19 test
MD	Micron monitoring deep
MS	Micron monitoring shallow
M5	Micron No. 5 production
N12	Nampa No. 12 production
N19	Nampa No. 19 production
P10	Parma No. 10 production
StL	Saint Lukes fire control
Sch	Schwisow domestic
SH	State Hospital production
SW	Sunset West production
TV1	TVHP1 multi-level monitoring 1
TV2	TVHP1 multi-level monitoring 2
UI	University of Idaho production
Wm	Westmoreland production
Wr	Wright domestic

1. INTRODUCTION

1.1. Problem Statement

Ground water in a system of deep, confined aquifers is a primary source of potable water for Treasure Valley residents. These aquifers are tapped by most of the region's municipal and industrial wells and are increasingly targeted for additional development as the Treasure Valley population grows. Expanding use of ground water resources necessitates greater knowledge about recharge and flow in the regional ground water system. The goal of this study is to develop a better understanding of the regional flow system, with emphasis on recharge mechanisms and ground water residence times. The following introduction (1) describes a basic conceptual model of the regional system, (2) provides background on the geochemical tools used in the analysis, (3) reviews previous and related work, and (4) presents the purpose and objectives of the present study.

1.2. Regional Ground Water System

The Treasure Valley region of southwestern Idaho (Figure 1) has a complex history of lacustrine and alluvial deposition that influences regional ground water movement. In general, basin sedimentary deposits grade from coarser, more permeable sediments near the Boise Front[1] to finer, less permeable sediments at the distal end of the basin. At the basin scale, sediments are a finer grade with depth. These regional trends are interrupted by a complex arrangement of highly permeable deposits associated with paleo-river channels, river deltas, alluvial fans, and other features characteristic of a dynamic lacustrine history. Productive units are often surrounded by lower permeability deep-lake deposits, which, in some cases, limit interaction between productive units. The complexity of the ground water environment is well documented in the Boise area (Wood, 1997; Squires et al., 1992) and near Caldwell (Wood, 1994).

Additional influences on the movement of ground water are attributed to structural processes, including downwarping of the basin and faulting along the basin margin. Basin downwarping and an associated downslope trend in sediment deposition contribute to steeply dipping sedimentary deposits along the northern basin margin, which may cause deeper aquifer units to pinch out at depth (Wood, 1997). An erosional unconformity associated with changing lake levels in Pliocene Lake Idaho

[1] Boise Front describes the portion of the Idaho Batholith that forms the northern boundary of the lower Boise River basin.

truncates down-dipping units along the basin margin near Boise (Wood, 1997; Squires et al., 1992). The relationship between ground water above the unconformity and ground water in the underlying delta deposits, while unclear, is thought to be significant to the regional system (Wood, pers. comm.). In addition to complexity inherent in deposition and erosion, a series of major faults bisect the stratigraphic section along the northern basin margin. The hydrologic impact of these faults is poorly understood, but they are likely to be an important influence on ground water flow in Boise-area aquifers.

Less is known about the western portions of the valley. The relatively stable deep-water lake that covered this portion of the basin probably resulted in a less complex depositional environment than is found near the basin margin. Within this more uniform geologic environment, productive aquifers are interspersed with less permeable sediments, and vertical stratification of ground water is apparent from changes in water quality. Natural mixing between shallow aquifers and underlying regional ground water appears to be minimal and deep aquifers are generally confined.

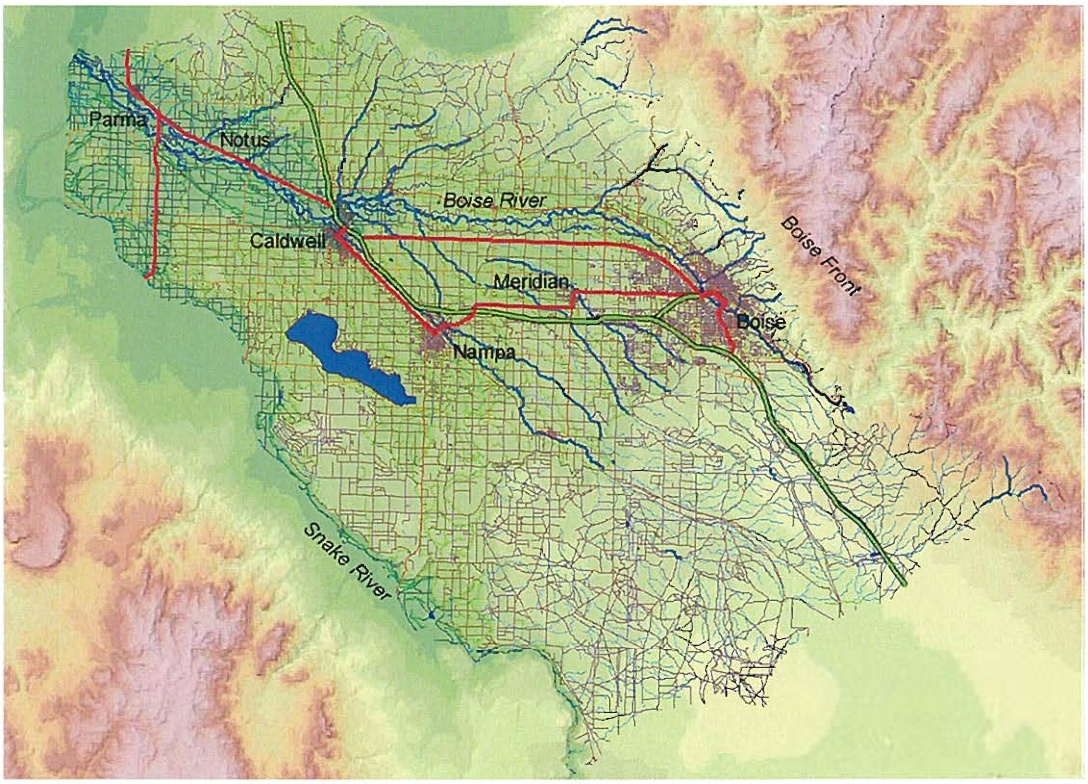

Figure 1. Map of the Treasure Valley project area.

Recharge to shallow aquifers in the basin is dominated by seepage from the dense network of irrigation canals and percolation from irrigation water (Urban and Petrich, 1998). Additional sources include mountain front recharge, underflow from the granitic Idaho Batholith and tributary sedimentary aquifers, and direct precipitation. There is no doubt that irrigation represents the primary source of recharge to shallow aquifers; however, the extent that surface water contributes to deep, regional aquifers, or that shallow aquifers recharge deep, regional aquifers, remains unclear.

The present conceptual model of ground water recharge and flow in the Treasure Valley consists of (1) aquifers contained in shallow alluvium and (2) aquifers contained in deeper Idaho Group sediments. Shallow alluvial aquifers are recharged by seepage from canals and deep percolation below irrigated fields. These aquifers discharge locally at nearby irrigation drains, creeks, or rivers. Deep Idaho Group aquifers are confined or semi-confined and do not appear to be in direct hydraulic connection with surface water. Deep ground water most likely originates as underflow from the granitic rocks and paleo-river channels that border the northern margin of the Treasure Valley near Boise. It may also originate as river or canal seepage in the northeastern portion of the valley. These deeper waters are thought to comprise a regional ground water system that ultimately discharges to the Snake River. A series of NW-SE trending faults is thought to influence both vertical and horizontal ground water flow.

1.3. Geochemical Tools for Analyzing Ground Water Flow

The developing body of scientific knowledge about chemical interactions between ground water and aquifer minerals provides a unique set of tools for interpreting changes in dissolved ions and other constituents along ground water flow paths. These interpretations allow hydrologists to (1) investigate the relative importance of various recharge sources, (2) confirm likely ground water flow paths, and (3) gain insight into the evolution of ground water chemistry within a flow system. Recent applications of these tools include the Milk River Aquifer, Canada (Hendry and Schwartz, 1990); the Cambrian-Ordovician Sandstone Aquifer, eastern Wisconsin (Weaver and Bahr, 1991); and the Mahomet Bedrock Aquifer, east-central Illinois (Panno et al., 1994).

Environmental isotopes are useful tracers of water movement because unique isotopic signatures are related to particular recharge environments. Analysis of isotopic tracers allows one to (1) establish the environment in which ground water recharge took place and/or (2) constrain the window of time during which recharge occurred. These techniques have proven useful for analyzing a number of ground water systems in the western U.S., including San Juan Basin, New Mexico (Phillips et al., 1989); Aravaipa Valley and Tucson Basin, Arizona (Adar and Neuman, 1988; Adar et al., 1988; Campana and Simpson, 1982); Santa Clara Valley, California (Muir and Coplen,

1981); White River Flow System, Nevada (Kirk and Campana, 1990); and the Eastern Snake River Plain, Idaho (Plummer et al., 2000).

Tritium (^3H), carbon-14 (^{14}C), and carbon-13 (^{13}C) are environmental isotopes used in the present study. Tritium and ^{14}C are radioisotopes, and although they differ in application, these radioactive species are both used to estimate the time that a unit of water resides in the ground water system. Tritium is used to identify "modern" ground waters, while ^{14}C is used to date "paleo" ground waters.[2] The potential for dating ground water using atmospheric ^3H has been explored by numerous researchers, beginning with Kaufman and Libby (1954). Worldwide atmospheric testing of thermonuclear weapons during the 1950s and 1960s resulted in relatively high concentrations of ^3H in rain water.[3] This well-documented influx of ^3H into the ground water environment has become a standard for the definition of "modern" ground water (Clark and Fritz, 1997). Ground water with ^3H concentrations greater than ~10 picoCuries per liter (pCi/L) is "modern" in that a substantial portion of that water entered the subsurface during the past 50 years. Present-day precipitation contains very little ^3H because most of the bomb ^3H has been removed (rained) from the atmosphere.

The discovery in 1946 of naturally-occurring ^{14}C (radiocarbon) in atmospheric CO_2, the estimation of its 5,730-year half-life, and the early recognition of its utility for dating carbon-rich material, resulted in development of a useful ground water dating technique. Most ^{14}C in ground water is introduced when recharge water percolates through the soil zone. Carbon dioxide released in the soil from decomposing plants accumulates at a concentration between 10 and 100 times greater than that of the atmosphere. The high CO_2 pressure of the soil increases the concentration of ^{14}C-containing dissolved inorganic carbon (DIC) in percolating water. Once beyond the influence of the soil zone, percolating water ground water is no longer exposed to ^{14}C-rich DIC. With time, the dissolved ^{14}C slowly decays to carbon-12 (^{12}C), leaving measurably less ^{14}C behind in the water.

Estimating the residence time of ground water using ^{14}C-dating requires quantifying the decrease in ^{14}C from radioactive decay after the initial CO_2 charging. Two key assumptions must be evaluated in order to establish residence times: (1) the original concentration of ^{14}C in the charged water must be known; and (2) sources or sinks of ^{14}C (other than radioactive decay) encountered after leaving the soil zone must be quantified. If these two assumptions are valid, then the residence time of ground water in the aquifer is calculated using an exponential model of radioactive decay and the

[2] In practical terms, "modern" ground waters are those recharged during the past five decades, while "paleo" ground waters are those recharged thousands to tens-of-thousands of years ago.
[3] Even at peak atmospheric concentrations, tritium fallout was not a direct threat to human health (Clark and Fritz, 1997).

known half-life of ^{14}C. To address the first assumption, two independent historic records have been developed that establish the activity of ^{14}C in the atmosphere. These records are Holocene tree rings and late Pleistocene coral. The records provide convincing evidence that atmospheric ^{14}C has decreased about 40% during the past 30,000 years (Clark and Fritz, 1997).

The second assumption, that sources and sinks of ^{14}C along a ground water flow path can be quantified, is much more problematic in ground water systems. Ground water is subjected to perpetual changes in its chemical make-up caused by reaction with the mineral assemblages through which it passes. This process, known as geochemical evolution, often results in dilution of dissolved ^{14}C by biogenic and mineral carbon that, because of its extreme age, no longer contains ^{14}C. In addition, certain chemical and biological reactions partition different carbon isotopes into various reaction products, resulting in isotopic fractionation of the dissolved carbon. In general, these geochemical and biological reactions reduce the amount of ^{14}C in ground water and, if not accounted for, may cause ground water ages to be grossly overestimated. The practical range of ground water ages that can be determined using ^{14}C analysis is 5,000 to 30,000 years (Clark and Fritz, 1997). Even when the sources and sinks of ^{14}C are known and ground water age falls within this range, mixing between different aquifers may add considerable uncertainty to travel time estimations.

Measuring the relative abundance of the stable isotope ^{13}C in ground water provides another means of tracing carbonate evolution and is particularly useful for determining the importance of biogeochemical reactions in the ground water system. Large differences in $\delta^{13}C$ among the various carbon reservoirs in a regional flow system make this technique a useful diagnostic tool. The evolution of DIC in ground water begins with atmospheric CO_2 ($\delta^{13}C \approx -7‰$).[4] Photosynthetic uptake of atmospheric CO_2 is accompanied by a substantial depletion in $\delta^{13}C$ (approximately 22‰ for C_3 plants, resulting in plant $\delta^{13}C$ values of between -24 and -30‰).[5] Subsequently, when dead vegetation is decomposed in the soil and converted back to CO_2, the isotopically-light CO_2 accumulates in the soil at concentrations between 10 and 100 times that of the atmosphere. The CO_2 is further fractionated by diffusion away from the production zone. As a result of these processes, soil CO_2 typically has a $\delta^{13}C$ value of about -23‰.

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[4] Del notation is used to describe the proportion of ^{13}C relative to the more ubiquitous isotope ^{12}C. The defining relationship is $^{13}C/(^{13}C+^{12}C)$. The ratio is expressed per mille (‰), which is, one unit per thousand.

[5] The amount of fractionation depends on the type of plant and its particular photosynthetic pathway. Most terrestrial ecosystems are dominated by C_3 plants. A good discussion of these pathways can be found in Clark and Fritz (1997).

As soil CO_2 dissolves into percolating water some of it becomes hydrated and dissociates into HCO_3^- and CO_3^{2-}. This geochemical process fractionates ^{13}C once again. The extent of this ^{13}C fractionation is dependent on pH, but is close to -15‰ for ground waters with pH greater than 7.5. In carbonate terranes, weathering of calcite and other carbonate minerals causes DIC concentrations to increase and $\delta^{13}C$ to evolve to higher values until calcite saturation is reached. The saturation $\delta^{13}C$ value depends on the starting P_{CO_2}, the $\delta^{13}C$ value of the carbonate material and whether the ground water system is open or closed to exchange with atmospheric CO_2.

Several complicating factors associated with chemically reduced ground waters are also recorded in the ^{13}C signature, namely oxidation of organic matter and methanogenesis. Microbial oxidation of organic matter adds additional CO_2 to the ground water system. The added CO_2 is depleted in ^{13}C because of fractionation during the biochemical reaction. This process can add carbon to the ground water DIC pool that has $\delta^{13}C$ of between -25 and -30‰. Methane-producing bacteria strongly affect $\delta^{13}C$ of DIC by adding CO_2 with $\delta^{13}C$ of about +10‰.

1.4. Previous Geochemistry and Isotope Studies in the Treasure Valley

Although no existing geochemical studies directly address regional-scale ground water recharge and flow in the Treasure Valley, a number of studies contribute to understanding particular parts of the system. Previous investigators have used naturally occurring stable isotopes to describe recharge of cold-water springs in the granitic foothills above Boise (Mariner et al., 1989). Stable isotopic signatures (^2H and ^{18}O) of spring water suggest that these shallow aquifers on the mountain-front have contemporary and local recharge sources. On the other end of the age continuum, ^{14}C-ages of geothermal water emanating from structural faults deep beneath Boise suggest recharge some 14,000 to 30,000 years ago (Mariner et al., 1989; Mayo et al., 1984). Radiocarbon-ages have also been determined for ground water from the Goddard, Westmoreland, and MAC wells, which penetrate non-thermal aquifers near Boise (Parliman and Spinazola, 1998). These data show that some deep ground water beneath Boise originated as much as 11,000 years ago. The existence of paleo-ground water precludes a direct, dynamic connection to shallow aquifers or surface water. This distinction is supported by measurements of ^3H in ground water samples from five shallow wells adjacent to the New York Canal. These measurements indicate that downward movement of surface water originating from canal seepage and flood irrigation has been limited to a depth of about 200 feet since the 1950s (D. Parliman, pers. comm. 1999).

A general, basin-scale geochemical and isotope study of ground water in the Eastern Snake River Plain evaluated geochemical controls on non-thermal and geothermal

water using major ion chemistry (Wood and Low, 1988). The study also addressed the source of recharge to the geothermal system using both stable isotopes and radioisotopes. Results suggested that non-thermal aquifers of the Eastern Snake River Plain recharge from tributary basins and local irrigation. In contrast, geothermal waters are on the order of 20,000 years old. These geothermal aquifers are thought to derive recharge from precipitation in the high mountains of central Idaho (Wood and Low, 1988). The layered sedimentary aquifers of the Treasure Valley are clearly different from the basalt aquifers of the Eastern Snake River Plain; however, a similar geochemical and age dating approach is likely to provide similar information for the Treasure Valley ground water system.

1.5. Purpose and Objectives

The primary purpose of this investigation was to refine the present conceptual model of ground water recharge and flow. A secondary purpose was to provide data for estimating regional-scale hydraulic parameters. The specific objectives were to:

1. Describe hydrochemical characteristics of principal aquifers that comprise the regional ground water flow system.
2. Assess likely sources of recharge.
3. Examine patterns in dissolved ion concentrations and abundance of carbon isotopes along regional ground water flow paths.
4. Determine whether known geochemical processes describe the observed patterns.
5. Estimate residence times for regional ground waters.

2. METHODS

2.1. Ground Water Sampling and Chemical Analysis

The completion of several preliminary tasks was necessary to acquire an appropriate data set that represents the regional ground water system. The tasks included: (1) selecting wells for ground water sampling, (2) collecting samples, (3) measuring the appropriate constituents, and (4) determining the most suitable analytical tools. This section describes the methodology used to accomplish these tasks.

2.1.1. Well Selection

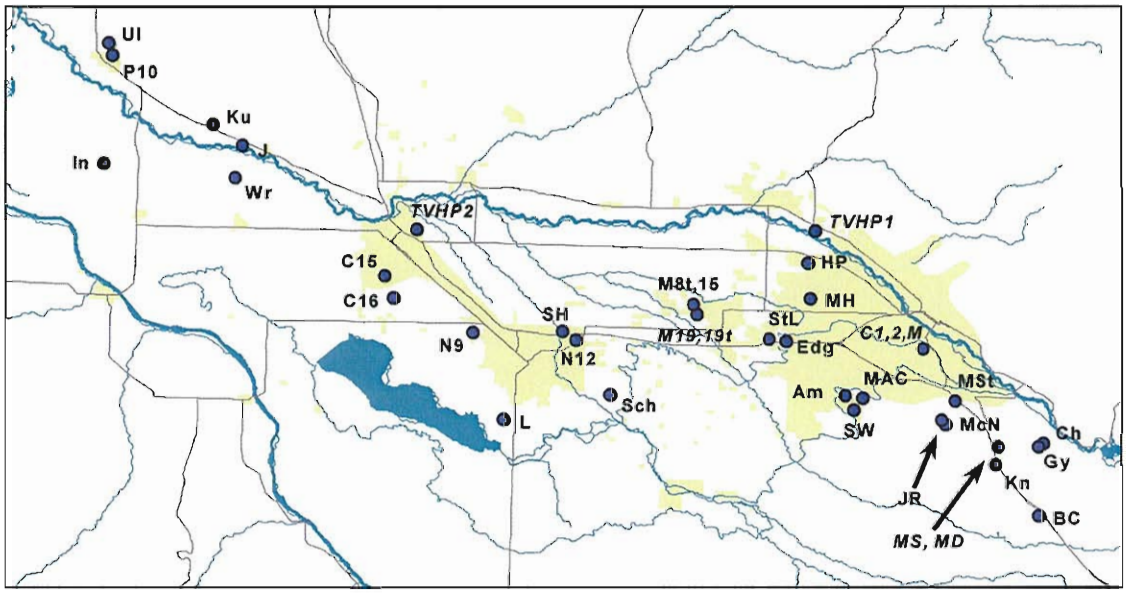
Thirty-eight wells were selected for ground water sampling (Figure 2). The wells, all completed in Idaho Group sediments, lie about the axis of the basin between southeast Boise and Parma, generally along the hypothesized path of ground water flow.[6] Particular attention was given to driller's logs and as-built drawings to ensure that sampling wells had (1) adequate surface seals; (2) grout seals, packers, and/or formation seals at all casing reductions; (3) minimal overbore; and (4) clearly identified water bearing zones (WBZs) defined by a screened and/or gravel packed interval. The tops of the WBZs were between 338 and 800 feet below ground surface and the WBZs were less than 213 feet thick. Exceptions to these criteria were multi-level monitoring wells, which are completed over several discrete WBZs; and the United Water Idaho, Inc., Market Street well, which is completed in a WBZ between depths of 510 and 912 feet. The Market Street well has undergone rigorous geophysical examination and, although open for 402 feet, is considered important for interpreting estimates of ground water residence times in nearby wells.

2.1.2. Ground Water Sampling and QA/QC

The Idaho Department of Water Resources contracted with the U.S. Geological Survey to obtain water samples from the wells shown in Figure 2. Sampling was conducted during the 1999 and 2000 field seasons. Sampling protocol closely followed Standard Operating Procedures (SOPs) developed for the Statewide Ambient Ground Water Quality Monitoring Program (Statewide Program). Each water sample required a field site inventory (SOP 1.00); well purging (SOP 3.00); equipment decontamination (SOP 4.00); proper collection (applicable parts of SOP 5.00); quality control sampling

[6] Petrich and Urban et al. (1999) gives a full analysis of water level measurements in the basin.

(SOP 9.00); appropriate labeling (SOP 8.00); and storage (SOP 6.00) (IDWR, 1998a). Quality control checks consisted of duplicate samples, an equipment blank per month of sampling, and one blind reference of each analyte per month of sampling. Following this plan ensured that (1) data were collected in a manner consistent with the research objectives, (2) data accurately represented the actual ground water conditions, and (3) data were technically defensible.



Italics identify multi-level wells. Well information is provided in Appendix 1.

Figure 2. Sampling well locations and labels.

The Quality Assurance (QA) Plan for the Statewide Program was adopted to evaluate the sampling and analysis protocol used during the present study. The Statewide Program QA plan was selected because sampling requirements were similar to the present study and because the Statewide Program benefited from state and federal review (IDWR, 1998b). Quality assurance observations were conducted at the field and laboratory level. These observations included: (1) previewing laboratory QA procedures prior to sample submission; (2) reviewing laboratory QA data upon receipt by TVHP personnel; (3) observing field sampling techniques; and (4) evaluating quality control (QC) data, including ion balances, precision of duplicate analyses, and accuracy of blind references.

2.1.3. Measurements and Reporting

Temperature, pH, dissolved oxygen (DO), and specific conductance (C_s) were measured in a flow-through cell connected to the discharge of each well. After these parameters stabilized, samples were collected and stored according to the procedures

described in Section 2.1.2. Alkalinity was titrated immediately after each sample was collected. All ground water samples were submitted to the USGS National Laboratory in Arvada, Colorado, for chemical analyses of major ions (Ca, Mg, Na, K, HCO_3, CO_3, Cl, and SO_4), NO_3, SiO_2, F, Fe, Mn, and ^3H.[7]

Twenty-eight samples from deep wells in the central basin were selected for ^{14}C age-dating from the pool of 38 wells. The selection criteria described in Section 2.1.2, together with the chemical information, were used to establish that the 38 wells produced water exclusively from the regional ground water system. The absence of ^3H and NO_3 in the age-dating samples ensured that no modern water contaminated the wells. The University of Waterloo Radioisotope Laboratory conducted measurements of ^{13}C and prepared graphite targets for ^{14}C analysis from DIC extracted from the ground water samples. Carbon-13 was measured using standard Mass Spectroscopy methods. Carbon-14 was measured using Accelerator Mass Spectroscopy (AMS) methods.[8] Carbon-14 measurements were conducted at The Canadian Centre for Accelerator Mass Spectroscopy (ISOTRACE), Toronto, Canada, and at the Rafter Radioisotope Laboratory, Lower Hutt, New Zealand.

All data except P_{CO_2} and isotope measurements are reported using International System of Units (SI).[9] For direct comparison with historic data, P_{CO_2} data are given in bars and ^3H measurements are given in units of picoCuries per liter (pCi/L). Carbon isotope reporting follows protocol outlined by Stuvier and Polach (1977). Values of $\delta^{13}C$ are reported as per mil (‰) with respect to the PDB standard. Carbon-14 ages based on the activity of ^{14}C relative to the absolute international standard activity, normalized to ^{14}C activity in 1950 wood, and corrected for isotopic fractionation are reported as conventional radiocarbon ages. All age calculations are based on the Godwin half-life for ^{14}C (5730 y). Radiocarbon ages are reported in years before present (ybp) with AD 1950 equal to 0 ybp. Statistical certainty based on the number of accumulated sample counts, oxalic acid standard counts, and background counts, plus analytical uncertainty and instrument error are given as ± one standard deviation. Elevations are reported in feet above mean sea level (MSL).

[7]Specific information about analytical methods can be found at http://www.nwql.cr.usgs.gov/.
[8]Accelerator Mass Spectrometry employs a particle accelerator to count the number of atoms of each carbon isotope in the target material. Additional information about AMS can be found at http://www.gns.cri.nz/atom/rafter/measure.htm.
[9]A reference of SI units can be found at http://www.unc.edu/~rowlett/units/sipm.html.

2.2. Data Analysis

2.2.1. Aquifer Correlation and Geochemical Evolution

Analysis of chemical data collected from poorly constructed wells or from natural mixing zones could clearly bias the results of our study. To establish confidence in our analysis we identified and rejected data that showed evidence of mixing between discrete zones in the stratigraphic section. Tritium and NO_3 were used as the primary indicators of mixing with contemporary waters. Elevated DO and SO_4 indicated mixing in cases where deep ground water was known *a priori* to be chemically reduced. Samples that showed elevated concentrations of fluoride, very high Na/Ca ratios, and elevated temperatures were identified as possibly mixed with hydrothermal water.

Hydrochemical data were mapped, compared to previous interpretations of hydrogeologic unit boundaries, and considered relative to aquifer stratigraphy. Values of C_s, pH, relative molar concentrations of major ions, redox status (DO and SO_4), and P_{CO_2} were used to correlate chemistry with detailed geophysical and stratigraphic interpretations.[10] Saturation indices for the most important mineral phases, including dissolved CO_2 gas, were calculated using the chemical equilibrium model WATEQF (Plummer et al., 1976). Analysis of basin-scale ground water evolution closely followed seminal works by Garrels (1967) and Garrels and Mackenzie (1967).

2.2.2. Carbon Isotope Analysis

Flow path geochemistry was also evaluated using $\delta^{13}C$ data from both dissolved and mineral-phase inorganic carbon. Dissolved inorganic carbon measurements in well samples were supplemented by $\delta^{13}C$ measurements of drill cuttings from the Cassia, Julia Davis, and Simplot Geothermal wells. The carbonate data were used to strengthen the analysis of geochemical evolution and to correct ^{14}C-age calculations.

2.2.3. Carbon-14 Age Dating

Four reservoir correction techniques were considered to adjust the conventional radiocarbon ages for geochemical processes that influence ^{14}C activity in the Treasure Valley ground water system. These techniques include: (1) an empirical model, (2) a chemical mass balance model, (3) a $\delta^{13}C$-mixing model, and (4) a Matrix Exchange model. All of these models assume that the diluting source of carbon is old enough to

[10] Dissolved CO_2 gas is often expressed in terms of partial pressure as P_{CO_2}.

be ^{14}C-free and that carbonate dissolution occurs below the water table. Results from the correction models were subjected to an additional correction for long-term changes in atmospheric ^{14}C.

2.2.3.1. Empirical Model

An empirical approach proposed by Vogel (1970) assumes that measurements of ^{14}C activity in ground water located near the recharge zone accurately represent the initial activity of ^{14}C. In this model of ground water recharge and flow, water percolating through the soil and into the first part of the flow system is rapidly charged with CO_2 (and therefore ^{14}C). Beyond the recharge zone, ground water is shut off to CO_2 inputs (a closed-system model). The only reaction addressed by this model is the addition of old carbon via carbonate dissolution beyond the recharge zone. The correction factor (q) is introduced to adjust the ^{14}C activity ($a\,^{14}C$) of DIC entering ground water from the recharge zone. The correction factor is found using

$$q = a^{14}C_{DIC} / a^{14}C_{rech},$$

where $a^{14}C_{rech}$ is obtained by estimating (or preferably, measuring) ^{14}C in the recharge zone. Often ^{3}H is used to identify recharge zone water. The important assumption underlying the empirical approach is that the recharge environment of paleo-ground water is the same as that of modern recharge water.

2.2.3.2. Chemical Mass Balance (CMB) Model

A more robust approach to correcting ^{14}C data is to use measured geochemical parameters. Several variations of this approach, including the alkalinity correction model (CMB-ALK) of Tamers (1975) and the chemical mass balance model (CMB-CHEM) of Fontes and Garnier (1979), are collectively known as geochemical models. Generically, a geochemical mass balance is simply a budget that accounts for all inputs and outputs of dissolved constituents. The basic CMB correction model consists of a two-step correction. The steps are (1) correct ^{14}C in the recharge zone for carbonate loading using assumed P_{CO_2} and pH values; and (2) correct for carbonate dilution during movement through the aquifer using either titrated alkalinities or mass balance based on major ion data. The correction factor is obtained using

$$q = m\mathrm{DIC}_{rech}/m\mathrm{DIC}_{final},$$

where $m\mathrm{DIC}_{rech}$ is the molar concentration of DIC gained during transit through the recharge zone and $m\mathrm{DIC}_{final}$ is the sum of the ^{14}C-active (recharge) DIC and the "dead" DIC gained during transit through the aquifer. The CMB approach does not apply to ground waters open to atmospheric CO_2 or to systems in which carbonate is precipitated from solution.

2.2.3.3. $\delta^{13}C$-mixing Model

Carbon-13 measurements provide a useful tool for estimating corrections to ^{14}C-age calculations, because ^{13}C is a good tracer of carbonate evolution in ground water. The underlying assumption is that any process affecting ^{14}C during ground water recharge and flow, other than radioactive decay, affects ^{13}C in a similar fashion. The working conceptual model begins with soil CO_2 gas at equilibrium with the soil solution, resulting in open system dissolution of soil carbonate in the recharge zone. Once the solution passes beyond the recharge zone, carbonate dissolution is controlled by the amount of dissolved CO_2 in the water. The primary difference between the $\delta^{13}C$ mixing model and other correction models is that it allows incorporation of ^{14}C-active DIC during carbonate dissolution under open-system conditions in the recharge zone. The biggest limitation of this approach is that ground water age calculations are profoundly affected by small changes in the enrichment factor used to estimate isotope exchange in the soil zone. The enrichment factor depends heavily on the pH chosen for the recharge water, which is difficult to quantify for waters recharged thousands of years ago. The $\delta^{13}C$-mixing model correction factor is calculated using the following:

$$q = (\delta^{13}C_{DIC}-\delta^{13}C_{carb})/(\delta^{13}C_{soil} + \varepsilon^{13}C_{DIC\text{-}CO2} - \delta^{13}C_{carb}),$$

where: $\delta^{13}C_{DIC}$ = measured $\delta^{13}C$ in ground water

$\delta^{13}C_{carb}$ = $\delta^{13}C$ of calcite being dissolved (between +5‰ and -15‰)

$\delta^{13}C_{soil}$ = $\delta^{13}C$ of soil CO_2 (usually close to -23‰)

$\varepsilon^{13}C_{DIC\text{-}CO2}$ = the pH dependent enrichment of $\delta^{13}C_{soil}$ by fractionation between soil CO_2 and DIC_{soil}

2.2.3.4. $\delta^{13}C$-Matrix Exchange Model

Isotopic exchange between $^{14}C_{DIC}$ and primary calcite along the ground water flow path is recorded by closed system enrichment of ^{13}C. This exchange process is accounted for in the $\delta^{13}C$-mixing model above. A second exchange process, which is not accounted for in the basic $\delta^{13}C$-mixing model, is exchange of $^{14}C_{DIC}$ with carbon contained in secondary calcite minerals. This exchange process may play an important role in controlling $^{14}C_{DIC}$ of waters that remain at equilibrium with calcite along much of their flow path. The $\delta^{13}C$-matrix exchange model proposed by Fontes and Garnier (1979; 1981) uses (1) a cation mass balance to estimate the contribution of ^{14}C-free carbonate from the aquifer matrix and (2) isotope mass balance to distribute $^{14}C_{DIC}$ into that exchanged with soil CO_2 (open-system exchange) and/or the carbonate matrix (matrix exchange).

The total matrix-derived DIC ($m\mathrm{DIC}_{carb}$) is estimated from a cation mass balance equation proposed by Fontes and Garnier (1979):

$$m\mathrm{DIC}_{carb} = m\mathrm{Ca}^{2+} + m\mathrm{Mg}^{2+} - m\mathrm{SO}_4^{2-} + 1/2(m\mathrm{Na}^{+} + m\mathrm{K}^{+} - m\mathrm{Cl}^{-})$$

This portion of the correction model accounts for carbonate dissolution based on Ca and Mg, with a correction for evaporite dissolution ($m\mathrm{SO}_4^{2-}$) and cation exchange ($m\mathrm{Na}^{+} + m\mathrm{K}^{+} - m\mathrm{Cl}^{-}$).

The total matrix-derived DIC is then distributed into the open-system exchange (containing ^{14}C-active carbonate) component and the matrix exchange component (containing old, ^{14}C-dead carbonate) based on $\delta\,^{13}$C. The open-system component is calculated using

$$mDIC_{CO_2-exch} = \frac{\delta^{13}C_{meas} \cdot mDIC_{meas} - \delta^{13}C_{carb} \cdot mDIC_{carb} - \delta^{13}C_{soil} \cdot (mDIC_{meas} - mDIC_{carb})}{\delta^{13}C_{soil} - \varepsilon^{13}C_{CO_2-CaCO_3} - \delta^{13}C_{carb}}.$$

Using this calculation to estimate the open-system contribution, the correction factor becomes

$$q = (m\mathrm{DIC}_{meas} - m\mathrm{DIC}_{carb} + m\mathrm{DIC}_{CO2\text{-}exch})/m\mathrm{DIC}_{meas}.$$

2.2.3.5. Which Model to Use?

All of these models for correcting ^{14}C-ages are gross simplifications of processes occurring in real ground water flow systems. Deciding which correction model is most appropriate for the Treasure Valley system is not straightforward; however, a model selected using reasoned consideration of the actual geochemical environment provides ground water ages that are more accurate than uncorrected ^{14}C-ages. A well-characterized recharge environment is the main assumption underlying the empirical approach. This assumption is not valid in the Treasure Valley where the recharge environment is not characterized well enough to allow adequate empirical determination of q and long-term climatic changes have clearly altered the recharge environment. For these reasons the empirical approach is not used in our analysis. The CMB models are sensitive to pH and P_{CO_2} conditions in the recharge zone. These values are rarely known for older ground waters and are especially difficult to resolve in complex recharge environments. Regional ground water in the Treasure Valley may be quite old and may be recharged from a variety of sources, including underflow from fractured granite aquifers, underflow from tributary sedimentary aquifers, seepage from rivers and canals, and percolating irrigation water. In addition, it is unclear whether the stringent closed-system assumption is valid for this system. As a result, the suitability of the CMB model for correcting ^{14}C in this ground water system is questionable. Like the CMB model, the δ^{13}C-mixing models are also strongly dependent on unknown recharge conditions; however, when combined with the matrix exchange approach of Fontes and Garnier (1979, 1981), this class of models offers a correction that is less dependent on knowledge of recharge conditions and can be applied to both open and

closed systems. Based on this analysis, our approach to evaluating which model best represents the Treasure Valley is based on comparing the results from the CMB models and $\delta^{13}C$-mixing models and weighing other geochemical information.

3. HYDROGEOLOGIC SETTING

Aquifers that supply most municipal and industrial ground water in the Treasure Valley lie in the Idaho Group of sediments that are, roughly, the upper 1,000 feet of a sedimentary section that extends to depths of several thousand feet. Idaho Group aquifers underlie a system of shallow aquifers that exist in the upper 100 to 300 feet of surficial Pleistocene sediments and recent alluvium. A review of the hydrogeologic characteristics of the Idaho Group aquifers that may be part of the regional flow system provides a framework from which to correlate and interpret geochemistry data. The following review describes (1) geographical boundaries of the Idaho Group aquifers, (2) relative position of the aquifers in the flow system, (3) depositional environments, (4) important physical and chemical characteristics, and (5) representative sampling wells used for this study. The review is followed by a discussion of a regional geologic unconformity that appears to play an important role in regional ground water flow.

3.1. Review of Principal Aquifers

Our review of the important aquifers of the Treasure Valley begins in the Boise area and relies heavily on geophysical and stratigraphic interpretations of Burnham and Wood (1992), Squires et al. (1992), and Squires and Wood (2001). Interpretation of seismic data by Wood and Anderson (1981) and Wood (1994) provide the basis for our understanding of the hydrogeology near Meridian, Nampa, and Caldwell. Stratigraphic work by Beukleman (1997) gives insight into the hydrogeology of the down-valley reaches of the basin.

Squires et al. (1992) segregate Boise area aquifers by depositional boundaries based largely on detailed analysis of well cuttings and interpretation of geophysical logs. Distinct hydrogeologic units are described in relation to sediment deposition in a dynamic paleo-river delta system that entered shallow water at the head of a large lake that once covered much of the Treasure Valley. The units identified by Squires et al. (1992) are (1) southeast Boise alluvial fan deposits, (2) south Boise fan-to-lake transition deposits, (3) central Boise shallow-water lacustrine deposits, (4) west Boise deep-water lacustrine and alluvial deposits, and (5) north Boise lake-margin deposits.

3.1.1. Southeast Boise alluvial fan deposits

Southeast Boise alluvial fan deposits are thought to be remnants of an ancient alluvial fan and/or fan-delta system emanating from the mountain front near Lucky Peak Reservoir (Figure 3). These interbedded silt, sand, and gravel deposits underlie the Tenmile Ridge area and include the Old Penitentiary, Micron Technology, Inc.

campus, and Blacks Creek area. Ground waters in the southeast Boise alluvial fan deposits lie in an upgradient position relative to the central portion of the basin. Geophysical logs obtained from wells in these deposits exhibit a "spikey" character, which reflects the heterogeneous nature of the strata, and high resistivity, which indicates low dissolved solids in the ground water.[11] No substantial aquitards are apparent in geophysical logs (Squires et al., 1992); however, lack of water level responses in shallow wells during the Micron No. 5 pumping test indicates some hydraulic separation between aquifer zones (Scanlan, 1998). Sediments in these deposits are oxidized and the regional hydraulic gradient is downward. These characteristics are consistent with the hypothesis that the southeast Boise alluvial fan deposits constitute a recharge area. Two authors have suggested that seepage from the New York Canal near its diversion from the Boise River is the primary source of recharge to the alluvial fan aquifers (Robison and Brockway, 1999; Squires et al., 1992). This important hypothesis has not been confirmed. Six wells sampled during this study are believed to draw from the southeast Boise alluvial fan deposits: Guyer, Christiansen, Micron Shallow, Micron Deep, Knox, and Blacks Creek (Figure 2).

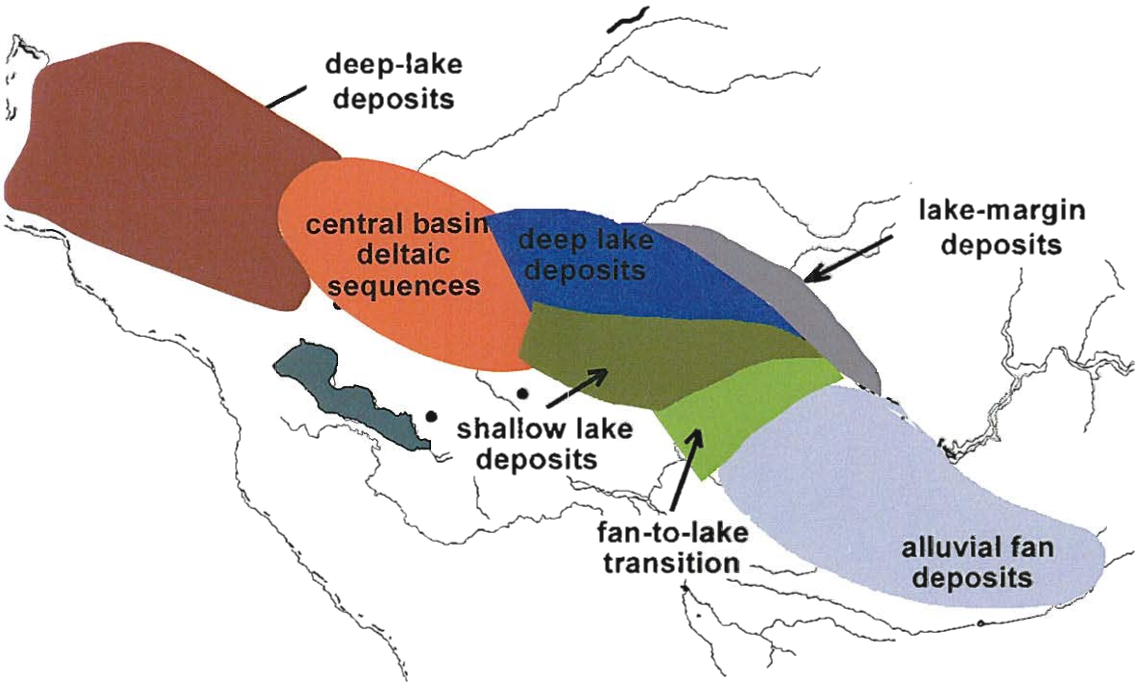


Figure 3. Important hydrogeologic units of the Treasure Valley regional ground water system (after Squires et al., 1992 and Wood, 1994).

[11] Resistivity is a measure of resistance of the aquifer to an induced electrical current. The measure is indicative of the concentration of dissolved ions in ground water.

3.1.2. South Boise Fan-to-Lake Transition Deposits

The south Boise fan-to-lake transition deposits embody a change from coarse-grained fluvial sands and gravels of the alluvial fan to finer-grained lake sediments. The zone of transition lies west of the fan sediments in approximately a three-mile-long crescent centered along the New York Canal (Figure 3). Ground water mounding from canal seepage affects hydraulic gradients in some aquifers in the transition deposits; however, it is likely that these deposits were hydraulically down-gradient from the alluvial fan aquifers prior to surface water diversion. The transition zone consists of layers of oxidized fluvial deposits interbedded with reduced lake sediments. Coarse-grained oxidized sands are thought to have been deposited by fluvial activity when lake levels were low, while finer, reduced silts and clays were deposited in a lacustrine environment associated with high lake levels. Some organic matter is found in silt and clay beds. The silt and clay beds are thicker than those found in the fan deposits, ranging from 50 to 100 feet thick (Squires et al., 1992). These authors suggest that these thicker layers may be more laterally extensive than those of the fan deposits. Seepage from the local canal system is reported to be a primary source of recharge to aquifers in the transition deposits (Squires et al., 1992). Six wells are completed in the south Boise transition deposits: JR Flat, Market Street, McNabb, MAC, Amity, and Sunset West (Figure 2).

3.1.3. Central Boise Lacustrine Deposits

The central Boise lacustrine deposits are located along a 2- to 3-mile-wide band centered approximately on I-184, north and west of the transition deposits (Figure 3). The western boundary has not been characterized and may extend west to Meridian. The deposits are characterized by oxidized sediments in the uppermost 200 to 300 feet of the section underlain by reduced sands, silts, and clays. The oxidized zone is marked by the existence of oolites and organic detritus, which indicates proximity to a shoreline (Squires et al., 1992). A blue color in the deeper sediments reflects deposition in an anoxic lacustrine environment. The deeper section is marked by an angular unconformity (Wood and Anderson, 1981; Squires et al., 1992). Units above the unconformity have relatively horizontal bedding, while the units below the unconformity dip 3° to 7° west. Four wells are completed in the central Boise lacustrine deposits: Cassia monitoring well, Cassia 2, Edgeview, and St. Lukes.

3.1.4. West Boise Lacustrine Deposits

The west Boise deep-water lacustrine deposits lie generally north and northwest of the central Boise lacustrine deposits. Where the deep-water deposits abut the Boise Foothills, they are often juxtaposed beneath lake-margin fluvial sand and gravel deposits (Figure 2). The western extent of the deep-water deposits has not been

identified, but they probably extend beyond Meridian, Nampa, and Caldwell, toward the western end of the basin. Stratigraphic interpretation of these facies is similar to the central Boise lacustrine deposits in that a thick layer of oxidized, horizontally-interbedded sands, silts, and clays overlie a reduced section of steeply-dipping beds. Drill cuttings show the presence of reduced sediments below an elevation of approximately 2,100 feet. Squires et al. (1992) note that the top of the reduced section is marked by an unconformity at about 500 feet below ground surface and perhaps by a layer of red alluvial gravel. The range of 3° to 7° west-trending dip translates to between 400 and 650 feet of elevation per mile, making stratigraphic correlation of individual aquifer units difficult (Squires et al., 1992). Geophysical logs show that the deep-water deposits lie below the unconformity and consist of monotonous silt and clay layers interspersed with thin sand beds. Examples of the sand aquifers of the deeper section are found in the Hewlett-Packard (HP) well. These depositional units are described as "Gilbert-type" deltas that were formed by streams draining the Boise foothills (Wood, 1997). Stratigraphic offset across the east Boise-Eagle fault zone allows correlation of these delta sands with similar deposits in the foothills (Wood, 1997). The deep sand beds contain water under confined conditions. Some production wells have experienced substantial drawdowns when pumped at about 1,000 gpm, suggesting a limited lateral extent of the productive zones. A number of wells may be completed in these deposits, including: HP, Goddard 1, Goddard 2, Meridian 19, Meridian 19-test, and Meridian 15 production wells (Figure 2).

3.1.5. North Boise Fluvial Lake-Margin Deposits

A zone of laterally continuous arkosic sands, river gravels, and silts lies in an apron along the contact with the Boise Foothills (Figure 3). These horizontally bedded deposits make up the first 400 to 500 feet of sediment along the basin margin (Squires et al., 1992). Because they are located proximate to the basin margin, wells drilled below an elevation of 2,200 feet in these deposits often encounter volcanic rocks and signs of underlying geothermal aquifers. Proximity to the basin margin also explains the occurrence of numerous structural faults that offset the stratigraphic section as much as 1,200 feet (Burnam and Wood, 1992). In west Boise, a similar zone of silts, sands and gravels overlies the west Boise lacustrine deposits (Squires et al., 1992). The TVHP 1 multi-completion monitoring well appears to be completed in north Boise lake-margin deposits.

3.1.6. Nampa and Caldwell Lacustrine and Delta Deposits

Deep pro-grading sand aquifers east of Caldwell are also identified with a river delta system (Wood and Anderson, 1981). These units occur between 2,000 and 2,300 feet below land surface, far beyond depths penetrated by most production wells. Wood (1994) addresses the morphology of similar delta deposits near Caldwell. His study

correlates seismic data to geophysical and stratigraphic data from the Simplot Geothermal Well. Here, a number of river delta facies are revealed in the upper 1,500 feet of the section. A lower unit consists of a pro-delta sequence of north-dipping calcareous mudstones between depths of 1,200 and 1,500 feet (830 to 1,130 feet above mean sea level). This unit is overlain by a delta front sequence between 1,000 and 1,200 feet (1,130 to 1,330 feet above mean sea level). The delta front consists of 9- to 20-foot-thick fine sands interspersed with thin clay lenses, which grade upward into interbedded sand and mud of a delta plain. The delta plain section, which occurs between 350 feet and 1,000 feet (1,330 to 1,980 feet above mean sea level), is characterized as well-sorted fine sand interbedded with moderately to slightly calcareous mud (Wood, 1994). The sand beds are between 10 and 40 feet thick. Wood and carbonized organic matter are reported in the silt beds. Most of the large-capacity production wells in the Nampa and Caldwell areas are completed between 350 and 1,000 feet below ground surface, including Nampa 12, State Hospital, Nampa 9, Caldwell 15 and Caldwell 16. Sediments above 350 feet are characterized by non-calcareous mudstones and medium-grained sands with some coarser material.

3.1.7. Down-Valley Lacustrine Deposits

In the far western, or down-valley reaches of the Treasure Valley, between Caldwell and Parma, many wells penetrate confined or semi-confined aquifers in the upper few hundred feet of the sedimentary section. Reports of hydrogen sulfide odor and methane gas in wells drawing water from depths of less than 100 feet are not uncommon (D. Parliman and E. Squires, pers. com. 1999) and provide evidence that a transition between oxidized sediments and reduced sediments occurs at relatively shallow depths. These observations are confirmed by a distinct color change from yellow and brown sediments to gray-blue and gray sediments in a series of three NE-SW trending geologic cross-sections of the area (Beukelman, 1997). The redoximorphic transition occurs uniformly at elevations between 2,150 and 2,250 feet deep in all the three cross-sections. The uniform elevation of the transition and the existence of a similar feature near the Boise and Snake Rivers (where oxygen-containing surface waters could percolate downward and oxidize sediments below the contact) are construed to mean that the feature is a result of original diagenesis rather than post-depositional geochemical processes (Beukleman, 1997). Based on this information, the color change is probably akin to similar color changes observed in the eastern part of the Treasure Valley near Boise. These redoximorphic features appear to mark the transition between surficial alluvial deposits and underlying deep-lake deposits. Sampling wells in the down-valley lacustrine deposits include: Wright, Johnson, Kuespert, Inouye, Parma 10, and UI (Figure 2).

3.2. Significance of Redoximorphic Features and the Boise Unconformity

Recent stratigraphic interpretations indicate that, in the Boise area, redoximorphic color changes are related to an angular unconformity found at depths between 300 and 450 feet below ground surface (Squires and Wood, 2001). The abrupt color changes may be a useful indication of the transition between shallow aquifers and the regional ground water flow system. The purpose of this section is to explore the importance of these features and to set the stage for distinguishing regional ground water from shallow ground water using hydrochemical data.

With exception of the north Boise lake-margin deposits, the southeast Boise alluvial fan deposits, and the south Boise fan-to-lake transition deposits, all aquifer units discussed in the previous subsections exhibit redoximorphic color changes in the vertical section. Transitions from brown or yellow sediments to gleyed blue and gray sediments are reported valley-wide in driller's logs. Stratigraphic work by Wood (1994) suggests that the transition to reduced sediments occurs deeper in the stratigraphic section near Caldwell than in the Boise area. Cuttings from the Simplot Geothermal well near Caldwell indicate that blue or gray sediments first appear at elevation of approximately 1,130 feet. This compares to 1,950 feet in Caldwell 16; 2,080 feet in the State Hospital well; 1,970 feet in Nampa 12; 2,120 feet in Meridian 19-test; 2,260 feet in St. Lukes, and 2,350 in the Cassia wells. Blue clays are noted at elevations between 2,150 and 2,250 feet in down-valley wells near Notus and Parma.

Near Boise, the redoximorphic transition may be related to an angular unconformity that appears in two stratigraphic cross-sections that extend from the Boise Foothills out to the fluvial-lacustrine sediments that underlie the city (Squires and Wood, 2001). The main features of the unconformity are tilted silt and clay-stone beds overlain by horizontally-bedded gravel, overlain by mudstone. Squires et al. (1992) propose that receding lake levels in Pliocene Lake Idaho caused previously uplifted and/or depositionally-tilted strata to be eroded by river systems, truncating the dipping sediments. The authors argue that occurrence of these paleo-river systems is marked by gravel deposits found atop the erosional surface. Subsequent sediment deposition on top of the gravel would have occurred at a much lower angle than the truncated strata, resulting in nearly horizontal beds overlying steeply dipping beds. The horizontal deposits overlying the gravel layer consist of lake-bed muds interbedded with delta sands and lake-shore sands. Delta and lake-shore sediments indicate that recession of the lake was followed by an episode of lake filling.

Influence of the unconformity(s) on local and regional hydrology is presently the subject of much discussion. Horizontal ground water movement between wells completed in different aquifer units below the unconformity would have to flow across highly reduced low conductivity clay/mudstone interbeds. Such a configuration

suggests low horizontal flow rates within the dipping beds. If the high conductivity fluvial gravel atop the erosional surface is in contact with the truncated, dipping aquifer units below, ground water may be distributed rapidly along the unconformity when the deeper units are pumped. In this scenario, drawdown of aquifers in the steeply dipping beds below the unconformity could induce recharge from a large area along the plane of the unconformity. Atop the fluvial gravels, mudstone deposits from subsequent lake filling may inhibit downward movement of shallow ground water across the unconformity. Correlation between the apparent redoximorphic transition and the erosional unconformity has not been extended beyond the Boise–Meridian area.

4. HYDROCHEMICAL INTERPRETATION OF PRINCIPAL AQUIFERS

In the previous section we describe a set of contiguous aquifers bounded by mountains and a major river that, conceptually at least, are the framework for ground water flow in the Treasure Valley. We show that each aquifer rests in a unique position in the flow system and that each aquifer has a characteristic depositional history. We call these hydrogeologic units principal aquifers to highlight their function in the regional ground water system. The following analysis expands the interpretation of principal aquifers by (1) comparing hydrochemical characteristics of recharge waters to characteristics of principal aquifers located near the northeastern margin of the basin; (2) comparing hydrochemical characteristics among principal aquifers located in the central portion of the basin; and (3) considering regional trends in hydrochemistry data.

Several criteria are used to determine whether data from our sampling wells represent the principal aquifers listed in Section 3. The sampling wells are considered to uniquely represent a given aquifer unit if: (1) they are located within the boundary of the unit as described in Section 3; (2) their screened intervals are located in the same stratigraphic section with respect to oxidized and reduced sediments; and (3) they exhibit hydrochemical characteristics similar to other wells in the unit. A record of all physical and hydrochemical data compiled during this study is contained in Appendix 1.

4.1. Characteristics of Potential Recharge Sources

A substantial portion of recharge to deep aquifers in the basin is thought to originate in the mountains north and east of Boise. We hypothesize that aquifers located adjacent to the mountain front convey a substantial amount of recharge water into deep aquifers in the central portion of the basin. To evaluate this hypothesis, we compare the hydrochemical characteristics of mountain front recharge waters to the hydrochemical characteristics of ground waters in adjacent recharge zone aquifers.

Water in the Boise River at Diversion Dam is chiefly a mixture of surface runoff and shallow ground water from smaller drainages in the upper Boise River system. As noted in Section 3.1.1, contemporary seepage from the river and its many irrigation diversions has been suggested to be an important source of recharge to portions of the regional aquifer system; and there is some indication of a longer-term connection between the upper Boise River system and aquifers in southeast Boise (Squires and Derricott, 1992). Our hydrochemical data from the Boise River at Diversion Dam allows us to characterize the river system as a source of recharge. A second plausible recharge source is direct underflow from mountain front aquifers that are tributary to

the basin. Hydrochemical data from wells in shallow alluvium beneath Banner Creek, a drainage in the Silver Creek Experimental Watershed in the Boise National Forest (J. Clayton, unpublished data) and data from spring waters emanating from the mountain front above Boise (Young et al., 1988) provide a range of hydrochemical data for characterizing mountain front recharge.

Dissolved gasses typically remain near equilibrium with atmospheric pressure in surface waters and in shallow ground waters near recharge areas (Drever, 1988). The concentration of DO in the Boise River at Diversion Dam is 11 mg/L and the partial pressure of CO_2 (P_{CO_2}) is $10^{-3.3}$ bar (Table 1). Dissolved oxygen was not measured in the Banner Creek wells or in the Boise Front springs, so no comparisons can be made with respect to DO; however, we used measurements of pH and dissolved HCO_3 to calculate P_{CO_2} values between $10^{-1.6}$ and $10^{-2.3}$ bar in the three Boise Front springs and $10^{-2.2}$ bar for an average of 20 shallow monitoring wells in the Banner Creek drainage (Table 1). The subsurface waters, unlike water in the Boise River, are charged with CO_2 as they pass through the soil zone, hence the greater values of P_{CO_2} in the mountain front springs and shallow wells. For the same reason, pH of river water is 7.9, while the pH of mountain front ground water ranges between 5.8 and 6.6 (Table 1). Water in the Boise River and shallow ground water on the mountain front have low specific conductance (C_s) (Table 1). Low C_s reflects a scarcity of dissolved ions due to minimal contact with weathering minerals. Dissolved ions are dominated by Ca and HCO_3 in all of the recharge waters, with the Boise Front springs showing slightly greater influence of Na, SO_4 and other ions (Figure 4).

Recharge Source/ Aquifer Unit	C_s (uS/cm)	DO (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	pH	P_{CO_2} (mg/L)
Banner Creek wells	58	nd	.01	1.16	6.6	$10^{-2.2}$
Boise Front springs	nd	nd	<0.2-1.1	3.6-5.2	5.8-6.2	$10^{-1.8}$-$10^{-1.6}$
Boise River	62	11	0.1	1.5	7.9	$10^{-3.3}$
north Boise margin	135-247	0.1-0.9	<0.1	5.3-10	7.1-7.3	$10^{-2.5}$-$10^{-2.0}$
alluvial fan north	138-185	3.6-4.0	1.5-1.6	4.2-7.8	8.1-7.8	$10^{-3.3}$-$10^{-2.9}$
alluvial fan south	208-230	3.8-6.2	1.8-2.1	6.9-7.5	7.4-7.6	$10^{-2.6}$-$10^{-2.3}$
transition zone east	217-288	2.1-5.2	0.6-1.6	14-20	7.6-7.7	$10^{-2.5}$-$10^{-2.7}$
transition zone west	317-374	0.8-1.2	<0.1-0.2	24-44	7.6-7.8	$10^{-2.7}$-$10^{-2.4}$

Table 1. A comparison of selected hydrochemistry data from recharge waters and aquifers near the mountain front. Banner Creek Watershed data are from J. Clayton (unpublished data). Boise Front spring data are from Young et al. (1988).

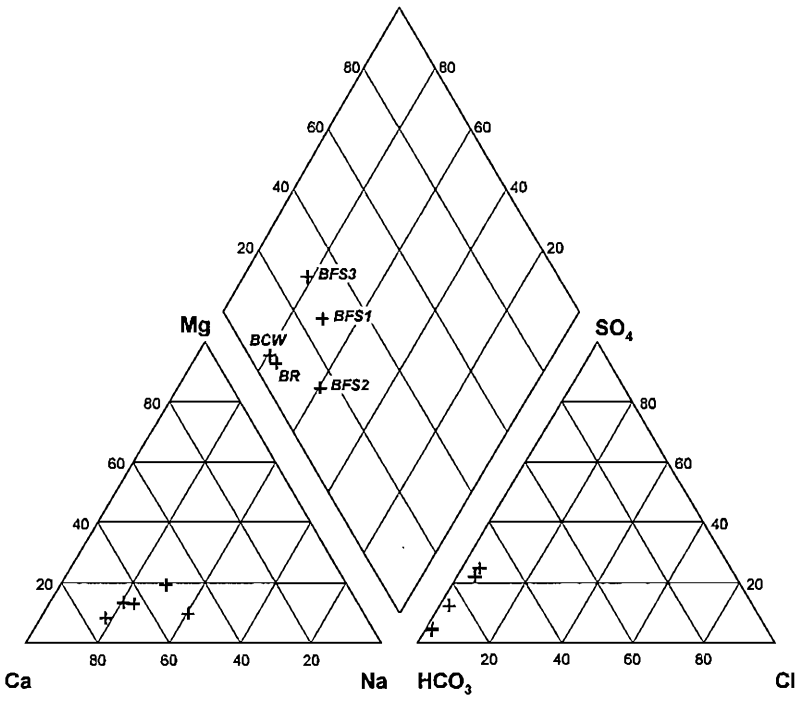


Figure 4. Distribution of cations and anions in selected mountain front recharge waters. The data are for the Boise River at Diversion Dam (BR), springs on the Boise Front (BFS), and shallow wells in the Banner Creek drainage of the Silver Creek Experimental Watershed (BCW).

4.2. Characteristics of Recharge Zone Aquifers

Ground water in the southeast Boise alluvial fan deposits and the north Boise basin margin are hydrochemically midway between mountain recharge waters and aquifers in the central portion of the basin. Specific conductance is lower in the recharge waters than in the recharge-zone aquifers (Table 1). The Banner Creek wells and Boise Front springs exhibit substantially lower pH values than are found in the recharge-zone aquifers (this does not hold true for the Boise River, because pH in the river is buffered by atmospheric CO_2). Like the recharge waters, dissolved ions in the recharge zone aquifers are dominated by Ca and Hco_3; however, there is a greater influence of Na and SO_4 in the recharge zone ground waters than in the river and Boise Front springs (Figure 5).

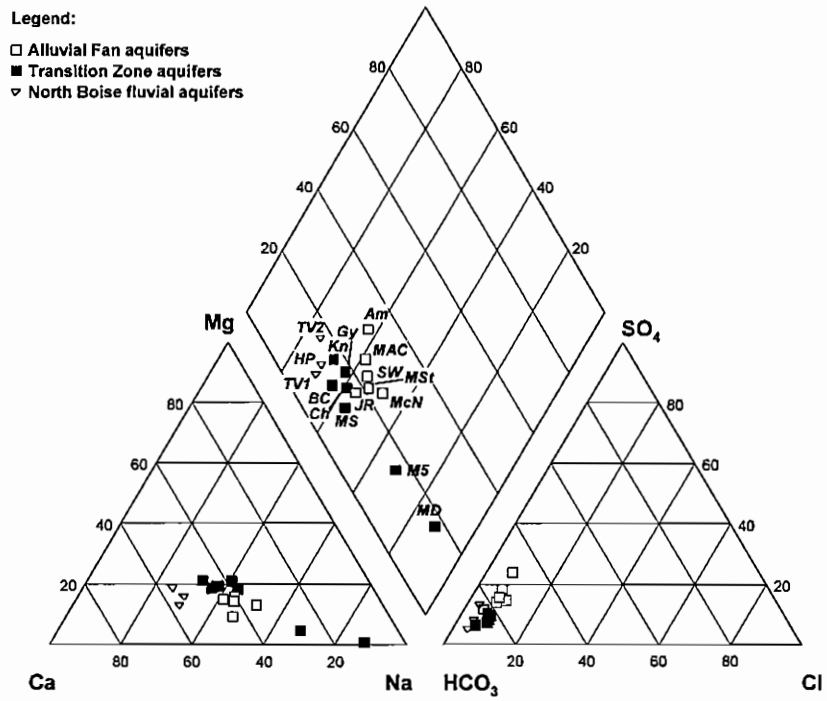


Figure 5. Distribution of cations and anions in selected ground water wells located near the Boise mountain front.

4.2.1. Aquifers in the Southeast Boise Alluvial Fan

Wells in the southeast Boise alluvial fan sediments can be grouped according to their proximity to the Boise River. The Guyer and Christiansen wells penetrate more than 500 feet of unsaturated sediments in the northeastern portion of the alluvial fan region, not far from the New York Canal diversion from the Boise River at Diversion Dam (Figure 2). Water samples from the Guyer well and Christiansen well have P_{CO_2} similar to the atmospheric equilibrium values observed in the river (Table 1). These relatively low P_{CO_2} values are an indication that the source of recharge is direct seepage from a surface water source, rather than percolation through the soil zone.[12] This finding supports the idea that ground water entering the subsurface in the upper reaches of the river and major irrigation diversions is a source of recharge to unconfined or semi-confined aquifers in the northeastern portion of the alluvial fan. Based on the fact that we detected no ^3H in these wells, the water that is presently in these aquifers must have originated as seepage prior to 1950's bomb testing. Another plausible recharge scenario is that the alluvial fan ground waters originated in the Boise river system long

[12]Recall that P_{CO_2} is generally two to three orders of magnitude higher in soil water than in surface waters. Details about CO_2 charging in soil are discussed in Section 5.

ago and moved slowly into the fan sediments through paleo-river channels (Squires et al., 1992).

The Alluvial Fan aquifer is represented by Christiansen (Ch), Guyer (Gy), Knox (Kn), Blacks Creek (BC), Micron monitoring shallow (MS), Micron monitoring deep (MD), and Micron production no. 5 (M5). The Transition Zone aquifer is represented by McNabb (McN), JR Flat (JR), Market Street (MSt), Amity (Am), Sunset West (SW), and MAC. The north Boise basin margin is represented by TVHP1 multilevel monitoring wells 1 and 2 (TV1 and TV2) and the Hewlett-Packard production well (HP).

The Micron Technology, Inc., monitoring wells, the Knox well, and the Blacks Creek rest area wells are in a similar production zone as the Guyer and Christiansen wells and also penetrate more than 500 feet of unsaturated sediments before encountering unconfined or semi-confined ground water. The Micron, Knox, and Blacks Creek wells are located several miles further from the Boise River and New York Canal than Guyer and Christiansen. Water samples from the more distant wells contain no measurable ^3H but slightly higher C_s and P_{CO_2} than the Guyer and Christiansen wells. Higher C_s and P_{CO_2} indicate that a portion of aquifer recharge comes from deep percolation of soil water. The influence of Na is substantially greater in the Micron No. 5 production well and the Micron Deep monitoring well than in other wells in the southeast Boise alluvial fan (Figure 5). We conclude that these deeper wells are influenced by geothermal water because (1) Boise area geothermal waters typically have Na/Ca ratios between 60 and 100 (Mariner et al., 1989), so that any mixture of cold water and geothermal water would result in a substantial increase in the proportion of Na in the mixture; (2) the Micron No. 5 well and Micron Deep monitoring well pump water at temperatures in the range of low-temperature geothermal wells (27°C and 24°C, respectively); and (3) both wells exhibit slightly elevated concentrations of fluoride. In spite of our conclusion, we are somewhat skeptical about the reliability of the ion data from the Micron Deep well because drilling mud was noted in the well discharge during sampling. Even so, high Na concentrations in Micron No. 5, which penetrates the same zone as the Micron Deep monitoring well, is reason for a more detailed analysis of the influence of geothermal water on these deeper alluvial aquifers.

All of the alluvial fan ground waters have NO_3 concentrations between 1.5 and 2.1 mg/L. Some have informally suggested that these slightly elevated NO_3 concentrations result from land application of wastewater at the Micron facility. Elevated NO_3 concentrations in drinking water is a public health concern; therefore, it is worthwhile to use our new data to shed some light on the feasibility of waste-water as the source. Land application at the Micron facility occurred post-atmospheric bomb testing, so any percolating wastewater would have carried ^3H into the aquifer. Because ^3H concentrations are below the detection limit in all of the wells we sampled in the alluvial fan deposits, it is unlikely that land application is the cause of elevated NO_3.

Two natural hydrogeologic processes could explain these elevated NO_3 concentrations. First, natural downward percolation of water through the unsaturated sediments overlying the aquifer could cause a small, long-term NO_3 flux to the water table. Second, weathering of alluvial fan sediments in the oxic ground water environment could introduce N into the ground water. These hypotheses could be tested by (1) measuring the concentrations of NO_3 and CO_2 in unsaturated-zone water; (2) analyzing N in archived well cuttings from the Micron No. 5 well; and (3) reviewing existing water quality data.

4.2.2. Aquifers in the South Boise Fan-to-Lake Transition Zone

Ground water in the fan-to-lake transition zone contains less DO, less NO_3 and greater SO_4 than ground water in the alluvial fan aquifer (Table 1). In addition, the relative proportion of the various dissolved ions found in transition zone water is shifted toward a greater influence of Na over Ca and SO_4 over HCO_3 (Figure 5). These distinctions are particularly relevant considering that the Amity, Sunset West and MAC wells in the western portion of the transition zone have less DO, less NO_3 and greater SO_4 than the McNabb, JR Flat, and Market Street wells in the eastern part of the transition zone. The trends are consistent with ground water flowing from the alluvial fan aquifers and through the transition zone.

With the exception of the Market Street well, all of the transition zone wells draw water from above the unconformity described in Section 3.2. In fact, the Market Street well at the eastern margin of the transition zone is the easternmost occurrence of this unconformity, which is observed in the stratigraphic section as far west as Meridian (Squires and Wood, 2001). In spite of substantial mudstone units overlying the unconformity, ground water above and below the mudstone remains chemically undifferentiated at the Market Street well. The basis for original determination of the fan-to-lake transition zone is the observation that thick shoreline or lacustrine deposits do not appear in the alluvial fan aquifer(s), but that shoreline and lacustrine deposits begin to appear in the transition zone (Squires et al., 1992). The trends observed in the hydrochemical data support this interpretation and perhaps extend it by suggesting that the transition zone may mark the initial divergence of ground water into regional-scale flow paths. Unfortunately, no sampling wells fully penetrate the transition-zone mudstones west of Market Street; therefore, it is not possible to confidently resolve that hydrochemical differences between shallow and deep ground water first occur in the transition zone.

4.2.3. Aquifers at the North Boise Basin Margin

Ground water in the north Boise fluvial deposits differs from ground water in the southeast Boise alluvial fan in some important aspects. First, ground water in the north

Boise area has substantially lower DO (Table 1). Second, NO_3 is below detection in all wells in this aquifer (Table 1). Third, some north Boise wells (TVHP1 monitoring wells 3 and 4) exhibit an odor of hydrogen sulfide. Fourth, the relative proportion of Na is less than observed in the southeast Boise alluvial fan aquifer (Figure 4). Very low DO combined with the odor of hydrogen sulfide and NO_3 concentrations below detection reflect reducing conditions in the recharge zone directly adjacent to the mountain front. At first glance, this condition does not fit our conceptual model of ground water recharge from the mountain front, because ground water near a recharge source is expected to retain evidence of the oxic environment from which it originated. However, pyrite is documented in the deep lake deposits along the north Boise margin and SO_4 is present in ground water at concentrations between 5 and 10 mg/L.[13] Given that sulfide oxidation uses DO and forms sulfate, pyrite and other sulfide minerals in aquifer sediments may be rapidly oxidized by oxygen-rich recharge water, resulting in reduced conditions immediately adjacent to the mountain front recharge source.

The significance of reduced ground water in the recharge zone is that the flow rate of oxygen-rich recharge water through the aquifer must be relatively small. With respect to identifying a primary source of recharge, the range of P_{CO_2} calculated for north Boise ground water and the distribution of dissolved ions are most similar to the characteristics of the Banner Creek wells. Most importantly, P_{CO_2} values indicate that the ground water once percolated through a soil zone (Table 1). This finding contradicts the possibility that recharge to these aquifers originates in the Boise River or in the Farmers Union Canal; however, because of the complexity of the north Boise aquifer system, too much should not be made of similarities to the Banner Creek waters. Using well log correlations, geophysical logs and seismic data, Squires and Wood (2001) make a convincing argument for a paleo-delta system that originates in the Boise foothills and extends out into the basin in the vicinity of the TVHP 1, Goddard and HP wells. These authors describe a series of southwest dipping fluvial sand and gravel aquifers bounded above and below by mudstone aquitards and terminated by prodelta mudstone deposits. Squires and Wood (2001) conclude that long-term hydraulic connection may exist between aquifer zones, but that local lenses of mudstone lead to short-term responses to well pumping. The idea that productive sand and gravel units in deeper portions of the north Boise aquifers are discontinuous and somewhat isolated is supported by the chemically reduced ground water. This observation, along with the presence of NW-SE trending structural faults that may also inhibit ground water flow, gives credence to the idea that these aquifers are not capable of rapidly conveying large quantities of recharge from the mountain front to aquifers in the central portion of the basin.

[13] Dittus et al. (1998) document pyrite in the completion zones of TVHP 1.

4.3. Hydrochemical Characteristics of Central Basin Aquifers

4.3.1. Aquifers in Central and West Boise Lacustrine Deposits

Shallow ground water is readily distinguished from ground water in deeper zones in the lacustrine environments of central and west Boise. Ground water from aquifers above thick mudstone deposits is oxic, contains ^3H, exhibits elevated P_{CO_2}, has relatively high C_s, and is enriched in SO_4 compared with groundwater below the mudstone (Table 2, Figure 6). Ground water below the mudstone exhibits substantially greater Na/Ca ratios than overlying aquifers (Table 2, Figure 6). Where two mudstone layers exist, ground water between them exhibits mixed characteristics. Wells that exhibit these differentiated hydrochemical characteristics include the Goddard wells, the three Cassia Street wells in central Boise, Edgeview and St. Lukes in west Boise/Meridian, and the Meridian 19 production and test wells in Meridian (Table 2).

Well Name	TWBZ Elev. feet	C_s (uS/cm)	DO (mg/L)	pH	P_{CO_2} (mg/L)	SO_4 (mg/L)	Na/Ca
Goddard 2	2,199	349	nd	6.8	$10^{-2.7}$	32	0.5
Goddard 1	1,771	204	nd	7.8	$10^{-1.6}$	2.5	1.7
Cassia 1	2,551	432	1.7	7.3	$10^{-2.1}$	32	1.2
Cassia Monitor	2,226	209	0	8.0	$10^{-3.0}$	12	1.4
Cassia 2	1,901	198	0	8.2	$10^{-3.6}$	7.2	20.9
Edgeview	2,268	304	0.1	7.5	$10^{-2.4}$	30	1.1
St. Luke's	1,980	220	0	7.7	$10^{-2.7}$	1.4	1.5
Meridian 19-Test	2,210	370	4.7	7.2	$10^{-2.2}$	59	0.5
Meridian 19	2,010	135	0	8.0	$10^{-3.2}$	4.7	1.4

These wells represent aquifers above and below mudstone layers. The acronym TWBZ means top of the water-bearing zone as determined from well logs.

Table 2. Selected hydrochemical data from wells in central and west Boise lacustrine deposits.

High P_{CO_2} in aquifers above the mudstone layers show that a substantial portion of their recharge is derived from percolating surface water - probably associated with irrigation. Additionally, SO_4 is comparatively high. Where the ground water is oxic and sulfide minerals are absent from the aquifer matrix, SO_4 is often derived from dissolution of evaporite minerals in the unsaturated zone. Interestingly, very little NO_3 is measured in these shallow regional aquifers.[14] In comparison to these shallow aquifers, ground water in deep aquifers below the mudstone is probably recharged through a system of paleo-deltas extending into the basin from the Boise foothills

[14] Recall that these "shallow" regional aquifers are distinct from overlying shallow alluvial aquifers that are affected by anthropogenic activities on the land surface.

(Squires and Wood, 2001). From a hydrochemical standpoint the recharge scenario appears to be similar to the scenario we described for the north Boise system. Reduced conditions and relatively high Na/Ca ratios prevail in these ground waters.

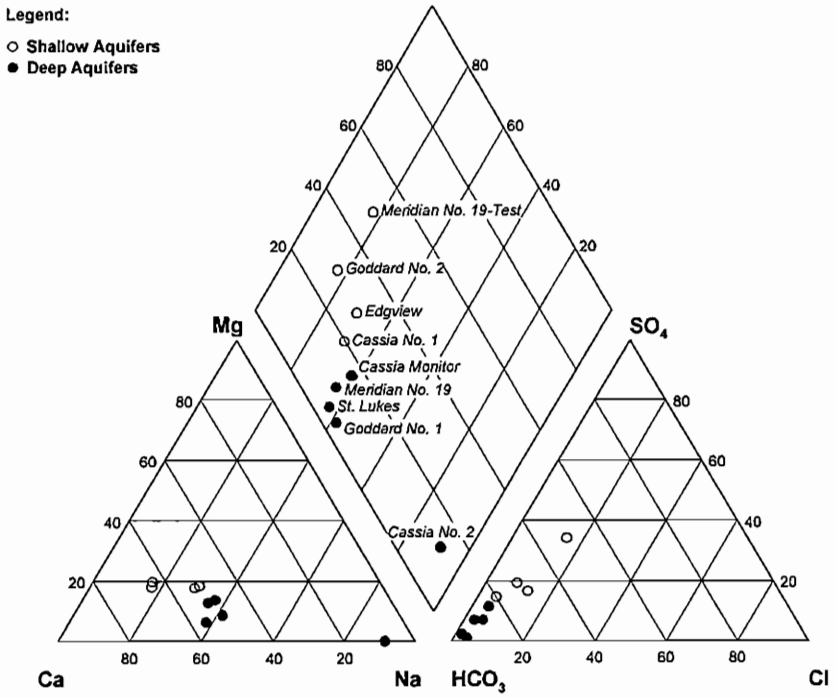


Figure 6. Distribution of cations and anions in selected ground water wells located in central and west Boise lacustrine aquifer.

4.3.2. Meridian to Caldwell Lacustrine Deposits

Distinct shallow and deep hydrogeologic units also are apparent in ground water chemistry data from wells located between Meridian and Caldwell. A comparison between wells drawing water from aquifer units above and below an elevation of about 2,100 feet above mean sea level shows clear differences in C_s, DO, and Na/Ca (Table 3, Figure 7). The differences are similar to those observed in the central and west Boise deposits. All three sampling wells drawing water from above 2,100 feet contain ^3H at levels indicative of modern recharge.

Well Name	TWBZ Elev. feet	C_s (uS/cm)	pH	DO (mg/L)	SO_4 (mg/L)	P_{CO2} (mg/L)	Na/Ca
State Hospital	2,181	547	7.6	5.3	84	$10^{-2.5}$	1.2
Nampa 12	2,166	505	7.6	5.7	81	$10^{-2.6}$	1.2
Caldwell 15	2,220	615	7.8	4.2	89	$10^{-3.1}$	1.6
Nampa 9	2,082	247	7.7	2.2	8.1	$10^{-2.6}$	4.1
Caldwell 16	2,012	276	8.2	0.5	14	$10^{-2.6}$	3.0
Down-valley wells	1,900-2,040	261-360	7.9-8.1	0	0.1-2.1	$10^{-2.9}$-$10^{-2.5}$	2.4-6.5

The acronym TWBZ means top of the water-bearing zone as determined from well logs.

Table 3. Selected hydrochemical data from wells between Meridian and Parma.

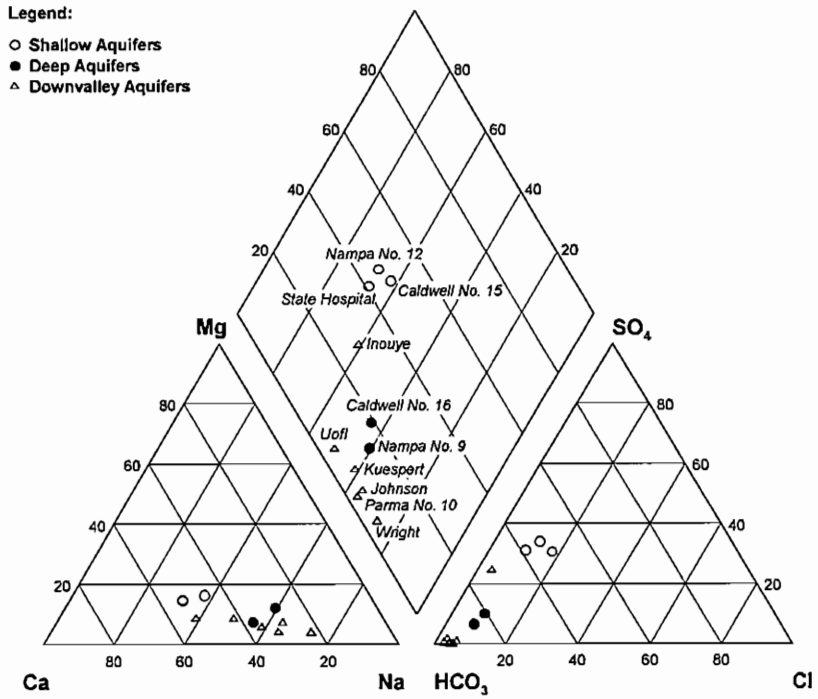


Figure 7. Distribution of cations and anions in selected ground water wells in Nampa, Caldwell, and down-valley locations.

In spite of similarities with the central and west Boise lacustrine aquifers, all of the ground waters we sampled near Nampa and Caldwell unexplainably contain higher concentrations of DO and SO_4 (Table 3). The Nampa 9 and Caldwell 16 wells, both below the 2,100-foot elevation, have measurable DO and SO_4 concentrations near 10 mg/L. This contrast with the Boise aquifers may be explained by the observation made in Section 3.2, that thick mudstones associated with erosional unconformities occur deeper in the section near Caldwell than they do in the deltaic environment near Boise.

4.3.3. Caldwell to Parma Down-Valley Lacustrine Deposits

Ground water in down-valley aquifers is more distinctive than anywhere else in the basin. Very low SO_4 concentrations in combination with DO and NO_3 below the analytical detection limit suggest highly reduced conditions (Table 3, Figure 7). Highly reduced ground water environments are commonly caused by anaerobic oxidation of organic matter by microbes. Sulfate reduction and methane fermentation are the main anaerobic processes thought to contribute to reduced conditions in down-valley aquifers, because hydrogen sulfide odor and methane have been observed emanating from several wells in the area (D. Parliman, E. Squires, pers. com. 1999).

Another characteristic of down-valley aquifers is high Na/Ca ratios (Table 3, Figure 7). Excluding aquifers influenced by geothermal water, down-valley aquifers exhibit greater Na/Ca ratios than aquifers east of Caldwell. Assuming that aquifer mineralogy is similar throughout the central basin, higher Na/Ca ratios may indicate longer ground water residence times.

5. THE CARBONATE SYSTEM

Bicarbonate is the dominant anion in nearly all waters in the Treasure Valley ground water system in spite of the fact that carbonate minerals are not ubiquitous in the basin. The prevalence of bicarbonate reflects the importance of carbonate reactions in the geochemical evolution of regional ground water. A thorough analysis of the carbonate system is important for evaluating sources of recharge and evaluating ground water flow between principal aquifer units. In addition, analysis of carbonate geochemistry is essential for determining ground water residence times from ^{14}C data.

Near the recharge zone, where ground waters are relatively young, calcium carbonates are often the dominant weathering minerals. This is because carbonates are more readily weathered than silicate minerals, so even in small amounts they dominate the ionic signature of ground water. The capacity of recharge waters to dissolve carbonate minerals in the aquifer is defined by temperature, pH, and P_{CO_2}. When compared quantitatively with the state of DIC in ground water, this information can be used to validate or invalidate recharge hypotheses. In more evolved waters farther along a regional ground water flow path, analysis of carbonate geochemistry must be enhanced by isotopic information about carbon cycling, and silicate weathering must be considered. The ensuing analysis ties geochemical concepts of carbonate dissolution and ^{13}C tracing into the present conceptual model of ground water recharge and flow.

5.1. Carbonate Geochemistry

Our study of carbonate geochemistry in the Treasure Valley system involves calculating carbonate equilibria for each recharge source and sampling well and comparing the state of carbonate mineral saturation among the principal aquifers. Carbonate geochemistry is the subject of numerous texts including Garrels and Christ (1965) and Drever (1997). We refer readers to these sources for detailed discussion of the analytical methods.

The amount of calcium carbonate that recharge water can dissolve is controlled by the temperature, pH, and P_{CO_2} conditions imposed in the soil zone. The higher the CO_2 concentration of the water, the lower its pH and the more aggressively the water dissolves aquifer minerals. The Saturation Index (SI) is a measure of how much calcite a particular ground water has dissolved relative to how much it can potentially hold. The logarithm of SI (logSI) is often used to express SI graphically because values of SI commonly range over several orders of magnitude. Ground waters that are under-saturated with respect to calcite have logSI values less than zero. In simple terms, under-saturation means that the ground water has not dissolved as much carbonate as it

has capacity to dissolve. Ground waters saturated with respect to calcite have logSI values near zero. Saturation means that the ground water has dissolved as much carbonate as it can hold. Ground waters that are super-saturated with respect to calcite have logSI values greater than zero. Super-saturation indicates that carbonate is precipitating from the ground water solution.

As expected, all of the recharge waters are far under-saturated with respect to calcite. Values of logSI are -3.1 for the Boise Front springs, -2.5 for Banner Creek wells, and -1.1 for the Boise River. Most ground waters in the Boise area are slightly under-saturated, having logSI values less than zero (Figure 5). In contrast, most ground waters in the western portion of the basin exhibit logSI values near zero (Figure 5). These waters are saturated with respect to calcite. In a simplistic way, these observations bear out our conceptual model of relatively fresh recharge water entering the system along the eastern basin margin and becoming more saturated with respect to carbonate further along the flow path.

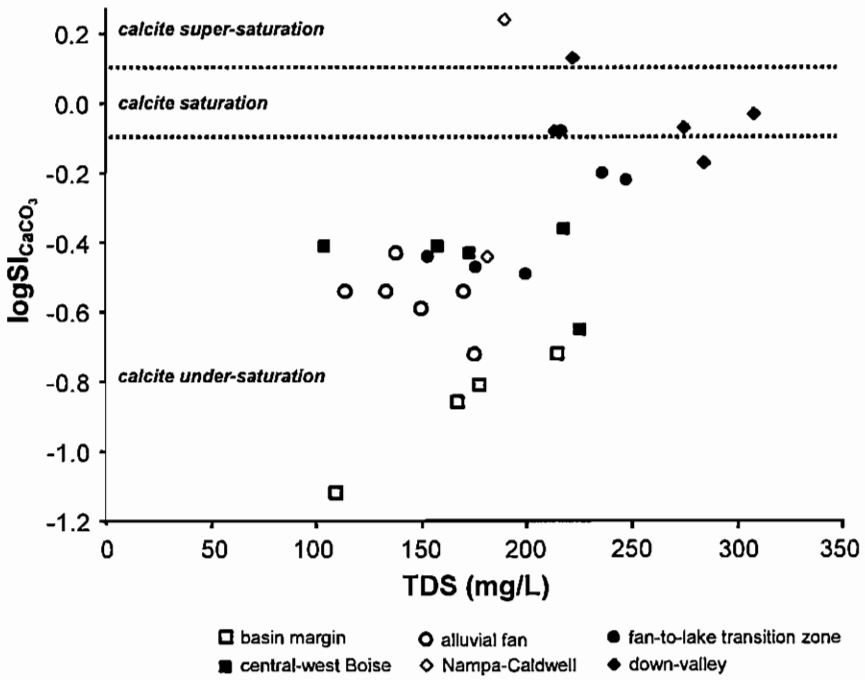


Figure 5. Calcite saturation indices for principal aquifers of the Treasure Valley ground water system. Data for Amity, Sunset West and MAC wells are shown in red.

An interesting deviation from what we are calling a regional trend in carbonate saturation is found in the transition zone. Waters from the Amity, Sunset West, and MAC wells are much closer to saturation with respect to calcite than are other wells in

the Boise area (Figure 5). Although we can offer no clear explanation for this anomaly, it is instructive to recall that there are several other notable differences between chemical parameters in the Amity, Sunset West, and MAC wells, and the other transition zone wells (Table 1). In spite of the inconsistency, regional progression of carbonate saturation fits plausibly into the general conceptual model of regional recharge and flow. Because ground water radiocarbon dates must be corrected for carbonate dissolution along the flow path, this conclusion bodes well for obtaining realistic ground water residence times.

5.2. Open versus Closed Carbonate System

In the previous section we developed a conceptual relationship between the capacity for recharge waters to dissolve aquifer minerals, and the amount of dissolved calcium carbonate measured in the principal Treasure Valley aquifers. Taking this relationship a step further, we evaluate recharge conditions by comparing open-system and closed-system models of carbonate dissolution.

The evolution of DIC in ground water begins with weathering reactions in the recharge zone. These reactions are driven by acidity created during the solution of CO_2 gas and organic acids in the soil. Under *open-system* conditions, where ground water acidity is continuously replaced by CO_2-rich recharge from the soil, weathering reactions persist until chemical equilibrium is reached between aqueous phases and aquifer minerals. Under *closed-system* conditions, where there is no continuous flux of CO_2-rich recharge, weathering reactions neutralize the ground water acidity. The net result is that chemical equilibrium is reached sooner than in an open-system and less weathering occurs relative to open-system conditions. In other words, greater weathering occurs in aquifers open to continuous recharge from the soil zone.[15]

Plotting the molar concentrations of dissolved Ca^{2+} in the ground waters as a function of P_{CO_2} and considering where the data lie relative to theoretical calcite weathering trajectories based on open and closed-system assumptions is a useful method of accomplishing this task (Drever, 1988). It is important to recognize that the theoretical calculations are based solely on calcite equilibria and do not account for silicate weathering, biological fluxes, or any other biogeochemical process that may affect Ca^{2+} concentrations in the aquifer. This problem is likely to be particularly acute in the older, more evolved ground waters down-valley; therefore, the following discussion focuses on ground waters in the eastern portion of the basin.

[15] Under some closed-system conditions, oxidation of organic matter and reduced minerals such as pyrite (FeS_2) may contribute additional acidity to ground water.

Measured concentrations of dissolved carbonate species, pH, and temperature from the (1) Boise River, (2) Boise Front springs, and (3) Banner Creek wells are used to define starting conditions for the theoretical carbonate dissolution trajectories. A set of open-system and closed-system trajectories for each starting condition is shown in Figure 6, together with measured data from Boise area aquifers. Note that all of the open-system trajectories increase along the ordinate axis with no change in P_{CO_2}. This is because the primary assumption of the open-system model is that CO_2 gas is continuously replenished, so P_{CO_2} is held constant. The closed-system model trajectories deviate toward less P_{CO_2} as the calcium concentration increases. This is because the total amount of CO_2 in the system is fixed before calcite dissolution begins and, as dissolution occurs, CO_2 gas is used up.

Of the six possible trajectories shown in Figure 6, a closed-system trajectory beginning with the range of mountain front recharge waters is the best model for most of the aquifers in the Boise area. This conclusion follows from:

1. The geochemical data describe a curvilinear trend along a generalized closed-system trajectory that has initial conditions similar to the Boise Front springs and Banner Creek wells.
2. Shallow oxic ground waters appear to be physically separated from deeper waters in all but the alluvial fan aquifers.
3. Low permeability blue clay deposits exist in all but the alluvial fan aquifers.
4. Water level measurements show upward hydraulic gradients in deep aquifers west of the transition-zone (Petrich et al., 1999).

The southeast Boise alluvial fan may be exception to the closed-system model. As noted in Section 3.2, the alluvial fan lacks redoximorphic color changes in the vertical section. Ground water is unconfined, oxic, has low C_s, and exhibits a downward hydraulic gradient. It stands to reason that ground water in the alluvial fan should be described using an open-system model.

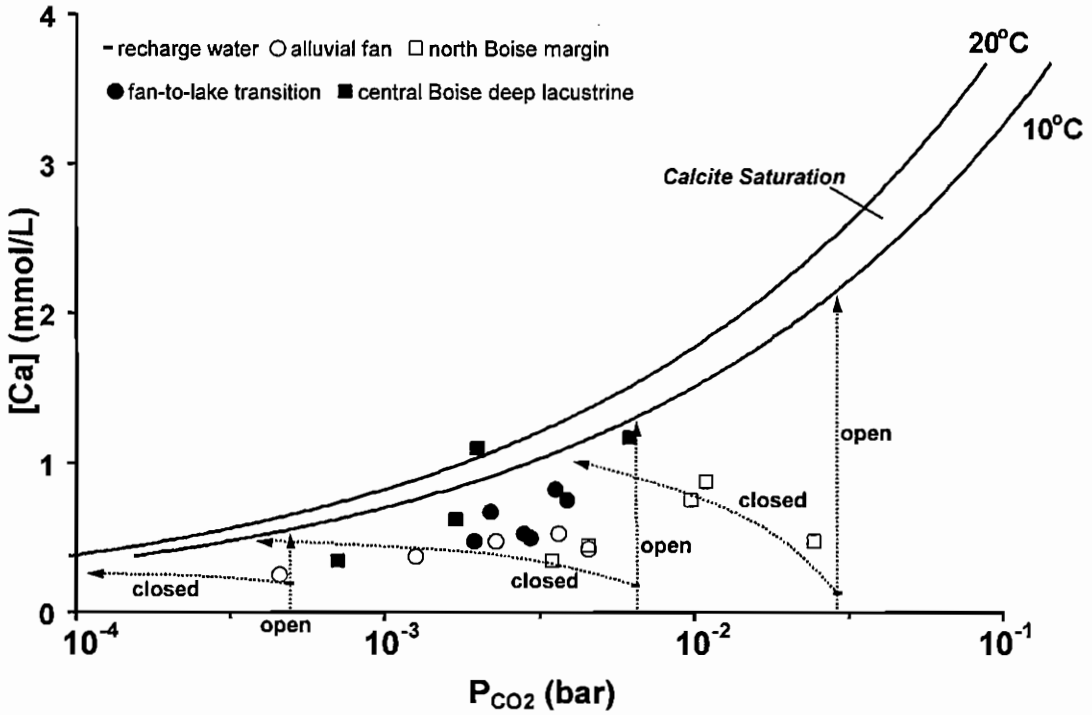


Figure 6. Open versus closed-system trajectories for calcite dissolution in basin margin aquifers.

5.3. Carbon Isotopes and the Carbonate System

Processes that control the quantity of DIC in ground water also affect the relative proportion of carbon isotopes; therefore, changes in isotopic character of ground water DIC can be used to evaluate the magnitude of carbonate dissolution on a regional scale. The first step in this analysis is to determine the range of $\delta^{13}C_{DIC}$ for recharge waters.[16] In the recharge zone, where substantial carbonate dissolution has not yet occurred, $\delta^{13}C_{DIC}$ is controlled by the distribution of carbonate species. Estimates of $\delta^{13}C_{rech}$ for the Boise Front springs, Banner Creek wells and Boise River were determined using a ^{13}C mixing-model (Appendix 2). Carbon-13 enrichment factors ($\varepsilon^{13}C$) for the distribution of DIC species depend on water temperature and were determined from relationships described by Vogel et al. (1970) and Mook et al. (1974). The fundamental mixing equation is:

$$\delta^{13}C_{rech} = \delta^{13}C_{soil} + \frac{mDIC_{H_2CO_3(aq)}}{mDIC} \cdot \varepsilon^{13}C_{H_2CO_3(aq)} + \frac{mDIC_{HCO_3^-}}{mDIC} \cdot \varepsilon^{13}C_{HCO_3^-},$$

[16] Refer to footnote 4 for discussion of del (δ) notation.

where $\delta^{13}C$ of soil CO_2 gas ($\delta^{13}C_{soil}$) is taken to be -23‰ (Clark and Fritz, 1997). Applying the mixing-model to our representative recharge waters provides the following $\delta^{13}C_{rech}$ values:

Boise Front springs, –21.4‰;
Banner Creek wells, –18.0‰;
Boise River, –13.7‰.

Note that these values are quite different. The acidic Boise Front springs, at pH 6, are weighted more to $\delta^{13}C$ of carbonic acid (-24.1‰) than $\delta^{13}C$ of bicarbonate (-15.1‰).[17] The opposite is true for Boise River water at pH 7.9. The Banner Creek wells, at pH 6.6, fall between these extremes.

Away from the recharge zone, where ground water is largely closed to soil CO_2, carbonate dissolution is the primary control on $\delta\ ^{13}C_{DIC}$. Potential sources of carbon in Treasure Valley aquifers include (1) oolites, carbonized wood and shells in shoreline deposits (-2‰ to +4‰), (2) calcareous muds and shells in deep lake areas (-3‰ to -6‰), and (3) biogenic CO_2 from oxidation of organic matter in confining beds (-25‰ to -30‰). With the exception of biogenic CO_2, dissolution of lacustrine carbonates introduces ^{13}C-enriched carbon to the recharge DIC pool. As $\delta\ ^{13}C_{DIC}$ evolves to greater values along the flow path, it becomes less and less diagnostic of the controlling open or closed-system conditions. This is because silicate dissolution becomes increasingly important, and the difference between $\delta\ ^{13}C_{DIC}$ and $\delta\ ^{13}C_{CaCO3}$ diminishes as ground water is enriched. Measurements of ^{14}C can increase the utility of $\delta\ ^{13}C_{DIC}$ measurements, because under open-system conditions ^{14}C in ground water is continually replenished and is maintained near 100 pmC. In contrast, ^{14}C is isolated from the soil atmosphere under closed-system conditions and radioactive decay reduces its activity. The longer ground water resides in isolation from soil CO_2, the lower the ^{14}C activity.

Ground water $\delta\ ^{13}C_{DIC}$ in the recharge-zone aquifers ranges between –12‰ and –15‰, while ground water in the deep deltaic aquifers beneath Boise and in down-valley locations have $\delta^{13}C_{DIC}$ values between -8‰ and -12‰ (Figure 7). One down-valley well (Parma No. 10) has a $\delta^{13}C_{DIC}$ of –5‰. Increasing $\delta^{13}C_{DIC}$ in wells west of Meridian is consistent with a regional flow model of carbonate evolution, because carbonate dissolution from $\delta^{13}C$-enriched calcareous muds in the deep lake environment adds $\delta^{13}C$-enriched DIC to the ground water. Calcareous silt stones and mud stones are documented in the Simplot Geothermal well near Caldwell (Wood, 1994). The substantial differences between $\delta^{13}C_{DIC}$ of ground water in the central

[17] Recall the discussion of ^{13}C fractionation in Section 1.1.

Boise deltaic sequences and ground water in the recharge-zone aquifers may reflect the closed-lake depositional environment of the shoreline sediments. These differences are consistent with isolated aquifers in the deep deltaic aquifers.

Like $\delta^{13}C_{DIC}$, $^{14}C_{DIC}$ also differentiates the various aquifers. Figure 7 shows that the highest ^{14}C-activities are in waters near the recharge area, while the lowest activities are found in down-valley wells and in wells penetrating the deep deltaic aquifers beneath Boise. In the western reaches of the basin increasing $\delta^{13}C$ generally accompanies decreasing ^{14}C-activity. This relationship is as it should be for a closed ground water system undergoing carbonate dissolution.

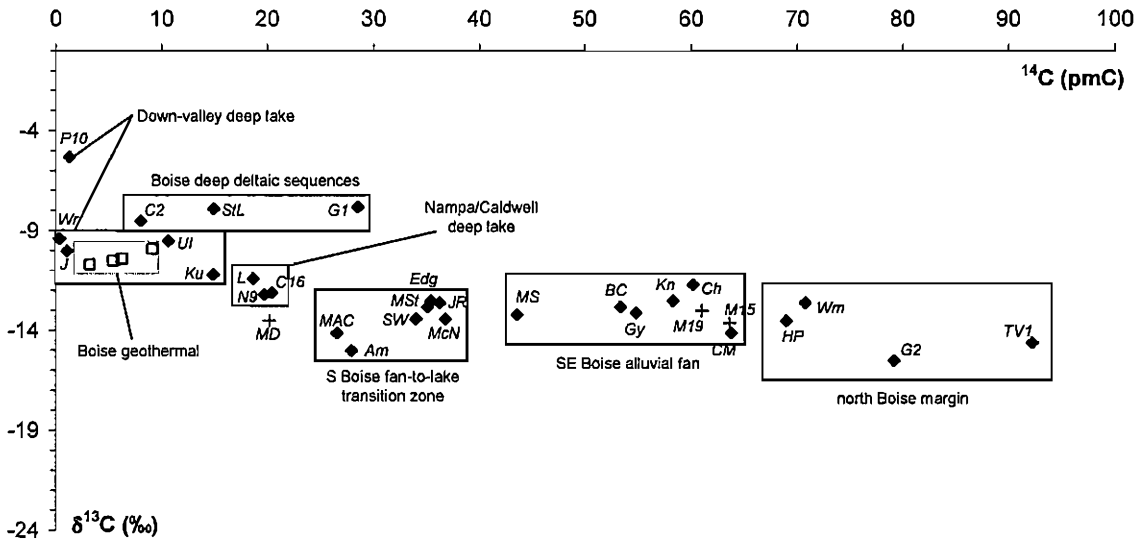


Figure 7. Isotopic trends of DIC in principal aquifers of the Treasure Valley ground water system. Plus symbols represent wells that do not conform to their principal aquifer designation.

Geochemical evolution of ground water often involves more than CO_2-driven dissolution of aquifer minerals. Carbon dioxide produced by microbial oxidation of organic carbon ($\delta^{13}C$=–25‰) can dilute ground water DIC with lighter ^{13}C, thereby reducing $\delta^{13}C_{DIC}$. Denitrification and sulfate reduction are examples of microbial oxidation. Under highly reduced conditions, methanogenic fermentation can contribute CO_2 with $\delta^{13}C$ greater than +10‰. Mixing of large quantities of methanogenic CO_2 would substantially increase $\delta^{13}C_{DIC}$ of ground water. No decreasing trend is observed in the $\delta^{13}C_{DIC}$ data, ruling out a strong influence of sulfate reduction, or a similar oxidation process. With the exception of the Parma No. 10 well ($\delta^{13}C_{DIC}$=-5.3‰), there are no wells that show exceptionally large increases of $\delta^{13}C_{DIC}$, suggesting that methanogenesis does not play a major role in regional geochemistry (although it may

be very important in isolated areas). The absence of these processes and the subtle evolution of $\delta\ ^{13}C$ along the flow path imply that carbonate dissolution, rather than microbial activity, is the primary control on ground water DIC.

5.4. Controls on Ground Water DIC–Silicate versus Carbonate

Our analysis of carbon cycling in the regional aquifer system leads to three main conclusions about geochemical processes in the regional ground water system: (1) dissolution of carbonate minerals is an important control on DIC in ground water near the recharge zone, (2) regional ground water is closed to inputs of CO_2 except along the basin margin, and (3) sulfate reduction and/or methanogenesis do not contribute gross amounts of CO_2 to ground water in the central portion of the basin. These conclusions explain in a regional sense how carbonate dissolution adds DIC to ground water; however, silicate weathering is also an important aspect of geochemistry in central basin aquifers. Silicate weathering is addressed in the following section.

6. SILICATE MINERAL WEATHERING

Beginning with aquifers at the northeastern margin of the basin and moving west toward the Snake River, we observe decreasing water levels, decreasing hydraulic conductivity, decreasing P_{CO_2}, decreasing DO, and decreasing ^{14}C activity. At the same time, we observe greater aquifer confinement, increasing C_s, increasing Na/Ca ratio, and increasing $\delta^{13}C_{DIC}$. Collectively, these trends implicate a continuous, interconnected, east-to-west-flowing regional ground water system. Given that the basin is bounded by silicate-rich geologic terrains and that these terrains are the source of much of the basin fill through which regional ground water flows, the implication is much more compelling if we can demonstrate that our hydrochemical data can be described by an appropriate model of silicate mineral weathering. Put another way, we can test our conceptual model of regional recharge and flow by evaluating ground water chemistry as it relates to established models of silicate mineral dissolution and precipitation. In this analysis, our objectives are to identify important silicate mineral phases and determine whether our hydrochemical data can be described as a function of primary silicate mineral dissolution and secondary silicate mineral formation.

6.1. Important Silicate Mineral Phases

Aquifers in the Treasure Valley are composed mainly of detrital sediments weathered from the granitic Idaho Batholith. Studies of mineral weathering in the Banner Creek watershed, located in the southwestern part of the Idaho Batholith, show the composition of the parent granite rock. The granite in the Banner Creek area consists of nearly equal amounts of quartz, orthoclase, and An_{19} plagioclase, with minor amounts of biotite (Clayton, 1988). Sand and silt-sized sediments weathered from similar material make up most of the important regional aquifers in the Treasure Valley (S. Wood, pers. com. 1999). Along paleo-shorelines the arkosic sediments are often interspersed with carbon-rich evaporite and biogenic mineral. Volcanic ash is present in many stratigraphic sections. In relation to geochemical evolution of ground water in the Treasure Valley, the most important mineral phases are (1) arkosic sediments, (2) evaporites or biogenic minerals associated with shoreline deposits, (3) volcanic glasses, and (4) secondary clay minerals. Particular mineral phases of geochemical importance are listed in Table 4.

Classification	Mineral Phase	Chemical Formula	Depositional Environment
Primary Arkose	quartz	SiO_2	basin-wide detritus
	CaNa plagioclase feldspars	$(Ca,Na)AlSi_3O_8$	basin-wide detritus
	K feldspars	$KAlSi_3O_8$	basin-wide detritus
	biotite	$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$	basin-wide detritus
Biogenic or Evaporite	calcite	$CaCO_3$	shoreline deposits
	aragonite	$CaCO_3$	shoreline deposits
Evaporite or Hydrothermal	gypsum	$CaSO_4$	shoreline deposits or hydrothermal vents
	pyrite	FeS_2	shoreline deposits or hydrothermal vents
Volcanic	rhyolite glass	SiO_2	basin-wide
	basalt glass	SiO_2	basin-wide
Secondary Clays	Ca-montmorillonite		weathering product
	halloysite		weathering product
	palagonite		weathering product
	zeolites		weathering product
Organic Matter		CH_2O	basin-wide detritus

Table 4. Plausible phases for ground water reactions in Treasure Valley aquifers (S. Wood, pers. com. 1999).

Like most waters that evolve in the presence of feldspathic igneous rock, deep Treasure Valley ground water is dominated by Na-Ca-HCO_3 and is rich in silica. The genesis of ground water in this environment is summarized below, following Garrels (1967).

1. The ionic make-up of ground water is driven by weathering reactions and is controlled by the P_{CO_2} of the recharge water.
2. Plagioclase feldspars, biotite, and other dark minerals are weathered much more rapidly than K-feldspars or quartz.
3. The high percentage of plagioclase feldspars relative to other rapidly-weathered silicate minerals results in a high percentage of Ca^{2+} and Na^{+} in the ground water.
4. K^{+} and Mg^{2+} are derived primarily from biotite.
5. Dissolved silica is almost entirely derived from plagioclase and related minerals.
6. Cl^{-} and SO_4^{-} are not derived from silicate weathering (except for pyrite oxidation) and generally indicate mixing of water from other sources.
7. The first alteration product formed by silicate weathering is often kaolinite, although a wide range of clay minerals and metal oxides may be present.

6.2. Weathering of Primary Minerals

Using these observations as a framework for evolution of regional Treasure Valley ground waters, several methods can be employed to evaluate whether the ground water system can be considered as a continuously evolving silicate system. The first method is based on the observation that Na/Ca mole ratios in feldspathic ground waters generally reflect the feldspar composition of the aquifer matrix (Drever, 1988). To evaluate the progressive dissolution of silicate minerals, the relationship between molar concentrations of Na^+, Ca^{2+}, and SiO_2 is evaluated with respect to theoretical Na/Ca ratios for plagioclase minerals present in Treasure Valley aquifers. A general trend is observed in which the Na/Ca ratio increases with increasing SiO_2 concentration (Figure 8). The trend is not completely consistent with the position of the sampled aquifer in the regional flow system. For example, SiO_2 decreases between the alluvial fan and transition zone aquifers, while the Na/Ca ratio increases slightly. Even so, the Na/Ca ratio is greatest in waters farthest from the northeastern basin margin even though these waters are influenced by $CaCO_3$ dissolution. Ground waters west of Nampa exhibit Na/Ca close to that of An_{19} plagioclase (Figure 8). This regional relationship reasonably suggests that ground water chemistry is not fully evolved in recharge area aquifers, but moves toward geochemical equilibrium as ground water transits the central basin. Alternatively, mineral assemblages could have been distributed in a systematic fashion during deposition and subsequent redistribution, resulting in different (but predictable) accumulations of minerals at varying distances from the batholith. The argument is that these mineral accumulations would prescribe the contemporary distributions of dissolved constituents like Na^+, Ca^{2+}, and SiO_2. By this explanation alone, the regional trend seen in Figure 8 is unlikely, because the depositional history of the Treasure Valley spans millions of years and is extremely complex; however, when combined with a continuous ground water flow system, the patterns observed in Figure 8 make sense. Our conclusion from the preceding discussion is that the geochemical trends observed in Figure 8 are an expression of a regionally-connected ground water flow system that moves through a locally heterogeneous, but regionally systematic, arrangement of sedimentary deposits.

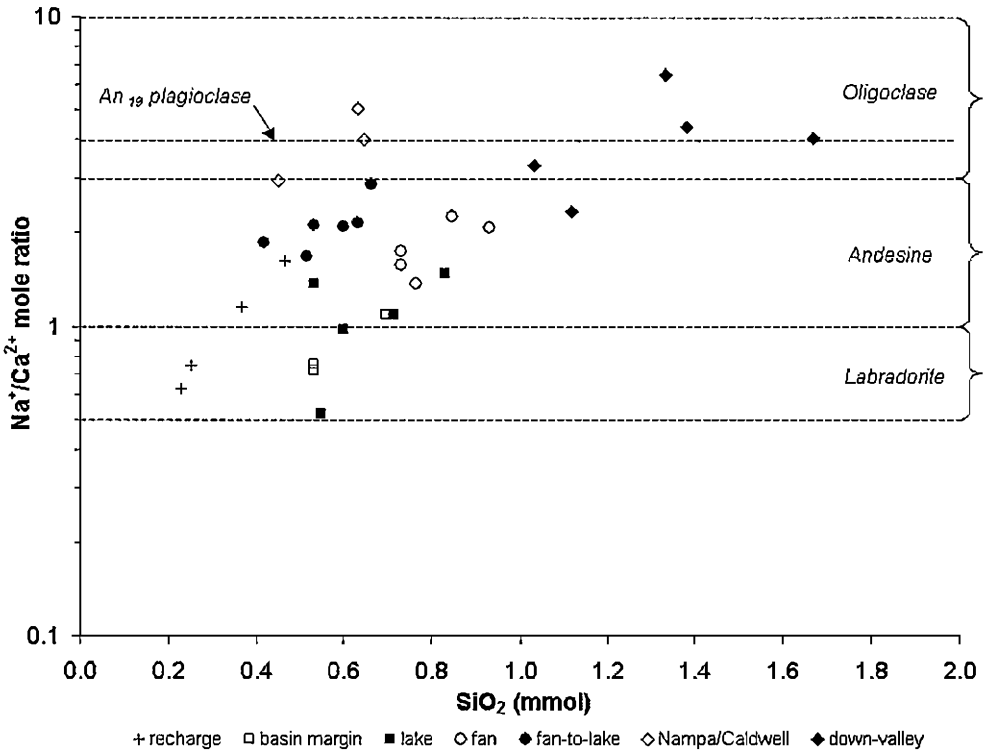


Figure 8. Relationship between Na/Ca mole ratios in regional ground waters and theoretical Na/Ca ratios for selected silicate minerals. Ranges of Na/Ca for Labradorite, Andesine and Oligoclase are taken from Garrels (1967).

6.3. Formation of Secondary Minerals

Weathering of primary silicate minerals is only one factor that controls Na/Ca ratios in evolving ground water systems. Another factor is the formation of silicate weathering products (i.e., secondary minerals such as kaolinite and montmorillonite clays). Evaluating the influence of secondary clay minerals on the ground water solution is a rather tenuous science because the composition of clays can be quite variable and because reliable free-energy data is not available. However, an analysis of the important kaolinite-montmorillonite[18] system offers valuable insight into the regional evolution of ground water in the Treasure Valley.

Kaolinite is often an early weathering product during the evolution of ground water in silicate terranes (Garrels, 1967). Formation of kaolinite may be accompanied by the formation of smectite clays later in the geochemical process. The important associations between the weathering minerals and weathering products, and their effect

[18] In this context the terms smectite and montmorillonite are equivalent.

on dissolved concentrations of cations and SiO_2 are (1) weathering of plagioclase feldspars releases cations and silica into solution; (2) formation of kaolinite removes silica, but does not affect cation chemistry; and (3) formation of smectite clays removes both silica and cations from solution.

Stability diagrams are the basic tools for examining equilibrium conditions of waters with respect to various aquifer minerals. Stability diagrams show which of a prescribed group of minerals is more stable in contact with a particular solution. When overlain by Na-mineral stability fields, data from the Treasure Valley wells show that some waters lie in the kaolinite field, the smectite field, or on the border between the kaolinite and smectite fields (Figure 9). One can deduce from Figure 9 that waters near the recharge source at the basin margin should form kaolinite, which according to Garrels (1967) is generally the first weathering product of Na-Ca-HCO_3 waters in feldspathic rocks. In contrast, Figure 9 suggests that waters in the down-valley locations are supersaturated with respect to Na-bedeillite (or a similar clay mineral). Waters from most of the central basin appear to be simultaneously at equilibrium with both kaolinite and Na-smectite minerals. A similar stability relationship exists for Ca mineral phases, although, because of the influence of calcite dissolution, the data plot entirely in the Ca-bedeillite field (Figure 10). The trajectory of water chemistry data in a K mineral stability diagram is odd because it suggests that ground water is at equilibrium with the primary K-feldspar mineral near the recharge zone, evolves to a condition in which kaolinite is formed, but then shifts away from that condition as ground water passes the Nampa-Caldwell aquifers on its way down-valley (Figure 11). This seemingly contradictory trend may be an indication that we have oversimplified the geochemical model by not representing an important K-mineral phase in our analysis.

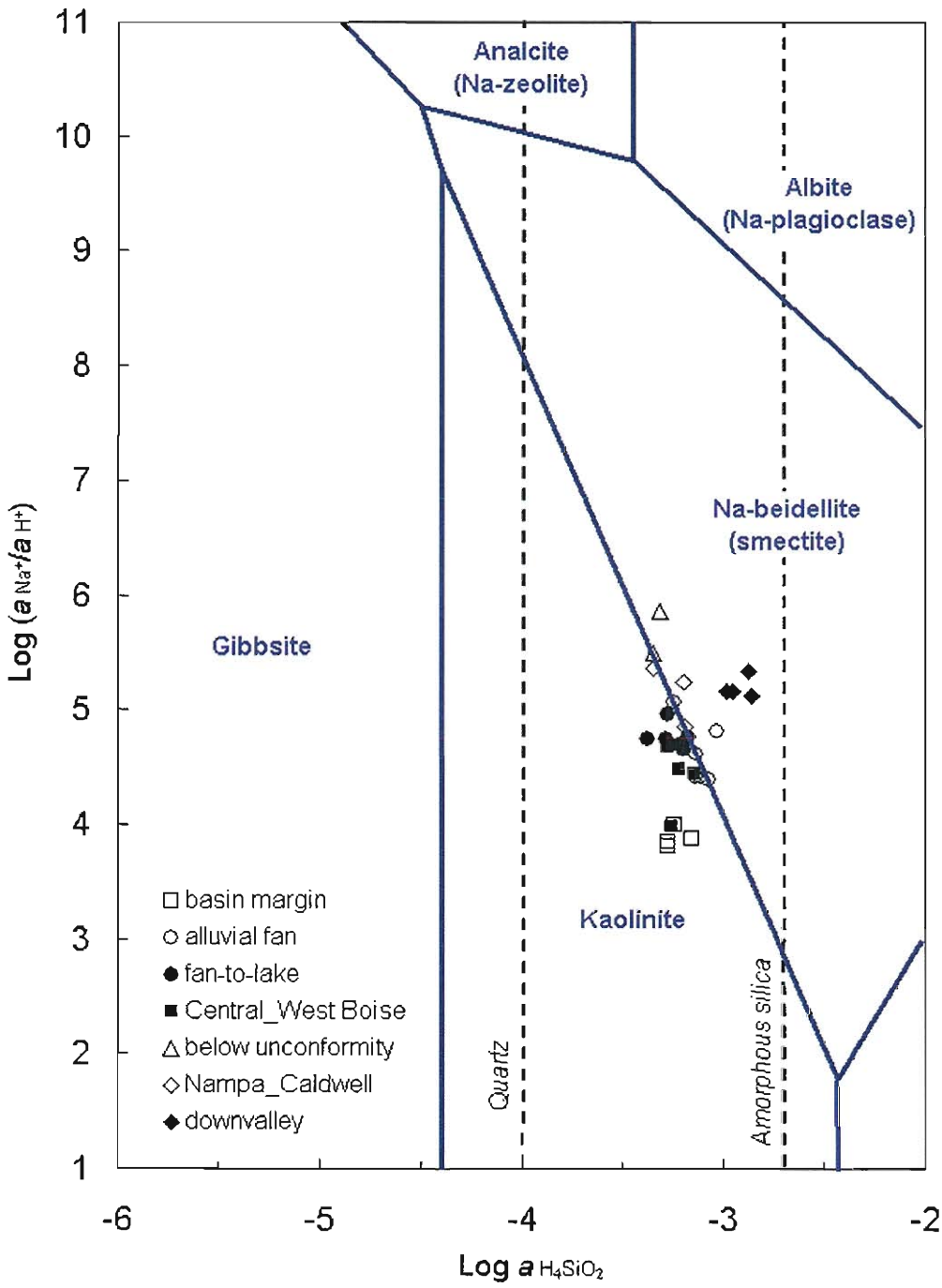


Figure 9. Relationship between regional Treasure Valley ground waters and stability fields for minerals in the system Na_2O-Al_2O_3-SiO_2-H_2O at 25°C (after Drever, 1988).

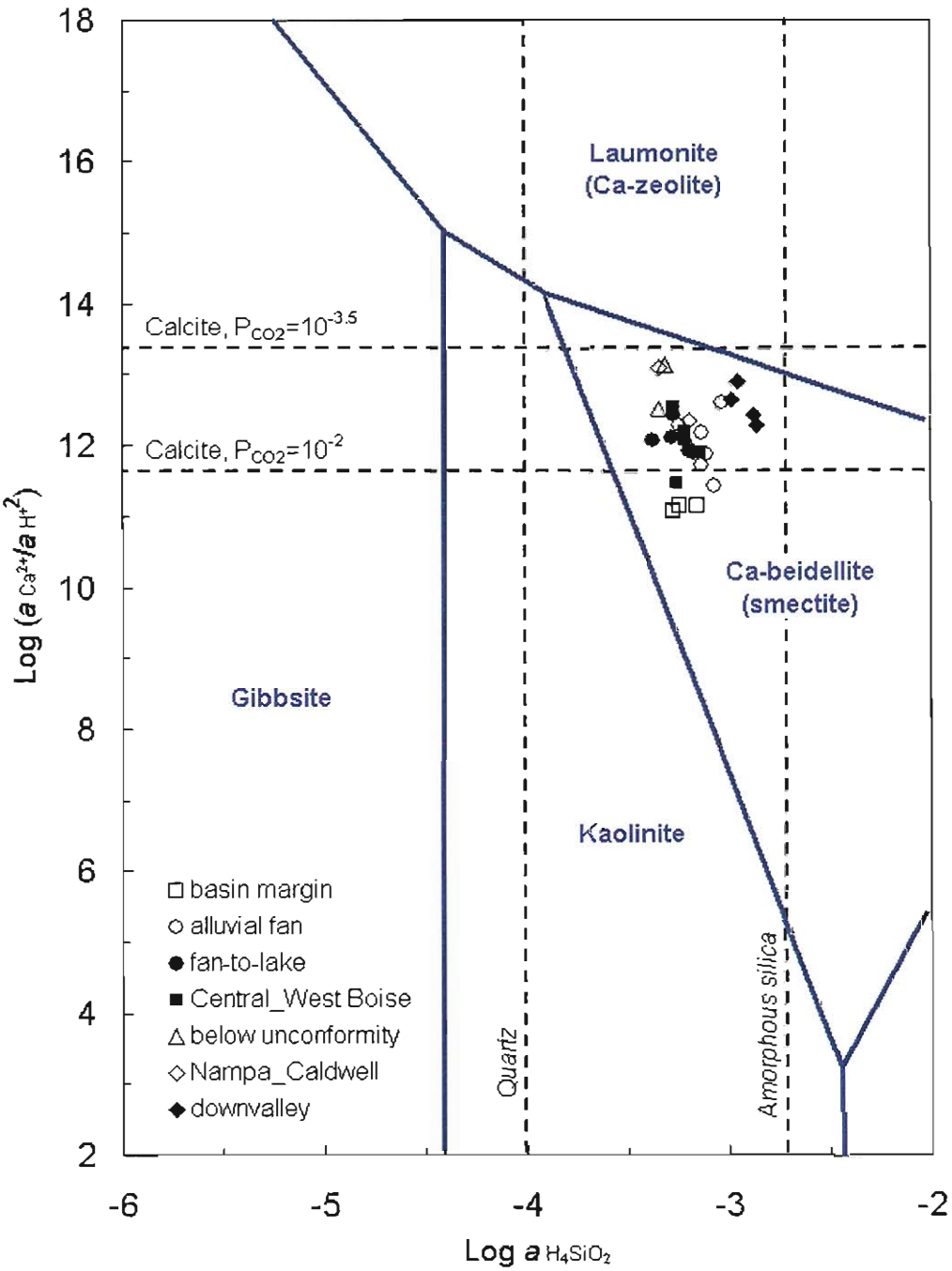


Figure 10. Relationship between regional Treasure Valley ground waters and stability fields for minerals in the system CaO-Al_2O_3-SiO_2-H_2O at 25°C (after Drever, 1988).

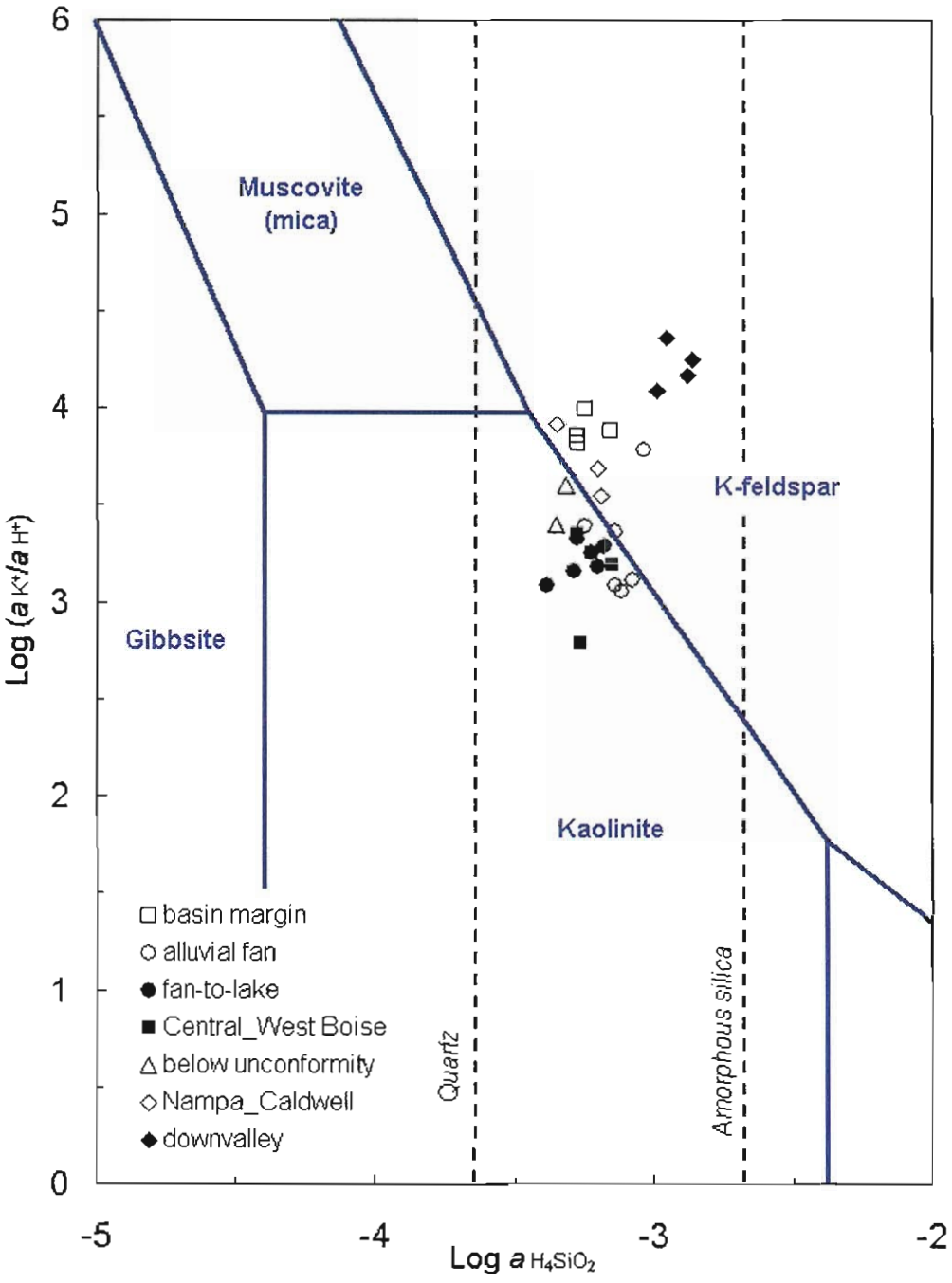


Figure 11. Relationship between regional Treasure Valley ground waters and stability fields for minerals in the system K_2O-Al_2O_3-SiO_2-H_2O at 25°C (after Drever, 1988).

The final step in our analysis of weathering products involves further development of the idea that regional ground waters progress toward an equilibrium condition between kaolinite and a smectite clay. Our evaluation is based on the suggestion that feldspars are altered to kaolinite early in the evolutionary process, while more geochemically evolved waters may be controlled by concurrent formation of kaolinite and smectite minerals (Garrels, 1967). Kaolinite-smectite reaction quotients for our data exhibit an asymptotic increase from about –20 (recharge) to about –10 (down valley aquifers) (Figure 12). The curve becomes asymptotic where equilibrium exists between kaolinite and the idealized Ca-montmorillonite (smectite) (Garrels, 1967).

Two important conclusions can be drawn from this analysis: (1) ground waters exist in equilibrium with a single weathering product (kaolinite) in the eastern portion of the basin; and (2) ground waters exist in equilibrium with both kaolinite and smectite in the western portion of the basin. These conclusions are another indication that ground water presently located at the western end of the valley once existed further east (upgradient) in a less geochemically evolved state.

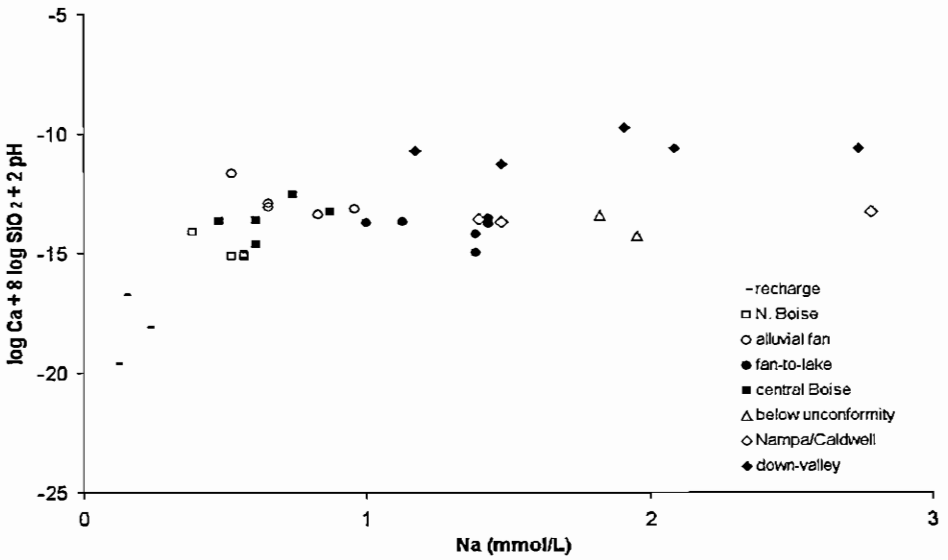


Figure 12. Changes in the kaolinite-smectite reaction quotient for regional ground waters in the Treasure Valley. After Garrels (1967).

7. GROUND WATER RESIDENCE TIMES

The previous sections focused on defining the most appropriate conceptual and geochemical models for the Treasure Valley regional ground water system. In this section, we use those models as the basis for estimating ground water ages and comparing ground water residence times among the principal regional aquifers.

7.1. Age Dating

Ground water ages are calculated from the activity of ^{14}C ($a^{14}C$) in ground water using the decay equation

$$t = -8267 \ln(a^{14}C/a_0{}^{14}C), \quad [1]$$

where $a^{14}C$ is the measured ^{14}C activity in the ground water and $a_0{}^{14}C$ is the ^{14}C activity of water in modern soil (100 pmC). In carbonate terranes, where carbonate dissolution dilutes $^{14}C_{DIC}$ with ^{14}C-free carbon, equation [1] cannot be applied without correction. Our analysis of regional-scale carbon cycling in the Treasure Valley system shows that carbonate dissolution contributes to ground water DIC (Section 5). Consequently, ^{14}C-ages calculated directly from the measured $^{14}C_{DIC}$ data would over-estimate ground water residence times. To establish ^{14}C-ages when carbonate dissolution occurs along the ground water flow path, a dilution factor (q) is determined that accounts for additions of ^{14}C-free DIC. When multiplied by $a_0{}^{14}C$, q gives a dilution-corrected value for the ^{14}C activity of DIC in recharge water. Substituting this value into [1], the corrected ground water age is given by

$$t = -8267 \ln(a^{14}C/ q\ a_0{}^{14}C) \text{ (Clark and Fritz, 1997).} \quad [2]$$

Dilution of ground water DIC by old carbonate generally results in $q<1$; therefore, corrections for dilution reduce the estimated age. In practice, values of q range between 0.60 and 1.0 (Clark and Fritz, 1997).

The simplicity of correcting ^{14}C data for flow path carbon inputs is deceiving. Estimating reasonable values of q requires detailed understanding of the carbonate system, particularly with respect to the recharge environment. Before considering the correction techniques in detail, it is useful to review our present conceptual model of carbon cycling in the flow system.

1. Recharge water is charged with ^{14}C-rich CO_2 as it passes through the soil.
2. Holocene carbonates slightly depleted in ^{14}C may be dissolved into the DIC pool in the recharge zone beyond the soil.

3. Beyond the recharge zone, where carbonate dissolution is controlled by closed-system assumptions, old (^{14}C-free) carbonate dilutes the ground water ^{14}C pool. Occurrence of these old carbonates is not uniform throughout the basin.
4. Isotopic exchange of dissolved ^{14}C for solid-phase ^{12}C and ^{13}C may occur along the flow path.
5. In isolated aquifers, free CO2 may be introduced from biochemical oxidation of old organic matter.

According to this model, carbon fixed from the atmosphere by plants is released into the soil as CO_2 gas when the plants decompose. High CO_2 pressure in the soil causes increased concentration of DIC in percolating water and charges the water with ^{14}C. When percolating water leaves the soil zone it may pass through late Pleistocene or Holocene carbonate deposits having a level of ^{14}C activity that is slightly less than that of modern carbonate. Dissolution of these carbonates would alter the ^{14}C activity of recharging water from the activity expected in a modern DIC pool (*i.e.*, 100 pmC) to a slightly lower value. At the present time there are no studies addressing the ^{14}C activity of contemporary vadose zone water in the Boise area, so for the purposes of our age corrections, ^{14}C activity of vadose zone carbonates are assumed to be 100 pmC. In light of long-term variations in atmospheric ^{14}C activity and considering the wide range of uncorrected ages of Treasure Valley ground waters, this assumption will have little influence on our corrections.

The decrease in atmospheric $a^{14}C$ during the past 30,000 years further confounds estimates of the activity of recharge water. A rough estimate of the decrease is obtained from a composite diagram of atmospheric ^{14}C activity compiled by Clark and Fritz (1997). The estimated rate of decrease is $2x10^{-3}$ pmC y^{-1} for ground waters recharged since the last glacial maximum. This rate corresponds roughly to an $a^{14}C$ value of 100 pmC for waters recharged during the past 2,500 years and 140 pmC for waters recharged 20,000 years ago. The data are too sparse to extend the estimate beyond 20,000 years.

In contrast to recharge-zone carbonates, carbonate deposits formed before the late Pleistocene have, by now, lost most of their original ^{14}C to radioactive decay. These carbonates do not contain measurable ^{14}C activity; therefore, ^{14}C in the DIC fraction is substantially diluted by dissolution of these carbonate minerals. Most carbonate in deep, regional aquifers falls in this category. Biochemical oxidation of organic matter can also have a profound effect on estimates of ^{14}C ages. Carbon-14-free organic matter contained in the aquifer matrix may be oxidized by sulfate reducing microbes. Another common biochemical reaction in sedimentary ground water environments is methanogenesis. Methanogenesis occurs when methane-producing bacteria break down organic carbon into methane and carbon dioxide. Biogenic sources of ^{14}C-free carbon would have the same diluting effect as dissolution of old carbonate minerals.

Fortunately, our analysis of ^{13}C data suggests that these biogenic sources do not contribute a great deal to dilution of DIC in the regional system (see Section 5.3).

7.2. Application of Correction Models

Corrections for sources and sinks of carbon along the ground water flow path were determined using the CMB-ALK, CMB-CHEM, $\delta^{13}C$-mixing and Matrix Exchange models (Section 2.2.3). Spreadsheets containing the complete calculations are contained in Appendix 3. Uncertainty about the source of recharge to the Treasure Valley aquifers and sensitivity of correction models to recharge water pH and P_{CO_2} required that corrections be evaluated for a range of recharge chemistries. Corrected ^{14}C ages were calculated using the range of recharge pH and P_{CO_2} values represented by the Boise Front springs, Banner Creek wells, and Boise River waters.

Comparisons among ground water ages determined using the CMB-ALK, CMB-CHEM, $\delta^{13}C$-mixing and Matrix Exchange models are shown in Figure 13. Two important observations from these comparisons are:

1. Except for the relatively young basin margin waters, all corrections result in decreased ages. Corrected ages greater than uncorrected ages in aquifers near the recharge zone result from incorrectly applying the restrictive closed-system assumptions;
2. The magnitudes of corrections are generally consistent among the various methods and among the various recharge conditions.

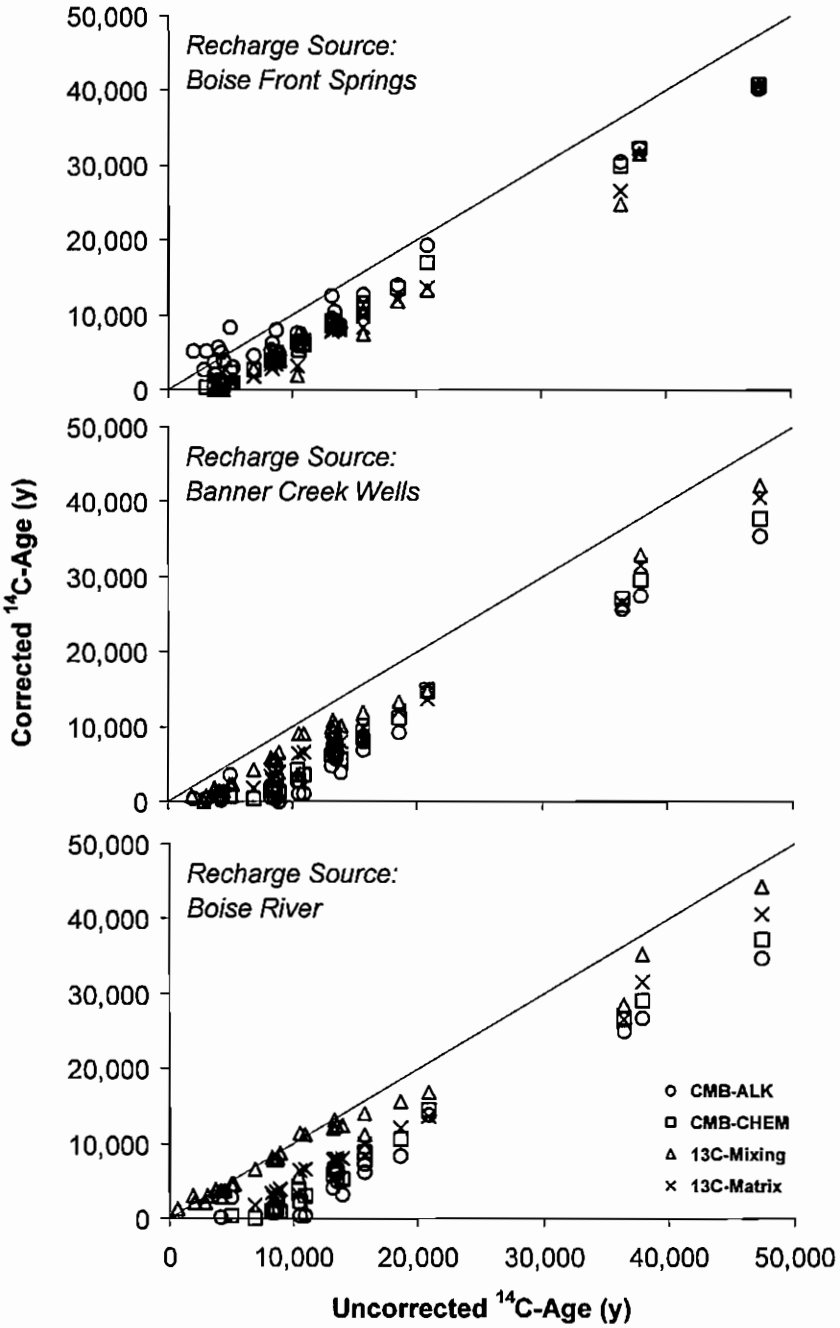


Figure 13. Comparison of ^{14}C-ages calculated for three recharge scenarios using the CMB-ALK, CMB-CHEM, $\delta^{13}C$-Mixing and $\delta^{13}C$-Matrix Exchange models. The 1:1 line represents the condition where corrected ages are the same as uncorrected ages.

These observations give us confidence that the corrected ages are reasonable estimates of true ground water residence times. The fact that the four models give relatively consistent results indicates that carbonate dissolution is indeed the primary geochemical factor affecting regional-scale ground water age calculations. The fact that the greatest differences between the strictly closed-system models (CMB) and the combined open/closed-system models (δ^{13}C-mixing) occur in younger waters near the recharge zone confirms that the closed-system assumption are too restrictive for the basin margin aquifers. Based on agreement between the CMB models and the δ^{13}C-mixing models for ground waters in the central basin, and considering that the δ^{13}C-mixing model is not constrained by closed-system assumptions, we consider ground water ages estimated using the δ^{13}C-mixing model to most accurately represent ground water residence times.

7.3. Ground Water Residence Times

We further constrain the range of residence times for each ground water by selecting the most appropriate recharge data for the aquifer as determined by previous discussions. For example, Boise River water was used as the starting condition to estimate the residence times of ground water in the alluvial fan and transition zone aquifers. This approach provides "best estimates" of ground water residence times that can be used to represent ground water flow in the regional system. These "best estimates" are shown in Table 5 along with a tabulation of the range of calculated residence times. Note that the practical limits of the ^{14}C-age dating method are 5,000 to 30,000 years; therefore, residence time estimates for the basin margin aquifers and some down-valley aquifers must be considered accordingly.

Principal Aquifer	Well Name	Top of Water Bearing Zone (feet above msl)	Ground Water Residence Time Minimum (years)	Maximum (years)	Best Est. (years)
North Boise	TVHP 1	2,282	0	1,000	<1,000
fluvial sands	HP	2,065	0	3,000	<3,000
Central and West Boise	Goddard 2	2,199	0	2,000	<2,000
lacustrine deposits	Cassia Monitor	2,226	0	4,000	<3,000
	Meridian 15	2,105	0	4,000	<4,000
	Meridian 19	2,010	0	4,000	<4,000
Southeast Boise	Christiansen	2,636	0	4,000	<2,000
alluvial fan deposits	Guyer	2,565	1,000	5,000	<2,000
	Micron Shallow	2,512	3,000	7,000	<4,000
	Knox	2,567	0	4,000	<5,000
	Blacks Creek	2,510	1,000	5,000	<5,000
South Boise	JR Flat	2,476	0	8,000	6,000
fan-to-lake transition	Market Street	2,382	0	8,000	6,000
deposits	McNabb	2,542	0	8,000	6,000
	MAC	2,372	0	11,000	9,000
	Amity	2,279	0	11,000	9,000
	Sunset West	2,295	0	9,000	7,000
	Edgeview	2,268	0	8,000	6,000
Below Unconformity	Micron Deep	2,266	7,000	13,000	11,000
deep deltaic deposits	Cassia 2	1,901	13,000	21,000	15,000
	Goddard 1	1,771	4,000	10,000	<10,000
	St. Luke's	1,890	7,000	13,000	9,000
Nampa and Caldwell	Lete	2,126	4,000	13,000	10,000
lacustrine deposits	Nampa 9	2,082	6,000	13,000	10,000
	Caldwell 16	2,012	5,000	13,000	10,000
Down-valley	Wright	1,898	35,000	47,000	42,000
lacustrine deposits	Johnson	2,010	28,000	38,000	32,000
	Keuspert	1,985	7,000	16,000	12,000
	Parma 10	2,036	24,000	31,000	26,000
	Uofl	1,984	9,000	19,000	13,000

Table 5. Ground water residence times for principal aquifers in the Treasure Valley regional ground water system. Residence times are based on ^{14}C-age dates using the CMB and $\delta^{13}C$-mixing models. Minimum and maximum represent the full range of possible recharge conditions, while best estimates are based on the $\delta^{13}C$-mixing model combined with the most appropriate recharge conditions as described in the text.

8. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1. Summary and Conclusions

The purpose of this study was to use principles of ground water geochemistry to refine the conceptual model of ground water recharge and flow in the Treasure Valley. Our objectives were to:

1. Describe hydrochemical characteristics of principal aquifers that comprise the regional ground water flow system.
2. Assess likely sources of recharge.
3. Examine patterns in dissolved ion concentrations and abundance of carbon isotopes along regional ground water flow paths.
4. Determine whether known geochemical processes describe the observed patterns.
5. Estimate residence times for regional ground waters.

To meet these objectives, the following tasks were completed:

1. Principal aquifers and associated mineral assemblages were delineated base on the work of previous researchers.
2. Thirty-eight ground water wells representing waters from the principal aquifers were identified and sampled.
3. Concentrations of a variety of dissolved constituents, including ^{3}H, were measured in all water samples; 28 samples representing deep, regional waters were analyzed for ^{14}C; and archived well cuttings from several deep wells were analyzed for carbon isotopes.
4. Spatial distributions of hydrochemical data were compared and used to substantiate the principal aquifer delineations.
5. Recharge sources were differentiated using ion chemistry and isotope-mixing models.
6. Likely regional flow paths were evaluated by observing patterns in dissolved ion concentrations and carbon isotope abundance, and by applying geochemical processes models.
7. Regional ground water residence-times were estimated from the measured abundance of ^{14}C.

Despite tremendous regional geologic complexity, results from the study show distinctive relationships between ground water chemistry and the unique depositional environments of the principal aquifers. These relationships are embodied in the following conclusions:

1. Tritium is non-existent in deeper, regional ground waters, except where poor well construction may allow inter-aquifer mixing. This finding indicates that ground water in deeper aquifers entered the flow regime prior to atmospheric nuclear testing during the 1950s and 1960s.
2. Specific conductance (and by inference, total dissolved solids) is greatest in shallow alluvial aquifers and decreases with depth. This finding indicates that water in deeper aquifers did not enter the ground water regime through the carbon-rich sediments found in Treasure Valley soils.
3. Concentrations of major ions and other dissolved constituents vary consistently with depth among aquifer zones. The high degree of consistency suggests that these hydrochemical data can be used to identify discrete aquifer zones in other areas of the basin.
4. Comparisons between measured constituents and established models of geochemical processes show that (1) ground water near the northeastern basin margin has experienced little interaction with aquifer minerals, and (2) ground water beyond the northeastern basin margin has experienced substantial interaction with aquifer minerals. Geochemical evolution of Treasure Valley ground water appears to be influenced by solution of both carbonate and silicate minerals.
5. Residence times of Treasure Valley ground water generally increase with depth and with distance along a regional east-to-west trending flow path. Residence times range from thousands to tens of thousands of years. The youngest waters entered the subsurface a few thousand years ago and are found along the northeastern boundary of the basin, adjacent to the Boise foothills. The oldest waters entered the subsurface between 20,000 and 40,000 years ago and are found in the western reaches of the basin near the Snake River. Ground water in the deep deltaic aquifers beneath Boise was recharged between 10,000 and 20,000 years ago. The proximity of these paleo-ground waters to the mountain front recharge area suggests that these aquifers sustain little natural flow.
6. Contemporary seepage from rivers and/or irrigation diversions is not the primary source of recharge for most deeper, regional aquifers. Paleo-river channels, fractured granite aquifers in the Idaho Batholith, and tributary sedimentary aquifers are the most likely sources of recharge to the regional flow system.

7. A strong relationship between concentrations of dissolved constituents and depositionally-defined aquifer units, the relevance of established geochemical principles to the apparent evolution of ground water geochemistry, and the general east-to-west increase of ground water residence times support a conceptual model of regional ground water flow consisting of (1) recharge in alluvial sediments in southeast Boise and at the base of the mountain front north of Boise, (2) movement of ground water from the recharge areas into the deeper Boise area fluvio-lacustrine aquifers, and (3) movement of ground water from the Boise area aquifers into regional deep-lake aquifers of Nampa and Caldwell. Although not specifically addressed in this study, a reasonable extension of this conceptual model includes regional upwelling at the distal end of the basin and removal of discharging ground water via surface drains to the Boise River system.

8.2. Recommendations

This study of regional-scale geochemistry in the Treasure Valley has provided new insight into basin recharge and flow-system processes. The following recommendations are offered as guidance toward aspects of the ground water system that warrant additional attention.

1. Recharge along the Boise Front. The present study underscores the inherent complexity of basin recharge and suggests that the basin/batholith interface plays an important role in the distribution of recharge of water to Boise area aquifers. Quantifying the contribution of natural recharge to Boise area aquifers from the various sources along the Boise mountain front would provide important information about the long-term impacts of present and future development in these aquifers. This information could be obtained using multi-level monitoring wells (e.g., Marden Lane), additional ground water level data, additional geophysical and stratigraphic work, and a recharge-focused geochemistry study.
2. Recharge and hydraulic connection in southeast Boise. The southeast Boise alluvial fan aquifers have been an area of recent concern because of depressed ground water levels. Using additional stratigraphic interpretations and geochemical work to (1) identify sources of recharge and (2) understand the connection of the alluvial fan to other Boise area aquifers would enhance the scientific basis for sound aquifer management. Related subjects of interest include identifying sources of elevated nitrate in water containing no tritium and evaluating the hydraulic connection of the southeast Boise aquifers to the Boise River system above the New York Canal diversion.
3. Discharge from down-valley aquifers. Regional ground water flow in the Treasure Valley appears to be constrained at the discharge end of the basin.

That is, fine-grained sediments at the western reaches of the basin may be the primary control on the amount of water moving through the system. Water level and hydrochemistry data obtained from the recently drilled multi-level monitoring well in Caldwell provide the first appropriate data for evaluating this theory. Similar wells in Nampa, Notus, and Parma would provide key information for a more complete understanding of regional discharge.

4. Improved estimates of ground water residence times. Regional-scale estimates of ground water residence times require broad assumptions about ground water flow and basin geochemistry. With more localized study, it is possible to address these assumptions with greater resolution and to improve estimates of ground water residence times. A focus on establishing residence times for smaller portions of the regional system may benefit from using a new inverse mass balance approach to evaluating ground water chemistry and isotope compositions (Zhu and Murphy, 2000). Inverse mass balance models can be developed for ground water flow between a series of wells along a flow path based on local geology, mineralogy, petrographic information, saturation indices, and specific knowledge about mineral dissolution.

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Appendix 1

Well Information and Laboratory Analyses of Water Samples

Well Name	Owner	USGS Station Name	LAT deg	LAT min	LAT sec	LON deg	LON min	LON sec	T	R	Sec
Christiansen	Micron Corporation	Christiansen Replacement	43	31	50	116	6	18	02N	03E	09BAA2
Blacks Creek	Idaho Deptartment of Transportation	Blacks Creek Rest Area	43	28	41	116	6	28	02N	03E	28CAC1
Blacks Creek	Idaho Deptartment of Transportation	Blacks Creek Rest Area	43	28	41	116	6	28	02N	03E	28CAC1
Guyer	Vern Guyer	Guyer-new deepened	43	31	39	116	6	34	02N	03E	09BCA2
Micron Shallow	Micron Corporation	Micron Shallow Monitor	43	31	37	116	8	43	02N	03E	07DBB1
Micron Deep	Micron Corporation	Micron Deep Monitor	43	31	37	116	8	46	02N	03E	07DBB2
Micron No. 5[1]	Micron Corporation	Micron No. 5	43	31	42	116	8	0	02N	03E	07ACD1
Knox	Tim Knox	Tim Knox	43	30	50	116	8	50	02N	03E	18BAC1
Market St.	United Water Idaho	BWC Market St.	43	33	34	116	11	6	03N	02E	35BAB1
JR Flat	United Water Idaho	BWC J.R. Flat Prod.	43	32	33	116	11	32	02N	02E	02BBC2
McNabb	Walter McNabb	1333 Lk Hazel	43	32	43	116	11	45	02N	02E	03AAB2
Cassia No. 1	United Water Idaho	UWID Cassia No. 1	43	35	47	116	12	53	03N	02E	16DAA1
Cassia No. 2	United Water Idaho	UWID Cassia No. 2	43	35	47	116	12	53	03N	02E	16DAA2
Cassia Monitor	United Water Idaho	UWID Cassia Monitor	43	35	47	116	12	53	03N	02E	16DAA3
MAC[2]	United Water Idaho	BWC MAC	43	33	26	116	15	8	03N	02E	32BBC1
Sunset West	United Water Idaho	BWC Sunset West	43	33	4	116	16	24	03N	01E	36DAD1
Amity	United Water Idaho	BWC Amity	43	33	40	116	16	54	03N	01E	36ABB1
Westmoreland[2]	United Water Idaho	BWC Westmoreland	43	38	21	116	16	11	04N	02E	31CBD1
Goddard No. 1[2]	United Water Idaho	BWC Goddard No. 1	43	38	43	116	17	16	04N	01E	36BAC1
Goddard No. 2[2]	United Water Idaho	BWC Goddard No. 2	43	38	42	116	17	16	04N	01E	36BAC2
TVHP No. 1	TVHP, State Street, Star	TVHP No. 1-zone 1	43	40	48	116	18	44	04N	01E	14CCB1
TVHP No. 2	TVHP, State Street, Star	TVHP No. 1-zone 2	43	40	48	116	18	44	04N	01E	14CCB2
TVHP No. 3	TVHP, State Street, Star	TVHP No. 1-zone 3	43	40	48	116	18	44	04N	01E	14CCB3
TVHP No. 4	TVHP, State Street, Star	TVHP No. 1-zone 4	43	40	48	116	18	44	04N	01E	14CCB4
HP	United Water Idaho	HP	43	39	22	116	19	2	04N	01E	27ADC1
Edgview	United Water Idaho	S. Co. Braddock (Edgeview)	43	35	58	116	20	2	03N	01E	16ADDA1
Edgview	United Water Idaho	S. Co. Braddock (Edgeview)	43	35	58	116	20	2	03N	01E	16ADDA1
St. Lukes	Saint Lukes Hospital	St. Lukes Med. Ctr.-887'	43	36	5	116	21	0	03N	01E	16BCA1
Meridian No. 15	City of Meridian, 8th St., Meridian	Meridian No. 15	43	37	3	116	24	48	03N	01W	11AADA1
Meridian No. 19-Test	City of Meridian, UstickxTen Mile	Meridian No. 19-Test	43	37	30	116	25	0	03N	01W	03AAA2
Meridian No. 19	City of Meridian, UstickxTen Mile	Meridian No. 19-Production	43	37	30	116	25	0	03N	01W	03AAA3
Schwisow	Duane Schwisow	4410 N. Star Rd., Nampa	43	33	30	116	29	20	03N	01W	32BBD1
Nampa No. 12	City of Nampa	Nampa No. 12	43	35	47	116	31	10	03N	02W	13DBBD1
State Hospital	State of Idaho	ID SS & State Hosp. No. 4	43	36	9	116	31	58	03N	02W	14ADA1
Lete	Inake Lete	3212 S. Stanford	43	32	18	116	34	54	02N	02W	04DBB1
Nampa No. 9	City of Nampa	Nampa No. 9	43	36	2	116	36	38	03N	02W	17BCB1
Caldwell No. 16	City of Caldwell	Caldwell No. 16 (Valley View School)	43	37	24	116	40	54	03N	03W	03DBC2
Caldwell No. 15	City of Caldwell	Caldwell No. 15	43	38	23	116	41	25	04N	03W	34CBB1
Johnson	Travis Johnson	21381 Hwy 20-26	43	43	49	116	49	11	05N	04W	33ACBA1
Wright	George Wright, 21626 Howe Rd, Caldwell	SQW-Wright	43	42	25	116	49	31	04N	04W	04CDC1
Kuespert	Paul Kuespert	25595 Don Lane	43	44	43	116	50	49	05N	04W	29BCAA1
Parma No. 10	City of Parma	Parma No. 10	43	47	33	116	56	15	05N	05W	04DCD1
Inouye	Kris Inouye	23605 Rodeo Lane	43	42	52	116	56	30	04N	05W	04BDD1
U of I	University of Idaho	Parma Research Sta.	43	48	5	116	56	30	05N	05W	04BDDA1

Well Name	Land Surf Elev ft (NGVD)	Total Depth ft	DTW ft	WL Elev[3] ft	TWBZ ft	TWBZ Elev[3] ft	BWBZ ft
Christiansen	3140	522	485	2655	504	2636	514
Blacks Creek	3355	975	672	2683	845	2510	900
Blacks Creek							
Guyer	3135	620	494	2641	570	2565	620
Micron Shallow	3067	561	491	2576	555	2512	nd
Micron Deep	3066	811	501	2565	800	2266	nd
Micron No. 5[1]	3088	1217	475	2613	598	2490	1212
Knox	3070	642	371	2699	503	2567	642
Market St.	2892	944	270	2622	510	2382	912
JR Flat	2911	567	258	2653	435	2476	536
McNabb	2910	395	0	2910	368	2542	392
Cassia No. 1	2751	410	75	2676	200	2551	400
Cassia No. 2	2751	1124	150	2601	850	1901	1105
Cassia Monitor	2751	1088	120	2631	525	2226	605
MAC[2]	2790	525	115	2675	418	2372	525
Sunset West	2810	620	120	2690	515	2295	603
Amity	2798	675	120	2678	519	2279	670
Westmoreland[2]	2683	900	25	2658	800	2373	901
Goddard No. 1[2]	2673	1005	12	2661	902	1771	960
Goddard No. 2[2]	2673	551	41	2632	474	2199	545
TVHP No. 1	2582	1005	-1	2583	300	2282	340
TVHP No. 2	2582	1005	-0.7	2583	270	2312	290
TVHP No. 3	2582	1005	0.5	2582	210	2372	250
TVHP No. 4	2582	1005	2.4	2580	130	2452	170
HP	2645	700	15	2630	580	2065	700
Edgview	2680	495	21	2659	412	2268	477
Edgview							
St. Lukes	2660	902	3.2	2657	770	1890	900
Meridian No. 15	2570	765	0	2570	465	2105	765
Meridian No. 19-Test	2550	1040	-4.7	2555	340	2210	420
Meridian No. 19	2550	732	-22.5	2573	540	2010	732
Schwisow	2555	456	-1	2556	454	2101	nd
Nampa No. 12	2570	602	72	2498	404	2166	598
State Hospital	2558	560	65	2493	377	2181	544
Lete	2570	458	80	2490	444	2126	nd
Nampa No. 9	2450	461	110	2340	368	2082	460
Caldwell No. 16	2432	553	19	2413	420	2012	535
Caldwell No. 15	2420	600	32	2388	200	2220	460
Johnson	2300	290	2	2298	290	2010	nd
Wright	2285	420	-1	2286	387	1898	nd
Kuespert	2295	320	0	2295	310	1985	nd
Parma No. 10	2281	505	68	2213	245	2036	479
Inouye	2423	325	126	2297	317	2106	nd
U of I	2305	397	95	2210	321	1984	385

nd=no data

[1]data from Micron Corp.

[2]data from USGS

[3]Elevation Above Mean Sea Level

Well Name	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	F mg/L	SiO2 mg/L	NO3 mg/L	Fe ug/L	Mn ug/L	TDS[3] mg/L	USGS TDS mg/L	Hardness mg/L as CaCO3
Christiansen	15	4.1	15	1.4	84	4.8	7.8	0.3	44	1.51	10	4.3	133	141	55
Blacks Creek	21	5.2	19	1.5	120	4.3	6.9	0.27	44	1.81	7.5	1.5	170	167	75
Blacks Creek	21	5.1	19	1.5	120	5.2	7.2	0.27	44	1.87	5.5	1.9	171	162	73
Guyer	10	3.3	12	1.9	61	3.4	4.2	0.29	56	1.66	32	3	114	128	40
Micron Shallow	17	4.9	22	2	120	4.2	7	0.31	51	2.08	96	28	175	176	64
Micron Deep	5.2	0.063	45	0.62	100	4	11	0.82	27	1.65	10	1.6	147	155	13
Micron No. 5[1]	11.9	1.2	33.6	1.22	88	3.13	8.55	0.38	34.2	1.79	nd	nd	138	190	nd
Knox	19	5.2	15	1.1	97	5.7	7.5	0.34	46	1.93	10	1.5	150	156	69
Market St.	19	2.4	23	1.4	100	5.7	14	0.39	36	0.562	20	1.9	153	154	57
JR Flat	21	4.9	26	1.5	120	5.7	12	0.39	38	1.55	10	3	176	175	73
McNabb	20	4.4	33	1.9	130	9.9	20	0.57	40	0.997	10	3.8	199	197	68
Cassia No. 1	46	10	31	1.5	220	8.1	32	0.65	30	0.65	280	85	295	271	160
Cassia No. 2	3.5	0.04	42	0.39	110	3.7	7.2	1.3	29	0.05	5.5	7.7	149	140	9
Cassia Monitor	23	1.6	18	0.53	110	3.5	12	0.58	20	0.05	10	31	142	131	65
MAC[2]	30	6.2	32	1.2	169	9.4	33	0.5	25	0.05	16	200	236	219	100
Sunset West	27	5.7	33	1.3	150	8.5	24	0.38	32	0.182	10	3	216	204	91
Amity	33	8.9	32	1.4	160	9.7	44	0.53	31	0.104	5.5	13	247	237	120
Westmoreland[2]	18	2.7	11	1.1	94	0.7	9.3	0.4	38	0.05	54	94	131	127	56
Goddard No. 1[2]	19	2	18	2.3	127	1.2	2.5	0.4	48	0.05	100	140	167	156	56
Goddard No. 2[2]	44	8.3	13	1.8	169	18	32	0.3	37	0.91	6	30	250	239	140
TVHP No. 1	30	5.1	13	1.4	140	2.1	9.6	0.32	32	0.099	10	12	178	162	97
TVHP No. 2	29	5	12	1.4	130	2.7	8.9	0.32	32	0.091	5.5	8.4	168	155	93
TVHP No. 3	35	7.1	18	1.7	160	3.7	20	0.38	34	0.05	600	37	215	200	120
TVHP No. 4	35	4.8	21	1.3	170	4.4	7.8	0.39	32	0.05	20	40	212	188	110
HP	14	2.5	8.8	1.3	72	2	5.3	0.37	42	0.086	10	3.4	109	112	45
Edgview	32	6.5	20	1.9	140	9.7	30	0.43	43	0.084	320	71	218	211	110
Edgview	32	6.6	20	1.9	140	9.6	30	0.41	43	0.082	320	71	218	208	110
St. Lukes	20	3.4	17	2.3	130	2.7	1.4	0.4	50	0.052	270	230	173	163	64
Meridian No. 15	25	4.6	14	1.4	92	10	25	0.29	36	0.103	30	63	158	162	80
Meridian No. 19-Test	47	8.1	14	1.5	110	19	59	0.24	33	1.31	10	3	225	240	150
Meridian No. 19	14	2.1	11	0.87	75	1.3	4.7	0.35	32	0.05	35	131	104	104	44
Schwisow	12	2.2	9.5	0.91	63	0.58	2.9	0.34	33	0.174	10	3	90	94	40
Nampa No. 12	54	9.1	37	1.7	160	22	81	0.44	32	1.68	10	1.5	310	325	170
State Hospital	61	10	42	1.9	200	20	84	0.31	33	1.71	10	3	354	355	190
Lete	22	4.2	64	3	170	19	45	1.5	38	0.171	5.1	1.9	284	279	72
Nampa No. 9	14	3.6	33	2.7	130	6.8	8.1	0.94	39	0.363	10	3	182	172	51
Caldwell No. 16	20	2.4	34	2	140	9	14	0.59	27	0	23	5.7	190	177	61
Caldwell No. 15	56	12	52	4.5	190	38	89	0.35	36	1.92	10	3	375	393	190
Johnson	19	1.4	44	4.8	180	5.8	0.1	1.4	70	0.05	83	91	252	nd	52
Wright	17	1.7	63	7.2	220	5.7	0.1	1.9	80	0.05	79	114	308	nd	50
Kuespert	18	1.7	34	4.8	150	5.5	1	1.1	62	0.05	450	114	213	203	52
Parma No. 10	19	2.8	48	11	186	3.4	0.73	0.94	83	0.05	74	126	275	280	58
Inouye	53	5.2	45	13	241	7.9	65	0.78	82	0.05	127	131	401	391	150
U of I	20	2.4	27	7.2	160	2.7	2.1	0.74	67	0.05	86	125	222	206	59

nd=no data

[1]data from Micron Corp.

[2]data from USGS

[3]sum of dissolved constituents

Well Name	Ca mmol/L	Mg mmol/L	Na mmol/L	K mmol/L	HCO3 mmol/L	Cl mmol/L	SO4 mmol/L	F mmol/L	SiO2 mmol/L	NO3 mmol/L	TDS[3] mmol/L
Christiansen	0.374	0.169	0.652	0.036	1.377	0.135	0.081	0.016	0.733	0.108	3.681
Blacks Creek	0.524	0.214	0.826	0.038	1.967	0.121	0.072	0.014	0.733	0.129	4.639
Blacks Creek	0.524	0.210	0.826	0.038	0.000	0.146	0.075	0.014	0.733	0.134	2.701
Guyer	0.249	0.136	0.522	0.049	1.000	0.096	0.044	0.015	0.933	0.119	3.162
Micron Shallow	0.424	0.202	0.957	0.051	1.967	0.118	0.073	0.016	0.850	0.149	4.807
Micron Deep	0.130	0.003	1.957	0.016	1.639	0.113	0.114	0.043	0.450	0.118	4.582
Micron No. 51	0.297	0.049	1.461	0.031	1.439	0.088	0.089	0.020	0.570	0.128	4.173
Knox	0.474	0.214	0.652	0.028	1.590	0.161	0.078	0.018	0.767	0.138	4.119
Market St.	0.474	0.099	1.000	0.036	1.639	0.161	0.146	0.021	0.600	0.040	4.215
JR Flat	0.524	0.202	1.130	0.038	1.967	0.161	0.125	0.021	0.633	0.111	4.911
McNabb	0.499	0.181	1.435	0.049	2.131	0.279	0.208	0.030	0.667	0.071	5.549
Cassia No. 1	1.147	0.412	1.348	0.038	3.607	0.228	0.333	0.034	0.500	0.046	7.693
Cassia No. 2	0.087	0.002	1.826	0.010	1.803	0.104	0.075	0.068	0.483	0.004	4.463
Cassia Monitor	0.574	0.066	0.783	0.014	1.803	0.099	0.125	0.031	0.333	0.004	3.830
MAC2	0.748	0.255	1.391	0.031	2.770	0.265	0.343	0.026	0.417	0.004	6.250
Sunset West	0.673	0.235	1.435	0.033	2.459	0.239	0.250	0.020	0.533	0.013	5.890
Amity	0.823	0.366	1.391	0.036	2.623	0.273	0.458	0.028	0.517	0.007	6.522
Westmoreland2	0.449	0.111	0.478	0.028	1.541	0.020	0.097	0.021	0.633	0.004	3.382
Goddard No. 12	0.474	0.082	0.783	0.059	2.082	0.034	0.026	0.021	0.800	0.004	4.364
Goddard No. 22	1.097	0.342	0.565	0.046	2.770	0.507	0.333	0.016	0.617	0.065	6.358
TVHP No. 1	0.748	0.210	0.565	0.036	2.295	0.059	0.100	0.017	0.533	0.007	4.570
TVHP No. 2	0.723	0.206	0.522	0.036	2.131	0.076	0.093	0.017	0.533	0.007	4.343
TVHP No. 3	0.873	0.292	0.783	0.043	2.623	0.104	0.208	0.020	0.567	0.004	5.517
TVHP No. 4	0.873	0.198	0.913	0.033	2.787	0.124	0.081	0.021	0.533	0.004	5.566
HP	0.349	0.103	0.383	0.033	1.180	0.056	0.055	0.019	0.700	0.006	2.885
Edgview	0.798	0.267	0.870	0.049	2.295	0.273	0.312	0.023	0.717	0.006	5.609
Edgview	0.798	0.272	0.870	0.049	0.000	0.270	0.312	0.022	0.717	0.006	3.314
St. Lukes	0.499	0.140	0.739	0.059	2.131	0.076	0.015	0.021	0.833	0.004	4.516
Meridian No. 15	0.623	0.189	0.609	0.036	1.508	0.282	0.260	0.015	0.600	0.007	4.130
Meridian No. 19-Test	1.172	0.333	0.609	0.038	1.803	0.535	0.614	0.013	0.550	0.094	5.761
Meridian No. 19	0.349	0.086	0.478	0.022	1.230	0.037	0.049	0.018	0.533	0.004	2.806
Schwisow	0.299	0.091	0.413	0.023	1.033	0.016	0.030	0.018	0.550	0.012	2.486
Nampa No. 12	1.347	0.374	1.609	0.043	2.623	0.620	0.843	0.023	0.533	0.120	8.135
State Hospital	1.521	0.412	1.826	0.049	3.279	0.563	0.874	0.016	0.550	0.122	9.212
Lete	0.549	0.173	2.783	0.077	2.787	0.535	0.468	0.079	0.633	0.012	8.096
Nampa No. 9	0.349	0.148	1.435	0.069	2.131	0.192	0.084	0.049	0.650	0.026	5.133
Caldwell No. 16	0.499	0.099	1.478	0.051	2.295	0.254	0.148	0.031	0.450	0.000	5.302
Caldwell No. 15	1.397	0.494	2.261	0.115	3.115	1.070	0.926	0.018	0.600	0.137	10.133
Johnson	0.474	0.058	1.913	0.123	2.951	0.163	0.001	0.074	1.167	0.004	6.926
Wright	0.424	0.070	2.739	0.184	3.607	0.161	0.001	0.100	1.333	0.004	8.622
Kuespert	0.449	0.070	1.478	0.123	2.459	0.155	0.010	0.058	1.033	0.004	5.839
Parma No. 10	0.474	0.115	2.087	0.281	3.049	0.096	0.008	0.049	1.383	0.004	7.546
Inouye	1.322	0.214	1.957	0.332	3.951	0.223	0.676	0.041	1.367	0.004	10.086
U of I	0.499	0.099	1.174	0.184	2.623	0.076	0.022	0.039	1.117	0.004	5.836

nd=no data

[1]data from Micron Corp.

[2]data from USGS

[3]sum of dissolved constituents

Appendix 2

Calculation of DIC_{rech} and $\delta^{13}C_{rech}$ for Specified Recharge Conditions

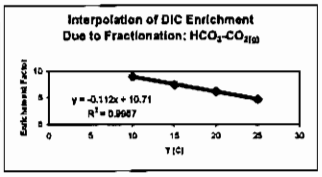
Recharge Conditions: Boise Front Springs			pP_{CO2} 1.7	pH 6.0	T (C) 9				
pK_{CO2}	pK_1	$p[H_2CO_3]$	$p[HCO_3]$	DIC_{rech} mmol	$\delta^{13}C$ Fractionation Factors $CO_{2(aq)}$-$CO_{2(g)}$	HCO_3-$CO_{2(g)}$	$CO_{2(g)}$-$CaCO_3$	DIC-$CO_{2(g)}$	$\delta^{13}C_{rech}$ ‰
1.25	6.48	2.95	3.43	1.50	-1.10	9.70	12.79	1.58	-21.42

Recharge Conditions: Banner Cr. Wells			pP_{CO2} 2.2	pH 6.6	T (C) 8				
pK_{CO2}	pK_1	$p[H_2CO_3]$	$p[HCO_3]$	DIC_{rech} mmol	$\delta^{13}C$ Fractionation Factors $CO_{2(aq)}$-$CO_{2(g)}$	HCO_3-$CO_{2(g)}$	$CO_{2(g)}$-$CaCO_3$	DIC-$CO_{2(g)}$	$\delta^{13}C_{rech}$ ‰
1.23	6.49	3.43	3.32	0.84	-1.10	9.81	12.94	5.04	-17.96

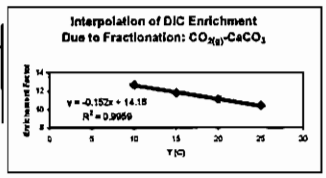
Recharge Conditions: Boise River			pP_{CO2} 3.3	pH 7.9	T (C) 9				
pK_{CO2}	pK_1	$p[H_2CO_3]$	$p[HCO_3]$	DIC_{rech} mmol	$\delta^{13}C$ Fractionation Factors $CO_{2(aq)}$-$CO_{2(g)}$	HCO_3-$CO_{2(g)}$	$CO_{2(g)}$-$CaCO_3$	DIC-$CO_{2(g)}$	$\delta^{13}C_{rech}$ ‰
1.25	6.48	4.55	3.13	0.77	-1.10	9.70	12.79	9.31	-13.69

Notes:
(1) Equilibrium constants K_{CO2} and K_1 determined using regression equations shown on p. 117 of Clark and Fritz (1997).
(2) Fractionation factors for the transition from HCO_3 to $CO_{2(g)}$ and from $CO_{2(g)}$ to $CaCO_3$ determined from regressed data shown in Clark and Fritz (1997) Table 5-3. Regression data are plotted below.

HCO_3-$CO_{2(g)}$	
T(C)	$\varepsilon^{13}C$
10	9.6
15	9
20	8.5
25	7.9



$CO_{2(g)}$-$CaCO_3$	
T(C)	$\varepsilon^{13}C$
10	12.7
15	11.8
20	11.1
25	10.4



Appendix 3

Ground Water ^{14}C-Age Corrections

Data Used for ^{14}C-Age Corrections

Well Name	Water Temp (deg C)	Field pH	^{14}C pmC	$\delta^{13}C$ ‰	Ca mmol/L	Mg mmol/L	Na mmol/L	K mmol/L	Cl mmol/L	SO4 mmol/L	HCO3 mmol/L	Chg Bal Error	ALK mmol/L	$DIC_{MassBal}$ mmol/L
Christiansen	20.4	7.8	60.14	-11.7	0.37	0.17	0.65	0.04	0.14	0.08	1.38	0.18	1.38	0.74
Blacks Creek	21.3	7.5	53.25	-12.8	0.52	0.21	0.83	0.04	0.12	0.07	1.97	0.18	1.9	1.04
Guyer	20.5	8.1	54.73	-13.1	0.25	0.14	0.52	0.05	0.10	0.04	1.00	0.20	1	0.58
Micron Shallow	21.9	7.4	43.53	-13.2	0.42	0.20	0.96	0.05	0.12	0.07	1.97	0.10	1.92	1.00
Micron Deep	24.4	8.2	20.17	-13.5	0.13	0.00	1.96	0.02	0.11	0.11	1.64	0.37	1.8	0.95
Knox	19.8	7.6	58.24	-12.5	0.47	0.21	0.65	0.03	0.16	0.08	1.59	0.23	1.6	0.87
Market St.	22.5	7.7	35.02	-12.8	0.47	0.10	1.00	0.04	0.16	0.15	1.64	0.24	1.64	0.86
JR Flat	19.5	7.6	36.15	-12.6	0.52	0.20	1.13	0.04	0.16	0.12	1.97	0.37	1.94	1.10
McNabb	18	7.6	36.67	-13.4	0.50	0.18	1.43	0.05	0.28	0.21	2.13	0.22	2.08	1.07
Cassia No. 2	30	8.6	8.02	-8.5	0.09	0.00	1.83	0.01	0.10	0.07	1.80	0.03	1.74	0.88
Cassia Monitor	20	8	63.72	-14.1	0.57	0.07	0.78	0.01	0.10	0.12	1.80	0.05	1.74	0.86
MAC	20	7.6	26.5	-14.1	0.75	0.26	1.39	0.03	0.26	0.34	2.77	0.05	2.7	1.24
Sunset West	20.1	7.8	33.93	-13.4	0.67	0.23	1.43	0.03	0.24	0.25	2.46	0.34	2.4	1.27
Amity	17.9	7.6	27.91	-15	0.82	0.37	1.39	0.04	0.27	0.46	2.62	0.45	2.54	1.31
Westmoreland	20.5	7.3	70.7	-12.6	0.45	0.11	0.48	0.03	0.02	0.10	1.54	-0.03	1.5	0.71
Goddard No. 1	23.5	7.8	28.5	-7.8	0.47	0.08	0.78	0.06	0.03	0.03	2.08	-0.19	2.04	0.93
Goddard No. 2	17.5	6.8	79.1	-15.5	1.10	0.34	0.57	0.05	0.51	0.33	2.77	-0.12	2.68	1.16
TVHP No. 1	15.7	7.1	92.12	-14.6	0.75	0.21	0.57	0.04	0.06	0.10	2.30	0.06	2.26	1.13
HP	19.9	7.3	68.88	-13.5	0.35	0.10	0.38	0.03	0.06	0.06	1.18	0.03	1.18	0.58
Edgview	18.7	7.5	35.32	-12.5	0.80	0.27	0.87	0.05	0.27	0.31	2.30	0.17	2.22	1.08
St. Lukes	19.8	7.7	14.92	-7.9	0.50	0.14	0.74	0.06	0.08	0.01	2.13	-0.15	2.16	0.99
Meridian No. 15	19.9	7.7	63.54	-13.6	0.62	0.19	0.61	0.04	0.28	0.26	1.51	0.22	1.5	0.73
Meridian No. 19	19.8	8	60.95	-13	0.35	0.09	0.48	0.02	0.04	0.05	1.23	0.06	1.24	0.62
Schwisow	13.6	8.5	77.96	-13.7	0.30	0.09	0.41	0.02	0.02	0.03	1.03	0.14	1.04	0.57
Lete	18.2	7.8	18.65	-11.38	0.55	0.17	2.78	0.08	0.54	0.47	2.79	0.51	2.72	1.42
Nampa No. 9	24.1	7.7	19.68	-12.2	0.35	0.15	1.43	0.07	0.19	0.08	2.13	0.09	2.08	1.07
Caldwell No. 16	20.6	8.2	20.4	-12.1	0.50	0.10	1.48	0.05	0.25	0.15	2.30	0.03	2.28	1.09
Johnson	16.5	7.9	1.02	-10	0.47	0.06	1.91	0.12	0.16	0.00	2.95	-0.02	2.9	1.47
Wright	19.2	7.9	0.32	-9.4	0.42	0.07	2.74	0.18	0.16	0.00	3.61	0.14	3.6	1.87
Kuespert	16.9	8	14.86	-11.2	0.45	0.07	1.48	0.12	0.15	0.01	2.46	0.01	2.46	1.23
Parma No. 10	24.3	7.8	1.23	-5.3	0.47	0.12	2.09	0.28	0.10	0.01	3.05	0.39	3.72	1.72
U of I	19.6	8.1	10.61	-9.5	0.50	0.10	1.17	0.18	0.08	0.02	2.62	-0.17	2.6	1.22

Calculation of DIC derived from matrix exchange processes

	Total DIC derived from exchange with aquifer carbonates	Portion of total DIC derived from CO_2 exchange in soil zone					
		Boise Front Springs		*Banner Creek Wells*		*Boise River*	
		$CO_{2(g)}$-$CaCO_3$	12.79	$CO_{2(g)}$-$CaCO_3$	12.94	$CO_{2(g)}$-$CaCO_3$	12.79
		$\delta^{13}C_{carb}$	$\delta^{13}C_{carb}$	$\delta^{13}C_{carb}$	$\delta^{13}C_{carb}$	$\delta^{13}C_{carb}$	$\delta^{13}C_{carb}$
		0	-5	0	-5	0	-5
Well Name	DIC_{carb} (mmol)	$DIC_{CO2-exch}$ (mmol)					
Christiansen	0.74	0.04	-0.07	0.04	-0.07	0.04	-0.07
Blacks Creek	1.04	0.11	-0.05	0.11	-0.04	0.11	-0.05
Guyer	0.58	0.10	0.02	0.09	0.02	0.10	0.02
Micron Shallow	1.00	0.10	-0.04	0.10	-0.04	0.10	-0.04
Micron Deep	0.95	0.17	0.05	0.17	0.05	0.17	0.05
Knox	0.87	0.09	-0.03	0.09	-0.03	0.09	-0.03
Market St.	0.86	0.09	-0.04	0.09	-0.04	0.09	-0.04
JR Flat	1.10	0.14	-0.02	0.14	-0.02	0.14	-0.02
McNabb	1.07	0.12	-0.04	0.12	-0.04	0.12	-0.04
Cassia No. 2	0.88	-0.17	-0.33	-0.16	-0.33	-0.17	-0.33
Cassia Monitor	0.86	0.11	-0.02	0.11	-0.02	0.11	-0.02
MAC	1.24	0.11	-0.08	0.11	-0.08	0.11	-0.08
Sunset West	1.27	0.16	-0.02	0.16	-0.02	0.16	-0.02
Amity	1.31	0.25	0.08	0.25	0.08	0.25	0.08
Westmoreland	0.71	0.01	-0.11	0.01	-0.11	0.01	-0.11
Goddard No. 1	0.93	-0.28	-0.48	-0.28	-0.48	-0.28	-0.48
Goddard No. 2	1.16	0.16	0.00	0.16	0.00	0.16	0.00
TVHP No. 1	1.13	0.19	0.03	0.19	0.03	0.19	0.03
HP	0.58	0.06	-0.03	0.06	-0.03	0.06	-0.03
Edgview	1.08	0.02	-0.15	0.02	-0.15	0.02	-0.15
St. Lukes	0.99	-0.27	-0.47	-0.27	-0.47	-0.27	-0.47
Meridian No. 15	0.73	0.08	-0.03	0.08	-0.03	0.08	-0.03
Meridian No. 19	0.62	0.05	-0.04	0.05	-0.04	0.05	-0.04
Schwisow	0.57	0.10	0.02	0.10	0.02	0.10	0.02
Lete	1.42	0.00	-0.22	0.00	-0.22	0.00	-0.22
Nampa No. 9	1.07	0.04	-0.12	0.04	-0.12	0.04	-0.12
Caldwell No. 16	1.09	0.00	-0.18	0.00	-0.17	0.00	-0.18
Johnson	1.47	-0.13	-0.39	-0.13	-0.39	-0.13	-0.39
Wright	1.87	-0.17	-0.50	-0.17	-0.49	-0.17	-0.50
Kuespert	1.23	-0.02	-0.22	-0.02	-0.22	-0.02	-0.22
Parma No. 10	1.72	-0.40	-0.75	-0.40	-0.75	-0.40	-0.75
U of I	1.22	-0.21	-0.44	-0.21	-0.44	-0.21	-0.44

Corrected Values of $^{14}C_{rech}$ Used in Ground Water Age Calculations Based on Boise Front Spring Recharge Conditions

Recharge Conditions Boise Front Springs		pP_{CO2} 1.7	pH 6.0	T(C) 9	$\delta^{13}C_{carb}$ 0	DIC_{rech} 1.50
Well Name	Uncorrected	CMB-ALK	CMB-CHEM	δ^{13}C-Mixing $\delta^{13}C_{rech}$ (‰)		MATEXCH
				-23.0	-21.4	
		closed system (Tamers, 1975)	closed system (Fontes and Garnier, 1979)	closed system (Pearson, 1965)[1]	open and closed system (Pearson, 1965)[2]	open and closed system (Fontes and Garnier, 1979; 1981)
Christiansen	100	108.9	67.0	50.9	54.7	49.3
Blacks Creek	100	76.3	59.1	55.7	59.8	52.7
Guyer	100	150.0	72.2	57.0	61.2	51.7
Micron Shallow	100	76.3	60.1	57.4	61.7	54.5
Micron Deep	100	91.5	61.3	58.7	63.1	52.8
Knox	100	94.3	63.3	54.3	58.4	51.1
Market St.	100	91.5	63.4	55.7	59.8	52.7
JR Flat	100	76.3	57.6	54.8	58.9	50.9
McNabb	100	70.4	58.3	58.3	62.6	55.2
Cassia No. 2	100	83.2	63.0	37.0	39.7	42.0
Cassia Monitor	100	83.2	63.5	61.3	65.9	58.0
MAC	100	54.1	54.8	61.3	65.9	59.2
Sunset West	100	61.0	54.1	58.3	62.6	54.7
Amity	100	57.2	53.4	65.2	70.1	59.8
Westmoreland	100	97.3	68.0	54.8	58.9	54.6
Goddard No. 1	100	72.0	61.6	33.9	36.4	41.5
Goddard No. 2	100	54.1	56.4	67.4	72.4	64.1
TVHP No. 1	100	65.4	57.1	63.5	68.2	58.9
HP	100	127.1	72.2	58.7	63.1	56.0
Edgview	100	65.4	58.2	54.3	58.4	53.9
St. Lukes	100	70.4	60.4	34.3	36.9	41.3
Meridian No. 15	100	99.5	67.1	59.1	63.6	56.3
Meridian No. 19	100	122.0	70.8	56.5	60.7	54.1
Schwisow	100	145.2	72.5	59.6	64.0	54.3
Lete	100	53.8	51.5	49.5	53.2	49.4
Nampa No. 9	100	70.4	58.4	53.0	57.0	51.9
Caldwell No. 16	100	65.4	57.9	52.6	56.5	52.6
Johnson	100	50.8	50.6	43.5	46.7	45.9
Wright	100	41.6	44.5	40.9	43.9	43.4
Kuespert	100	61.0	54.9	48.7	52.3	49.1
Parma No. 10	100	49.2	46.6	23.0	24.8	30.4
U of I	100	57.2	55.2	41.3	44.4	45.7

[1] Assumes a value of $\delta^{13}C_{rech}$ equal to that of soil DIC, with no fractionation. This assumption may be reasonable for waters with pH<7.5.

[2] Fractionation factor estimated from regression of Table 5.3, Clark and Fritz (1997).

Corrected Values of $^{14}C_{rech}$ Used in Ground Water Age Calculations Based on Banner Creek Well Recharge Conditions

Recharge Conditions Banner Cr. Wells		pP_{CO2} 2.2	pH 6.6	T(C) 8	$\delta^{13}C_{carb}$ 0	DIC_{rech} 0.84
Well Name	Uncorrected	CMB-ALK	CMB-CHEM	δ^{13}C-Mixing $\delta^{13}C_{rech}$ (‰)		MATEXCH
				-23.0	-18.0	
		closed system (Tamers, 1975)	closed system (Fontes and Garnier, 1979)	closed system (Pearson, 1965)[1]	open and closed system (Pearson, 1965)[2]	open and closed system (Fontes and Garnier, 1979; 1981)
Christiansen	100	61.0	53.2	50.9	65.0	49.3
Blacks Creek	100	42.7	44.7	55.7	71.1	52.7
Guyer	100	84.0	59.2	57.0	72.8	51.7
Micron Shallow	100	42.7	45.7	57.4	73.3	54.5
Micron Deep	100	51.2	47.0	58.7	75.0	52.8
Knox	100	52.8	49.1	54.3	69.4	51.1
Market St.	100	51.2	49.3	55.7	71.1	52.7
JR Flat	100	42.7	43.2	54.8	70.0	50.9
McNabb	100	39.4	43.9	58.3	74.4	55.2
Cassia No. 2	100	46.6	48.8	37.0	47.2	42.0
Cassia Monitor	100	46.6	49.3	61.3	78.3	58.0
MAC	100	30.3	40.4	61.3	78.3	59.2
Sunset West	100	34.2	39.8	58.3	74.4	54.7
Amity	100	32.0	39.1	65.2	83.3	59.8
Westmoreland	100	54.5	54.3	54.8	70.0	54.6
Goddard No. 1	100	40.3	47.4	33.9	43.3	41.5
Goddard No. 2	100	30.3	42.0	67.4	86.1	64.1
TVHP No. 1	100	36.6	42.7	63.5	81.1	58.9
HP	100	71.2	59.3	58.7	75.0	56.0
Edgview	100	36.6	43.8	54.3	69.4	53.9
St. Lukes	100	39.4	46.0	34.3	43.9	41.3
Meridian No. 15	100	55.7	53.4	59.1	75.6	56.3
Meridian No. 19	100	68.3	57.6	56.5	72.2	54.1
Schwisow	100	81.3	59.6	59.6	76.1	54.3
Lete	100	30.1	37.2	49.5	63.2	49.4
Nampa No. 9	100	39.4	44.0	53.0	67.8	51.9
Caldwell No. 16	100	36.6	43.5	52.6	67.2	52.6
Johnson	100	28.5	36.4	43.5	55.6	45.9
Wright	100	23.3	30.9	40.9	52.2	43.4
Kuespert	100	34.2	40.6	48.7	62.2	49.1
Parma No. 10	100	27.5	32.8	23.0	29.4	30.4
U of I	100	32.0	40.8	41.3	52.8	45.7

[1] Assumes a value of $\delta^{13}C_{rech}$ equal to that of soil DIC, with no fractionation. This assumption may be reasonable for waters with pH<7.5.

[2] Fractionation factor estimated from regression of Table 5.3, Clark and Fritz (1997).

Corrected Values of $^{14}C_{rech}$ Used in Ground Water Age Calculations Based on Boise River Recharge Conditions

Recharge Conditions		pP_{CO2}	pH	T(C)	$\delta^{13}C_{carb}$	DIC_{rech}
Boise River		3.3	7.9	9	0	0.77
Well Name	Uncorrected	CMB-ALK	CMB-CHEM	$\delta^{13}C$-Mixing $\delta^{13}C_{rech}$ (‰)		MATEXCH
				-23.0	-13.7	
		closed system (Tamers, 1975)	closed system (Fontes and Garnier, 1979)	closed system (Pearson, 1965)[1]	open and closed system (Pearson, 1965)[2]	open and closed system (Fontes and Garnier, 1979; 1981)
Christiansen	100	55.9	51.1	50.9	85.4	49.3
Blacks Creek	100	39.1	42.6	55.7	93.4	52.7
Guyer	100	77.0	57.1	57.0	95.6	51.7
Micron Shallow	100	39.1	43.6	57.4	96.4	54.5
Micron Deep	100	47.0	44.8	58.7	98.5	52.8
Knox	100	48.4	47.0	54.3	91.2	51.1
Market St.	100	47.0	47.1	55.7	93.4	52.7
JR Flat	100	39.1	41.1	54.8	92.0	50.9
McNabb	100	36.1	41.8	58.3	97.8	55.2
Cassia No. 2	100	42.7	46.7	37.0	62.0	42.0
Cassia Monitor	100	42.7	47.1	61.3	102.9	58.0
MAC	100	27.8	38.3	61.3	102.9	59.2
Sunset West	100	31.3	37.7	58.3	97.8	54.7
Amity	100	29.4	37.0	65.2	109.5	59.8
Westmoreland	100	50.0	52.1	54.8	92.0	54.6
Goddard No. 1	100	37.0	45.2	33.9	56.9	41.5
Goddard No. 2	100	27.8	39.9	67.4	113.1	64.1
TVHP No. 1	100	33.6	40.5	63.5	106.6	58.9
HP	100	65.2	57.2	58.7	98.5	56.0
Edgview	100	33.6	41.7	54.3	91.2	53.9
St. Lukes	100	36.1	43.9	34.3	57.7	41.3
Meridian No. 15	100	51.1	51.2	59.1	99.3	56.3
Meridian No. 19	100	62.6	55.5	56.5	94.9	54.1
Schwisow	100	74.6	57.5	59.6	100.0	54.3
Lete	100	27.6	35.2	49.5	83.1	49.4
Nampa No. 9	100	36.1	41.9	53.0	89.1	51.9
Caldwell No. 16	100	33.6	41.4	52.6	88.3	52.6
Johnson	100	26.1	34.4	43.5	73.0	45.9
Wright	100	21.4	29.1	40.9	68.6	43.4
Kuespert	100	31.3	38.5	48.7	81.8	49.1
Parma No. 10	100	25.3	31.0	23.0	38.7	30.4
U of I	100	29.4	38.8	41.3	69.3	45.7

[1] Assumes a value of $\delta^{13}C_{rech}$ equal to that of soil DIC, with no fractionation. This assumption may be reasonable for waters with pH<7.5.

[2] Fractionation factor estimated from regression of Table 5.3, Clark and Fritz (1997).

Corrected Ground Water ^{14}C-Ages Based on Boise Front Spring Recharge Conditions

Recharge Conditions	pP_{CO2}	pH	T(C)
Boise Front Springs	1.7	6.0	9

Well Name	uncorrected	CMB-ALK	CMB-CHEM	$\delta^{13}C$-mixing	$\delta^{13}C$-mixing	MATEXCH
		closed system (Tamers, 1975)	closed system (Fontes and Garnier, 1979)	closed system (Pearson, 1965) for recharge waters w/ pH<7.5	open and closed system (Pearson, 1965); fractionation factors calculated from Table 5.3	open and closed system (Fontes and Garnier, 1979; 1981)
Christiansen	4,204	4,911	896	-1,384	-788	-1,647
Blacks Creek	5,210	2,968	863	365	961	-93
Guyer	4,983	8,335	2,285	330	926	-478
Micron Shallow	6,876	4,634	2,661	2,285	2,881	1,858
Micron Deep	13,235	12,501	9,187	8,831	9,427	7,955
Knox	4,469	3,987	689	-572	24	-1,078
Market St.	8,674	7,940	4,912	3,829	4,425	3,372
JR Flat	8,412	6,170	3,850	3,437	4,033	2,825
McNabb	8,294	5,390	3,830	3,827	4,423	3,376
Cassia No. 2	20,860	19,337	17,043	12,630	13,226	13,697
Cassia Monitor	3,726	2,203	-33	-320	277	-774
MAC	10,979	5,906	6,003	6,934	7,530	6,639
Sunset West	8,936	4,849	3,857	4,469	5,065	3,946
Amity	10,550	5,930	5,366	7,017	7,613	6,303
Westmoreland	2,866	2,644	-324	-2,109	-1,513	-2,143
Goddard No. 1	10,377	7,667	6,376	1,438	2,034	3,107
Goddard No. 2	1,938	-3,134	-2,791	-1,324	-728	-1,737
TVHP No. 1	679	-2,837	-3,961	-3,079	-2,483	-3,690
HP	3,082	5,063	393	-1,323	-727	-1,712
Edgview	8,604	5,088	4,134	3,563	4,159	3,496
St. Lukes	15,728	12,824	11,554	6,893	7,489	8,415
Meridian No. 15	3,749	3,704	456	-595	1	-994
Meridian No. 19	4,093	5,737	1,239	-624	-27	-989
Schwisow	2,058	5,144	-603	-2,225	-1,629	-2,989
Lete	13,883	8,762	8,390	8,066	8,662	8,050
Nampa No. 9	13,439	10,535	8,990	8,197	8,793	8,016
Caldwell No. 16	13,142	9,626	8,627	7,832	8,428	7,827
Johnson	37,907	32,314	32,270	31,022	31,618	31,472
Wright	47,491	40,238	40,789	40,093	40,690	40,596
Kuespert	15,761	11,675	10,806	9,812	10,408	9,886
Parma No. 10	36,360	30,495	30,050	24,225	24,821	26,519
U of I	18,546	13,926	13,636	11,236	11,832	12,073

Corrected Ground Water ^{14}C-Ages Based on Banner Creek Well Recharge Conditions

Recharge Conditions	pP_{CO2}	pH	T(C)
Banner Cr. Wells	2.2	6.6	8

Well Name	uncorrected	CMB-ALK closed system (Tamers, 1975)	CMB-CHEM closed system (Fontes and Garnier, 1979)	$\delta^{13}C$-mixing closed system (Pearson, 1965) for recharge waters w/ pH<7.5	$\delta^{13}C$-mixing open and closed system (Pearson, 1965); fractionation factors calculated from Table 5.3	MATEXCH open and closed system (Fontes and Garnier, 1979; 1981)
Christiansen	4,204	117	-1,009	-1,384	642	-1,647
Blacks Creek	5,210	-1,825	-1,440	365	2,391	-93
Guyer	4,983	3,542	650	330	2,356	-478
Micron Shallow	6,876	-159	405	2,285	4,312	1,858
Micron Deep	13,235	7,708	6,992	8,831	10,857	7,955
Knox	4,469	-807	-1,406	-572	1,455	-1,078
Market St.	8,674	3,146	2,824	3,829	5,856	3,372
JR Flat	8,412	1,377	1,472	3,437	5,463	2,825
McNabb	8,294	597	1,485	3,827	5,854	3,376
Cassia No. 2	20,860	14,544	14,935	12,630	14,657	13,697
Cassia Monitor	3,726	-2,590	-2,119	-320	1,707	-774
MAC	10,979	1,113	3,489	6,934	8,960	6,639
Sunset West	8,936	56	1,312	4,469	6,496	3,946
Amity	10,550	1,137	2,787	7,017	9,043	6,303
Westmoreland	2,866	-2,150	-2,180	-2,109	-82	-2,143
Goddard No. 1	10,377	2,874	4,197	1,438	3,464	3,107
Goddard No. 2	1,938	-7,927	-5,225	-1,324	702	-1,737
TVHP No. 1	679	-7,631	-6,364	-3,079	-1,052	-3,690
HP	3,082	270	-1,239	-1,323	704	-1,712
Edgview	8,604	294	1,788	3,563	5,589	3,496
St. Lukes	15,728	8,031	9,313	6,893	8,920	8,415
Meridian No. 15	3,749	-1,089	-1,442	-595	1,432	-994
Meridian No. 19	4,093	944	-469	-624	1,403	-989
Schwisow	2,058	350	-2,221	-2,225	-198	-2,989
Lete	13,883	3,969	5,718	8,066	10,092	8,050
Nampa No. 9	13,439	5,742	6,651	8,197	10,223	8,016
Caldwell No. 16	13,142	4,832	6,265	7,832	9,858	7,827
Johnson	37,907	27,520	29,557	31,022	33,048	31,472
Wright	47,491	35,445	37,795	40,093	42,120	40,596
Kuespert	15,761	6,881	8,299	9,812	11,839	9,886
Parma No. 10	36,360	25,702	27,155	24,225	26,252	26,519
U of I	18,546	9,133	11,143	11,236	13,263	12,073

Corrected Ground Water ^{14}C-Ages Based on Boise Front Spring Recharge Conditions

Recharge Conditions	pP_{CO2}	pH	T(C)
Boise River	3.3	7.9	9

Well Name	uncorrected	CMB-ALK closed system (Tamers, 1975)	CMB-CHEM closed system (Fontes and Garnier, 1979)	$\delta^{13}C$-mixing closed system (Pearson, 1965) for recharge waters w/ pH<7.5	$\delta^{13}C$-mixing open and closed system (Pearson, 1965); fractionation factors calculated from Table 5.3	MATEXCH open and closed system (Fontes and Garnier, 1979; 1981)
Christiansen	4,204	-602	-1,353	-1,384	2,899	-1,647
Blacks Creek	5,210	-2,545	-1,845	365	4,648	-93
Guyer	4,983	2,822	349	330	4,613	-478
Micron Shallow	6,876	-878	7	2,285	6,568	1,858
Micron Deep	13,235	6,988	6,602	8,831	13,114	7,955
Knox	4,469	-1,526	-1,779	-572	3,711	-1,078
Market St.	8,674	2,427	2,451	3,829	8,112	3,372
JR Flat	8,412	657	1,056	3,437	7,720	2,825
McNabb	8,294	-122	1,074	3,827	8,111	3,376
Cassia No. 2	20,860	13,825	14,559	12,630	16,913	13,697
Cassia Monitor	3,726	-3,309	-2,491	-320	3,964	-774
MAC	10,979	394	3,053	6,934	11,217	6,639
Sunset West	8,936	-663	871	4,469	8,753	3,946
Amity	10,550	418	2,342	7,017	11,300	6,303
Westmoreland	2,866	-2,869	-2,516	-2,109	2,174	-2,143
Goddard No. 1	10,377	2,154	3,811	1,438	5,721	3,107
Goddard No. 2	1,938	-8,647	-5,649	-1,324	2,959	-1,737
TVHP No. 1	679	-8,350	-6,784	-3,079	1,205	-3,690
HP	3,082	-449	-1,539	-1,323	2,960	-1,712
Edgview	8,604	-425	1,376	3,563	7,846	3,496
St. Lukes	15,728	7,312	8,917	6,893	11,176	8,415
Meridian No. 15	3,749	-1,809	-1,786	-595	3,689	-994
Meridian No. 19	4,093	224	-782	-624	3,660	-989
Schwisow	2,058	-369	-2,519	-2,225	2,058	-2,989
Lete	13,883	3,249	5,260	8,066	12,349	8,050
Nampa No. 9	13,439	5,023	6,241	8,197	12,480	8,016
Caldwell No. 16	13,142	4,113	5,851	7,832	12,115	7,827
Johnson	37,907	26,801	29,092	31,022	35,305	31,472
Wright	47,491	34,725	37,291	40,093	44,377	40,596
Kuespert	15,761	6,162	7,864	9,812	14,095	9,886
Parma No. 10	36,360	24,982	26,665	24,225	28,508	26,519
U of I	18,546	8,413	10,710	11,236	15,519	12,073

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33 H

Influence of Canal Seepage on Aquifer Recharge near the New York Canal

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EXECUTIVE SUMMARY

The purpose of this study was to provide constraints on the interaction between surface water and ground water near the New York Canal (NYC). To accomplish this, spatial distributions of key hydrochemical parameters were analyzed with respect to aquifer stratigraphy.

Occurrence of tritium (^3H) in most of the ground water samples taken from the upper 200 to 300 feet of stratigraphic section near the NYC provides strong evidence of rapid recharge of Snake River Group aquifers. Ground water residence times range from several years in shallow, perched aquifers adjacent to the canal to approximately 100 years in deeper, confined or semi-confined aquifers. Elevated concentrations of nitrate (NO_3) and carbon dioxide (CO_2) in aquifers underlying irrigated fields west of the canal demonstrate the effect of flood-irrigation on ground water recharge. Ground water in aquifers east of the canal do not underlie irrigated land and do not exhibit elevated concentrations of NO_3 and CO_2. A ground water divide directly beneath the canal appears to minimize mixing of these waters.

Lack of ^3H and NO_3 and an abrupt decrease in conductivity (C_s) in ground water from wells that penetrate thick, blue clay layers at approximately 2,400 feet below mean sea level suggests that these aquifers do not receive substantial recharge from overlying ground water. Previous analysis of ground water ages suggest that these aquifers contain paleo-water and are part of a much larger, regional ground water system.

Our investigation provided the following primary conclusions:

1. Losses from and gains to the NYC correlate strongly with local stratigraphy.
2. Aquifers contained in the first few hundred feet of alluvial sediment near the canal are recharged by canal seepage and by percolating irrigation water where they are overlain by flood-irrigated fields.
3. Ground water in these shallow alluvial aquifers was recharged during the past 50 years.
4. Distinct geochemical signatures can be used to differentiate between ground water in shallow, alluvial aquifers and ground water in deeper, regional aquifers.
5. Contemporary surface water is not a major source of recharge to deep, regional aquifers beneath the NYC.

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1 INTRODUCTION

1.1 Background

Rapid population growth and changes in agricultural land use have contributed to increased ground water withdrawals in the Treasure Valley[1] during the past ten years. Public concerns about localized ground water declines in some areas of the Treasure Valley have prompted the Idaho Department of Water Resources (IDWR), United Water Idaho, Inc. (UWI), Ada and Canyon Counties, U.S. Geological Survey (USGS), U.S. Bureau of Reclamation (USBR), and a number of city governments to initiate the Treasure Valley Hydrologic Project (TVHP). The purpose of the TVHP is to develop a better understanding of ground water resources in the Treasure Valley and to evaluate how the ground water system will respond to long-term changes in regional hydraulic stresses. To accomplish these goals it is necessary to (1) understand and quantify the various sources of recharge to the regional ground water system and (2) accurately distribute inflows and outflows of water among the primary aquifer layers.

Canal seepage and deep percolation of irrigation water dominate the basin water balance (Urban and Petrich, 1998). Ground water mounding beneath the extensive canal system is often attributed to canal seepage. An analysis of seepage from the New York Canal (NYC) estimates that cumulative seepage rates range between 12% and 20% at canal flows of 439 to 980 cubic feet per second (cfs) (Berenbrock, 1999; Carlson and Petrich, 1999).[2] Carlson and Petrich (1999) conclude that (1) cumulative seepage rates are proportional to canal flow, and (2) seepage rates in various reaches of the canal are controlled largely by underlying geology and depth to ground water. The extent to which canal seepage mixes in the underlying aquifers is presently unknown; however, it is an important aspect of describing recharge to the regional ground water system.

Environmental tracers provide an excellent opportunity to address water movement in the subsurface (Clark and Fritz, 1997). Tritium (^3H) is particularly useful for understanding near-surface ground water flow. Large quantities of this radio-isotope of hydrogen were released into the atmosphere during nuclear bomb testing in the 1950s and 1960s. After these releases, concentrations of ^3H in the atmosphere diminished because of radioactive decay and removal by rain. Presence of ^3H in ground water allows ground water recharge during the period of 1960–2000 to be distinguished from

[1] Treasure Valley is a socio-economic area that includes the entire lower Boise River watershed and extends south and west to the Snake River.

[2] Estimates of seepage from the NYC were obtained from flow measurements taken in 1997 and 1998 during periods of no diversion. These measurements are discussed by Berenbrock (1999) and Carlson and Petrich (1999).

ground water recharged prior to 1950. In some cases, more accurate estimates of ground water age can be obtained.

In addition to ^{3}H, measurements of nutrients and dissolved ions in ground water can be used to identify the recharge environment of ground water in some Treasure Valley aquifers. For example, the presence of nitrate greater than about 2 mg/L^{-1} is generally associated with agricultural applications of nitrogen fertilizer via deep percolation of irrigation water. Very low dissolved nitrate concentrations in seepage from the NYC contrast sharply with elevated nitrate concentrations in percolating irrigation water. The canal transports high-quality water from the upper Boise River drainage, and in its upstream reaches, has no surface water return flows. Thus, water seeping from the NYC contains very low concentrations of nitrate. Similarly, other dissolved constituents like chloride and sulfate can be used to distinguish sources of ground water recharge.

Dissolved CO_2 is also an indicator of the ground water recharge environment. The partial pressure of CO_2 in natural precipitation and in rivers and streams fed by natural precipitation is approximately $10^{-3.5}$ bar. This value is relatively constant because of equilibrium exchange with atmospheric CO_2. When water passes through the soil, however, the P_{CO_2} is enriched by microbial respiration. The value of P_{CO_2} in soil water is about 10^{-2} bar. Partial pressures of $>10^{-2.5}$ bar are strong evidence that the water did not originate as canal seepage.

1.2 Previous and Related Work

No previous work conducted in the Treasure Valley documents the extent of surface and ground water interaction associated with canal seepage. However, the results of several limited isotope geochemistry studies in the Boise area warrant review. Radiocarbon (^{14}C) ages of water sampled from the Amity, Mac, and Sunset West wells, which are all completed at depths of 400 to 500 feet in Idaho Group sediments beneath the NYC, show that these waters were recharged between 5,000 and 9,000 years ago (Hutchings and Petrich, 2001; Parliman and Spinazola, 1998). The existence of paleo ground water precludes a direct, dynamic connection to surface water. It is also unlikely that these aquifers are recharged by shallow, alluvial aquifers that are in direct connection with surface water. This temporal distinction is further supported by measurements of ^{3}H in ground water samples from five shallow wells adjacent to the NYC (USGS, unpublished data). These measurements suggest that downward movement of surface water originating from canal seepage and flood irrigation is limited to a depth of about 200 feet since the 1950s (D. Parliman, pers. comm.). Additional anecdotal evidence is found in the vertical distribution of nitrate (N) in Treasure Valley ground water. Occurrence of elevated N (>2 mg N/L^{-1}) is common in shallow aquifers but sparse in deeper aquifers (Parliman and Spinazola, 1998; Neely and Crockett, 1998).

The aforementioned studies are limited in scope and do not directly address ground water recharge. Nonetheless, they suggest that canal seepage and percolating irrigation water may be important sources of recharge to underlying shallow aquifers. Conceptually, these shallow aquifers discharge at nearby drains; however, downward hydraulic gradients beneath the NYC raise the question of whether these shallow aquifers supply water to deeper, regional aquifers.

1.3 Project Purpose and Objectives

The purpose of the present study was to provide additional constraints on the distribution of water balance data among principal aquifer layers and add to the reliability of canal seepage data. The specific objectives are to (1) measure key hydrochemical indicators in canal water and in ground water beneath the canal, and (2) use these indicators to trace water movement from the canal into underlying aquifers.

2 METHODS

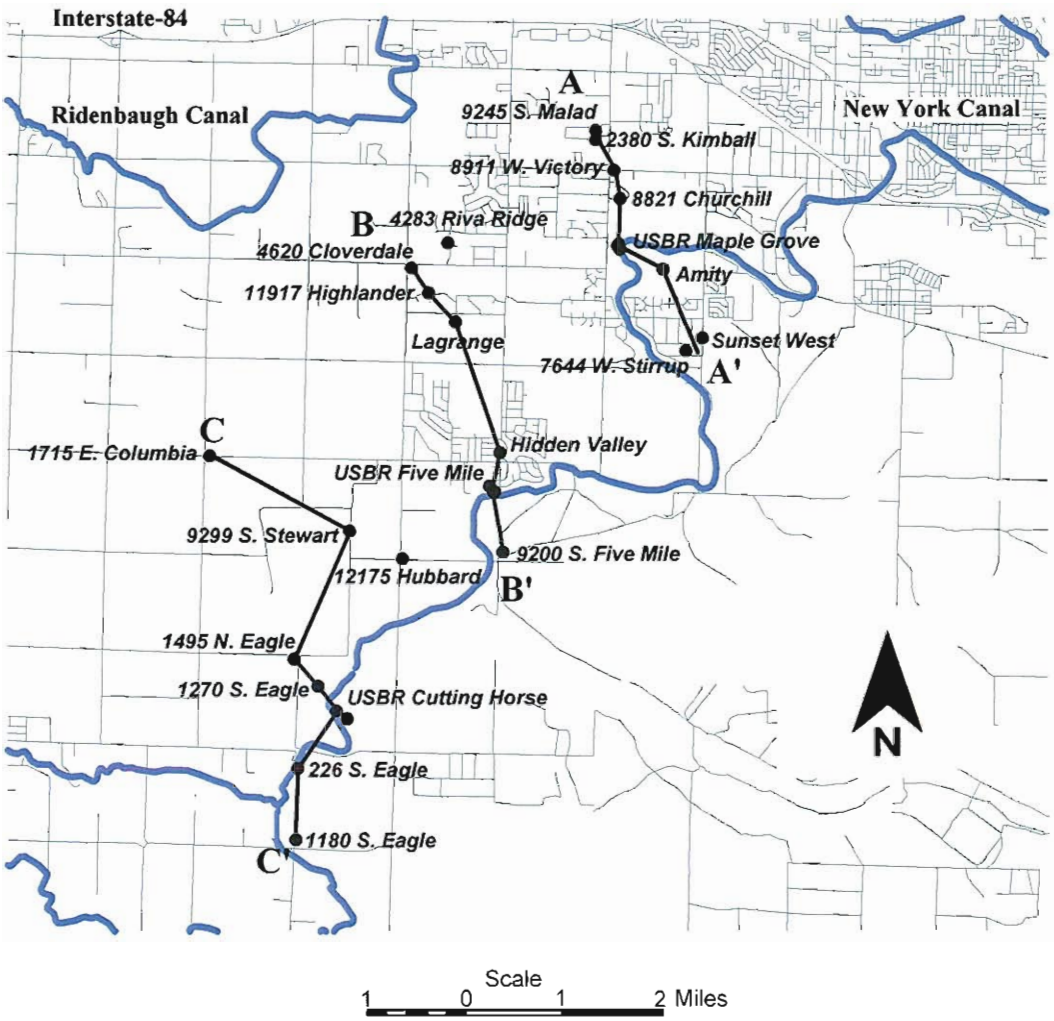
The objectives of this study required collection of ground water samples and measurement of a suite of dissolved constituents. Sampling well selection criteria, sampling procedures, chemical analyses, and the Quality Assurance (QA) plan are summarized below. The summary is followed by a detailed description of data analysis procedures. A complete listing of well information and water sampling data is given in Appendix A.

2.1 Well Selection

Twenty-eight wells adjacent to the NYC were selected for ground water sampling (Figure 1). The wells lie along three transects that bisect the canal and include eight recently drilled USBR monitoring wells. Fewer wells exist on the east side of the canal, resulting in a somewhat disproportionate coverage. The selected wells encompass a range of shallow and intermediate completion depths in aquifers underlying the canal. Most wells selected for sampling are pumped for domestic water supplies and meet the following depth criteria: (1) the top of the water-bearing zone (WBZ) is between 0 and 99 feet below ground surface (bgs) and the WBZ is less than 50 feet thick, or (2) the top of the WBZ is between 100 and 299 feet bgs and the WBZ is less than 200 feet thick. Drillers' logs were reviewed to insure that detailed lithologic information was available and that an adequate surface seal minimized the possibility for surface water leakage down the casing. Additional criteria included well accessibility and the presence of water level data.

2.2 Ground Water Sampling and QA/QC

The USGS (under contract with IDWR) obtained ground water samples from the wells shown in Figure 1. These wells were sampled within a 45-day period (to minimize temporal changes in ground water chemistry that could occur in shallow aquifers) beginning in March 1999. Sampling closely followed Standard Operating Procedures (SOPs) developed for IDWR's Statewide Ground Water Quality Program. Well sampling required completion of a field site inventory (SOP 1.00), well purging (SOP 3.00), equipment decontamination (SOP 4.00), sample collection (applicable parts of SOP 5.00), quality control sampling (SOP 9.00), sample labeling (SOP 8.00), and sample shipping (SOP 6.00). Quality control sampling consisted of two duplicate samples per each sampling effort, one equipment blank per month of sampling, and one blind reference of each analyte per month of sampling.



Well names correspond to data tabulated in Appendix 1. Lines A-A', B-B', and C-C' correspond to geologic cross-sections shown in Figure 3, Figure 4, and Figure 5.

Figure 1. Names and locations of NYC sampling wells.

The QA Plan for the Statewide Water Quality Monitoring Program was adopted to evaluate ground water sampling and analysis during this study. The plan ensured that date were (1) collected in a manner consistent with the research objectives, (2) accurately represented the actual ground water conditions, and (3) technically defensible. Applicable sections of the QA Plan as they applied to the analytes listed above are QA Objectives, Sampling Procedures, Quality Control (QC) Checks, and Calculation of Data Quality Indicators. Quality Assurance observations were conducted at the field and laboratory level. These observations included (1) previewing laboratory QA procedures prior to sample submission, (2) reviewing laboratory QA data upon receipt by project personnel, (3) observing field sampling

techniques, and (4) evaluating QC data, including ion balances, precision of duplicate analyses, and accuracy of blind references.

2.3 Units of Measurement

All data, except isotopic measurements, are reported using International System of Units (SI).[3] For straightforward comparisons with previously reported data, ^3H measurements are reported in units of picoCuries per liter (pCi/L^{-1}).

2.4 Data Analysis

The contribution of surface water to aquifers underlying the NYC was examined by (1) creating and examining geologic maps and cross-sections showing permeable and impermeable stratigraphic units beneath the canal, and (2) correlating the stratigraphy to spatial distribution of C_s, ^3H, NO_3, SO_4, CO_2, and other geochemical indicators of recent surface water. Interpretation of subsurface geology was based on a detailed survey of driller's logs (using IDWR's WELL_LOG software) and on previous geologic mapping. The relative influence of canal seepage and percolating irrigation water was resolved by comparing concentrations of NO_3, SO_4, and CO_2 in different strata and at various distances from the canal. The P_{CO_2} in ground water was calculated from measurements of dissolved HCO_3^- and CO_3^-, and pH. This information was compared to measurements of canal seepage (Carlson and Petrich, 1999) and to water level measurements in shallow wells near the canal (Berenbrock, 1999).

A qualitative approach was employed to estimate ground water residence times in the shallow aquifers. The approach was based on known changes in atmospheric ^3H levels and on timing of agricultural development associated with Boise Project diversions. A thorough review of age interpretations of ^3H in ground water is given in Clark and Fritz (1998). Interpretations used for this study are summarized in Table 1. Substantial irrigation from diversions in the NYC and Mora Canal began in about 1911 with the construction of Arrowrock Reservoir (Warnick and Brockway, 1974; Higginsen, 1981). The acreage of irrigated land was comparatively small prior to construction of Arrowrock Reservoir; therefore, it is unlikely that surface water diversions were a major source of recharge prior to 1911. Large-scale commercial use of nitrogen fertilizer began after World War II; therefore, ground water containing NO_3-N concentrations greater than a few parts per million (ppm) most likely originated in the 1940s or later. Together, relative concentrations of ^3H and N place a limit on the age of ground water. For example, ground water containing 16 to 50 pCi/L^{-1} ^3H and 10 mg/L^{-1} NO_3-N is clearly modern and was recharged during the past ten years. In contrast, ground water containing <3 mg/L^{-1} ^3H and <2 mg/L^{-1} NO_3-N is older than

[3] A reference of SI units can be found at http://www.unc.edu/~rowlett/units/sipm.html.

1940. Ground water containing <3 mg/L^{-1} ^3H and 5 mg/L^{-1} NO_3-N probably originated in the late 1940s.

^3H (pCi/L^{-1})	Interpretation
<3	Submodern water recharged before 1952
3-15	Mixture of submodern and modern water
16-50	Modern water recharged during the past ten years
50-100	Considerable proportion of recharge during the 1960s
>100	Dominant proportion of recharge during the 1960s

Table 1. Interpretation of ground water recharge based on ^3H concentrations (after Clark and Fritz, 1997).

3 GEOHYDROLOGY

3.1 Geologic Setting

Three general groups of sediment underlie the NYC in the first 1,000 feet of stratigraphic section. The groups consist of (1) Idaho Group lacustrine clays and sands overlain by (2) Snake River Group sediments and (3) Snake River Group basalts. The Idaho Group sediments were deposited during episodes of basin filling and lie below an erosional unconformity in the vicinity of the NYC. Idaho Group clays and sands are present at depths along the entire reach of the canal and appear to correlate with previously mapped Pliocene Idaho Group sediments (Burnham and Wood, 1992; Malde, 1991). Sand and clay units beneath the northeastern reaches of the NYC have similar positions and elevations as the Terteling Springs Formation, while sands and clays underlying the southwestern portion of the NYC appear to match the Glenns Ferry Formation.

The Snake River Group includes deposits that lie above the gravel and erosional unconformity. Thin terrace gravels of the upper Snake River Group appear to overlie the Idaho Group sand and clay units in much of the section. Tertiary Bonneville Point gravels and sands are believed to underlie younger Pleistocene terrace gravels near the eastern extent of the canal (Othberg, 1994). In these areas, alluvial gravel units occur to depths of approximately 600 feet bgs. In the western reaches of the canal the gravel units are considerable thinner and most likely correlate with gravels of the Tenmile terrace. Tenmile terrace gravels are believed to be Pliocene and Pleistocene in age (Othberg, 1994). In general, stratigraphic sequences appear to be more laterally continuous under the western portion of the study area than under the eastern portion. Pleistocene basalts cap the Tenmile gravel in the western portion of the study area. These basalts most likely erupted from local shield volcanoes such as Kuna Butte, Pickles Butte, and Powers Butte. Isolated basalt flows along the northeastern reaches of the canal likely correlate to basalts of the Gowen and Fivemile terraces. A generalized geologic map delineates Quaternary basalt flows and unconsolidated sediments in the upper section of the study area (Figure 2).

Several faults may affect water-bearing sedimentary units in central reaches of the canal (Figure 2). Map locations of the offset units are based on prior investigations and lithologic interpretation of well logs. One such fault, which occurs in section 19, Township 3 North, Range 2 East, is thought to represent the most recent period of faulting in the area (Burnham and Wood, 1992). This fault offsets Sunrise terrace gravels by approximately 1.5 feet. This small offset is unlikely to have an observable effect on ground water flow. Numerous faults with more substantial offset are documented in older sedimentary units (Burnham and Wood, 1992; Othberg, 1994).

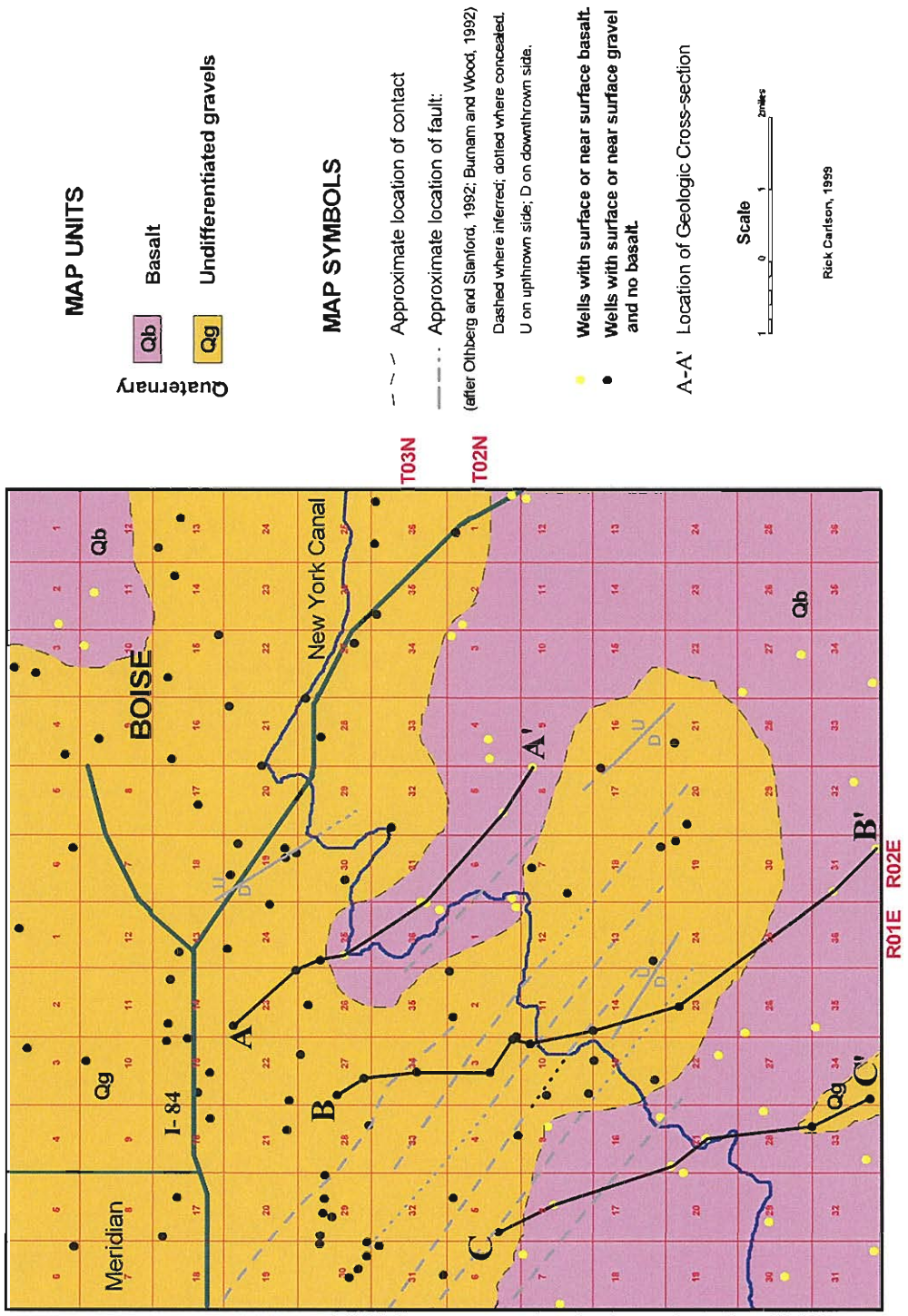


Figure 2. Map of surficial geology in the NYC study area emphasizing the occurrence of Quaternary Basalt and undifferentiated alluvial gravel. Cross-sections A-A', B-B', and C-C' are shown in Figure 3, Figure 4, and Figure 5.

3.2 Hydrostratigraphy

Geologic cross-sections constructed from well logs display more detail of the basalt and alluvium directly underlying the NYC (Figure 3, Figure 4, and Figure 5). These cross-sections are based on drillers' records of well cuttings. The most important hydrologic features of these cross-sections are clay beds intercalated into the coarser sand and gravel aquifer layers. At elevations above approximately 2,400 feet, the clay beds are between 10 and 20 feet thick and appear to be horizontally continuous on a scale of up to 2 or 3 miles. Below approximately 2,400 feet, individual beds range between 30 and 80 feet thick. In the Maple Grove cross-section, these beds are laterally continuous over distances greater than 6 miles (Figure 3). A similar series of continuous beds may exist in two wells below 2,500 feet in the Five Mile cross-section, although lack of deeper wells in the eastern portion of the cross-section makes this finding uncertain (Figure 4). These clay beds may play an important role in restricting vertical mixing of water between adjacent aquifer units.

Another important feature of the cross-sections is the location of faults. The fault locations are transferred from the surficial geologic maps of Othberg and Sanford (1992); as a result, the locations are approximate and the affected sedimentary units are not known. The point of locating these faults on the cross-sections is to show where lithologic offset may provide the hydraulic connection between aquifer units. No faults are mapped on the Maple Grove section, a single fault may bisect sediments of the Cutting Horse section, and numerous faults appear on the Five Mile section. Finally, surficial basalt is observed in all three cross-sections. The contact between the basalt and the underlying alluvium may provide highly permeable pathways through which water could rapidly move into deeper aquifers.

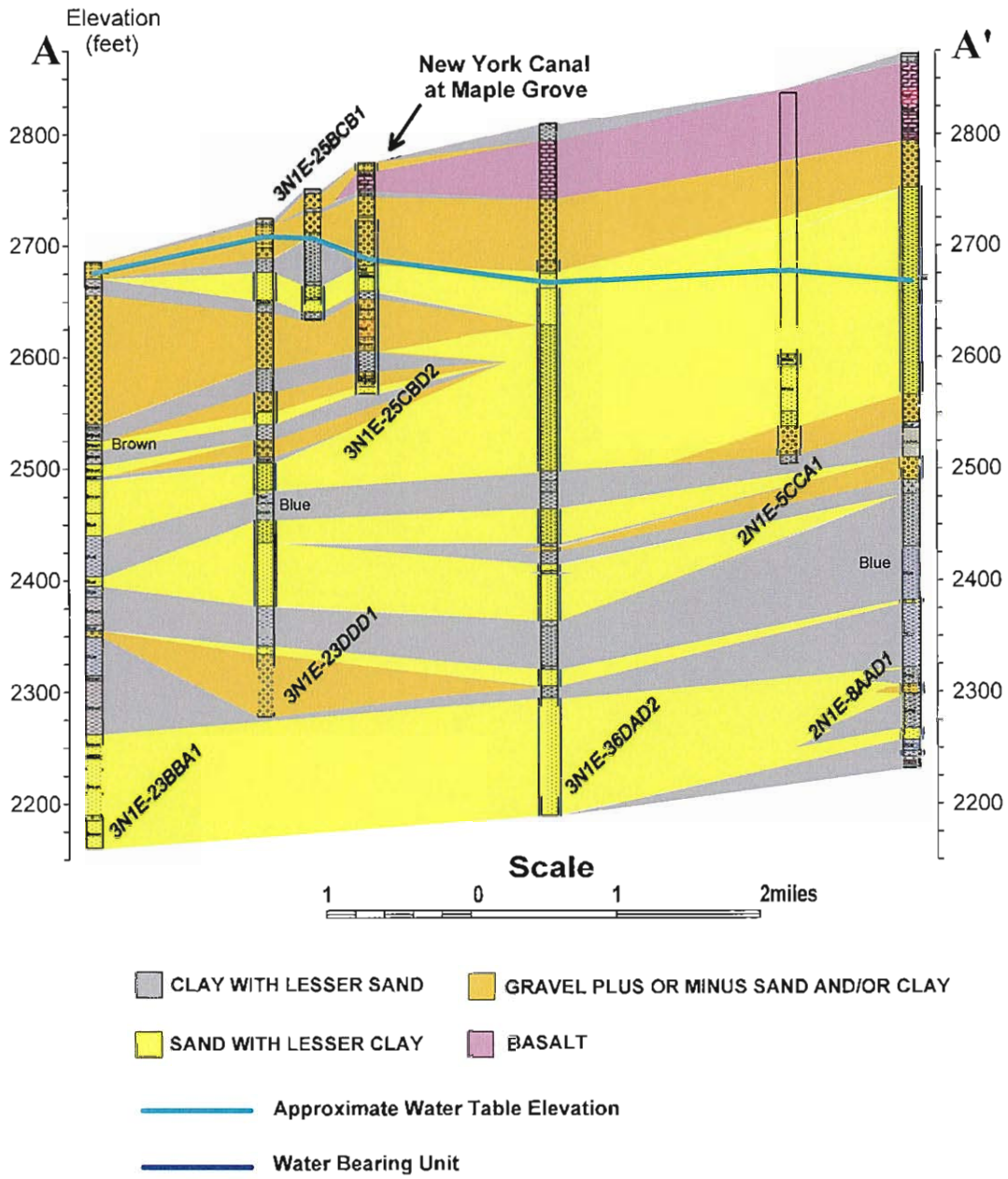


Figure 3. Geologic cross-section bisecting the NYC at Maple Grove Road. The location of A-A' is shown in Figure 2. Stratigraphy, water table, and occurrence of water are interpreted from drillers' logs.

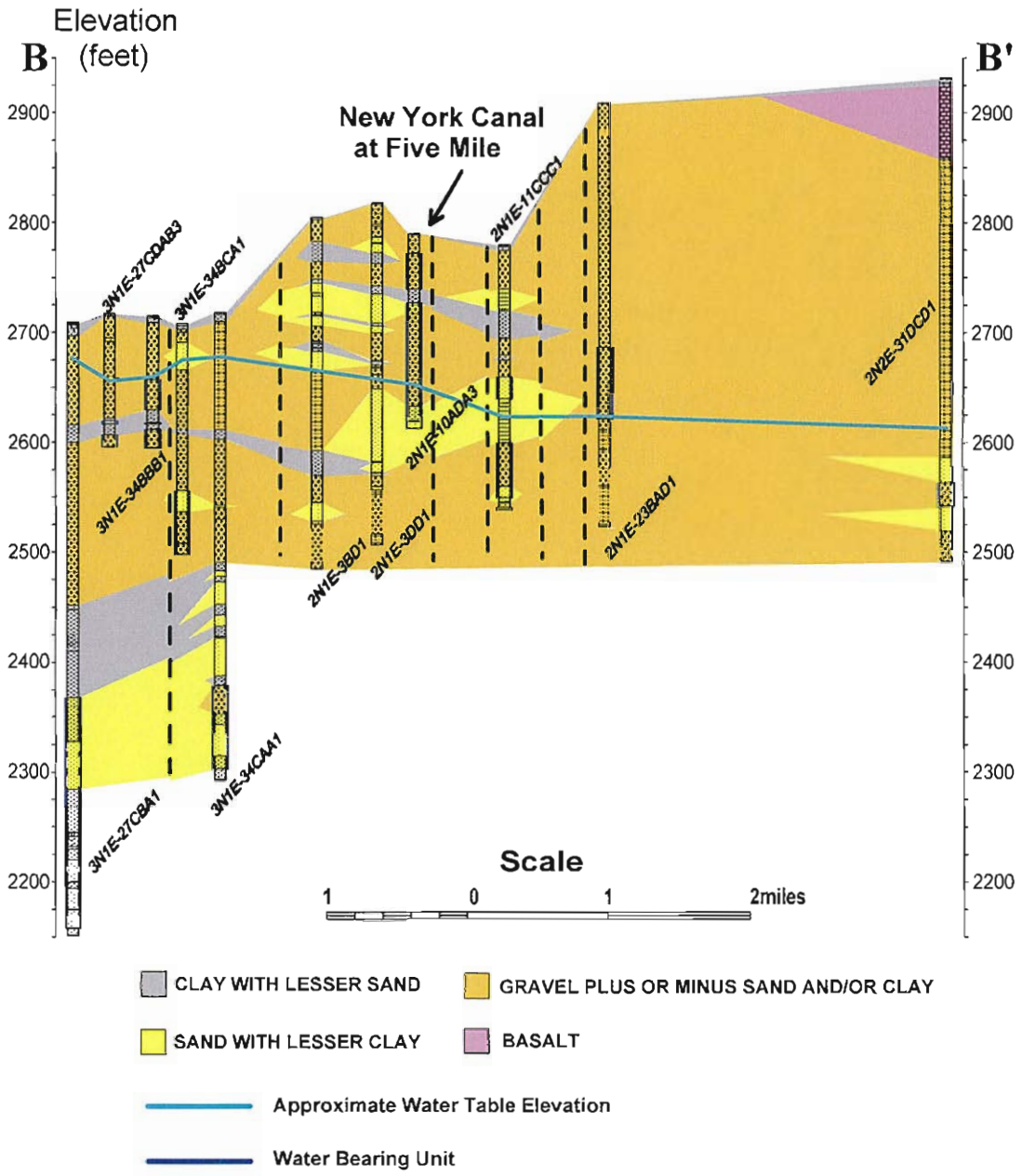


Figure 4. Geologic cross-section bisecting the NYC at Five Mile Road. The location of B-B' is shown in Figure 2. Stratigraphy, water table, and occurrence of water are interpreted from drillers' logs.

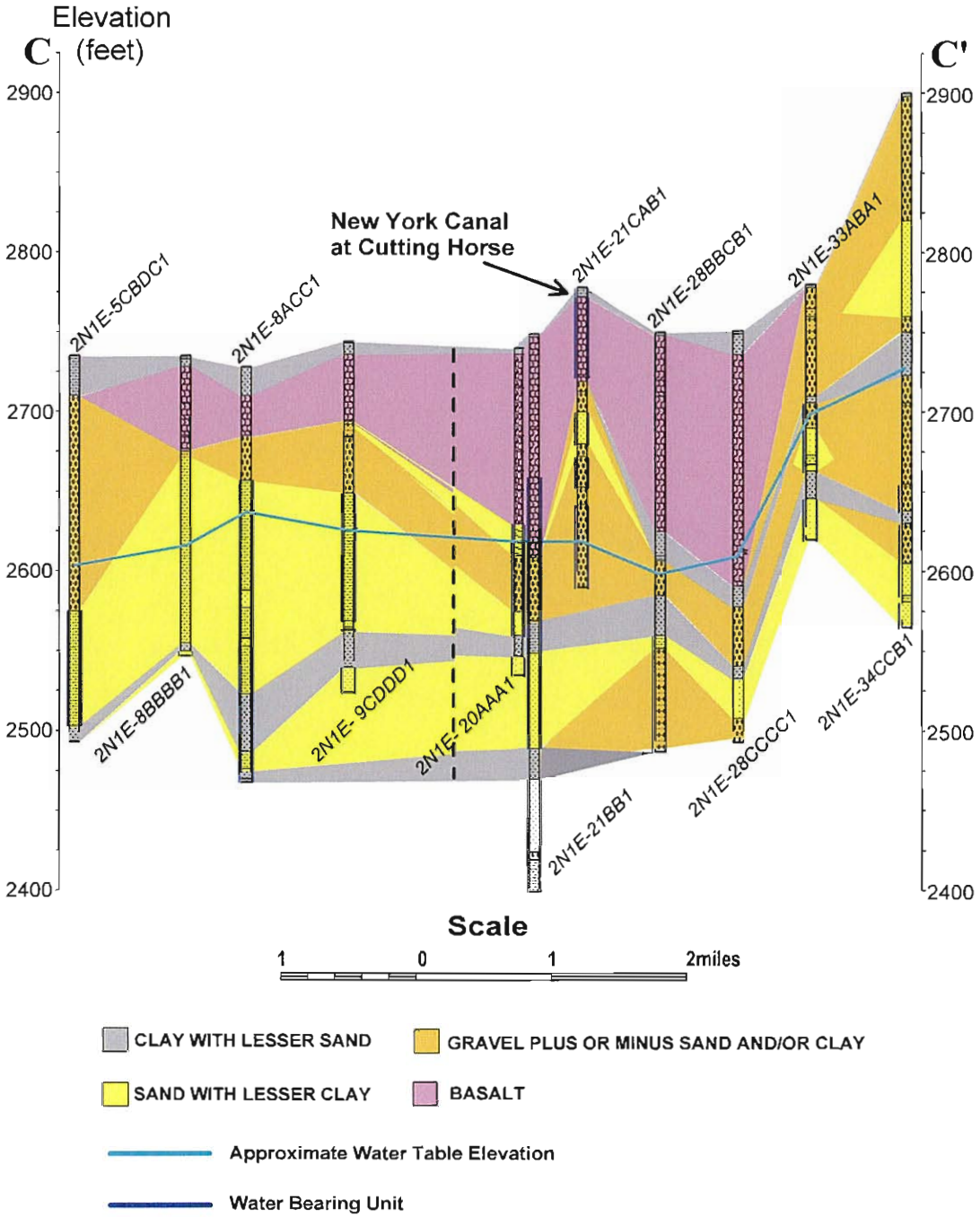


Figure 5. Geologic cross-section bisecting the NYC at Cutting Horse Road. The location of C-C' is shown in Figure 2. Stratigraphy, water table, and occurrence of water are interpreted from drillers' logs.

The shallowest aquifers that we sampled were penetrated by the USBR wells located within approximately 300 feet of the canal bank shown in the Maple Grove, Five Mile, and Cutting Horse cross-sections. These aquifers appear to be perched above shallow clay beds that occur at an elevation of approximately 2,675 feet and extend several miles northwest from the canal. Shallow clay zones are not ubiquitous in the first 50 to 100 feet of section beneath basalt flows. However, an unconfined aquifer clearly exists at approximately 160 feet beneath the canal at the USBR Cutting Horse well where the upper 20 to 60 feet of section at this location is comprised of basalt (Figure 5). Water levels in all of these shallow aquifers respond to changes in canal flow within a few days (Spinazola, pers. comm.). The dynamic character of the perched aquifers appears to be closely related to the shallow clay beds. Existence of perched ground water west of the canal at Maple Grove and Five Mile may reflect the gaining/losing character of the canal along the reaches upstream from these wells. The reach between Gowen Road and Cole Road lost 80 to 150 cfs in the four measurements taken at canal flows between 440 and 980 cfs (Carlson and Petrich, 1999). The Maple Grove well site lies in the middle of this reach, where the canal bends around a basalt outcrop (Figure 1 and Figure 2). In contrast, the reach between Cole Road and Hubbard Road, which encompasses the Five Mile well site, gained between 20 and 130 cfs over the same range of canal flows. Shallow clay extending west from beneath these reaches may conduct water recharged along the losing reaches back into the canal near the Five Mile well site.

The canal reach between Hubbard Road and Kuna Road, which includes the Cutting Horse well site, lost between 15 and 30 cfs. An unconfined aquifer zone lies directly beneath the NYC under the surficial basalt at this location (Figure 5). This aquifer appears to be perched above a clay layer at approximately 2,550 feet.

4 SPATIAL DISTRIBUTIONS OF GEOCHEMICAL TRACERS

A conceptual model of recharge processes near the NYC can be developed from the observed spatial distribution of geochemical tracers underlying the canal. Geochemical data from the shallow USBR wells (which penetrate perched aquifers in the upper 100 feet of section adjacent to the canal) are similar to data from surface water sampled in the canal at Diversion Dam (Table 2). Tritium concentrations in the shallow aquifers at the Maple Grove site are the same as the ^3H concentrations measured in canal water, showing that both the aquifer water and the source water are modern (Table 2, Figure 6). Low temperature, C_s, and SO_4 concentrations indicate that the water has not moved far from its recharge source. Concentrations of NO_3 are at background levels, while P_{CO_2} in canal water and in perched water at the Maple Grove site reflect atmospheric equilibrium.

Sampling Zone	Approx. elev. (feet)	^3H (pCi/L)	T (°C)	C_s (µS/cm)	NO_3-N (mg/L)	SO_4 (mg/L)	P_{CO_2} (bar)
Canal Water	surface	28	9	62	0.1	1.5	$10^{-3.3}$
Shallow/Perched	>2,675	26-33	11-14	83-175	0.1-0.3	1.6-9.8	$10^{-2.7}$-$10^{-3.4}$
Middle West	2,500-2,675	27-89	11-15	435-644	0.7-5.0	22-65	$10^{-2.2}$-$10^{-2.7}$
Middle East	2,500-2,675	32-49	13-14	119-330	0.2-2.3	6.1-21	$10^{-2.7}$-$10^{-3.4}$
Deep	2,400-2,500	<2.5-19	13-24	660-907	0.1-5.6	110-170	$10^{-2.3}$-$10^{-2.6}$
Regional	<2,400	<2.5-7	18-20	317-374	0.1-0.2	24-44	$10^{-2.4}$-$10^{-2.7}$

Table 2. Geochemical indicators of canal seepage and deep percolation and their relation to aquifer stratigraphy.

Similar relationships exist between canal water and shallow aquifers at the Five Mile and Cutting Horse sites (Figure 7 and Figure 8). There are two exceptions. First, P_{CO_2} of water from the shallow Five Mile and Cutting Horse USBR wells are between $10^{-2.7}$ and $10^{-2.8}$ bar, implying that some mixing occurs between canal seepage and percolating irrigation water in shallow aquifers adjacent to the canal. Second, conductivity in the Cutting Horse well is about 50 µS/L greater than observed at the two upstream locations. The increase is not large compared to C_s observed deeper in the section. Greater C_s at downstream locations suggests that downward seepage from the canal is not the only recharge process at work. A scenario that can explain these observations includes (1) recharge of the shallow aquifers by canal seepage in the Gowen Road to Cole Road losing reach, (2) a contribution of percolating flood-irrigation water from fields that boarder the canal, and (3) flow of this mixture back toward the gaining reaches.

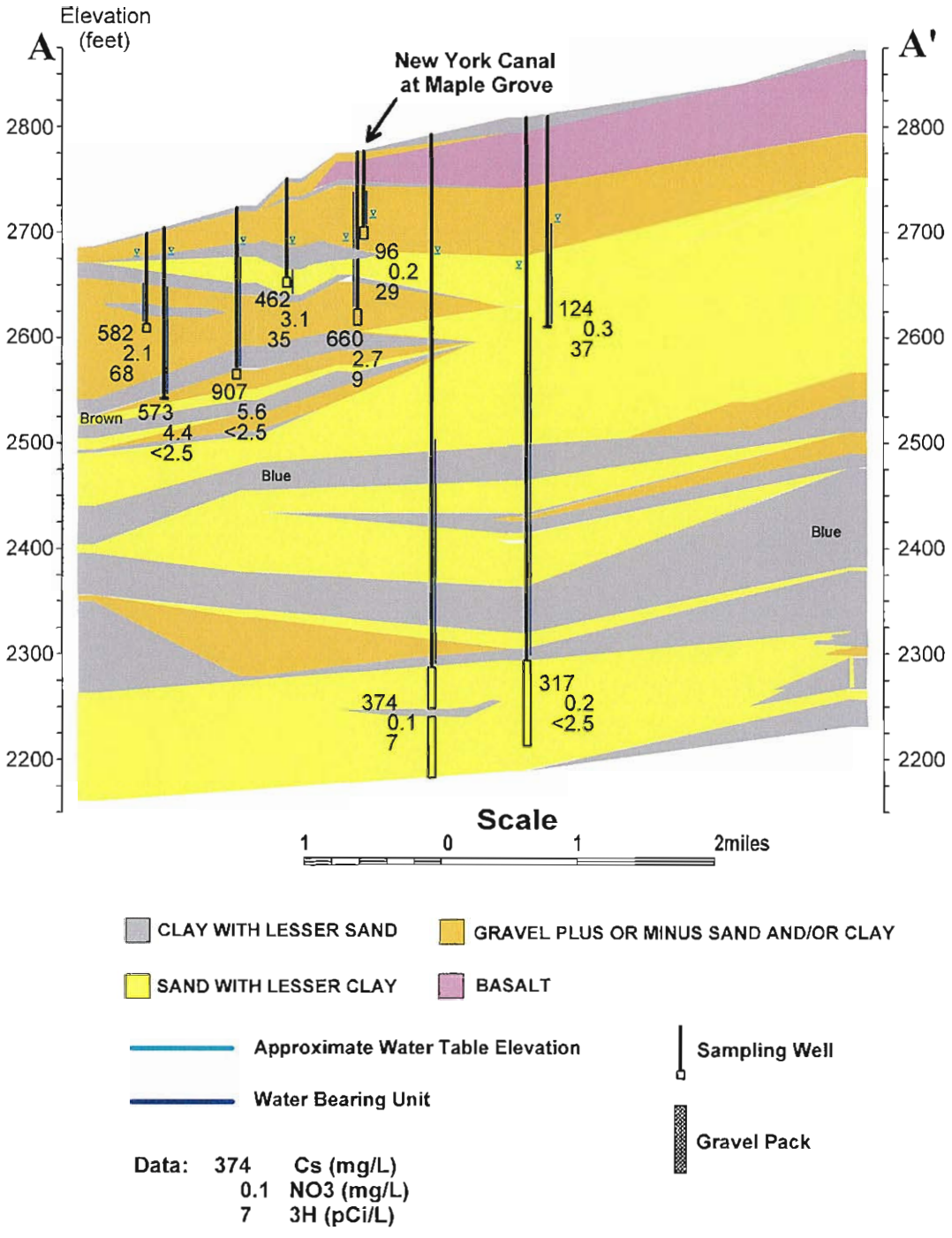


Figure 6. Ground water chemistry and aquifer stratigraphy near the NYC at Maple Grove Road. The geologic cross-section A-A' is shown in Figure 2. Names and locations of sampling wells are shown in Figure 1.

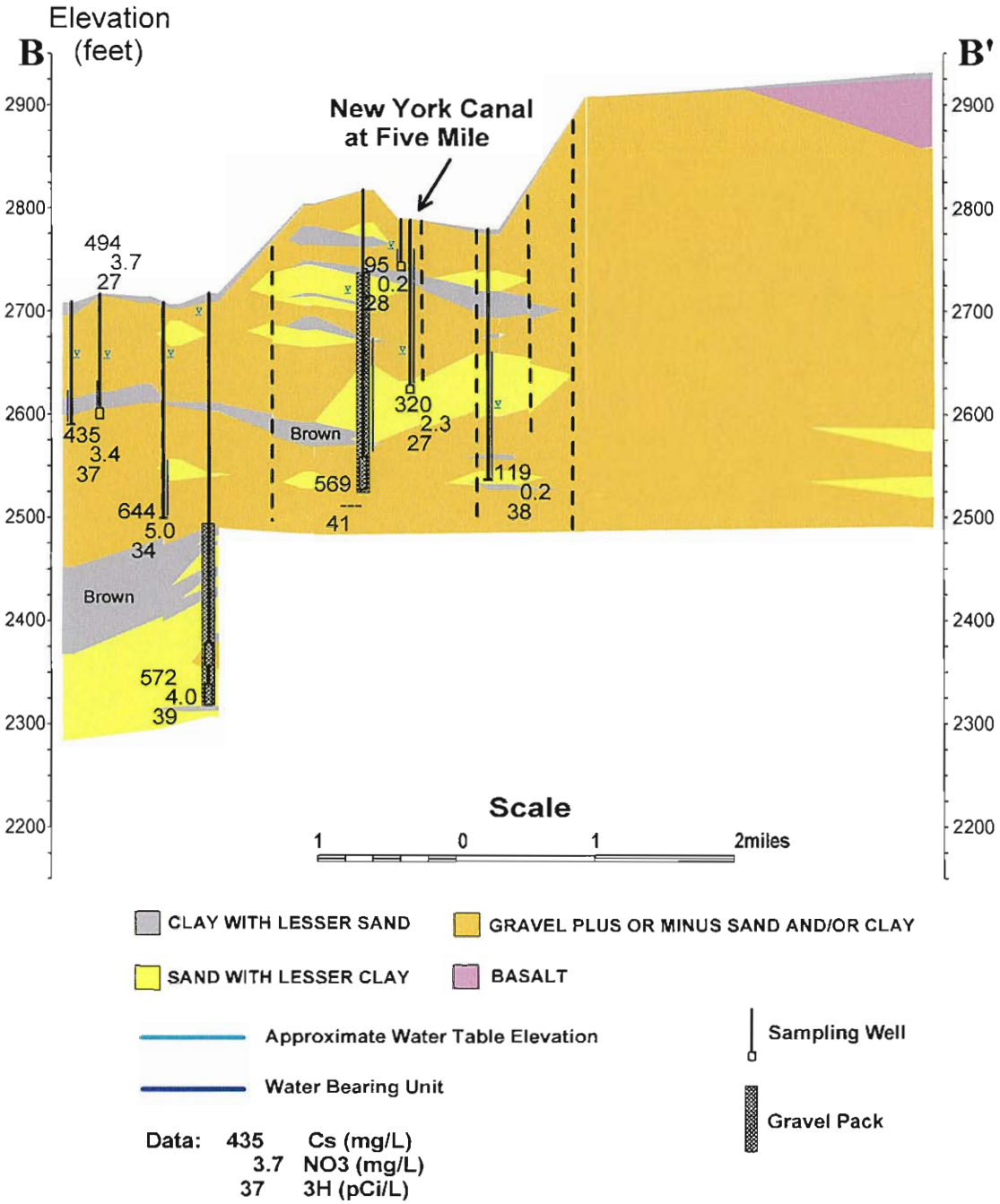


Figure 7. Ground water chemistry and aquifer stratigraphy near the NYC at Five Mile Road. The geologic cross-section B-B' is shown in Figure 2. Names and locations of sampling wells are shown in Figure 1

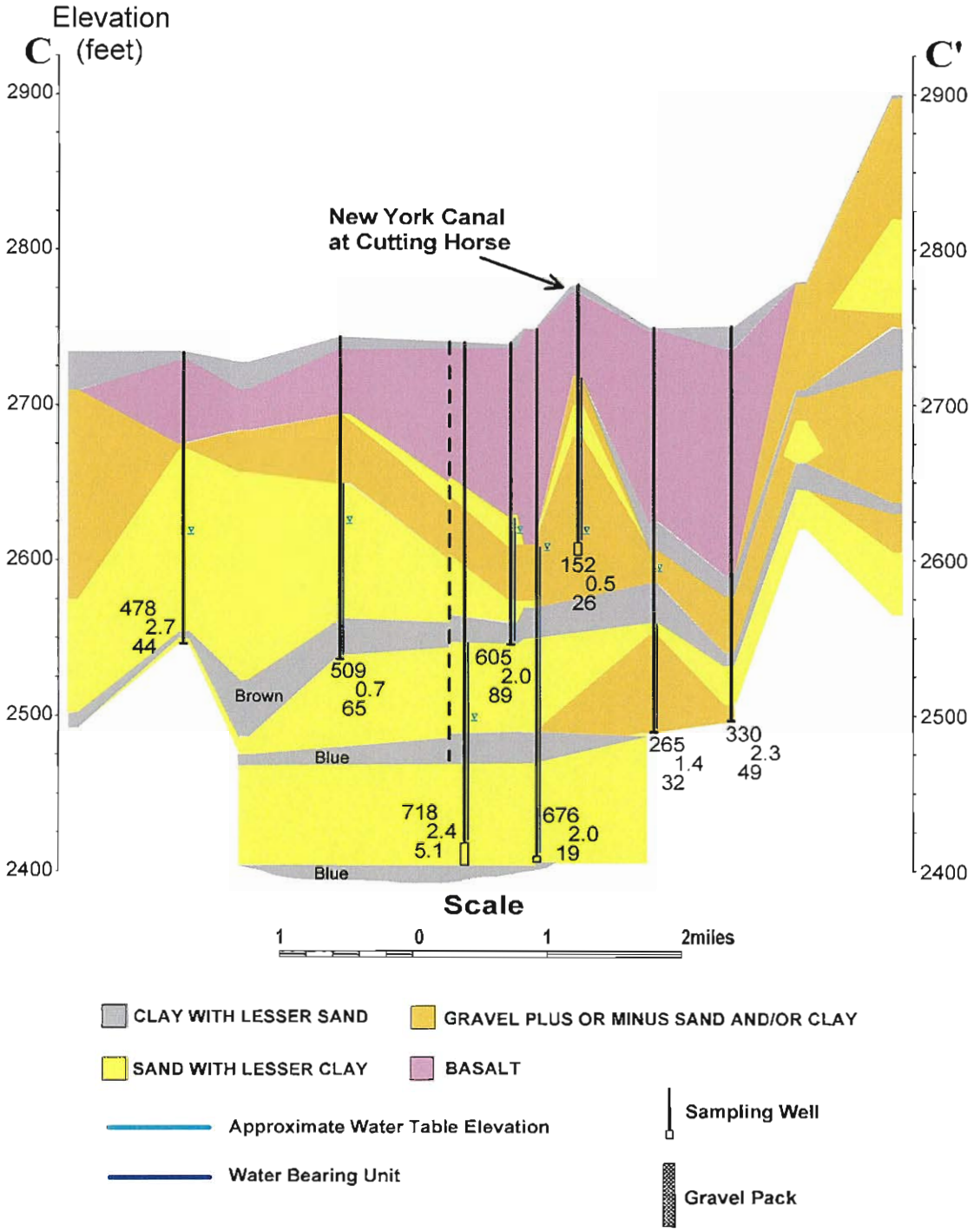


Figure 8. Ground water chemistry and aquifer stratigraphy near the NYC at Cutting Horse Road. The geologic cross-section C-C' is shown in Figure 2. Names and locations of sampling wells are shown in Figure 1.

Deeper aquifers west of the canal lie below the shallow clay beds. These waters exhibit a greater range of ^3H concentrations than is seen in the perched zones (Table 2). Ground water with ^3H concentrations greater than 50 pCi/L has received substantial contributions from recharge sources that originated during the 1960s (Clark and Fritz, 1997) (Table 1). Most waters below the 2,600-foot elevation in the Maple Grove cross-section are older than present recharge, with wells below the series of substantial clay layers at approximately 2,550 feet exhibiting ^3H below the detection limit of 2.5 pCi/L (Figure 7). Tritium concentration of less than 3 pCi/L is evidence of pre-1950s water (Clark and Fritz, 1997). Nitrate concentrations in these wells are between 2.1 and 5.6 mg/L, a range that likely reflects anthropogenic contributions via percolating surface water (Table 2, Figure 7). Elevated values of C_s and P_{CO_2} also implicate surface water percolation as a major contribution to ground water recharge. The combination of non-detectable ^3H and anthropogenic NO_3 constrains ground water residence times to between 50 and 90 years.

Similar distributions of geochemical indicators are seen in ground water aquifers between 2,500 and 2,600 feet in the Five Mile and Cutting Horse cross-sections (Figure 7 and Figure 8). One notable exception concerns ^3H in the Five Mile cross-section. Unlike the pattern of increasing then decreasing ^3H concentrations with depth observed in the Maple Grove and Cutting Horse sections, all wells west of the canal at Five Mile have ^3H concentrations between 27 and 41 pCi/L. This observation suggests that all waters contained in the stratigraphic aquifer zones are modern. Possible explanations for this apparent contradiction include (1) poor lateral continuity in horizontal clay zones, (2) faulting, and/or (3) poor well construction (i.e., extensive gravel packs or poor annulus seals). Each of these possibilities could allow vertical mixing of water between aquifer zones resulting in the observed distribution of ^3H concentrations. Nitrate concentrations between 3 and 5 mg/L and P_{CO_2} between $10^{-2.7}$ and $10^{-2.3}$ bar indicate that percolating surface water is the major source of recharge.

In contrast to aquifers west of the canal, ground water east of the canal in aquifers between 2,500 and 2,600 feet exhibit different characteristics. Most ground water samples east of the NYC exhibit ^3H values in the range of contemporary recharge, contain negligible NO_3, have conductivity similar to canal water, and exhibit P_{CO_2} values that reflect atmospheric equilibrium (Table 2, Figure 6, Figure 7, and Figure 8). This combination suggests that these aquifers do not receive major contributions from percolating irrigation water. Corroborating evidence is the fact that little or no irrigation occurs east of the canal where land surface elevations are greater than the canal elevation. We conclude from these observations that water in mid-level aquifers lying east of the canal are recharged solely by long-term seepage from the canal and that ground water mounding caused by canal seepage prevents mixing of waters west of the canal with those east of the canal.

Our analysis thus far has been confined to aquifers in the Snake River Group of sediments. To evaluate the relationship between ground water in the Snake River

Group and ground water in deeper aquifers we analyzed chemistry and isotope data from three United Water Idaho, Inc. (UWI) production wells. The Amity, Sunset West, and MAC wells penetrate a series of blue clay beds that lie between 2,300 and 2,400 feet (Figure 6). The data indicate that ground water below 2,300 feet is quite different from ground water in overlying aquifers. Specific conductance in the deeper aquifers is approximately one-half of the C_s measured in the overlying aquifers. Similarly, SO_4 is less than one-fourth and NO_3 is one-tenth of the corresponding values measured in the overlying aquifers. Tritium concentrations confirm that the water is sub-modern, while P_{CO_2} values suggest that these aquifers are recharged in a soil environment.

Movement of water from shallow aquifers into deeper, regional aquifers appears to be limited by clay aquitards. If the rate of leakage across these aquitards were substantial, then one would observe similar chemical analyses in aquifers above and below the clays. The abrupt decrease in C_s, SO_4, and NO_3 observed in the transition from the near-surface aquifers to the aquifers penetrated by the UWI productions wells suggests otherwise. It appears that the clay layers prevent downward movement of ground water despite a downward hydraulic gradient. This conclusion is supported by a 5,000- to 9,000-year range of ^{14}C age-dates in the Amity, Mac, and Sunset West wells (Hutchings and Petrich, 2001; Parliman and Spinazola, 1998). Superposition of contemporary ground water atop ground water of ancient origin, the existence of unique chemical characteristics, and the identification of a likely aquitard are convincing evidence that canal seepage and percolating irrigation water do not recharge the regional ground water system in the study area.

5 CONCLUSIONS

The purpose of this study was to provide constraints on the interaction between surface water and ground water near the NYC. Spatial distributions of key hydrochemical parameters were analyzed with respect to aquifer stratigraphy. Our investigation provided the following conclusions:

1 Losses from and gains to the NYC correlate strongly with local stratigraphy.

2 Aquifers contained in the first few hundred feet of alluvial sediment are recharged by canal seepage and by percolating irrigation water where they are overlain by flood-irrigated fields.

3 Ground water in these shallow alluvial aquifers was recharged during the past 50 years.

4 Distinct geochemical signatures can be used to differentiate between ground water in shallow, alluvial aquifers and ground water in deeper, regional aquifers.

5 Contemporary surface water is not a major source of recharge to deep, regional aquifers beneath the NYC.

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APPENDIX A

Well Information and Water Sample Data

Glossary

DTW	depth to water
TWBZ	top of water-bearing zone
BWBZ	bottom of water-bearing zone

Well Name	LATd	LATm	LATs	LONd	LONm	LONs	T	R	Sec	Land Surf Elev ft	Total Depth ft	DTW ft	WL Elev ft	TWBZ ft	TWBZ Elev ft	BWBZ ft	BWBZ Elev ft
NYC_SW																	
7644 W. Stirrup	43	32	57	116	16	36	03N	01E	36DDB2	2800	200		2800	190	2610	200	2600
7644 W. Stirrup	43	32	57	116	16	36	03N	01E	36DDB2								
Sunset West	43	33	4	116	16	24	03N	01E	36DAD1	2810	620	120	2690	515	2295	603	2207
Amity	43	33	40	116	16	54	03N	01E	36ABB1	2798	675	120	2678	519	2279	670	2128
Maple Grove No. 3	43	33	50	116	17	26	03N	01E	25CCBA2	2780	207		2780	185	2595	207	2573
8821 Churchill	43	34	17	116	17	27	03N	01E	25BCB1	2751	117		2751	99	2652	110	2641
Maple Grove No. 1	43	33	53	116	17	27	03N	01E	25CCBA1	2780	100	68	2712	49	2731	115	2665
Maple Grove No. 2	43	33	52	116	17	28	03N	01E	25CCBA3	2780	98	72	2708	92	2688	98	2682
8911 W. Victory	43	34	32	116	17	32	03N	01E	25BBBB1	2730	170		2730	161	2569	166	2564
2380 S. Kimball	43	34	53	116	17	46	03N	01E	23DAB1	2715	173		2715	173	2542		
2380 S. Kimball	43	34	53	116	17	46	03N	01E	23DAB1								
9245 S. Malad	43	34	48	116	17	46	03N	01E	23DACD1	2718	96		2718	88	2630		
9200 S. Five Mile	43	31	7	116	18	45	02N	01E	11CCC1	2795	241		2795	239	2556	241	2554
9200 S. Five Mile	43	31	7	116	18	45	02N	01E	11CCC1								
Hidden Valley	43	32	0	116	18	49	02N	01E	03DDD1	2795	311		2795	140	2655		
Five Mile No. 2	43	31	39	116	18	52	02N	01E	10ADAA1	2790	78	29	2761	28	2762	56	2734
Five Mile No. 1	43	31	39	116	18	53	02N	01E	10ADAD1	2790	51	25	2765	38	2752	43	2747
Five Mile No. 3	43	31	42	116	18	56	02N	01E	10ADAC1	2790	177			158	2632	176	2614
Lagrange	43	33	9	116	19	24	03N	01E	34CAA1	2718	425			232	2486	415	2303
4283 Riva Ridge	43	33	51	116	19	31	03N	01E	27CDAB3	2717	121			110	2607	121	2596
11917 Highlander	43	33	24	116	19	44	03N	01E	34BCA1	2705	210			185	2520	210	2495
4620 Cloverdale	43	33	37	116	19	57	03N	01E	34BBB1	2715	120			103	2612	0	0
12175 Hubbard	43	31	2	116	19	58	02N	01E	15BBBB1	2770	335			319	2451	335	2435
Cutting Horse No. 2	43	29	36	116	20	35	02N	01E	21CAD1	2780	187			131	2649	187	2593
9299 S. Stewart	43	31	16	116	20	37	02N	01E	09CDDD1	2742	220			204	2538	0	0
Cutting Horse No. 1	43	29	40	116	20	43	02N	01E	21CAA1	2780	188			136	2644	188	2592
1270 S. Eagle	43	29	53	116	20	57	02N	01E	21BBDD1	2750	350			280	2470	330	2420
226 S. Eagle	43	29	9	116	21	10	02N	01E	28BBCB1	2770	263			198	2572	263	2507
1180 S. Eagle	43	28	31	116	21	10	02N	01E	28CCC1	2750	258			243	2507	258	2492
1495 N. Eagle	43	30	7	116	21	15	02N	01E	20AAAA1	2740	205			193	2547		
1715 E. Columbia	43	31	54	116	22	20	02N	01E	08BBB1	2740	188			185	2555		
2491 Beverly	43	34	51	116	16	6	03N	02E	19CBD1	2752	100	63	2690	100	2652		
2428 S. Liberty	43	34	45	116	15	36	03N	02E	19DBD1	2761	210	62	2699	165	2596		
2615 S. Liberty	43	34	41	116	15	39	03N	02E	19DCB1	2763	133	63	2700	127	2636		
2785 S. Liberty	43	34	38	116	15	40	03N	02E	19DCC1	2763	115	64	2699	110	2653		
2613 S. Liberty	43	34	42	116	15	38	03N	02E	19DCD1	2762	184	68	2694	178	2584		

Well Name	Sample Date	Pump Period	Water Temp	Field Cond	Field pH	DO	Field Alk
		min	deg C	uS/cm @ 25		mg/L	mg/L as CaCO3
NYC_SW	19991105		9	62	7.9	10.9	30
7644 W. Stirrup	19990429	35	12	124	8.1	8	48
7644 W. Stirrup	19990429						
Sunset West	19990421	20	20	317	7.8	1	120
Amity	19990421	>20	18	374	7.6	1	127
Maple Grove No. 3	19990412	30	15	660	7.6	5	93
8821 Churchill	19990315	37	13	462	8.0	8	203
Maple Grove No. 1	19990319	20	13	119	8.0	4	54
Maple Grove No. 2	19990319	30	12	96	8.0	4	42
8911 W. Victory	19990412	30	13	907	7.7	4	276
2380 S. Kimball	19990429	25	13	573	7.4	10	173
2380 S. Kimball	19990429						
9245 S. Malad	19990315	35	12	582	7.7	4	259
9200 S. Five Mile	19990412	25	11	121	8.3	5	48
9200 S. Five Mile	19990317	25	11	119	8.2	4	49
Hidden Valley	19990423	>20	14	569	7.7	7	221
Five Mile No. 2	19990319	30	12	95	7.4	6	41
Five Mile No. 1	19990319	25	7	83	7.3	6	37
Five Mile No. 3	19990414	85	12	320	7.6	5	85
Lagrange	19990423	>30	13	572	7.7	8	215
4283 Riva Ridge	19990317	>30	13	494	7.6	5	193
11917 Highlander	19990317	50	13	644	7.7	0	235
4620 Cloverdale	19990317	30	13	435	7.9	4	166
12175 Hubbard	19990316	20	15	718	7.8	5	208
Cutting Horse No. 2	19990414	25	14	175	7.5	5	69
9299 S. Stewart	19990316	15	14	509	7.8	7	245
Cutting Horse No. 1	19990414	20	13	152	7.5	5	63
1270 S. Eagle	19990517	>30	24	676	7.9	0	155
226 S. Eagle	19990316	25	12	265	7.8	3	113
1180 S. Eagle	19990318	27	15	330	8.2	4	130
1495 N. Eagle	19990316	25	13	605	7.8	3	235
1715 E. Columbia	19990316	30	12	478	7.8	5	176
2491 Beverly	19990622		14	1070	7.6		407
2428 S. Liberty	19990622		15	748	7.1		204
2615 S. Liberty	19990623		13	540	7.3		254
2785 S. Liberty	19990623		13	435	7.4		228
2613 S. Liberty	19990622		14	466	7.2		163

Well Name	Ca	Mg	Na	K	HCO3	Cl	SO4	F	SiO2	NO3-N	Fe	Mn	TDS	Hardness	d3H
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L	mg/L	mg/L as CaCO3	PiC/L
NYC_SW	7.7	0.95	3.3	0.64	38	0.39	1.5	0.23	15	0.128	14	4.9	75		28
7644 W. Stirrup	5.8	1.6	20	0.52	58	1.9	11	1	24	0.272	8.3	3	96	21	37
7644 W. Stirrup	5.8	1.6	20	0.52	58	2.8	11	1	24	0.259	6.2	3.3	97	21	34
Sunset West	27	5.7	33	1.3	150	8.5	24	0.38	32	0.182	10	3	204	91	2.5
Amity	33	8.9	32	1.4	160	9.7	44	0.53	31	0.104	5.5	13	237	120	7
Maple Grove No. 3	59	13	57	1.6	110	27	170	0.91	20	2.69	10	3	416	200	9
8821 Churchill	45	15	34	0.97	250	3	26	0.85	45	3.06	10	3	305	170	35
Maple Grove No. 1	15	3.5	4.1	0.73	66	0.5	2.3	0.35	30	0.232	10	17	91	53	29
Maple Grove No. 2	10	3.4	4.1	0.57	51	0.34	1.6	0.31	22	0.171	10	3	68	39	29
8911 W. Victory	92	23	79	2.5	340	32	120	0.41	25	5.55	10	23	568	320	2.5
2380 S. Kimball	55	14	42	4.1	210	28	64	0.33	39	4.4	17	7	370	200	2.5
2380 S. Kimball	54	14	41	2.4	210	29	64	0.33	39	4.52	16	5.6	368	190	2.5
9245 S. Malad	44	15	65	2.4	320	6.5	33	0.5	34	2.14	120	2.1	366	170	68
9200 S. Five Mile					58					0.187					
9200 S. Five Mile	7.8	1.1	17	0.42	60	2.4	6.1	0.61	18	0.201	110	19	84	24	38
Hidden Valley	41	7	75	1.4	270	9.1	44	0.39	38		10	3	349	130	41
Five Mile No. 2	12	1.6	3.8	0.66	50	0.73	2.4	0.27	18	0.241	10	3	65	37	28
Five Mile No. 1	11	1.4	3	0.54	45	0.66	2.2	0.18	13	0.148	5	3	55	33	33
Five Mile No. 3	28	7.1	29	0.61	100	12	40	0.57	20	2.27	10	3	197	99	27
Lagrange	41	6.9	71	1.5	260	9	44	0.38	37	3.96	10	3	358	130	39
4283 Riva Ridge	52	15	33	1	240	7.4	22	1	48	3.71	10	3	311	190	27
11917 Highlander	62	15	60	1.5	290	18	44	0.66	44	5.03	8.6	3	407	210	34
4620 Cloverdale	34	8.6	49	1.6	200	8.3	26	1	34	3.4	10	3	278	120	37
12175 Hubbard	85	7.8	60	2	250	30	110	0.19	30	2.35	43	3	458	240	5.1
Cutting Horse No. 2	14	7.1	10	1.3	84	2.5	9.8	0.44	26	0.695	7.5	1.9	116	65	27
9299 S. Stewart	63	14	31	1.8	300	3.2	21	0.4	25	0.676	10	3	309	210	65
Cutting Horse No. 1	13	6.9	7.5	1.2	77	2.1	6.8	0.42	25	0.513	10	3	103	60	16
1270 S. Eagle	30	0.89	122	0.79	190	30	140	0.69	27	0.05	78	39	446	79	19
226 S. Eagle	25	12	10	1.8	140	2.3	13	0.56	36	1.4	52	35	175	110	32
1180 S. Eagle	29	10	25	3.4	160	4.2	21	0.24	40	2.27	5.6	3	220	120	49
1495 N. Eagle	52	9.4	69	1.9	290	11	54	0.5	27	1.95	10	1.9	374	170	89
1715 E. Columbia	35	11	54	1.6	150	9.1	65	0.75	33	2.71	8.1	3	294	130	44
2491 Beverly					496	32				4.5					93
2428 S. Liberty					249	23				0.63					14
2615 S. Liberty					310	11				2.7					77
2785 S. Liberty					278	2.6				1.2					56
2613 S. Liberty					199	13				0.5					26

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TREASURE VALLEY HYDROLOGIC PROJECT
RESEARCH REPORT

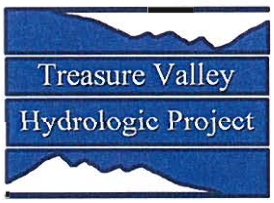
WATER BUDGET FOR THE TREASURE VALLEY AQUIFER SYSTEM

FOR THE YEARS 1996 AND 2000

Prepared by

Scott M. Urban

Idaho Department of Water Resources



Executive Summary

This report presents water budgets for the Treasure Valley's shallow aquifer system for the calendar years 1996 and 2000. It also represents an updated version of the water budget previously published for the year 1996 (Urban and Petrich, 1998). While general comparisons can be made between the 1996 and 2000 water budgets, different methods were used to estimate some of the parameters. As a result, direct comparisons of some water budget components should not be made.

A water budget provides an estimate of the current balance between total aquifer withdrawals and discharge, aquifer recharge, and changes in aquifer storage. Specific objectives for these water budgets were to (1) define major water budget components, (2) estimate inflows and outflows for the Treasure Valley aquifer systems, (3) describe, where possible, the spatial characteristics of the water budget data, (4) create, where possible, GIS coverages of the water budget data, and (5) create input files (e.g., recharge, withdrawals and ET) for the Treasure Valley ground water flow model.

Inflows to the Treasure Valley aquifer system include:

1. Seepage from canals
2. Seepage from rivers and streams
3. Seepage from Lake Lowell
4. Underflow
5. Infiltration of precipitation and surface water
6. Seepage from rural domestic septic systems

Outflows include:

1. Municipal withdrawals
2. Industrial withdrawals
3. Irrigation withdrawals
4. Rural domestic withdrawals
5. Stock withdrawals
6. Discharge to canals, drains, and rivers
7. Evapotranspiration (ET)

Total inflow for 1996 is estimated at 1,020,300 acre-feet (af), while total outflow is estimated at 1,013,000 af. The net difference shows an apparent increase in aquifer storage of 7,300 af. This difference is less than 1% of the total recharge or discharge and is well within the estimated margin of error of 20% for some of the individual water budget component estimates. For the year 2000, total inflow was estimated to be 1,145,200 af, with an outflow

of 1,056,600 af, for a positive net difference of 88,600 af. At this time, the condition of ground water surplus is obscured by the error margin associated with some water budget components. Also, much of the difference between the 1996 and 2000 values may be attributed to differences in estimating components.

The largest source of ground water recharge appears to be seepage from the canal system, followed by seepage from flood irrigation and precipitation. The aggregate discharge to the Boise and Snake Rivers (through canals, drains, or to the rivers directly) is far greater than all withdrawals combined. On a valley-wide basis, the volume of ground water pumped during the year represents approximately 15 to 20% of the total ground water recharge.

Primary withdrawal areas and primary recharge areas do not coincide throughout the valley. The primary recharge areas are those with extensive canals and/or flood irrigation, while the greatest withdrawals occur in areas that are not flood irrigated. For example, agricultural irrigation withdrawals (non-supplemental) are concentrated in areas where surface water irrigation is unavailable, and municipal withdrawals are concentrated near the urban areas of Boise, Nampa, Caldwell, and Meridian. As a result, withdrawals may exceed recharge in local areas within the Treasure Valley, resulting in local water level declines. Water level increases were noted in areas where recharge exceeded local withdrawals.

The water budgets estimate the amount of water infiltrating to, and discharging from, the entire aquifer system. However, much of this water encounters the shallow aquifer only; recharge to the deeper aquifers is much less than to the shallow system.

The aggregate nature of the water budget masks the temporal characteristics of ground water recharge, withdrawals, and natural discharge. Infiltration from the surface water distribution system and irrigation occurs primarily in the summer. The actual aquifer recharge from irrigation activities lags the infiltration, so that water levels may be rising months after irrigation has ceased. Also, municipal withdrawals vary throughout the year and are greatest during the summer irrigation season.

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Disclaimer

Some of the values and estimates provided in this report are changing on the basis of new information. For the latest estimates, please contact Scott Urban, Idaho Department of Water Resources, Boise, Idaho (email: surban@idwr.state.id.us, or telephone: 208-327-5441).

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1. INTRODUCTION

Water budgets have been used throughout the western United States to help understand, quantify, and manage surface and ground water supplies. A water budget provides an estimate of the current balance between total aquifer withdrawals and discharge, aquifer recharge, and changes in aquifer storage.

This report presents water budgets for the Treasure Valley aquifer system for the calendar years 1996 and 2000. The water budgets include estimates of recharge to the Treasure Valley aquifer system and estimates of ground water discharge. The water budgets estimate the amount of water infiltrating to, and discharging from, the entire aquifer system. However, much of this water encounters the shallow aquifer only; recharge to the deeper aquifers is much less than to the shallow system (Petrich, 2004). The report outlines specific water budget components and provides estimates of aquifer recharge and discharge rates. The water budget also provides data for the development of a numerical ground water flow model for the Treasure Valley aquifer system. (Note: model input files for 2000 were not created at the time of this report as the model was calibrated using 1996 data.)

While the updated 1996 water budget (Urban and Petrich, 1998) remains largely the same as before, some errors are corrected and revised estimates provided. In some cases, these updated data resulted in relatively large changes to specific parameters.

Due to improved technology, some water budget parameters for the years 1996 and 2000 were estimated using different methods. For example, evapotranspiration (ET) for 1996 was estimated using averaged AgriMet data, whereas ET for the year 2000 was estimated using Landsat imagery and the Surface Energy Balance Algorithm for Land (SEBAL) (see Section 2 for further discussion). Also, the 1996 water budget relied on land use interpretations using 1994 satellite imagery, while the 2000 water budget utilized imagery for the year 2000. Due to such variations in methodology, conclusions made from direct comparisons of the two years should be made with caution.

1.1. Purpose and Objectives

The purpose of the Treasure Valley water budget was to estimate recharge to and discharge from the Treasure Valley aquifers. Specific objectives for this water budget were to:

1. Define major water budget components.
2. Estimate inflows and outflows for the Treasure Valley aquifer system.
3. Describe, where possible, the spatial characteristics of the water budget data.
4. Create, where possible, GIS coverages of the water budget data.

5. Create input files (e.g., recharge and withdrawals) for the Treasure Valley ground water flow model.

1.2. Background

This section provides a review of water budgets for arid regions within the western United States. This review of water budget methods, applications, and results was conducted to help define Treasure Valley water budget components. Selected results from these water budgets are shown for the purpose of comparison. Results from these water budgets do not necessarily reflect conditions within the Treasure Valley.

Water budgets have been compiled for many areas, including Utah's Ogden Valley (Thomas, 1963), Las Vegas Valley (Patt, 1987), the Uinta Basin of Utah (Holmes, 1985), the Coconino Aquifer in Arizona (Mann, 1979), and California's San Joaquin Valley (Gronberg and Belitz, 1992). Newton (1991) and Kjelstrom (1995) prepared water budgets for the Western Snake River Plain (WSRP), which includes the Treasure Valley area. Garabedian (1992) completed a water budget for the eastern Snake River Plain. Newton's (1991) water budget was prepared in conjunction with a ground water model of the WSRP. However, the range of uncertainty associated with the water budget was large because some of the component values could not be well defined (Newton, 1991). For example, the amount of irrigation water that returns to canals and drains was not measured. As a result, the amount of return flow attributed to ground water discharge could not be defined.

Irrigation with surface water is intensive in the Boise and Payette River valleys, and along the Snake River. Newton (1991) estimated that 80% of ground water recharge resulted from surface water irrigation. Precipitation was shown to be a source of recharge, though on average, it was estimated only about 2% of total annual precipitation became ground water recharge for the WSRP. Recharge from precipitation on irrigated land was assumed to be equivalent to the average annual precipitation. Nearly 83% of ground water discharge was estimated to be to rivers and drains, the remainder was pumping withdrawals. Power-consumption records were used to estimate that about 300,000 af of ground water were pumped to irrigate about 130,000 acres on the western plain. The mean application rate was estimated to be about 2.2 feet/acre (ft/ac) (Newton, 1991).

Kjelstrom (1995) reported that changes in ground water storage were the net result of 100 successive years of irrigation on the entire Snake River Plain. During the 1930 to 1972 time period, ground water storage increased about 3 million af. From 1972 to 1980, storage generally decreased. Furthermore, from 1930 to 1980, several short-term cycles of gains and losses are evident. Kjelstrom attributed some cycles to periods of above and below normal precipitation. Sources of recharge, in order of decreasing magnitude, were infiltration of surface water irrigation and infiltration of precipitation. According to Kjelstrom (1995), precipitation for the WSRP contributes an average of

about 0.03 ft/ac of aquifer recharge per year. Most ground water discharge is to rivers and drains, primarily during the irrigation season (Kjelstrom, 1995).

Garabedian (1992) developed a numerical model for the eastern Snake River Plain. Ground water withdrawals were shown to be an important discharge component of the water budget. Withdrawals were estimated at about 1.8 million af for 1980 by using power billings for irrigation pumps. Some pumped water was returned to the aquifer from canal loss and field seepage. Therefore, withdrawals estimated from power-consumption were compared with estimated consumptive irrigation requirements; the smaller of the two estimates was used to determine net ground water withdrawals. For 1980, net ground water withdrawals were estimated at about 1.1 million af, or about two-thirds of total withdrawals as estimated from power data (Garabedian, 1992).

1.3. Physiography and Climate

This water budget focuses on the Treasure Valley of southwestern Idaho. The project area is shown in Figure 1. The term "Treasure Valley" refers to the lower Boise River watershed area. The lower Boise River begins where the Boise River exits the mountains near Lucky Peak Reservoir. From Lucky Peak Reservoir, the lower Boise River flows about 64 (river) miles northwestward through the Treasure Valley to its confluence with the Snake River. The valley is bounded to the northwest by the Boise Foothills. Topography within the valley can be described as generally flat with some rolling hills within the southern-most portion of the area. The project area extends to the southwest to the Snake River. This area was included in the study because some ground water originating in the lower Boise River area discharges to the Snake River.

Precipitation in the Treasure Valley ranges from about 8 to 14 inches/yr with a 30-year average of about 11 inches/yr. Figure 2 is a precipitation map of the Treasure Valley; Figure 3 shows the mean monthly precipitation at four sites. About 50% of the precipitation falls during the non-irrigation season. The average precipitation in the southern portion of the valley is about 10 inches/yr. The average precipitation for flood-irrigated lands during 1996 was 12.8 inches (based upon data for Deer Flat Dam, Boise, Caldwell, and Parma [NOAA, 1996]). The average for the year 2000 was 11.2 inches (Boise and Parma stations only [NOAA, 2000]). The mean annual temperature for the valley is about 51 degrees for the 30-year period.

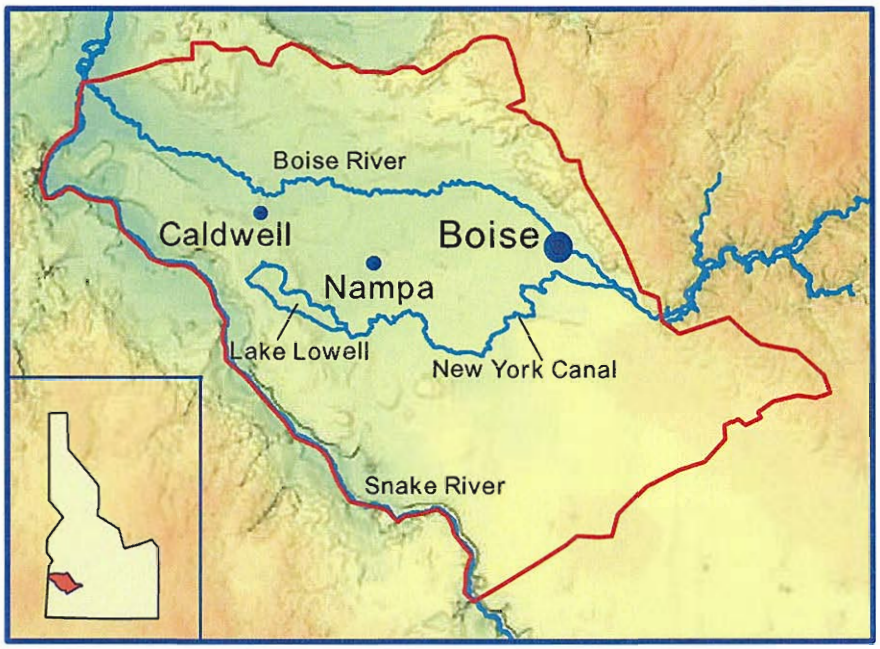

Figure 1: Project Area.

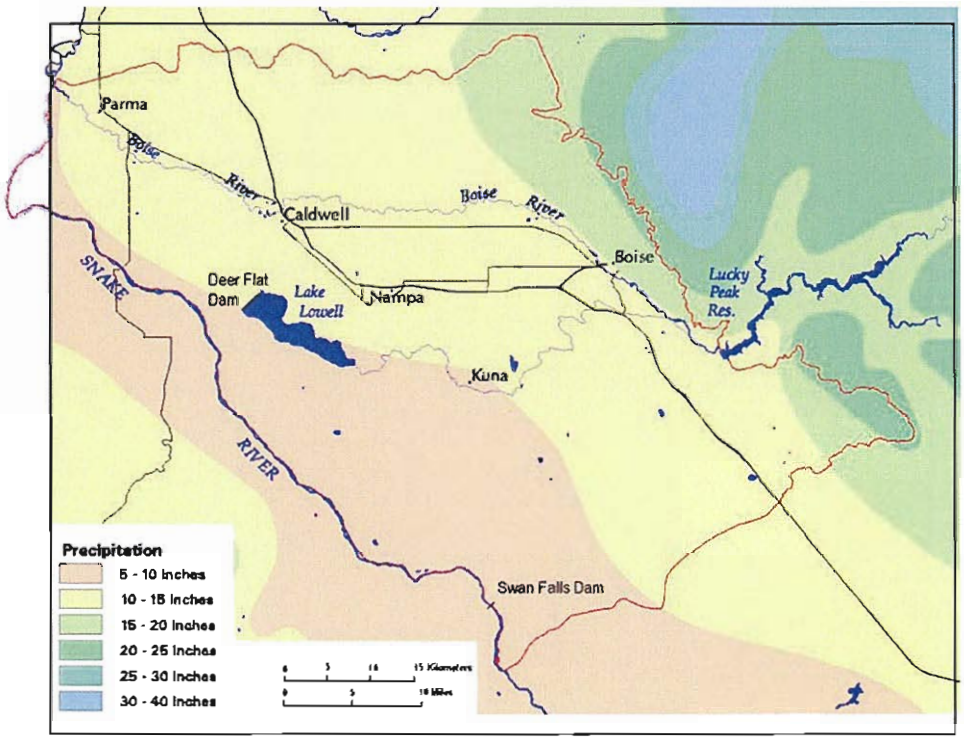

Figure 2: Precipitation map of the Treasure Valley.

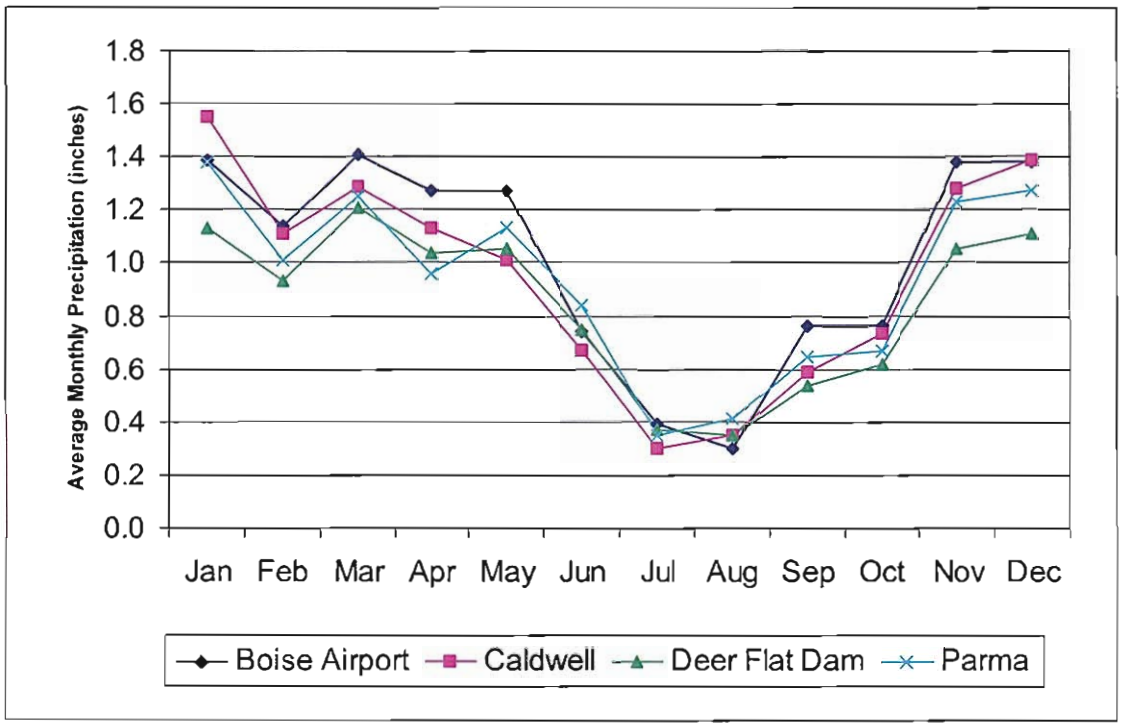

Figure 3: Average monthly precipitation for 1971-2000.

1.4. Water Budget Area and Time Frame

The water budget area corresponds with that of the Treasure Valley Hydrologic Project (TVHP) area (Figure 1). Water budgets can be constructed for an entire aquifer system, individual aquifers, or both. The Treasure Valley contains a deep, regional aquifer system (typically confined, with depths ranging from about 250 to more than 1,500 feet) and a shallow aquifer system (typically unconfined, generally less than about 250 feet in depth). The shallow system may contain local perched aquifers. This water budget focuses on the entire Treasure Valley aquifer system as a whole, although direct recharge is estimated for the shallow aquifer only.

Subsurface flow rates between the shallow and deeper regional aquifer systems have not been quantified. Percolating water from surface sources recharges shallow zones first. Recharge to the deeper regional system depends on local hydraulic gradients and on the hydraulic characteristics of aquifer materials. Recharge to the deep, regional aquifer system can only occur in areas with downward hydraulic gradient. Shallow system recharge can occur in areas of regional upward hydraulic gradient, although this "recharge" may quickly discharge into the nearest drain or canal (Figure 4). Vertical flow between aquifer systems has been evaluated with the help of the numerical model (Petrich, 2004).

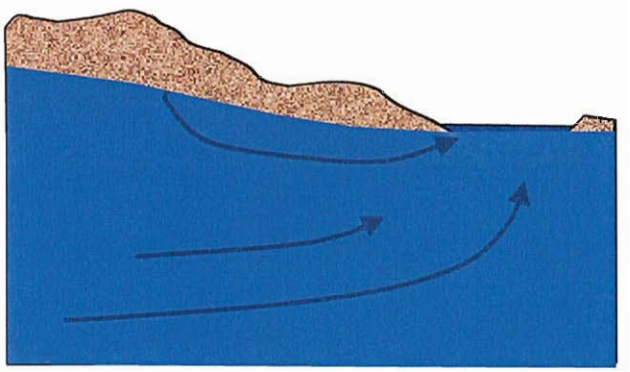

Figure 4: Schematic diagram showing recharge in a regional discharge area.

1.5. Water Budget Components

Water budget components include all significant sources of ground water inflows (recharge) and outflows (discharge) to the Treasure Valley aquifer system. In general,

Inflows – Outflows = Change in Aquifer Storage (Eqn 1)

Ground water recharge is defined (Driscoll, 1986) as the amount of water added to the saturated zone. Ground water discharge is the sum total of water leaving the saturated zone and can be in the form of aquifer discharge into canals, drains, or rivers, evapotranspiration (ET), and withdrawals from wells.

Inflows into the Treasure Valley aquifer system (Figure 5) include:

6. Seepage from canals
7. Seepage from rivers and streams
8. Seepage from Lake Lowell
9. Underflow
10. Infiltration of precipitation and surface water used for irrigation
11. Seepage from rural domestic septic systems

Outflows include:

1. Municipal withdrawals
2. Industrial withdrawals
3. Irrigation withdrawals
4. Rural domestic withdrawals
5. Stock withdrawals
6. Discharge to canals, drains, and rivers
7. Evapotranspiration (ET)

These inflows and outflows are related as shown in the following equation:

$$R_C + R_R + R_L + I_U + R_P + R_{FI} + R_{SI} + R_S$$
$$-P_M - P_{MI} - P_{IN} - P_{IR} - P_R - P_S - D_R - D_C - ET \qquad \text{(Eqn. 2)}$$
$$= \Delta S_{(S+R)}$$

where

R_C = recharge from canal seepage
R_R = the recharge from river seepage
R_L = the recharge from Lake Lowell seepage
I_U = subsurface inflow (underflow)
R_P = recharge from precipitation
R_{FI} = recharge from agricultural flood irrigation
R_{SI} = recharge from agricultural sprinkler irrigation
R_S = recharge from rural domestic septic systems
P_M = municipal domestic and commercial withdrawals
P_{MI} = municipal irrigation withdrawals
P_{IN} = industrial withdrawals
P_{IR} = agricultural irrigation withdrawals
P_R = rural domestic withdrawals
P_S = withdrawals for stock watering
D_R = discharge to rivers
D_C = discharge to canals
ET = loss to evapotranpsiration
$\Delta S_{(S+R)}$ = aggregate change in aquifer storage for the shallow and regional aquifers.

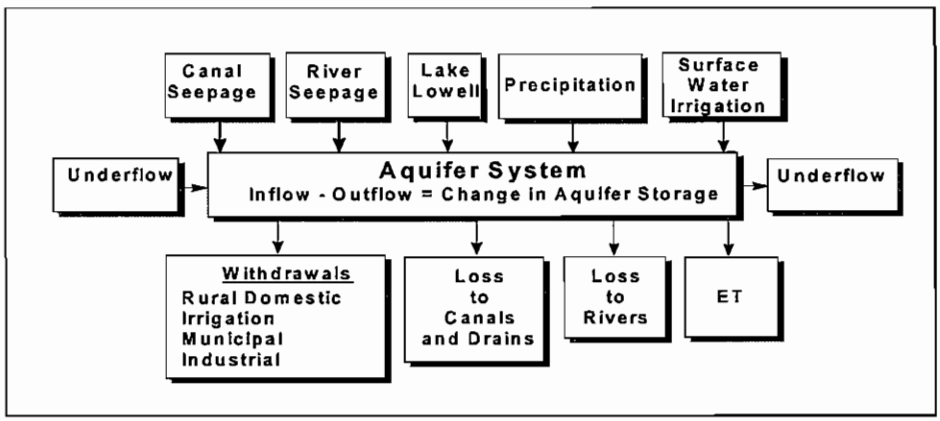

Figure 5: Generalized water budget schematic .

Equation 2 describes water budget components for the Treasure Valley ground water system as a whole. The Treasure Valley covers a large area (over 1,500 square miles),

and aggregate values for the water budget components may mask some of the spatial characteristics of individual water budget components. For instance, recharge and withdrawal areas may not coincide spatially or temporally, resulting in local changes in aquifer storage. The spatial distribution of inflows and outflows are also important to the numerical ground water flow model. The spatial distribution of individual water budget components is therefore provided whenever possible.

The following sections provide a discussion of individual water budget components. Included are descriptions of analysis methods and preliminary water budget results. Note that the 1996 water budget was completed in 1998 using data and technology available at that time. The 2000 water budget was completed in 2003 using improved data collection and analysis methods. As a result of these differing methods and data sets, it may be difficult to draw certain conclusions between the two water budget years.

1.6. Units

Data provided in this report are generally presented in the form of acre-feet per year (af/yr) or cubic feet per second (cfs). Managers of surface water supplies commonly use acre-feet when evaluating water volumes stored in reservoirs or when describing volumes allotted for irrigation. The unit of cubic feet per second is commonly used to describe flows in rivers and canals and is also used in water rights to specify the permitted rate of ground water withdrawals. It is important to note that all flow rates presented in this report are average annual rates, even though some flows are seasonally variable.

2. ESTIMATES OF INFLOWS

The primary inflows to the Treasure Valley aquifer system include: Seepage from canals

1. Seepage from rivers and streams
2. Seepage from Lake Lowell
3. Underflow
4. Infiltration from precipitation and irrigation
5. Seepage from septic systems

Estimates of inflows from these sources are presented in the following sections.

2.1. Canal Seepage

There are about 1,170 miles of major irrigation canals throughout the Treasure Valley (D. Palmer, IDWR, personal communication, 1997), and seepage from these is a major contribution to ground water recharge. These large and intermediate canals are shown in Figure 6. In addition to these larger canals, many miles of small canals and ditches exist within the valley. However, most of these smaller canals have not been mapped, and as a result, the total length and spatial distribution of such canals is unknown. Because the length and location of the smaller canals is unknown, estimates of seepage from these canals are not provided in this water budget. Rather, this water budget provides an estimate of total canal seepage and assigns the total seepage to the large and intermediate sized canals, which have been located spatially.

The total canal seepage was estimated using the following relationship:

$$C_{seep} = T_{div} - Evap - ET - LL_{loss} + LL_{dS} - F_A \qquad \text{(Eqn. 3)}$$

where

C_{seep} = total canal seepage

T_{div} = total amount of water diverted to the valley

$Evap$ = direct evaporation from the canal surface

ET = evapotranspiration from phreatophytes along the canals

LL_{loss} = amount of water lost from Lake Lowell (seepage plus evaporation)

LL_{dS} = change in storage at Lake Lowell

F_A = average amount of water delivered to the fields

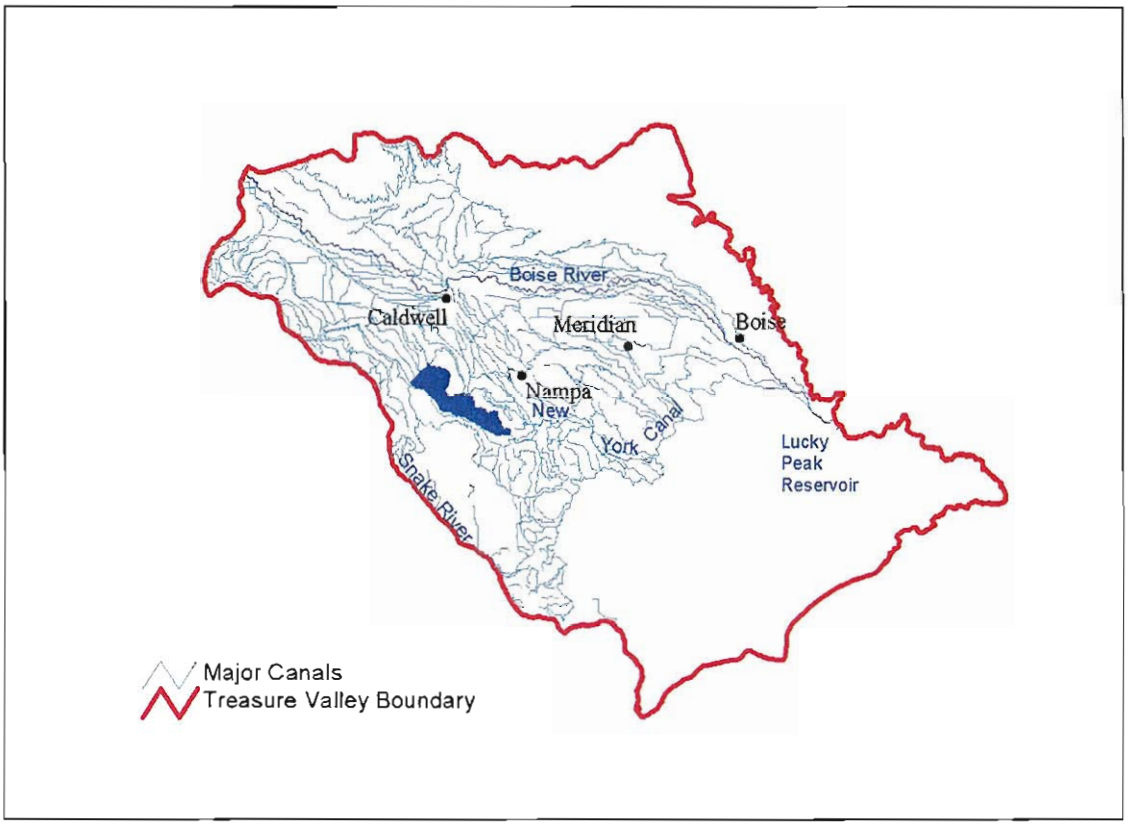

Figure 6: Distribution of major and intermediate canals and drains

In estimating canal seepage, it was assumed that none of the diverted water passes directly to the Boise or Snake Rivers (i.e., it was assumed that return flow to the river system consists only of runoff from the fields and ground water discharge to canals, drains, and rivers).

The total 1996 diversion (T_{div}) for all irrigation districts within the Treasure Valley was about 1,539,000 af during the irrigation season (April 15 through October 15). (Note: all water volumes presented in this report are totals for a calendar year period). About 1,351,000 af were diverted to the Boise Project and other districts from the Boise River (USGS, 1997), while approximately 188,000 af were diverted from the Payette River to irrigate farmland within the Black Canyon Irrigation District (Personal communication, Roy Orr, Black Canyon Irrigation District, 2003). Total diversion from the Boise River in 2000 was 1,327,000 af, with an additional 188,000 af imported from Black Canyon; total diversion to the valley was estimated at 1,515,000 af. Note that the Black Canyon water is provided via a pump station, and the pumps run at the same rate and for the same period of time each year, thus both 1996 and 2000 have the

same estimate (Personal communication, Roy Orr, Black Canyon Irrigation District, 2003).[1]

Total flood-irrigated area for 1996 was estimated to be about 252,000 acres using 1994 imagery (IDWR GIS data, 1997). Flood-irrigated acreage for 2000 was estimated at 269,000 acres using 2000 imagery (IDWR data). The increase in irrigated land was attributed to previously idle land being brought back into production.

Evaporation from canals (*Evap*) was estimated with the following assumptions: (1) total length of the canal system (major canals only) is about 1,170 miles (IDWR, 1996); (2) average canal width is 10 feet, and (3) the evaporation rate is about 33 inches/yr (see Section 2.3 for further discussion). Based upon these assumptions, about 3,600 af of canal water may be lost as evaporation. This is less than 1% of the total diversion of 1,539,000 af.

Evapotranspiration (ET) from phreatophytes along the canals was estimated based upon the following assumptions: (1) total canal length is about 1,170 miles; (2) average vegetated width is about 5 feet along each side of the canal; and (3) evapotranspiration is about 2.4 ft/yr (see Section 2.5 for further discussion). Based upon these assumptions, ET from phreatophytes along the canals was estimated to be about 3,600 af, which is less than 1% of the total diversion.

Water loss data (USGS, 1997) for Lake Lowell (Ll_{loss}) showed a total loss of about 46,300 af in 1996 (evaporation plus seepage) and 48,100 af in 2000 (BPBC annual report). Change in storage at Lake Lowell (LL_{dS}) was estimated at 224,000 af for 1996 and 218,500 af for 2000. This is the amount of water diverted from Lake Lowell during the irrigation season. Note that data for 2000 were not available, so the 2000 value is estimated from the below regression equation obtained by plotting total Boise River diversion data against lake Lowell outflow data for the calendar years 1980 through 1998. In comparing calculated outflow to recorded outflow, maximum error for this period of time was 19%, with an average error of 0.23%.

[1] Note that the original water budget showed a value of 360,200 acre-feet; 360,200 is the <u>total</u> Payette River diversion, not the amount diverted to the Treasure Valley from the Payette River.

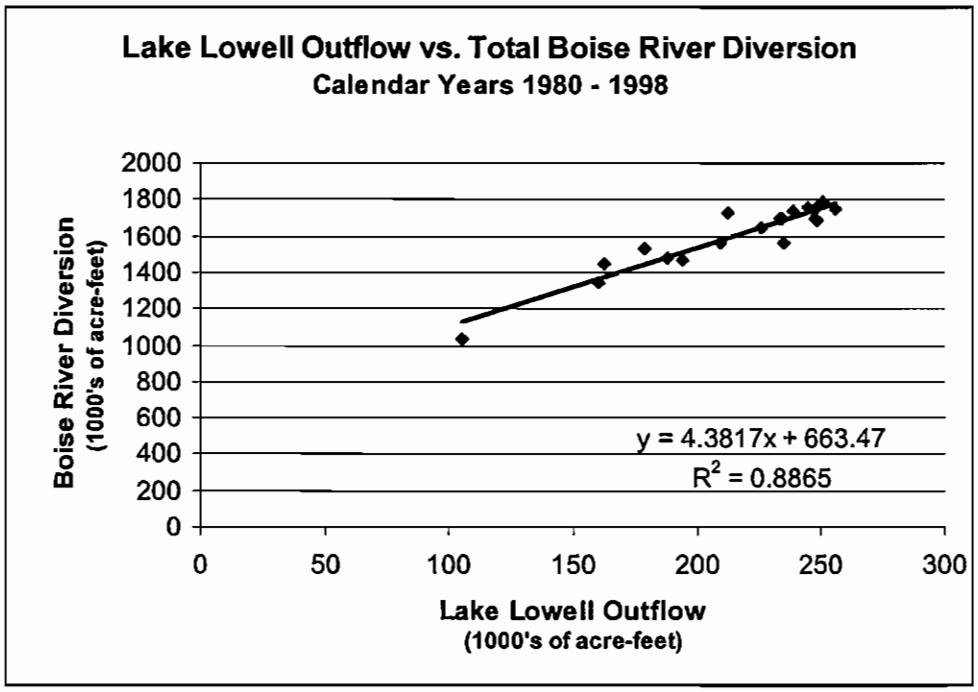

Figure 7: Lake Lowell Outflow Regression Plot

The average amount of water delivered to the fields (F_A) was estimated to be about 4.3 ft/ac (refer to Section 2.5 for additional discussion). Assuming a total flood-irrigated area of 252,000 acres, this is about 1,083,600 af for 1996, and 1,156,700 af in 2000 (applied to 269,000 acres).

Using these estimates, Treasure Valley canal seepage was estimated as follows:

$$C_{seep} = T_{div} - Evap - ET - LL_{loss} + LL_{dS} - F_A$$

$$= 1{,}539{,}000 - 3{,}600 - 3{,}600 - 46{,}300 + 224{,}000 - 1{,}083{,}600$$

$$= 625{,}000 \text{ acre-feet/year for 1996}$$

and

$$= 1{,}515{,}000 - 3{,}600 - 3{,}600 - 48{,}100 + 218{,}500 - 1{,}156{,}700$$

$$= 521{,}500 \text{ acre-feet/year for 2000}$$

This result suggests canal seepage for 1996 was greater than in 2000; total diversion for 1996 was also greater than 2000, but by a lesser percentage. Since the year 2000 had more irrigated lands than 1996, a greater volume of water was allotted to these fields during 2000, thus reducing the residual amount assumed to represent canal

seepage. In reality, less water is delivered on a per-acre basis during a low water year. The seepage equation used in this estimate assumes 4.3 ft/ac is applied to all fields, regardless of total diversion. Better data regarding actual delivery would improve this estimate.

These estimates were then compared to conveyance loss data from the Boise Project Board of Control and the Black Canyon Irrigation District. The Boise Project is an irrigation operations entity comprised of five irrigation districts: Big Bend, Boise-Kuna, Nampa and Meridian, New York, and Wilder. These districts comprise approximately 48% of Treasure Valley flood-irrigated acreage (about 137,700 acres). The Black Canyon Irrigation District irrigated about 45,300 acres of land within the northern portion of the valley (north and west of the City of Caldwell).

According to Board of Control annual reports (IDWR files), the average conveyance loss during the 1985-1990 period was about 49% of the amount diverted to the Boise Project area. About 3% of the conveyance loss was attributed to losses from Lake Lowell, while an additional 1% was lost through direct evaporation and ET along the canals. Using these estimates, conveyance loss attributed to canal seepage was estimated to be about 45% of the total diversion. The Black Canyon Irrigation District reported canal seepage losses of about 33% of the diversion for 1992 (USBR, 1997).

In addition to the above estimates, seepage measurements were taken by the USGS in 42 canal reaches throughout the Treasure Valley during the beginning and end of the 1996 irrigation season (Berenbrock, 1999). These data appear to be influenced by local hydraulic factors and do not necessarily reflect regional seepage patterns.

The USGS also measured seepage in the New York Canal during March 1997 (Berenbrock, 1999). The New York canal lost approximately 12% of the flow between the Boise River and Lake Lowell when approximately 430 cfs were being diverted at Diversion Dam. At a diversion rate of 870 cfs the canal lost approximately 17% of its flow over the same reach. Causes for the flow loss include channel loss (seepage) and evaporation. Evaporation at the March measuring time is considered to be minimal, so most of the loss was attributed to channel loss. These seepage tests were of relatively short duration, and it is possible that the measured seepage rate would decrease over time as the local soils became saturated and as shallow ground water levels rise in response to the seepage. For the purpose of this water budget, it was assumed that under equilibrium conditions New York Canal, seepage was approximately 13% of the total 1996 diversion during the irrigation season.

In conclusion, canal seepage rates will vary throughout the valley, depending on soil type and elevation of the water table. For the purpose of this water budget, total canal seepage for the valley was estimated to be about 625,900 af in 1996, or about 40% of the total diversion to the valley; seepage for 2000 was estimated at 521,500 af, which is about 34% of the total diversion for 2000. Assuming a total canal length of

1,170 miles (major and intermediate canals only), canal seepage occurs at an average rate of about 0.75 cfs/mile.

2.2. Recharge from Rivers and Streams

Additional sources of aquifer recharge include seepage from the Boise River and from small streams and drainages located within the Boise Foothills. Other streams within the valley are ephemeral in nature and are thought to contribute very little ground water recharge. Many serve as drains where they pass through flood-irrigated lands (B. Ondrechen, IDWR, personal communication, 1997).

Streams draining the Boise Foothills either discharge to the Boise River or provide seepage into the ground, which then enters the valley as underflow. Recharge within the Boise Foothills was treated as a source of underflow and is discussed further in Section 2.4 below.

The Boise River loses water to the aquifer system from the Lucky Peak Reservoir to Capitol Bridge reach (about 11 miles), while it gains water from the aquifer along the Capitol Bridge to Parma reach (based on stream gage data; USGS, 1996). Reach gain data indicate an annual average loss of about 15,000 af/yr along the Lucky Peak to Capitol Bridge reach during 1958-1996, a period of time reflecting a wide variety of river flow conditions following the construction of Lucky Peak Dam (B. Sutter, IDWR, personal communication, 1996). Data for 1996 suggests the Boise River lost about 15,500 af to the aquifer system along the Lucky Peak to Capitol Bridge reach (USGS, 1997). About 77,000 af were lost during 2000 (IDWR data, 2003).

2.3. Recharge from Lake Lowell

Lake Lowell is a 9,800-acre reservoir located in the southwest portion of the valley. Data for 1996 were not available at the time of this report. However, total loss during 1995 was about 46,000 af (IDWR data) and 48,100 af in 2000 (BPBC annual report), including evaporative losses from the lake surface. About 26,900 af are lost to evaporation each year, assuming a total surface area of 9,800 acres and a mean evaporative loss of 33 inches/yr (Dion, 1972). Net recharge to the shallow aquifer for 1995 was therefore estimated to be about 19,000 af. This value was used for the 1996 water budget. About 21,200 af were lost to seepage in 2000 (BPBC annual report).

2.4. Subsurface Inflow (Underflow)

Subsurface inflow (or underflow) is defined as the ground water that flows across the water budget boundary and can include both horizontal and vertical components of flow. There appears to be no evidence (on the basis of regional ground water contours [Newton, 1991]) of ground water flow across the northern boundary (the watershed divide between the Payette and Boise Rivers) or underneath the Snake River. There is

potential underflow across the northeast water budget boundary and across the east and southeast boundaries.

The magnitude of underflow across the northeast boundary was estimated by assuming all precipitation within the Boise Foothills, less ET and stream discharge, seeps into the rocks and sediments and ultimately flows across the northeastern boundary as ground water. The net precipitation was estimated using water yield maps (Rosa, 1968) and total drainage area (B. Ondrechen, IDWR, 1996). These maps correct for ET, thus allowing an estimate of water available for recharge and runoff. The total drainage area bounded by the valley floor and the hydrographic divide was estimated at 55.4 mi^2. This area includes Stuart Gulch, Crane Creek, Hulls Gulch, Freestone Creek, Cottonwood Creek, Warm Springs Creek, Squaw Creek, Maynard Gulch, Highland Creek, and other unnamed tributaries between Highland Creek and Lucky Peak Reservoir. Based on this approach, the average annual amount of water available for runoff and ground water recharge was estimated to be 7,600 af/year (2.6 area inches). Less than 1 area inch of recharge is estimated for the foothills area west of Stuart Gulch.

Total stream discharge from the Foothills was estimated to be about 4 cfs using published data (e.g., USGS, 1956). Total underflow across the northern and northeast boundaries was therefore estimated to be about 4,300 af.

The underflow across the eastern and southeastern project boundaries also appears to be very small. Ground water level maps drawn from spring and fall 1996 mass ground water level measurements indicate ground water flow lines somewhat parallel to the southeastern project boundary, indicating no-flow boundary conditions (see Berenbrock, 1999). Simulated ground water contours in deeper zones (Newton, 1991) also indicate minimal ground water flow across the southeastern project boundary. Newton's model (1991) was run to evaluate the possible magnitude of underflow across the southeastern project boundary. Calculations using transmissivity and head-difference values between rows 30 and 31 of layer 2 (which extends from 500 to 4,500 ft below ground surface) in the WSRP model (Newton, 1991) result in an estimate of approximately 5 cfs in the form of underflow across the eastern boundary. However, subsequent ground water modeling within the Treasure Valley (Petrich, 2004) suggests no underflow from this region. In summary, total underflow (as recharge) for the valley was estimated to be about 4,300 af. This represents less than 1% of the total aquifer recharge.

2.5. Recharge from Precipitation and Surface Water Irrigation

It is generally recognized that flood irrigation can be a significant source of recharge to Treasure Valley aquifers. Development of an extensive canal system, beginning in the 1880s, and associated irrigation using diverted surface water raised ground water levels in the shallow aquifers several tens of feet and has significantly increased the amount

of water held in storage (Dion, 1972). This section presents estimates of ground water recharge from precipitation and irrigation for several Treasure Valley land use types.

Precipitation and surface water irrigation are addressed together because precipitation and applied surface water jointly meet consumptive demands and a portion of each source may become aquifer recharge. For example, most of the precipitation is lost to ET in a low precipitation area. In an irrigated area, some of the soil moisture requirement is met by irrigation but some is also met by precipitation (especially in the spring and early summer months). Similarly, some precipitation may infiltrate to become aquifer recharge, and any excess water applied during the irrigation season may also become recharge.

The following sections provide estimates of ground water recharge for flood-irrigated lands using surface water (Section 2.5.1), sprinkle-irrigated lands using surface water, fallow land, rangeland, residential lands, and public lands, such as parks and greenways (Section 2.5.2).

2.5.1. Recharge from Flood Irrigation and Precipitation

Recharge was estimated using the following relationship:

$$R_{FI} = F_A + P - ET - R_{off} - F_c \qquad \text{(Eqn. 4)}$$

where

R_{FI} = recharge from flood irrigation

F_A = amount of surface water applied

P = precipitation

ET = crop evapotranspiration

$Evap$ = evaporation from bare soils

$Roff$ = total runoff (includes runoff from excess flood irrigation and precipitation into drains, and municipal discharges to the river)

Water application rates vary within the Treasure Valley, depending upon water availability, crop demand, and the efficiency of the irrigation district. The Boise Project, which includes most of the southern portion of the Treasure Valley, delivered an average of 2.5 ft/ac of water to the fields during the 1985-1990 time period. The Black Canyon Irrigation District (located in the northern portion of the valley) delivered about 5.2 ft/ac to fields during 1992 (USBR, 1997). Other districts within the valley delivered an unknown amount of water. According to Newton (1991), the USBR reported that farm delivery requirements for the Boise River valley averaged about 3.8 ft/ac. Lindgren (1982) evaluated average irrigation diversions for

29 subareas within the Treasure Valley. Net application ranged from less than 2 ft/ac to more than 8 ft/ac; the average was 4.3 ft/ac.

The actual amount diverted throughout the valley varies; the actual amount applied to a specific tract of land depends on crop demand and water availability. For this water budget, it was assumed that an average of 4.3 ft/ac was applied to 252,000 acres of flood-irrigated lands during 1996 (1,083,600 af). For the year 2000, it was also assumed the average application rate was 4.3 ft/ac, resulting in 1,156,700 af over 269,000 acres. It was also assumed that all precipitation, less ET, evaporation during the non-irrigation season, and direct runoff was available for recharge where land is used for flood irrigation because soil-moisture conditions are otherwise satisfied throughout much of the growing season (Newton, 1991). The mean annual precipitation for flood-irrigated land within the valley was about 12.8 inches (Section 1.3). This results in about 268,800 af of precipitation over a flood-irrigated area of 252,000 acres for 1996 and 251,000 af for 2000 (11.2 inches of precipitation applied to 269,000 acres).

Much of the total potential recharge from precipitation is lost to ET. For 1996, ET data for the Treasure Valley area were calculated for a variety of crops using the Kimberly-Penman equation, which incorporates variables representing local conditions (USBR, 1995). These variables include measured values for solar radiation, air temperature, relative humidity, and wind conditions. These variables are used to develop coefficients, which are updated yearly using water consumption data provided by local farmers. As a result, these data are considered by many to be most representative for this area (B. Ondrechen, IDWR, personal communication, 1996).

Typical crop rotations for 1995 (Idaho Agricultural Statistics Service, 1996) were examined and assumed to be relatively unchanged for 1996. Crop rotations and corresponding ET data are summarized in Table 1. Because crop types vary spatially, and ET varies by crop, a weighted average for ET was developed. This average takes into account the average crop acreage and ET for each crop type. As shown in Table 1, this approach resulted in a weighted average of about 29.1 inches (2.4 af/ac). This weighted average represented the average amount of water transpired for each acre of cropland within the Treasure Valley. Using this value, and a flood-irrigated area of 252,000 acres, total crop ET (consumptive use) was estimated to be 604,800 af/yr for 1996.

Crop	1995 Crop Acreages[a]		Total Acreage[a]	Percent of Acreage in Normal Rotation	Average Consumptive Use for 1988-1994[b] (inches/acre)
	Ada County	Canyon County			
Alfalfa Hay	26,400	33,500	59,900	23	38.8
Alfalfa Seed	1,900	18,100	20,000	8	29.9
Barley	2,300	13,900	16,200	6	24.3
Corn	4,900	22,800	17,700	10	25.7
Dry Beans	1,900	15,700	17,600	7	19.2
Mint	5,000	7,100	12,100	5	24.7
Oats	1,200	3,400	4,600	2	24.3
Onions	0	5,000	5,000	2	27.4
Potatoes	600	11,000	11,600	4	25.6
Sugar Beets	5,200	25,300	30,500	12	31.8
Wheat	7,300	49,700	57,000	22	24.3
Total	**56,700**	**205,500**	**262,200**	**101**	
			Weighted Average:		**29.1**

[a]1995 crop acreages from Idaho Agricultural Statistics Service (July 1996) EXCEPT data for alfalfa seed, mint and onions, which are 1992 values from USDA 1992 Census of Agriculture. For comparison, land use data for 1994 (IDWR, 1997) show about 258,370 acres of actively irrigated land in organized irrigation districts within the water budget area.

[b]Consumptive use data from Agricultural Water Use Summary, 1988-1994 (USBR, 1995). Consumptive use for alfalfa seed computed as 77 percent of alfalfa hay (Brockway and Allen, 1983)

Table 1: Estimates of irrigated acreage and consumptive use for 1995

For the year 2000, ET was estimated using SEBAL, a satellite image-processing model for computing ET data for large areas. SEBAL is comprised of computational steps that predict a complete radiation and energy balance for the earth's surface along with fluxes of sensible heat and ET. SEBAL uses digital image data collected by Landsat or other remote-sensing satellites measuring visible, near-infrared and thermal infrared radiation. ET is computed as a component of the energy balance on a pixel-by-pixel basis. Using year 2000 Landsat imagery, ET estimates were obtained for a variety of Treasure Valley land uses at the scale originally mapped by IDWR. For fields that were flood-irrigated with surface water, total ET for the 2000 irrigation season was estimated to be about 608,000 af, which is an average of 2.34 feet over 269,000 acres (Kramber, personal communication, 2003).

Data for evaporation from bare soils during the non-irrigation season (*Evap*) were not available for the valley, so this parameter was estimated using monthly values for reference ET (AgriMet data, USBR, 1997) and early season crop coefficients. During the early months of the growing season, crops such as peas and potatoes have relatively little foliage, thus most of the reported ET is from direct evaporation from the soils (B. Ondrechen, IDWR, personal communication, 1997). The early season crop coefficients for these plants suggested bare soil evaporation was about 25% of the reference ET. The total reference ET for the October-March period was about

10.2 inches during the 1996 calendar year (AgriMet data, USBR, 1997), and 10.6 inches in 2000. Using a crop coefficient of 25%, bare soil evaporation during the non-irrigation season was estimated to be about 2.5 inches for 1996 and 2.6 inches for 2000. This is equivalent to about 52,000 af of evaporation over a 252,000 acre area for 1996 and 58,200 af for 2000 (269,000 acres).

Run off of flood irrigation water and precipitation was estimated from reach gain data for the Boise River using the following relationship:

$$R_{off} = R_{gain} - GW_{disch} \qquad \text{(Eqn. 5)}$$

where

R_{off} = total runoff (flood irrigation and precipitation runoff)

R_{gain} = total gain

Gw_{disch} = estimated ground water discharge

Runoff represents excess flood-irrigation water and precipitation that has discharged to drains and canals that subsequently discharge to the Boise River. Reach gains represent the aggregate inflow along a particular reach and include ground water discharge and runoff from fields. Reach gains are determined using stream flow measurements at discrete points along the reach. Boise River stream flow data for Parma and Capitol Bridge were used for this estimate.

Reach gain data for the Boise River (IDWR data) showed a total gain of about 903,000 af during 1996 and 845,000 af for 2000. About 523,200 af of ground water were discharged to the Boise River during 1996, either directly, or through streams and canals (refer to Section 3.2). About 529,000 af were discharged in 2000. Based upon these estimates, total runoff (as drain discharge) to the Boise River was estimated to be about 379,800 af during 1996 and 315,000 af in 2000.

Reach gain data were not available for the Snake River for the year 1996. However, drain flow data from major canals and drains were available for 1992 and showed about 14,000 af of return flow to the Snake River (Section 3.2.3). This amount was assumed to represent total runoff (surface water plus precipitation) from the Treasure Valley to the Snake River during 1996; this same estimate was used for 2000 calculations total runoff from the Treasure Valley and was therefore estimated to be about 393,800 af for the year 1996. Spread over 252,000 acres of flood-irrigated land, this is equivalent to about 19 inches of runoff per acre. Runoff for 2000 is estimated to be about 329,000 af, or about 14 inches per acre. The actual amount of runoff may vary throughout the valley, ranging from about 3 to 30 inches/ac, depending on crop

and soil type, water availability, and method of application (T. Stieber, University of Idaho College of Agriculture, personal communication, 1997).

For comparison, an average of 11 inches/yr of runoff per acre was reported by the Natural Resource Conservation Service (NRCS) for farmlands within the Treasure Valley. The NRCS estimate is based on preliminary results from a computer model ("EPIC") that simulates field erosion. This preliminary estimate was thought to be a representative average for the valley; actual values vary depending upon soil types and field slopes (David Ferguson, NRCS, personal communication, 1997).

Based upon the above estimates, the net recharge to flood-irrigated land during 1996 was estimated as follows:

$R_{FI} = F_A + P - ET - Evap - R_{off}$

$= 1{,}083{,}600 + 268{,}800 - 604{,}800 - 52{,}000 - 393{,}800$

= 301,800 acre-feet/yr

= 1.2 feet/acre of flood-irrigated land

For 2000, recharge was estimated to be :

$= 1{,}156{,}000 + 251{,}000 - 616{,}100 - 58{,}200 - 329{,}000$

= 404,400 acre-feet

= 1.5 feet/acre of flood-irrigated land

It was assumed that the estimated recharge is distributed proportionately over flood-irrigated areas. This assumption, and the estimated recharge value will be reviewed as more data become available.

2.5.2. Recharge from Precipitation for Other Land Uses

This section presents estimates of ground water recharge from precipitation and irrigation for non-flood-irrigated areas. Specifically, this subsection presents estimates of recharge from (1) sprinkler-irrigated land, (2) fallow lands, (3) rangeland, (4) residential land, and (5) public lands. Except where specifically noted, it was assumed that most of these lands use ground water for irrigation purposes.

Previous investigations in the WSRP provided estimates of recharge from precipitation. Kjelstrom (1995) assumed an average of 0.03 ft/yr for the WSRP. Newton (1991) estimated that the total average to all lands within the WSRP was 2% of the average annual precipitation (about 0.02 ft/yr assuming an average precipitation of 10 inches/yr). In developing this estimate, Newton assumed that no recharge occurs

through non-irrigated lands if precipitation is less than 9 inches (i.e., ET from native vegetation exceeds precipitation).

Recharge rates from precipitation were estimated on the basis of 1986 and 1994 land use data (IDWR). Recharge sources by land use included precipitation, and where applicable, irrigation practices. Recharge rates were estimated for individual land use types. The rates were approximated based upon recharge estimates from Newton (1991), Kjelstrom (1995), Drost, et. al.(1997), and communications with IDWR staff. Actual recharge rates vary widely throughout the study area and depend on variables such as soil type, vegetative cover, and water application.

Table 3 provides a summary of estimated recharge rates. These rates represent an approximation of potential recharge based upon major land use classifications. For lands occupied by buildings, pavement, and irrigable lawn (such as residential lands, public lands, and recreational lands), it was assumed that 50% of the land was not irrigable. Given these assumptions, it was estimated that precipitation contributed about 47,900 af of recharge to Treasure Valley aquifers for non-flood-irrigated land uses in 1996 and 65,700 af in 2000. As shown in Table 3, the amount of irrigated land area increased between 1994 and 2000. Using aerial photography, IDWR GIS analysts (Kramber and Wilkins, personal communication, 2003) determined that some farmland that was classified as idle in 1994 had since gone back into production. As a result, an increase in total recharge is observed.

Land Use	Recharge Rate[a] (ft/yr)	Total Acreage[b]		Recharge from Precipitation (af/yr)	
		1996	2000	1996	2000
Arid/Barren Lands	.02	483,800	360,100	9,700	7,200
Residential[c]	.25	57,200	77,200	14,300	19,300
Public/Recreation[c]	.25	7,900	10,300	2,000	2,600
Farmland, Sprinkle Irrigated (ground water)	.20	42,300	27,700	4,200	5,500
Farmland, Sprinkle Irrigated (surface water)	.45	58,700	68,900	17,600	31,000
Dairy/Feedlot	.02	4,300	6,300	100	130
Industrial/Commercial	0.0	17,200	14,300	0	0
			Total	**47,900**	**65,700**

[a]Recharge rates are estimated values based on previous investigations (eg., Newton, 1991, Kjelstrom, 1995, and Drost, et. al., 1997) and communications with IDWR staff. Additional recharge estimates from precipitation on flood-irrigated land are provided in Section 2.5.1.

[b]Acreages from 1986 and 1994 GIS land use coverage for 1996 data (IDWR, 1995, 1997), and 2000 imagery for year 2000. Note that year 2000 has a model grid that is about 117,000 acres smaller than the initial model domain, resulting in less arid/barren lands.

[c]"Residential" includes rural dwellings, farmsteads, and old urban and new subdivisions. "Public" includes parks, colleges, hospitals, schools, etc. "Recreation" includes golf courses, racetracks, campgrounds, stadiums, etc. Recharge rate for these land uses was estimated to be about 0.5 ft/yr but was reduced to 0.25 ft/yr to correct for assumption that about 50% of these lands are not irrigable.

Table 2: Recharge from precipitation by land use.

2.6. Recharge from Rural Domestic Septic Systems

Recharge from septic systems can be significant in some regions, particularly where water use is high and where rural housing is relatively dense. It was assumed that all septic discharge becomes ground water recharge. This recharge was estimated using census data for numbers of rural dwellings and an estimated per-capita discharge rate.

House count data were obtained using census tract data (Bureau of Census, 1992). This GIS database provided an approximate spatial distribution of houses in the Treasure Valley and showed approximately 28,700 rural domestic houses existed within the Treasure Valley during 1990. (Note: the Treasure Valley includes all lands within Ada and Canyon Counties and portions of Elmore and Payette Counties). Similar GIS census tract data were not available for 1995 or 1996. However, county census data showed the number of rural houses in Ada and Canyon Counties increased from a total of 22,775 to 27,000 from 1990 to 1995. This represents an increase of about 20%. To provide an approximation of the spatial distribution of rural domestic houses within the entire Treasure Valley during 1995, the 1990 GIS estimate was increased by 20%, resulting in about 34,400 rural domestic houses.

For 2000, Census data obtained from COMPASS (Goodell, personal communication, 2003) show about 33,500 rural dwellings, with about 31,950 homes being occupied. An average of 2.9 people/house were reported for Ada and Canyon Counties.

The U.S. Environmental Protection Agency reported typical septic discharge to be about 45 gallons per day per person (gpd/person) (EPA, 1980). Assuming three persons per household (Idaho State Department of Commerce, 1996), and 34,400 houses, total recharge from septic systems during 1996 was estimated to be about 1.7 billion gallons, or about 5,200 af. Septic recharge for 2000 was estimated at 4,600 af based upon estimated occupancy.

3. ESTIMATES OF GROUND WATER DISCHARGE

3.1. Ground Water Withdrawal

Ground water withdrawals are comprised of water that is pumped or flows under artesian pressure from municipal, industrial, agricultural and rural domestic water supply wells. The category includes water that is withdrawn from a variety of depths and aquifers. The following sections describe how withdrawal data were obtained and provide estimates of 1996 withdrawals. With the exception of industrial withdrawals, all estimates refer to a total volume of ground water withdrawn and do not necessarily reflect consumptive use (i.e., water permanently removed from the system). For many land uses, some of the ground water withdrawn seeps into the ground as recharge (e.g., irrigated and rural domestic lands; refer to Sections 2.5 and 2.6). For industrial land uses it was assumed that the estimated withdrawal was a measure of consumptive use (i.e., no subsequent aquifer recharge occurs).

3.1.1. Municipal Withdrawal

Municipal wells in the Treasure Valley supply water to a large number of domestic and commercial users. Domestic use refers to water used for individual homes, while commercial use refers to water used by restaurants, industries, apartment complexes, miscellaneous businesses, etc. In addition to these uses, water pumped by municipalities is used to irrigate public lands, such as parks and golf courses. This section provides estimates of withdrawals for each of these uses. Not included are geothermal withdrawals for heating purposes. Geothermal water is withdrawn from an aquifer system, which is below, and largely isolated from, the aquifer systems considered in the TVHP.

3.1.1.1. Domestic and Commercial Withdrawal

Data for municipal ground water withdrawals were obtained from UWI (serving Boise), and the cities of Caldwell, Eagle, Kuna, Meridian, Middleton, Nampa, Parma, and Star.

Municipal pumping rates for areas where actual data were not available were estimated on a per capita basis for 1996. Data from the city of Kuna were used to estimate per capita pumping rates because user population was well known, and these pumping data represent largely domestic uses with some commercial uses. Based on 1995 population and water use data, the citizens of Kuna use about 230 (gpd/person). This was the same value reported by Goodell (1988) for non-industrial public-supply for Ada and Canyon Counties during 1980. Table 3 compares Kuna withdrawals with other suppliers from which actual pumping data were obtained.

A recent IDWR investigation (unpublished revision of Cook, et. al., 2001) resulted in similar water use coefficients, with an estimated 225 gpd/person for single-family homes in Ada and Canyon counties. For mobile homes and apartments, an estimate of 176 gpd/person and 169 gpd/person was developed for Canyon and Ada Counties, respectively.

City	Population[a]		Average Commercial and Domestic Water Use (gpd/person)[b]	
Year	1995	2000	1996	2000
Boise[c]	146,000	185,800	240	236
Caldwell[d]	24,000	25,970	160	178
Kuna[e]	2,400	5,400	230	224 (279)[e]
Nampa[d]	35,300	51,900	140	116

[a]1996 census data unavailable at time of report.

[b]Does not include municipal irrigation of public lands, or self-supplied industrial/commercial use.

[c]Assumes UWI serves a population equivalent to the city of Boise. Assumes domestic irrigation is supplied by UWI.

[d]Does not include domestic irrigation from municipal irrigation wells.

[e]Domestic irrigation was provided by municipal wells in 1996 and is included in water use coefficient. In 2000, pressurized domestic irrigation (107,197,800 gallons) was provided by a separate well. The 224 gpd/person coefficient does not include irrigation, whereas the 279 gpd/person includes irrigation (water that is delivered between April 15 and October 15). Beginning in 2001, Kuna's pressurized irrigation system used surface water pumped from a pond (Personal communication, Jim Taylor, City of Kuna, 2003).

Table 3: Summary of selected municipal water consumption

Figure 8 summarizes municipal water use for 1996. Total municipal use (less municipal irrigation) for 1996 was estimated to be about 66,100 af. For comparison, municipal withdrawal for 1980 (Goodell, 1988) was about 51,300 af. Based upon municipal pumping data for 2000, about 76,800 af of ground water were pumped for domestic, commercial, and industrial uses.

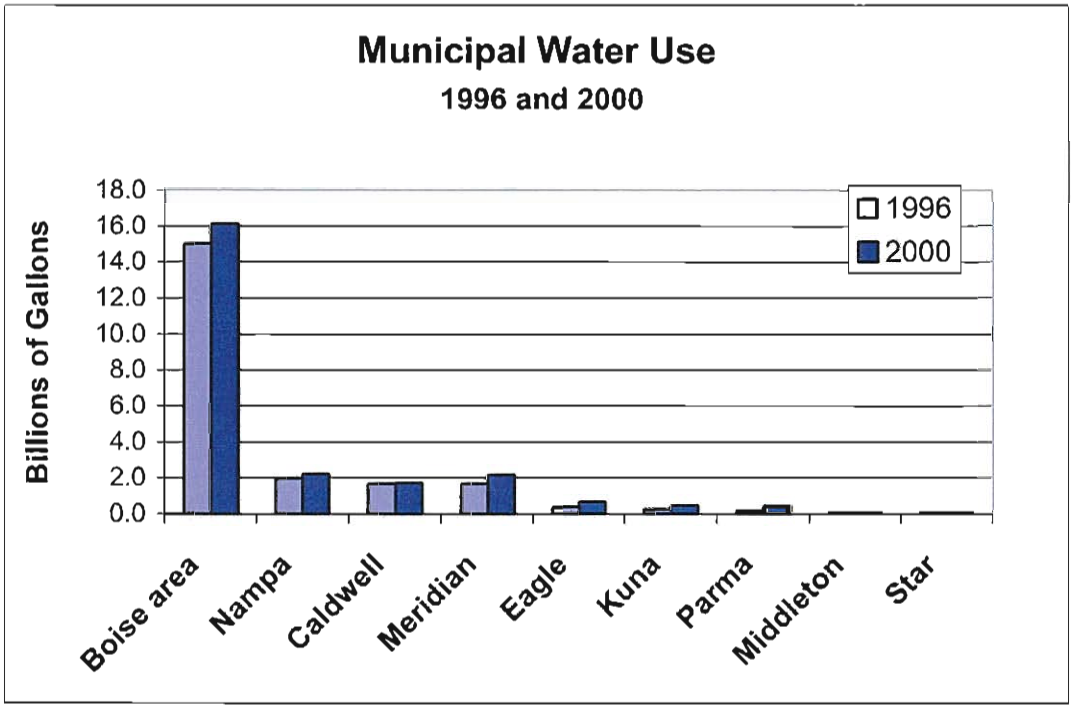

Figure 8: Municipal water use for 1996 and 2000

3.1.1.2. Municipal Irrigation of Public Lands

Most municipalities also use ground water to irrigate public areas such as parks, public golf courses, etc. The city of Nampa utilizes a dual-supply system, where culinary and irrigation water is supplied by two different distribution systems. Nampa used about 11,600 af for municipal irrigation of public and private lands from canals and irrigation wells during 1996 (T. Chavez, city of Nampa, personal communication, 1996).

The city of Boise irrigates about 435 acres of city parks and greenways using ground water and an additional 240 acres using surface water (L. Cody, personal communication, 1996). Most of Boise's irrigation wells lack flow meters, so estimates of ground water withdrawals for irrigating public lands were made using total acreage and ET data. A weather station located at Ann Morrison Park provided daily ET values, which were used to estimate lawn irrigation requirements. For 1995, total ET was estimated to be about 31 inches (2.6 feet). A minimum of 1,130 af were required to meet this demand. Assuming an irrigation efficiency of about 80% (T. Scanlan, Scanlan Engineering, personal communication, 1997), approximately 3.5 feet of water were required per acre. Total ground water withdrawal by the city of Boise for municipal irrigation was estimated to be about 1,500 af.

Total municipal irrigation of public lands throughout the valley was estimated using land use data (IDWR, 1997). These data show that the total area for public lands was about 7,900 acres (this includes public lands within the City of Boise). As discussed in

Section 2.5.2, it was assumed that approximately 50% of public lands were not irrigable, resulting in a revised irrigated acreage of about 3,950 acres. Assuming that 3.5 feet of water were applied (based on the above estimate for the city of Boise), total use of ground water for municipal irrigation was estimated to be about 13,800 af. However, some of this public land was irrigated with surface water. The city of Boise irrigated about 35% of its public lands with surface water, while the city of Nampa obtained about 24% of its irrigation water from surface sources. It was therefore assumed that 30% of the total municipal irrigation demand is satisfied with surface water sources.

In conclusion, it was assumed that about 70% of public lands are irrigated with ground water, resulting in about 9,700 af of ground water withdrawal. For the purpose of this valley-wide water budget, this estimate was assumed to represent both 1996 and 2000 conditions.

3.1.2. Self-Supplied Industrial

Industrial ground water use is difficult to quantify because many industries rely on different water sources, such as a combination of municipal supply and self-supplied water. Also, municipal suppliers usually do not distinguish between commercial and industrial use (i.e., the commercial category includes small businesses, multi-family housing, and industrial facilities).

Industrial pumping for 1996 was estimated from water use coefficients (USGS, 1997b) because actual pumping data were not available for most Treasure Valley industries. Water use coefficients relate average industrial water use, without regard to region or specific water conservation efforts, to the total number of employees for each industry. Actual water use for a specific industry may vary within a region depending on plant efficiency and/or the type of water conservation programs used (Burt, 1983). Goodell (1988) used this approach to estimate self-supplied industrial ground water withdrawal for 1980 and showed self-supplied industrial use was about 14,900 af for Canyon County and about 700 af for Ada County, or a total of about 15,600 af.

To estimate current self-supplied industrial withdrawal for the Treasure Valley, census data for industrial populations were obtained for 1995 (Idaho Department of Employment, 1997; 1996 data unavailable at time of report preparation). Industrial water use coefficients were obtained for industries typically found in the Treasure Valley (USGS, 1997b), assuming the majority of Treasure Valley industries are self-supplied.

Most industries within the Treasure Valley do not record or report water use. However, Micron Technology, Inc., of Boise provided estimates for 1995 water use and employee census. This allowed a water use coefficient to be calculated for the largest industrial employer in the Treasure Valley. In 1995, Micron employed about 7,000 persons and used about 2,650 af of water at its southeast Boise semiconductor facility. This resulted in a water use coefficient of about 340 gpd/employee. However,

about 960 af of the total used was purchased from UWI (M. Maupin, USGS, personal communication, 1997). Using this latter value yielded a water use coefficient of about 215 gpd/employee for the amount of water self-supplied by Micron (the balance of 960 af was included under total municipal withdrawal; refer to Section 3.1.1). Table 4 provides a summary of industry census data and water use coefficients.

Industry[a]	Numbers of Employees (1995)[a]		Water Use Coefficient[b] (gpd/person)	Self-Supplied Industrial Withdrawal by County (af/yr)		Total Self-Supplied Industrial Withdrawal (af/yr)
	Ada County	Canyon County		Ada County	Canyon County	
Agriculture[c]	400	3,000	15	10	50	60
Construction	10,300	2,500	390	4,480	1,070	5,550
Food Processing	2,400	3,900	1,287	3,470	5,710	9,180
Manufacturing[d]	10,000	4,700	204	2,240	1,070	3,310
Micron Technology[e]	7,000	0	215	1,690	0	1,690
Wood Products[f]	2,300	1,400	240	630	360	990
Total	**32,400**	**15,500**		**12,520**	**8,260**	**20,780**

[a]Industry categories and 1995 employee census data from Idaho Dept. of Employment, Research and Analysis, except for Micron Technology, Inc, which supplied its own population and water use data for 1995.

[b]Typical daily industrial water consumption (gpd/employee). Data from USGS website: http://h20.er.usgs.gov/public/wateruse. Exception for Micron Technology, which supplied specific water use and population estimates for 1995.

[c]Agriculture category refers to amount of water personally consumed by the employee; does not include irrigation water, livestock water, or other agricultural uses. Rate of 15 gpd/person obtained from Idaho Water Law Handbook, 1988, Appendix IV;value for "day camps, no lunch served."

[d]Manufacturing category includes electronics industries such as Hewlett-Packard (does not iclude Micron Technology, Inc., of Boise, which is considered separately).

[e]This rate reflects the amount of water pumped from Micron wells only; an additional 123 gpd/employee was purchased from UWI.

[f]Wood products category includes lumber and wood industries, such as lumber, plywood, and cabinet making. It does not include pulp and paper industries.

Table 4: Summary of self-supplied industrial ground water withdrawal for 1996

Approximately 12,500 af of self-supplied industrial ground water were self-supplied by industries in Ada County during 1995 (Table 5). About 8,300 af of self-supplied ground water were used by industries in Canyon County. Total self-supplied industrial ground water use for 1995 was estimated to be about 20,800 af based upon employee census data.

As discussed above, this approach assumes all major industries are self-supplied, except for Micron Technology, Inc.. The estimates of industrial withdrawal presented above may be higher than actual because some industries purchase an undefined amount of ground water from municipal suppliers. Also, with the exception of Micron Technology, Inc., the industrial water use estimates may contain some error because national water use coefficients were used, which may not accurately reflect local conditions (Burt, 1983). Despite these potential errors, total industrial ground water use is small relative to other water budget components.

For the year 2000, average annual industrial water use data were obtained from an IDWR project that investigated domestic, commercial, and industrial water demand for Ada and Canyon Counties (Cook, et. al., 2001). Two sets of data were used to calculate annual water demand coefficients. The first data, from the Idaho Department of Labor, contained monthly counts of employees for establishments covered by unemployment insurance during 1997 and 1998. The second data, from billing records of UWI, contained bimonthly water usage during 1997 and 1998 for all commercial, municipal, and industrial accounts in their service area. The two sets of data were matched and linked using business name and address. The composite data set contained a single record for establishments, with annual values for 1997 and 1998 on employees and water usage. Overall, the sample represented 58,200 (38%) of the estimated 151,560 employees in Ada County and 1,095 (8%) of the estimated 12,771 establishments. Results from this analysis suggested industrial water use was about 8,200 af for Ada and Canyon Counties. This value is less than the 1996 estimate of 20,800 af. This difference is likely the result of using different water use coefficients: the 1996 estimate used published national averages (from USGS, 1997b), whereas the 2000 estimate uses averaged coefficients developed for the local region (from Cook, et. al., 2001).

3.1.3. Irrigation Withdrawals

Significant portions of Treasure Valley agricultural lands are irrigated with ground water. Approximately 42,300 acres of farmland (primarily in the southern portion of the valley) utilize ground water exclusively (IDWR, 1997). In addition, many of the irrigators dependent on surface water supplies use supplemental irrigation wells during periods of drought.

There are three methods commonly used to estimate ground water pumping for irrigation wells (Collins, 1984; Frenzel, 1984; Bowman and Wilson, 1987; Morgan, 1988; Van Metre and Seevers, 1991). These methods include (1) direct readings from flow meters, (2) power billing records for the pump, and (3) consumptive use data and irrigated acreage. These methods are discussed below.

First, direct readings from flow meters require that a significant number of irrigation wells are fitted with totalizing flow meters. At this time, most wells within the Treasure Valley area are not metered.

Second, power consumption data are commonly used to estimate ground water withdrawal using the following relationship (Goodell, 1988):

$$Q = \frac{kWh}{K \times TH} \qquad \text{(Eqn. 6)}$$

where Q = total volume of water pumped (af/yr)

kWh = total power consumed in a year (kilowatt-hours)

K = number of kilowatt-hours required to lift 1 af of water 1 foot (kilowatt-hours/acre-feet-foot)

TH = total head, or pumping lift (feet)

Power consumption, as an indication of ground water pumping, is best suited to areas where pumping lifts are fairly constant throughout an irrigation season and where data are available for individual irrigation wells (Bowman and Wilson, 1987, Frenzel, 1984). Power billing data are available for Treasure Valley irrigation wells, but measurements of head are not available at this time. Consequently, errors in estimates of total head could be a major source of error with respect to calculating ground water use (Morgan, 1988).

The third approach is to use consumptive use and irrigated acreage data to estimate ground water withdrawals. This latter approach was used for the 1996 Treasure Valley water budget because of the limitations associated with the first and second approaches. Estimates of ground water withdrawal on a per-acre basis were obtained by multiplying the irrigated acreage by the average per-acre consumptive use for the valley. A consumptive use value of 29.1 inches/ac was used as described in Section 2.5.

The following assumptions were made in estimating agricultural ground water irrigation:

1. Because water pumping costs are high relative to flood irrigation costs, farmers will not over apply ground water used for irrigation.
2. With the exception of runoff, all precipitation goes into soil storage and is available to the crop.
3. The mean annual precipitation for areas irrigated with ground water was about 10 inches.
4. Topography in areas irrigated with ground water is relatively flat, and the soils are generally well-drained. Therefore, runoff from the fields was probably very low and was estimated to be about 1 inch/acre (B. Ondrechen, IDWR, 1996).

5. The amount of ground water withdrawn was estimated to be equivalent to the total consumptive use (ET), less the net precipitation.

The average ET throughout the valley was estimated in Section 2.5 to be about 29.1 inches/ac (2.42 ft), while the effective precipitation was estimated to be about 9 inches. Based upon these estimates, the amount of ground water required to meet crop consumptive use was estimated to be about 20 inches/ac (1.7 ft/ac). Multiplying this value by 42,300 acres (the total ground water irrigated acreage) resulted in about 71,900 af of ground water withdrawn for agricultural irrigation.

ET for 2000 was obtained using the SEBAL algorithm (Section 2.5.1). Results from this analysis showed about 9,300 acres of land were flood-irrigated with ground water, and about 27,700 acres were sprinkle-irrigated with ground water. Total ET for these lands was estimated at 20,600 af for the flood-irrigated land (2.21 ft/ac) and 66,800 af for the sprinkle-irrigated lands (2.41 ft/ac), for a total ET of about 87,400 af. Subtracting 11.2 inches of precipitation from the total ground water irrigated acreage (37,000 acres) yields a net pumping demand of about 53,000 af for the year 2000.

Pumpage from "supplemental" irrigation wells was not addressed in this water budget. Surface water irrigators frequently use supplemental wells during times when surface water supplies run short (such as during a drought period). Supplemental pumping was not addressed because it was judged to be relatively small given that surface water supplies were available throughout the growing season.

3.1.4. Rural Domestic Withdrawals

Rural domestic withdrawal refers to ground water used by rural residences located outside the boundaries of municipal distribution systems. This section describes estimates made for domestic use only; stock water use was described in Section 1.3.5.

Goodell (1988) assumed the average per-capita rural domestic use was about 98 gpd/person for a total rural population of 51,800 in 1980. The rural domestic ground water use for 1980 was therefore estimated to be about 5,600 af for Ada and Canyon Counties. The 98 gpd/person value used by Goodell was reported to be the average per-capita rural domestic use for 17 western states.

For the 1996 Treasure Valley water budget, rural domestic ground water use was estimated using census data for numbers of rural dwellings and occupants and an assumed per capita consumption rate. House count data were obtained using 1990 using census tract data (Bureau of the Census, 1992). This GIS database provided an approximate spatial distribution of houses and therefore ground water withdrawal (a more recent GIS database was not available). From this data set, the total number of rural domestic homes was estimated to be about 28,700 for the study area in 1990. As described in Section 2.6, 1995 census data were used to extrapolate a spatially distributed estimate for 1995. Results suggest that there were about 34,400 rural domestic houses in the Treasure Valley in 1995, and it was assumed that each house

had its own well. According to census records (Idaho Department of Commerce, 1996), each house is occupied by an average of 3 people. Total rural domestic population was therefore estimated to be about 103,200. Data for 2000 (Goodell, personal communication, 2003) suggests a total of 31,950 occupied homes (33,500 total), with 2.9 people/house, resulting in a total of 92,650 people. Note that the 1996 estimate is for total house, not "occupied" houses; using "total" houses for 2000 results in a population of 97,150. Note also that 2000 data may be more accurate than 1996 data.

In general, many rural houses occupy larger lot sizes (0.5 to 5 acres) than in urban areas. As a result, per capita water use may be higher in rural areas. However, many rural residences within the Treasure Valley have access to surface water supplies, which can be used for lawn and pasture irrigation, thus reducing overall ground water use during the irrigation season. As a result, overall per capita ground water use was assumed to be the same as for urban domestic use (230 gpd/person).

Based on the above, total rural domestic ground water withdrawal was estimated to be about 26,600 af during 1996 and 24,000 af in 2000 (2000 estimate based upon occupancy; amount increases to 25,000 af for total houses).

3.1.5. Livestock

Stock water refers to water used by livestock, such as cattle, horses, etc. Goodell (1988) reported 1980 stock ground water use in Ada and Canyon Counties to be about 2,100 af/yr, with an additional 900 af of surface water being used, or a total of about 3,000 af. This estimate was made using reported livestock populations and typical daily per animal water use.

Revised estimates of ground water consumption for stock watering were made for the 1996 Treasure Valley water budget using animal inventories (Table 5) as provided by the 1992 Census of Agriculture (U.S. Dept. of Commerce, 1994) and typical daily water consumption values (Idaho Water Law Handbook, 1988). Data for 1996 were not available at the time of the original report; data for 2000 were incomplete during this 2003 revision. This estimate was restricted to those animals using relatively large amounts of water (i.e., small animals were not included). It is not known how much surface water was used to augment stock ground water withdrawal during 1992. However, estimates previously provided by Goodell (1988) suggest about 30% of total stock demand is satisfied using surface water sources. Total stock water consumption for Ada and Canyon Counties for 1992 was estimated to be about 3.4 million gallons per day (MG/day) (about 3,800 af/yr). Assuming ground water comprises 70% of this total, it was estimated that ground water use was about 2,600 af.

Animal	1992 Census		Daily Water Consumption (gallons)	Total Consumption (surface and ground water)	
	Ada County	Canyon County		(gallons/day)	(af/yr)
Cattle/Calves	73,400	130,790	12	2,457,500	2,750
Dairy	9,430	14,010	35	820,600	920
Horses	2,910	2,840	12	69,000	70
Sheep	1,940	16,130	2	36,100	40
			Total	**3,383,200**	**3,780**

Table 5: Estimated stock water use.

3.1.6. Summary of Ground Water Pumping

In summary, total ground water withdrawal for 1996 was estimated to be about 197,700 af, with about 174,300 af pumped during 2000. Table 6 provides a summary of withdrawal estimates. Agricultural irrigation represents the largest amount of water pumped followed by municipal uses. Irrigation withdrawal is concentrated primarily within the southwestern portion of the valley.

Ground Water Pumping	Estimated Pumping for 1996 (ac/ft)	Estimated Pumping for 2000 (ac/ft)
Domestic and Industrial Withdrawal[a]	66,100	76,800
Municipal Irrigation	9,700	9,700
Self-Supplied Industrial	20,800	8,200
Agricultural Irrigation[b]	71,900	53,000
Rural Domestic Withdrawal	26,600	24,000
Stock Watering	2,600	2,600
Total	**197,700**	**174,300**

[a]Municipal pumping is concentrated in urban areas. The amount of water withdrawn for industrial use was considered to represent consumptive use (volume of water removed from the aquifer system). The volume estimates associated with the remaining water use classifications do not represent consumptive use because some ground water recharge was assumed to occur (from excess water applied for irrigation on these lands; refer to Section 2.5).

[b]According to IDWR land use data, there were 42,300 acres of farm land irrigated with ground water during 1996, and 37,000 acres in 2000.

Table 6: Summary of treasure valley ground water pumping for 1996

3.2. Discharge to Rivers and Drains

Discharge to rivers and drains refers to ground water that exits the valley by discharging into canals, drains, and rivers. According to Lindholm (1993), 83% of discharge from the WSRP is to rivers and drains, with the remaining 17% discharged via wells. Most discharge in the Treasure Valley occurs to the Boise River during the

irrigation season. The principal discharge area along the Boise River is the reach between the cities of Middleton and Parma (Kjelstrom, 1995). This reach represents the lower half of the valley, and it is along this reach that most of the drains (from the valley's extensive irrigation system) discharge to the river. Additional ground water discharge occurs to the Snake River between Murphy and Nyssa. The following sections provide estimates of ground water discharge to these reaches.

3.2.1. Previous Estimates

Newton (1991) estimated ground water discharge to the Boise River to be about 460,000 af for the year 1980. This estimate was based on river gain data for the non-irrigation season (October to April) and assumes all canal and drain flow to the river during this period was due to ground water discharge.

Thomas and Dion (1974) estimated ground water discharge directly to the Boise River to be about 3 cfs/mile (about 104,200 af) during 1971. This was determined by measuring river discharge at select points at a time when there were no releases from Lucky Peak Reservoir. Increases in river flow were attributed to ground water discharge.

Ground water discharge to the Snake River was estimated by Newton (1991) to be about 350,000 af for the year 1980 over the 101 mile reach between Murphy and Weiser. Gain measurements for the Snake River typically fall within the assumed 5% margin of error for gage measurements (Newton 1991), and as a result should be used with caution.

3.2.2. Boise River

For this water budget, ground water discharge to the Boise River was estimated by determining the mean monthly gain during the non-irrigation season and assuming the same discharge rate occurs during the irrigation season. With the exception of runoff from precipitation, it was assumed that this gain was from ground water discharge to canals and drains and ground water discharge directly to the river. Total gain during the non-irrigation season (e.g., October 15, 1995, through April 15, 1996) was estimated at 283,500 af, or an average of 47,175 af/month (data from USGS, 1996). However, about 3,600 af/month of the winter gain is from storm water and wastewater discharges from the cities of Boise, Caldwell, Meridian, and Nampa (DEQ, 1997). Subtracting this amount from the mean monthly gain results in about 43,600 af/month of ground water discharge for 1996; data for 2000 suggest a corrected monthly average of 44,100 af. Assuming these same rates of ground water discharge occurs during the irrigation season, a total of about 523,200 af of ground water were discharged during 1996 and about 529,200 af in 2000.

There are potential sources of error with this estimate. For example, the ground water discharge is not constant throughout the year. The discharge rate may be less than the

average winter flow at the start of the irrigation season and peak at an above-average value following the end of the irrigation season.

3.2.3. Snake River

Some ground water from the Treasure Valley also discharges to the Snake River. Reach gain data (USGS) for the 68-mile Murphy to Nyssa reach were examined to provide an updated estimate. This reach was coincident with much of the TVHP's southwestern boundary. Because the Snake River received discharge from sources outside the Treasure Valley, ground water discharge was estimated by subtracting estimates of these additional discharge sources from the total reach gain. The balance was assumed to represent ground water discharge and direct return flow from drains leaving the Treasure Valley project area. This approach was taken because data were not available for most drains along this reach.

Reach gain data for the Snake River were not available for 1995 or 1996, so the mean annual gain for the years 1976-1992 was used (period of record). The mean gain for the Murphy to Nyssa reach was estimated to be about 540,800 af. Of this total, about 250,000 af/yr was attributed to sources located south and west of the Snake River (e.g., the Owyhee River drainage, an area outside the TVHP; IDWR data). Subtracting this amount resulted in a net gain of about 290,800 af for 1996.

Discharge from drains was estimated using 1992 data from the Boise Project Board of Control. These data showed drain discharge was about 14,000 af. This amount was assumed to represent surface water runoff only. Subtracting this runoff amount from 290,800 af resulted in about 276,800 af of ground water discharge. Applying the same correction for 2000, about 352,600 af of ground water were discharged to the Snake River during that year.

In summary, ground water discharge to the Boise River during 1996 was estimated to be about 523,200 af, while discharge to the Snake River was estimated to be 290,800 af, for a total of 814,000 af. Data for 2000 suggest 529,000 af of discharge to the Boise River and 352,600 af to the Snake River, resulting in a total of 881,600 af.

Estimated Ground Water Discharge		
Reach	**1996 (af)**	**2000 (af)**
Boise River		
Lucky Peak to Boise	NA*	NA*
Boise to Parma	523,200	529,000
Snake River		
Murphy to Nyssa	276,800	352,600
Total	**814,000**	**881,600**

*Not applicable because river discharges to aquifer along this reach.

Table 7: Ground water discharge to rivers and drains.

3.3. Underflow

With the exception of ground water discharge to major rivers (Section 3.2), there appears to be no evidence of significant subsurface ground water flow leaving the project area. Based upon ground water contours for the region (Newton, 1991), the Snake River appears to be a major ground water divide along the downgradient southern and western project boundaries. Underflow from the project area is therefore considered to be negligible.

4. SPATIAL DISTRIBUTION OF RECHARGE AND PUMPING

The water budget results presented in the preceding sections focus on the Treasure Valley aquifer system as a whole. These aggregate values do not describe the spatial distribution of the water budget components. This section provides three maps describing the general spatial distribution of recharge to and withdrawals from the Treasure Valley aquifer system, as currently defined by the Treasure Valley water budget.

Maps shown in this section were created by kriging spatial data and interpolating the results to a grid with a one-mile cell size. This grid is the same as that used for the development of a Treasure Valley ground water flow model (Petrich, 2004).

4.1. Recharge

The estimated spatial distribution of 1996 ground water recharge in the Treasure Valley is presented in Figure 9. Recharge is concentrated in areas receiving flood irrigation and containing canals. Note that the ground water model uses recharge data compiled on a cell-by-cell basis. At the time of this report, the TVHP model utilized 1996 data for the purpose of calibration. As a result, cell-by-cell data sets were not compiled for 2000, and thus spatial plots for 2000 could not be created.

Some of the recharge is shown in areas of ground water discharge. Infiltration to shallow, local ground water flow systems may result in discharge to nearby canals and/or drains. The map does not distinguish between recharge entering local and regional ground water flow systems.

The spatial distribution of ground water recharge reflects the methods used for estimating recharge. For instance, recharge associated with flood-irrigated agriculture was estimated on the basis of land use; the spatial distribution of flood irrigation is therefore based on the estimated spatial distribution of flood-irrigated lands. Similarly, the recharge associated with canal seepage is distributed on the basis of aggregate canal length per unit area. The greatest canal seepage is therefore in areas having the greatest concentration of canals. A better method of distributing canal seepage throughout the canal system is not available because of the current lack of seepage data for individual canals (with the exception of the New York Canal).

Figure 9 shows significant recharge along the New York Canal. The New York Canal seepage estimate was based on measurements made during March 1997 (Berenbrock, 1999). The New York Canal was assumed to be leaking at a rate of 13% of the average irrigation season flow (refer to Section 2.1). This amount was subtracted from the general canal seepage estimate and was distributed evenly along the length of the New York Canal.

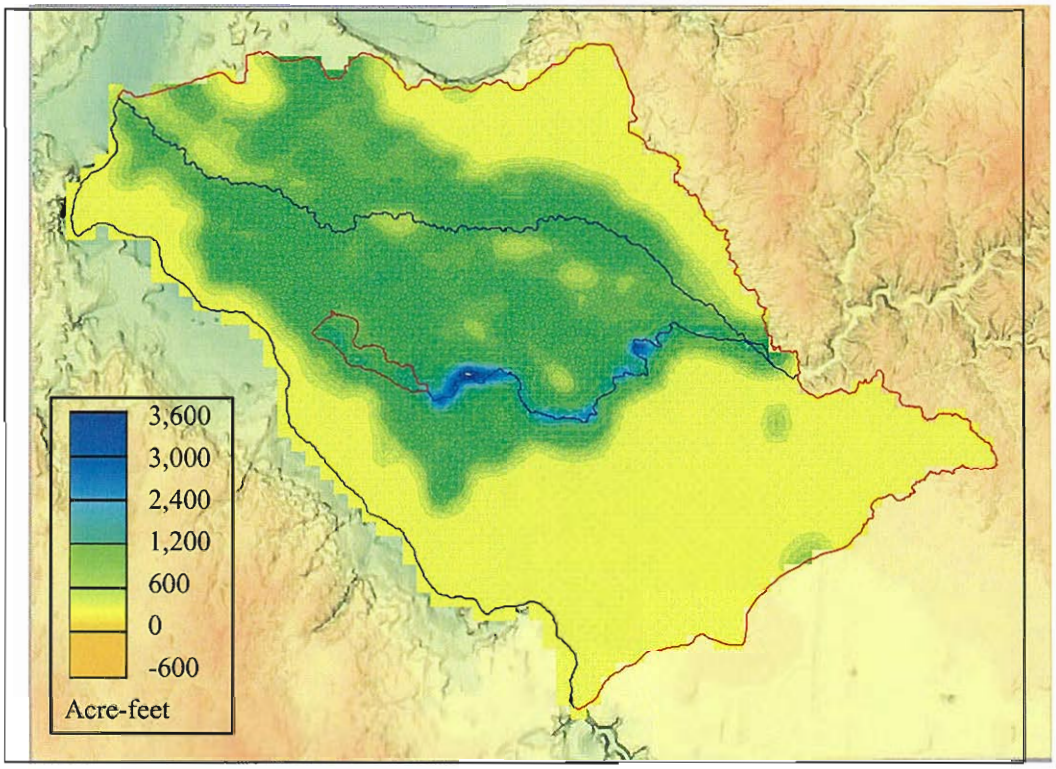

Figure 9: Estimated spatial distribution of 1996 ground water recharge.

4.2. Discharge

Ground water discharge from the Treasure Valley aquifer system consists of discharges to canals, drains, and rivers, and ground water pumping. Discharges to canals, drains, and rivers were estimated on the basis of river gains along Boise and Snake River reaches (Section 3.2). Ground water withdrawals were estimated for various water uses (municipal, irrigation, industrial, etc.).

The spatial distribution of ground water discharge to canals and drains cannot be determined using the aggregate reach gain measurements along the Boise and Snake Rivers. The spatial distribution of discharge to canals and drains will be made using the numerical ground water flow model currently under development.

The approximate spatial distribution of ground water withdrawals in the Treasure Valley is shown in Figure 10. The pumping distribution shows concentrated pumping in urban areas surrounding Boise, Nampa, and Caldwell, and in areas of significant irrigation use (e.g., south and southeast of Lake Lowell).

The distribution of ground water use shown in Figure 10 does not distinguish between source aquifers. Most rural domestic and some irrigation pumping occur from shallow aquifers; most of the municipal pumping occurs from deep, regional aquifers.

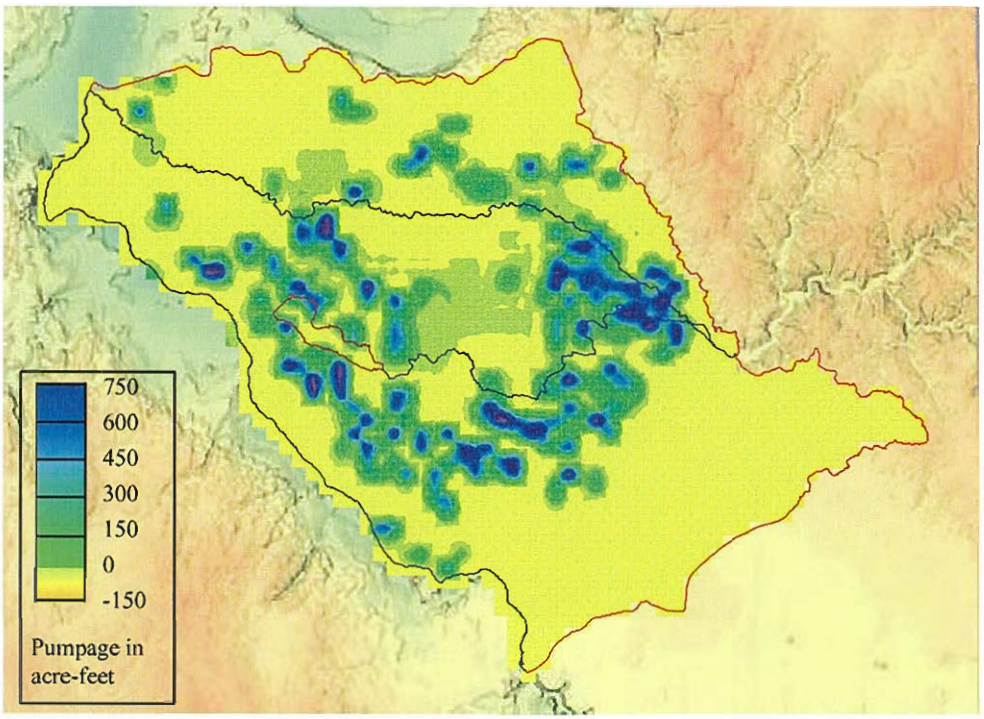

Figure 10: Estimated spatial distribution of 1996 withdrawals.

5. CHANGE IN AQUIFER STORAGE

A difference between net recharge and net discharge implies a change in aquifer storage. A net increase in aquifer storage of about 7,300 af was estimated on the basis of water budget results for 1996. For comparison, a change in regional ground water storage was estimated using water level data.

Water level measurements were compared from 72 Treasure Valley wells taken in March 1996 and March 1997. These measurements were part of monthly measurements in 74 Treasure Valley wells (Berenbrock, 1999). The 72 water level measurements were taken from wells completed at deep and shallow depths and from wells that may have been influenced by recent pumping. The time period of March 1996 to March 1997 does not fully coincide with that of the water budget, which was prepared for the 1996 calendar year; TVHP water level measurements did not begin until March 1996.

Water levels from the March 1996 measurement were subtracted from the March 1997 measurement and a surface map was prepared (using Surfer™) from the individual difference values (Figure 11). This method will produce similar values as subtracting one surface from another and is legitimate if the measurement points are the same (Davis, 1986). It was assumed that the increase in storage occurred in the uppermost aquifer and that this aquifer zone had an effective porosity of 0.30.

Based upon the above, an increase in aquifer storage of approximately 20,000 af was estimated using the 1996 and 1997 water level measurements. This was a preliminary estimate because it was based on water levels taken from a variety of wells (some of the water levels may have been influenced by pumping) completed in different aquifer zones.

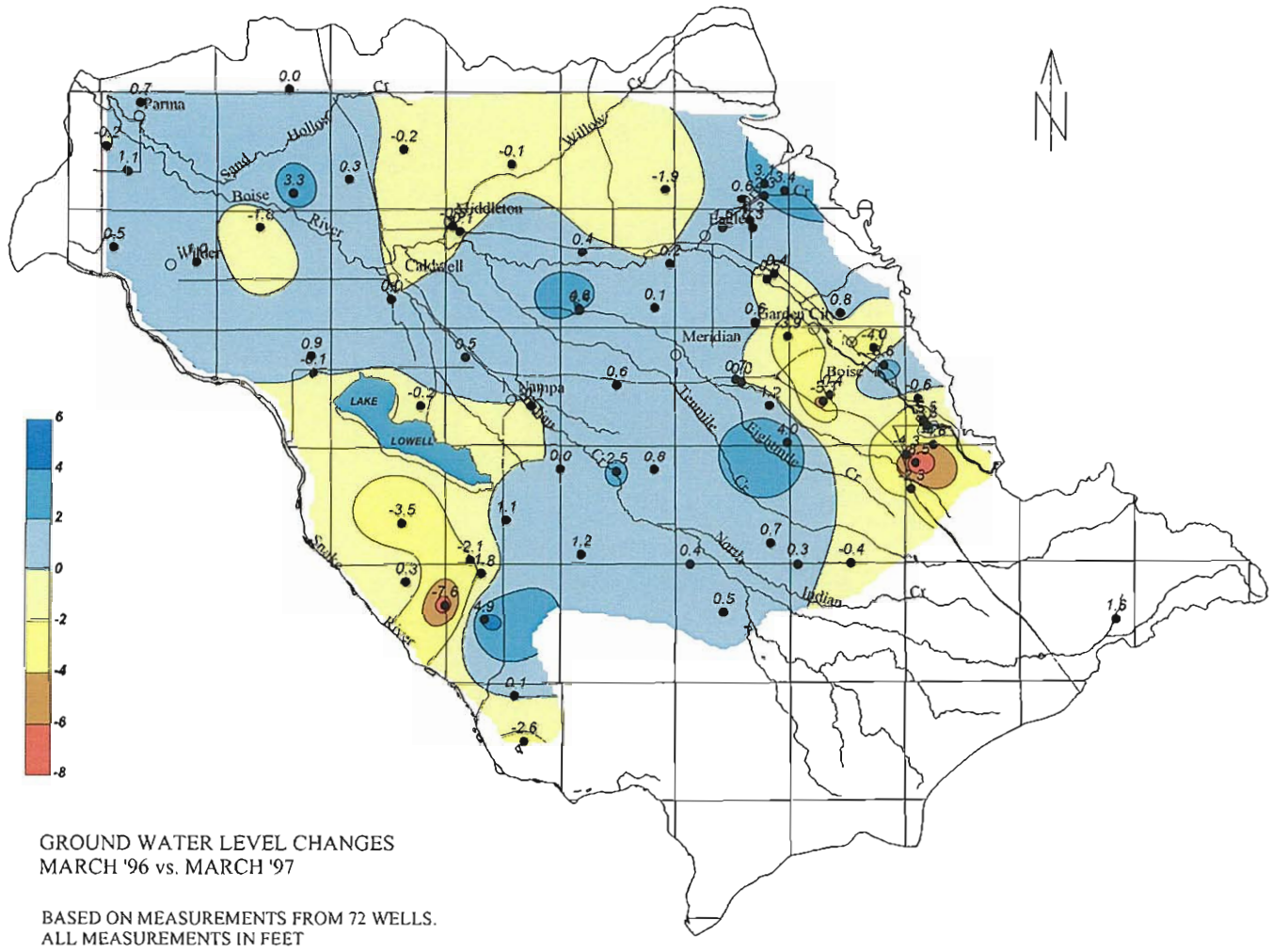

Figure 11: Ground water level change map created by comparing water level elevations for March 1996 and March 1997.

6. SUMMARY AND CONCLUSIONS

This section summarizes results presented in previous sections and provides a discussion of those results. Conclusions drawn from the water budget data are summarized at the end of this section.

This water budget provides an initial regional accounting of inflows and outflows to the Treasure Valley aquifer system. Results from this water budget are summarized in Table 8 and in Figure 12. The largest source of ground water recharge was seepage from the canal system, followed by flood irrigation and precipitation. The aggregate discharge to the Boise and Snake Rivers (through canals, drains, or to the rivers themselves) is far greater than all withdrawals combined. On a valley-wide basis, ground water withdrawals represent approximately 20% of the total ground water recharge.

Error ranges are associated with all of the water budget estimates. Sources of error include all of the measurement and estimation methods for each water budget component. The impact of a relatively small error in a large component can have a significant impact on the water budget balance. For example, seepage from the canal system appears to be the largest recharge component, but the actual magnitude and the distribution of the leakage has not yet been well defined. Similarly, the aquifer discharge to the Snake and Boise Rivers and to Treasure Valley canals and drains is the largest discharge mechanism, and a small error in this estimate could have a significant effect on the overall water budget. The error associated with individual water budget component estimates is expected to decrease as more information becomes available.

The water budget addresses the Treasure Valley aquifer system as a whole. However, the aquifer system clearly consists of a series of shallow and regional aquifers interconnected to varying degrees. This water budget does not take into account ground water flow between different aquifer zones. The numerical ground water flow model can be used to help quantify inter-aquifer flows (Petrich, 2004).

Sources of Recharge and Discharge	Estimated Recharge and Discharge[a]			
	1996		2000	
	(af)	(% of total)	(af)	(% of total)
Recharge[b]				
Canal Seepage	626,000	62	521,500	50
Seepage from Rivers and Streams	16,000	1	77,000	7
Seepage from Lake Lowell	19,000	2	21,200	2
Underflow	4,300	<1	4,300	<1
Flood Irrigation and Precipitation[c]	302,000	29	404,400	35
Recharge by Other Land Uses[c]	48,000	5	65,700	6
Rural Domestic Septic Systems	5,000	<1	4,600	<1
Total Recharge[d]	**1,020,300**		**1,098,700**	
Discharge				
Domestic and Industrial Withdrawals	66,000	7	76,800	7
Municipal Irrigation	10,000	1	10,000	1
Self-Supplied Industrial	21,000	2	8,200	<1
Agricultural Irrigation	72,000	7	53,000	5
Rural Domestic Withdrawals	27,000	3	24,000	2
Stock Watering	3,000	<1	3,000	<1
Discharge to Rivers and Drains	814,000	82	881,600	83
Total Discharge	**1,013,000**		**1,056,600**	
Net Differencee	**+7,300**		**+42,100**	

[a]Because the two years used differing methods of estimation, or revised data sources, some parameters should not be compared directly (e.g., idustrial pumping and recharge from irrigation).

[b]See text for explanations; values shown in this table are rounded to the nearest 1,000 af.

[c]Includes recharge from precipitation and irrigation on flood-irrigated lands only.

[d]Includes recharge from precipitation by land use; does not include flood-irrigated land.

[e]Because of the error associated with the individual water budget components, a positive net difference does not necessarily indicate a positive change in aquifer storage. Likewise, the net difference between the years 1996 and 2000 may not be significant.

Table 8: Water budget summary.

The aggregate nature of the water budget masks the temporal characteristics of ground water recharge, withdrawals, and natural discharge. Infiltration from the surface water distribution system and irrigation occurs primarily in the summer. The actual recharge from irrigation activities lags the infiltration so that water levels may be rising months after irrigation has ceased. Also, municipal ground water use varies throughout the year and is greatest during the summer irrigation season.

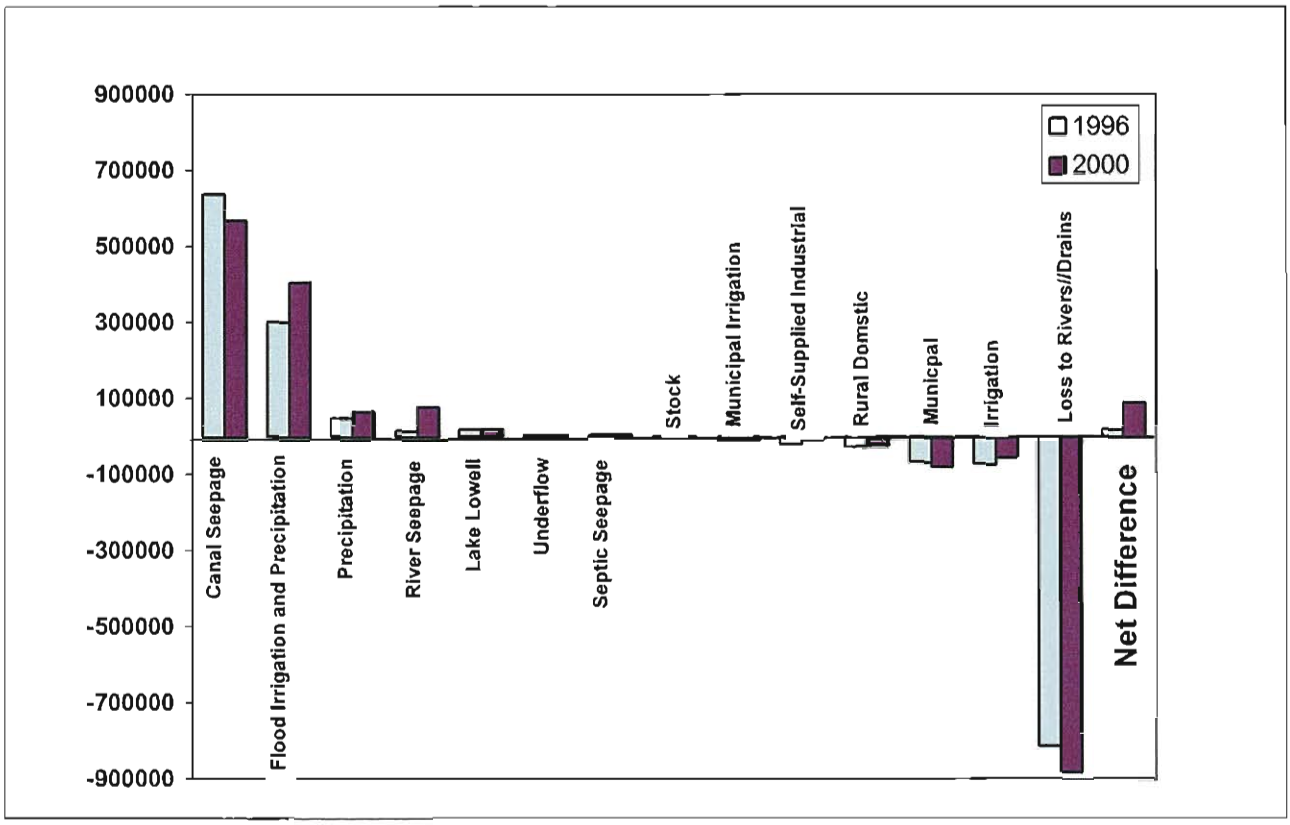

Figure 12: Graph showing water budget components.

The total estimated ground water recharge exceeded the estimated discharge by approximately 7,300 af during 1996 and 42,100 af in 2000. However, these positive net differences are less than 5% of the total recharge or discharge and are considered to be within the margin of error for the individual water budget component estimates. As a result, the net differences do not indicate conclusively that a condition of ground water surplus existed during the 1996 and 2000 calendar years.

Several general conclusions can be drawn from this water budget.

1. The largest components of aquifer recharge are seepage from the canal system and infiltration associated with irrigated agriculture.
2. Seepage to rivers, drains, and canals is the largest source of discharge from the Treasure Valley aquifer system.
3. Overall, total aquifer recharge to the Treasure Valley appears to exceed aquifer discharge. However, the net difference is well within the error range of the water budget components, and the system as a whole is considered to be in equilibrium. Recharge to the Treasure Valley aquifer

system is significantly influenced by land use (by the location of irrigation activities).

4. Evaluating water budgets for individual portions of the Treasure Valley aquifer system requires quantification of vertical and horizontal ground water movement between aquifer zones and the categorization of pumping data by aquifer zone.

7. RECOMMENDATIONS

The following recommendations are made on the basis of the water budget results:

1. Collect additional diversion and return flow data for all of the canal systems in the Treasure Valley to better define canal losses and gains. Some of these data are currently being developed by the USBR.
2. Measure seepage and gains in more intermediate-sized canals. These measurements should be conducted over longer reaches, with diversion and return flow measurements made along the measured reaches.
3. Evaluate the dynamics of canal seepage. This evaluation might be done by measuring directly the hydraulic conductivity of canal bottom sediments, installing piezometers near selected canal reaches and monitoring infiltration, or other means.
4. Separate pumping data by aquifer zone. The water budget could then be differentiated between shallow and regional portions of the aquifer system.
5. Evaluate withdrawals from irrigation wells by installing flow meters in selected wells (on a voluntary basis) and evaluating withdrawals data with electrical records, lift data, and crop type data.
6. Evaluate the impact of supplemental irrigation wells during typical normal and dry water years. This could be done by installing flow meters in selected wells (on a voluntary basis) in different parts of the valley, and evaluating withdrawals on acreage and crop-type basis.
7. The estimated recharge rates presented for some land use classifications may not reflect actual conditions. For example, the net recharge from domestic lawn irrigation may be much higher than 0.25 foot/yr in some areas, depending on soil type and efficiency of the irrigation system. In general, actual measurements of recharge rates for major land use classifications would improve the overall estimate of aquifer recharge.
8. Conduct a study to evaluate the hydrologic effects of land use changes, such as the conversion of irrigated lands to urban subdivisions.

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HYDROGEOLOGY, GEOCHEMISTRY, AND WELL CONSTRUCTION OF THE TREASURE VALLEY HYDROLOGIC PROJECT MONITORING WELL #1, ADA COUNTY, IDAHO

Oct. 22, 1999 Final Report to the TVHP Technical Advisory Committee

by

R. Dittus, J. Allred, and E. Squires
United Water Idaho

Treasure Valley Hydrologic Project

IDWR

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INTRODUCTION

In December 1996, United Water Idaho, Inc. (UWID) completed a 1,005-foot deep exploratory test-well in west Boise, Ada County, Idaho (legal location T4N, R1E, NW$^1/_4$, SW$^1/_4$, SW $^1/_4$, Sec. 14). The location of this well, now named the Treasure Valley Hydrologic Project #1 Monitoring Well (TVHP #1), is shown on Figure 1. .The well was originally drilled to evaluate for potential aquifer units that might be developed for municipal water supply for the City of Boise. Although an accumulated thickness of 100 feet of potentially productive aquifer sands were located, a series of water sampling piezometers completed to four depths showed some of the water quality to be less than desirable. Owing to elevated concentrations of dissolved iron, UWID decided against developing a municipal supply well at this site. Instead, UWID worked with the land owner, Mr. Bill Pierce, and with Mr. Hal Anderson of the Idaho Department of Water Resources (IDWR) who negotiated and secured a 50-year access agreement to the well in order to preserve it as a long-term observation well. The well is completed as a piezometer nest (Figure 2.), and is currently monitored by IDWR to document the annual water-level fluctuations in four sub-aquifer zones.

The well has been donated to the State of Idaho for continuing water chemistry and water-level monitoring. This report presents details of well construction, lithology, water chemistry, and water-level data obtained as a result of the drilling, completion, and monitoring of this well. UWID recognizes the need for a network of designated (long-term) observation wells in the Boise River Valley and has put special effort into preparing this report for the Treasure Valley Hydrologic Project.

WELL CONSTRUCTION

Drilling

The drilling of the exploratory test-well commenced in late October 1996 by Ron Stevens of Stevens & Sons Drilling, Inc. An 8-inch (.0250-inch wall) steel casing with drive shoe was drilled-and-driven through the unconsolidated sands and gravels of the present day Boise River floodplain using a Bucyrus Erie 22-L cable-tool drill. The oversized drive-shoe was stopped in a clay layer at 76 feet as a surface seal. A "Portadrill" direct mud-rotary rig was used to advance an 8-inch diameter bore from 76 to 1,005 feet below ground level (total drilled depth reached on 11/22/96). Drill cuttings, collected by the driller at 5-foot intervals during drilling, were examined in the Boise State University Department of Geoscience's soils lab.

Monitoring Well Design

UWID Geosciences ran natural gamma-ray, single point resistance, and normal resistivity geophysical logs (Figure 3) in the mud-filled borehole on 11/22/96. Several sand units between 15 and 25 feet in thickness, and separated by clay units of variable thicknesses, were delineated below the bottom of the steel casing (76 feet) and above 362 feet. Below 362 feet, mudstone accounts for 90 percent of the drilled section with the

remaining 10 percent consisting of thin (2-to-10-foot thick) fine sand lenses of low water production potential.

Based upon a comparison of the borehole geophysical logs with drill-cuttings from the bore, and taking into account distinct color differences within the drilled section, a "nest" of piezometers was constructed as follows.

Completion

The well was completed with 2-inch diameter schedule-80 flush-joint PVC pipe and factory-slotted PVC screens. Fresh drilling mud was circulated throughout the borehole prior to installation of flush-joint steel grout pipe (2-inch diameter) and four piezometer tubes. The viscosity of the drilling mud was lowered to facilitate pouring of the filter sand through the mud, from land surface (a Marsh Funnel viscosity of about 35 seconds was achieved). Caving sediments filled or bridged the borehole up to 410 feet sometime after geophysical logs were run and prior to well construction. A 53-foot thick cement pressure grout seal was placed on top of this bridged zone. This cement seal serves as a base for the piezometer nest.

Four, 2-inch diameter piezometers with slotted intervals were placed in the well as shown in Figure 2. Filter-pack was poured from the surface through the annular space between the drilled hole and the plastic casings. A weighted tag-line, inside the grout-pipe, was used to verify placement. Calculated volumes of cement grout were pumped through the grout pipe, at the top of each filter packed zone so that the grout was forced upwards. Between each grouting episode, the grout pipe was flushed with just enough water to displace the grout remaining in the pipe and to clear the pipe so a tag-line could be dropped through it. The process was repeated as alternating seals and filter envelopes were installed. Well construction is diagrammed in Figure 2. The uppermost seal is a high-solids (>21% bentonite by weight) bentonite grout. Powdered bentonite ("Industrial 200") from Teague Mineral Products pits in Adrian Oregon was used in this grout.

LITHOLOGY

Beneath the TVHP #1 site, the 30 foot thickness of river gravels (present day Boise River floodplain) are underlain by alternating sand and silty clay layers of variable thickness to 370 feet below ground level (bgl) (Figure 2). Three distinctly different color intervals, above 360 ft., were evident in the drill cuttings. Color changes occur at 167 ft. and 260 ft (Figure 3).Between about 370 feet and 500 feet, the silty clay steadily grades into a thick section of mudstone. A color change within the mudstone, from gray above to dark gray below occurs at about 700 feet. Sand lenses are present within the mudstone section between 780 feet and 900 feet.

The thick mudstone section encountered in the TVHP #1 well is probably correlative to the mudstone facies of the Terteling Springs Formation as mapped by Dr. Spencer Wood on the Boise North quadrangle (Spencer H. Wood, personal

communication, 1999). The geologic section from 515-to-365 feet bgl is interpreted as continuous deposition in an overall coarsening upwards sequence. This gradual change is best shown on the open hole electrical logs of Figure 3 and to a lesser extent (because of sampling inconsistencies) on the grain size percentage log (Figure 4). This 150-foot thick section may represent a regressive pro-delta gradation to delta sands of the Glenn's Ferry or Pierce Gulch sands as they are currently being differentiated by Dr. Wood. His evolving conceptual model , envisions the upper 360 feet of sand dominated section as meandering braided stream deposits overlaying a pro-delta sequence. The thin, discontinuous, fine-grained sand lenses within the thick mudstone section may be shoal deposits or fining upwards turbidite deposits from shoreline sands avalanching off of the delta front.

Grain-size percentage log

A grain-size percentage log of the TVHP #1 drill cuttings is shown on Figure 4. Boise State University graduate students Brian Cavanaugh and Mike Guilbert, of the Department of Geosciences, analyzed the drill cuttings mineralogy and grain-size distribution. In an attempt to be objective with respect to sample description, each five foot sample interval was wet-washed through a stack of U.S. Standard sieves and the percentage retained, by volume was measured. The silt and clay fractions were estimated by settling the wash-through water, and delineated from one another by setting time in a graduated cylinder.

The grain-size log cannot be directly correlated, by depth, with geophysical logs (or lithologic logs based on geophysics) owing to the "lag time" between when the cuttings were first drilled and when they arrived at the surface and also because of mixing within the drill stream. In addition, cavings from the borehole wall, and fine sand entrained within the drilling fluid affected the cuttings. The effects of the downhole mixing of drill cuttings within the mud stream increase with depth. For example, the thin sand layers, obvious on the geophysical logs between 770 feet and 900 feet, were not differentiable in the cuttings.

The grain-size percentage log covers the interval from 60-to-600 feet, and omits the lower 400 feet of the drilled section, which is dominantly olive gray, silty clay-to-mudstone with a few interbedded sand lenses, two-to-10 feet thick. The total cumulative thickness of the sand section within the mudstone totals about 40-feet. These beds stand out clearly on the geophysical logs, but are not well represented in the drill samples because of mixing within the mud-stream as cuttings are pumped to the surface. within the drill stream combine to effectively mask the identity of these sediments.

The complete lithologic log, inferred from cuttings analysis and geophysical logs, is shown on Figure 3. Four distinguishable color intervals are noted. The grain-size log shows the major color changes to be shifted downward due to cuttings return lag-time. In the lithologic log of Figures 2 and 3, adjustments have been made using the geophysical logs to show the color changes at the interpreted actual depth.

The sediments are predominantly arkosic sands derived from the granitic rocks of the Idaho Batholith, with medium-to-coarse-grained sand dominating above 362 feet. Sixty percent of the grains pass through a #18 US Standard sieve and are retained on a #30 sieve. The sands are poorly sorted (well graded), and grains range from angular to sub-angular. The ratio of quartz to feldspar, which comprise essentially 100% of the sand grains, varies from 80/20-to-40/60. Comprising less than 5 percent of the samples are muscovite, biotite, and lithic fragments of igneous intrusive rocks, usually in trace amounts.

Sand-sized pieces of wood are present in the cuttings below 175 feet. Wood comprises up to 5 percent of most samples between 175 feet and 362 feet. The wood is typically black in color and first appears in the sticky clay at 175 feet with the transition from oxidized to reduced sediments. Trace amounts of wood are present throughout the lower drill cuttings, but some or all of these may be re-circulated cuttings from the overlying section.

Iron oxide cementation, and staining of sand grains, occurs down to a depth of 365 feet (the top of the silty clay/ mudstone transition). In the upper oxidized zone (above 175 feet) up to 30% of the sand grains are coated with a red, rusty colored crust which acts as a cement. The mineral pyrite is also present as a cementing agent and grain coating below the oxidized/ reduced boundary at 175 feet bgl.

Calcite cementation, identified by reaction with dilute hydrochloric acid, was found on the very fine sand grains within the mudstone between about 450 feet and 650 feet. The major mineralogic variations with depth are diagrammed on Figure 5.

Geophysical logs

Natural gamma-ray, single-point resistance, and 16-inch and 64-inch normal resistivity logs were run in the open, mud-filled borehole to 1005-feet on 11/22/96. Logs were run immediately after the drill column was removed from the hole. A temperature log was not run because the borehole fluid had been circulated just prior to logging thus negating the potential to obtain meaningful information from this log. Geophysical logs to 450 feet below ground are shown in Figure 3.

The grain-size percentage log would suggest that less than one quarter of the section above 362 feet is comprised of silt sized or finer particles. However, the geophysical logs indicate that the actual percentage of sands is approximately equal to the silts and clays (above 362 ft.). This discrepancy points out the influence, on samples, of re-circulating sands within the drilling mud and the loss of silt-to-clay sized grains during sample collection.

Single point resistance log

The single point resistance log most clearly shows the lithologic contacts between the sand and silty clay beds. Sand units show measured resistance between about 110 and

150 ohms. Above 400 feet, silt and clay units measure about 100 ohms or less. The log below 500 ft. has generally lower resistance values than that measured above 400 ft. An interval of decreasing resistance, showing the transition from silty clay to a fissile mudstone, is apparent between 365 ft. and 515 ft. The steady decrease in measured resistance with depth, over this interval is interpreted to indicate increasing clay content, and diminishing coarse silt-to-sands. The higher-resistance excursions on the log between 760 feet and 900 feet are interpreted as thin sand units within the massive mudstone. Electrical logs were necessary to delineate these lower sands, as these beds were not readily apparent in the drill cuttings, and only weakly expressed on the natural gamma-ray log.

Natural gamma-ray log

The formation above 400 feet has more definition than the underlying mudstone. Natural gamma counts peak at 140 counts per second for the silts and clays above 400 feet. The mudstone section, between 400 and 770 feet is generally less radioactive than the overlying clay beds, averaging about 100 counts per second. The lower, 2-to-10-foot thick sand units have gamma counts similar to sands above 400 feet.

Normal resistivity logs

The slight separation between the 16-inch (short) normal and 64-inch (long) normal resistivity logs indicate that there was invasion of borehole fluids into most sandy units above 400 feet.

Both normal resistivities, below 400 feet and within the mudstone, are very closely spaced indicating that very little invasion of drilling fluids has occurred in the mudstone. The long-normal resistivity is quite low in the sands between 770 ft. and 900 ft. whereas the short-normal and single point resistances are fairly high. This contrast is probably due to the larger radius of investigation of the 64-inch normal reading which incorporates a percentage of the clayey sediments enveloping the very thin sand units. Groundwater chemistry may be a contributing factor as well. Higher salinity is expected on the deeper reading 64-inch normal log because of the stagnant or relatively slow moving groundwater within this low permeability section. The specific conductivity of the borehole fluid at the time of logging was measured at 509 uS. Later, after the well was air-lift developed, the conductivity of water pumped from the aquifer zones was found to be in the 200-275 uS range. The calibration of the electric logs was checked prior to logging.

WATER CHEMISTRY

The piezometer tubes were developed by bailing and air-lifting on 12/12/96. Each piezometer tube was air-lift developed for 1½ to 2 hours at a flow rate of about 10 gallons per minute until clear and sand-free. On 12/13/96 water quality samples were collected from each tube. A submersible sampling pump was used to purge 5 to 10 well-bore volumes prior to sampling. A 0.45-micron filter was used to filter water analyzed for dissolved metals. Inorganic analyses for each zone are tabulated in Figure 2. Duplicate samples were submitted to separate commercial labs (Alchem Laboratories, Inc., and

Analytical Laboratories, Inc.) for analysis. Laboratory results for individual constituents generally agree within 10%. The variation in the sulfide results between the two laboratories suggests that the sample submitted to Alchem may have oxidized some sulfide to sulfate.

Groundwater from all four zones is quite similar. All are a calcium-bicarbonate water chemistry type with a very dilute total dissolved solids (TDS) ranging from 164-to-200 milligrams per liter (mg/L) and a near-to-moderately alkaline field pH ranging from 7.03-to-7.42. With the exception of groundwater from zone-3, TDS ranges only from 164-to-188 mg/L. Groundwater from zone-3 has a slightly higher concentrations of iron, manganese, calcium, magnesium, potassium, and sulfated than the other three zones. Dissolved silica generally increases with depth and temperature. Other parameters are similar between zones.

A dissolved iron concentration of 0.5 mg/L was measured in zone-3 water, while the other zones have iron concentrations less than 0.05 mg/L. Fine crystalline iron sulfide (pyrite) was found on between 10-and-40 percent of the sand grains, both, on and as part of the cement between the sand grains. Finer-grained sands have a higher percentage of iron sulfide than the coarser-grained sands. Iron sulfide was absent or present only in trace amounts throughout the shallower and deeper parts of the boring but yellow-brown-to-brown iron oxyhydroxide occurs as both a stain and as a cementing agent throughout most of the boring.

The presence of dissolved iron in the groundwater of zone-3 was observed during the purging of the piezometer. The groundwater turned from clear to a yellow color when left standing, exposed to atmosphere, in a bucket for 15 minutes. The 210-to-250-foot depth interval is apparently somewhat isolated from both the upper and lower sub-aquifer units at this location. Also, the amount of iron sulfide undergoing oxidation only slightly increases the concentrations of other constituents. The dissolution of the minerals contributing these constituents serves to neutralize the acidity created by the oxidation of iron sulfide to a pH of 7.18, which is higher than the deepest zone-1 groundwater (7.03). The groundwater must be only slightly oxidizing in zone-3 compared to moderately-to-highly oxidizing in the other three zones to have a dissolved iron concentration of0.5 mg/L.

The color variations of freshly drilled sediments between the zones also serve as indicators of the oxidation-reduction potential of the groundwater. Drill-cuttings from zone–3 sub-aquifer unit are dark olive gray in color while the other zones are lighter hues of yellow-brown-to-pale gray. The light yellow-brown coloration in the shallowest depth interval (zone-4) is probably the most highly oxidized, zone-3 the most reduced, and the deeper sediments intermediate between these two shallow zones. The deeper zones are probably less oxidized because they of several interbedded thin clay zones that contain traces-to-abundant wood fragments. The organic wood materials, buried within the aquifer sediments, consume dissolved oxygen and thereby decrease the oxidation-reduction potential even in these moderately oxidized sediments.

WATER-LEVEL MONITORING

A hydrograph, from April 1997 to December 1998, of monthly water-level measurements taken near the beginning of each month, is shown on Figure 6. The missing data points occurred during access negotiations with the owners of the property on which the test well is located. The graph clearly shows that pressure increases with depth, and that fluctuations in the individual aquifer zones mirror one another. The head in the shallowest completion (zone 4) is approximately three feet below that of the other zones. The heads in the three lower zones are typically within ½ foot of one another and show increasing potential with depth.

A seasonal water-level fluctuation of approximately 3 ½-feet is apparent within all 4 zones. The water-level low occurs in December, and the water-level high occurs in the spring or early summer. The seasonal high and low water-levels coincide with increased flow in the Boise River, which begins in January or February (Figure 7.

It is unlikely that the aquifer zones tapped by the piezometers are directly hydraulically connected to nearby surface water sources because of artesian pressures which occur at relatively shallow depths (below 200 feet). Confining conditions are suggested in even the shallowest (zone-4) aquifer completion intervals (130 ft. to 140 ft. and 150 ft. to 170 ft.). Also, the hydrograph does not indicate recharge from nearby laterals because recovery begins before March when canals begin to fill.

A record of the daily water-level fluctuation is shown on Figure 8. These data are from a Stevens F-type water-level recorder and show the continuous day-to-day water-level fluctuation. Zone-1 (the deepest zone) was measured from 4/17/97 through 7/1/97. From 7/1/97 to 10/8/97 the recorder was measuring the water-level in zone-4 (the shallowest zone). The hydrograph for zone-1 begins when the head is at its highest. Ignoring smaller-scale fluctuations, both hydrographs in Figure 8 show an average decline of about 0.007 feet per day. The smaller-scale peaks and valleys, which range up to about 0.5 ft. from trough-to-crest, have not yet been evaluated for barometric effects.

SUMMARY AND CONCLUSIONS

The hydrogeologic conditions and geologic section beneath the TVHP #1 test well site have been investigated to a depth of 1005 feet bgl. Geophysical logs, grain-size distribution, lithologic log, and sub-aquifer water chemistry data are presented in this report. The following is a brief summary.

Underlying a 30-foot thickness of coarse, sandy river gravels, are alternating sand, silt and clay beds, about 2-to-40 feet in thickness, to a depth of 370 feet bgl. The sand layers comprise sub-aquifer units which are somewhat confined by lower permeability silts and clays. Sand and/ or predominantly sandy beds comprise about half of the section

below the surficial river gravel to a depth of about 370 feet. Four piezometer tubes were completed into the thickest of the sand beds between 130 and 340 feet (Figure 2). Below a depth of 370 feet the geologic section is comprised of silty clay which grades into a thick mudstone. Between 770 feet and 900 feet, the mudstone is punctuated by several fine to medium grained sand beds up to 10 feet in thickness (Figure 3).

Water-level measurements of the four piezometer tubes show that aquifer pressures increase with depth beneath this area of west Boise, To date, a 21-month water-level record has been collected for each piezometer. The water-level measurement in the deepest piezometer, open to aquifer zones between 300 feet and 340 feet, reaches a maximum of about two feet above ground level in late Spring. There is a seasonal water-level fluctuation of about four feet in each of the piezometers (Figure 6). The lowest pressure-level in each aquifer zone occurs in January and the highest-pressure levels occur in June, mirroring stream flow rate changes in the Boise River (Figure 7). Further monitoring would suggest the variability of seasonal changes, and whether or not the mean water/pressure-levels are declining, rising, or maintaining. While no piezometer tubes tap the sand beds between 770 feet and 900 feet, these likely have artesian pressures greater than those of the monitoring well piezometers.

Overall, water chemistry is similar within the interbedded section between 130 feet and 340 feet. Distinct color changes are present. The most significant water-quality difference occurs in the aquifer zone between 210 feet and 250 feet (zone-3) where dissolved iron is present at a concentration of 0.5 mg/l, compared to less than 0.05 mg/l in the other zones.

The cooperative work of United Water Idaho with IDWR through the Treasure Valley Hydrologic Project to obtain a long-term lease agreement to this well establishes the first designated long-term monitoring well for the Treasure Valley. It is our hope that this well is the first of many wells in a network of lasting water-level and water quality monitoring points for the Treasure Valley. United Water Idaho is pleased to contribute to the growing body of knowledge being synthesized for Treasure Valley Hydrologic Project.

The authors would like to recognize the contributions of the following people: Spencer Wood (BSU) for review and for pointing out the Boise River's effects on aquifer pressures, Brian Cavenaugh and Mike Guilbert (BSU) for laboratory analysis of drill cuttings, Dick Glanzman (CH2M Hill) for geochemistry review, and Hal Anderson (IDWR) for consistent support and for his persistence in securing the long-term site easements.

FIGURES

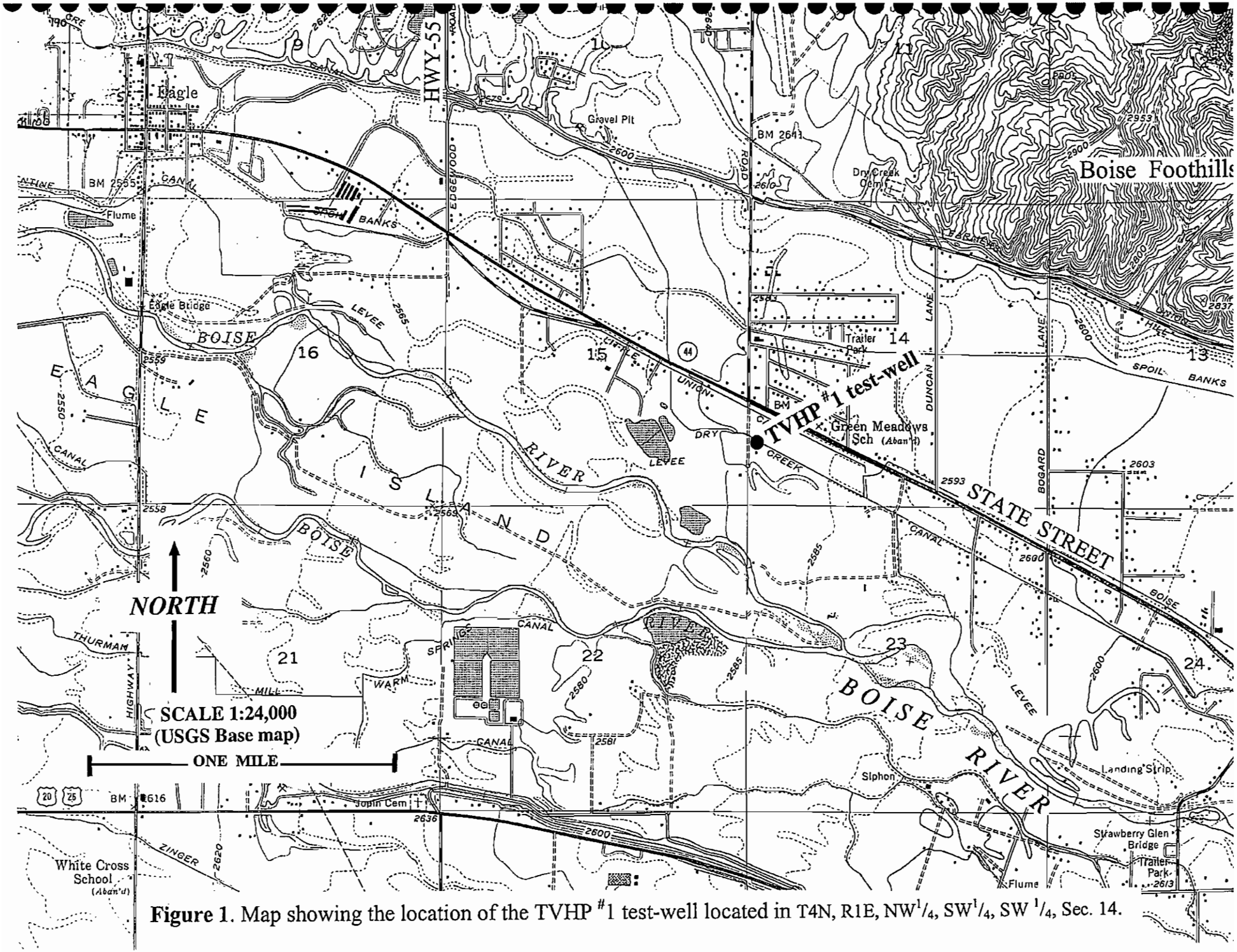


Figure 1. Map showing the location of the TVHP #1 test-well located in T4N, R1E, NW$^1/_4$, SW$^1/_4$, SW $^1/_4$, Sec. 14.

Treasure Valley Hydrologic Project Monitoring Well #1

Comparison of Water Chemistry in Piezometer Completion Zones

(Analyses in mg/l unless note otherwise.)

Constituent	Zone 4		Zone 3		Zone 2		Zone 1	
screen setting (ft below ground)	130-140 ft. 150-170 ft.		210-220 ft. 240-250 ft.		270-290 ft.		300-310 ft. 330-340 ft.	
Laboratory X: Alchem Y: Analytical	X	Y	X	Y	X	Y	X	Y
Date sampled	12/13/98		12/13/98		12/13/98		12/13/96	
Chloride	3.20	3	2.63	3	1.73	2	2.05	2
Fluoride (direct)	0.39	0.75	0.37	0.05	0.36	0.66	0.34	0.57
Nitrate (N)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.13	0.16
Sodium	24.9	24.2	20.3	19.4	15.2	14.2	17.3	15.8
Sulfate	10.2	11	22.5	22	11.4	12	14.4	14
Sulfide	<0.05	0.19	<0.05	0.16	<0.05	0.23	<0.05	0.07
Calcium	37.5	33.3	39.0	35.1	28.1	25.8	28.9	29.2
Potassium	2.17	1.64	2.55	2.06	2.07	1.63	2.00	1.58
Magnesium	4.16	3.62	7.22	6.55	3.94	3.70	4.54	4.58
Iron-total	0.03	<0.05	0.63	0.50	0.05	<0.05	0.06	<0.05
Iron-dissolved *	0.01	<0.05	0.57	0.45	0.01	<0.05	0.02	<0.05
Manganese-total	0.01	<0.05	0.06	0.05	0.04	<0.05	0.03	<0.05
Manganese -dissolved *	0.01	<0.05	0.05	0.05	0.04	<0.05	0.03	<0.05
Silica	28.7	30.6	31.5	32.9	33.6	33.6	32.5	29.9
Alkalinity	139.0	143	132.0	138	101.0	103	112.0	114
Conductivity - lab (uS)	299	294	313	305	224	237	260	255
Conductivity - field (uS)	262		273		213		247	
Corrosivity (Langlier)	-0.33	-0.7	-0.35	-0.8	-0.54	-0.8	-0.87	-1.1
Hardness	111.0	108	129.0	125	86.4	93.7	90.9	99.9
Phosphorus (total)	0.05	0.08	0.04	0.06	0.03	0.07	0.04	0.07
Total dissolved solids	248.0	188	173.0	200	188.0	164	218.0	182
pH -- lab (standard units)	7.70	8.0	7.65	7.9	7.70	8.1	7.30	7.6
pH -- field (standard units)	7.36		7.18		7.42		7.03	
Temperature	54.8 °F		56.6 °F		58.0 °F		58.4 °F	

* Samples for dissolved Iron and Manganese were filtered in the field

Location: NW ¼, SW ¼, SW ¼, Section 14, T4N, R1E, B.M., Ada County, Idaho
Well design by United Water Idaho Geosciences
Well completed 12/5/96 by Stevens & Sons Well Drilling, Boise, ID.

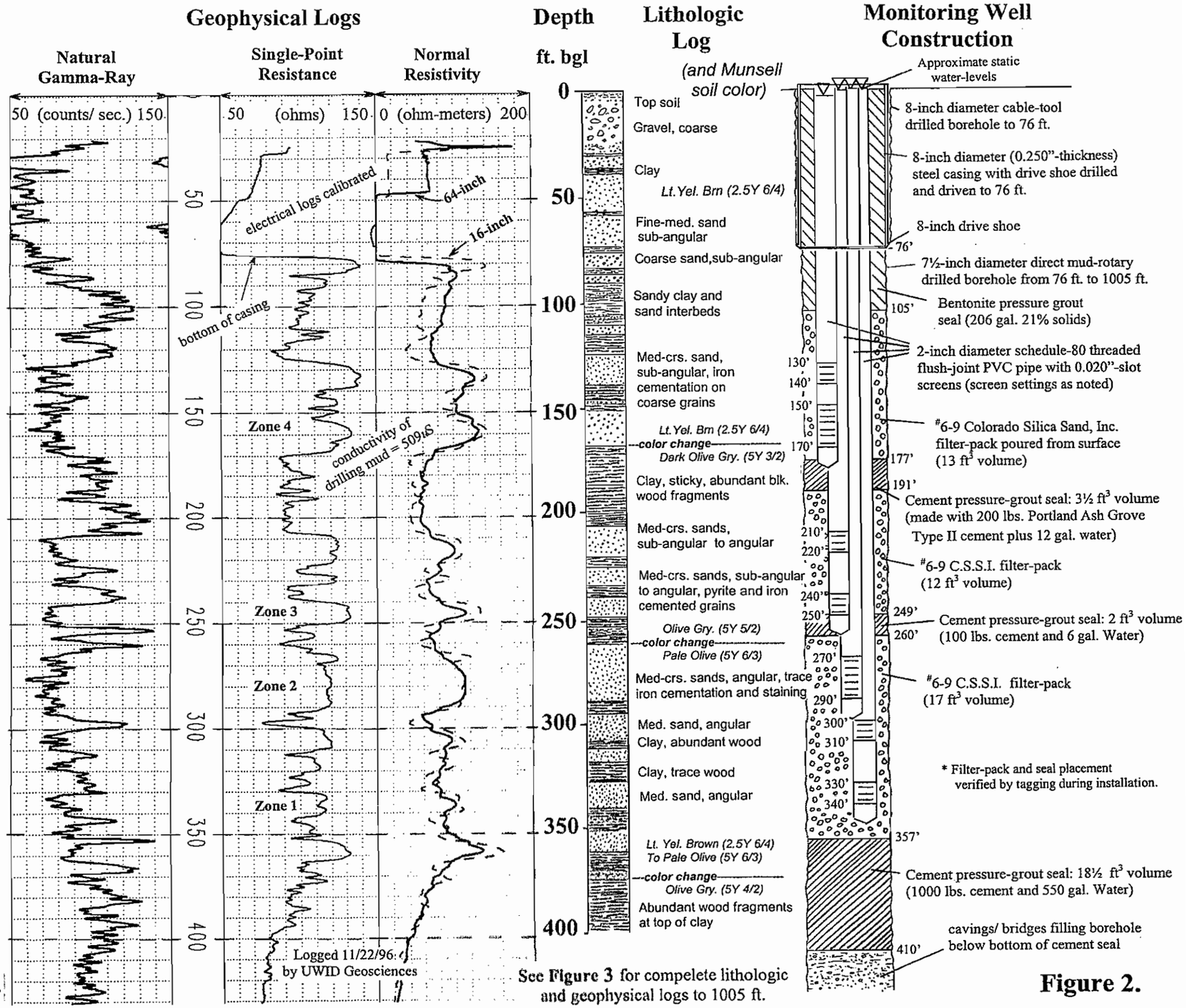


Figure 2.

Figure 2. Composite diagram showing well construction, lithologic log, geophysics and water chemistry at various depths.

Geophysical Logs and Lithologic Log
of the
Treasure Valley Hydrologic Project #1 test-well

T4N, R1E, NW¼, SW¼, SW ¼, Sec. 14

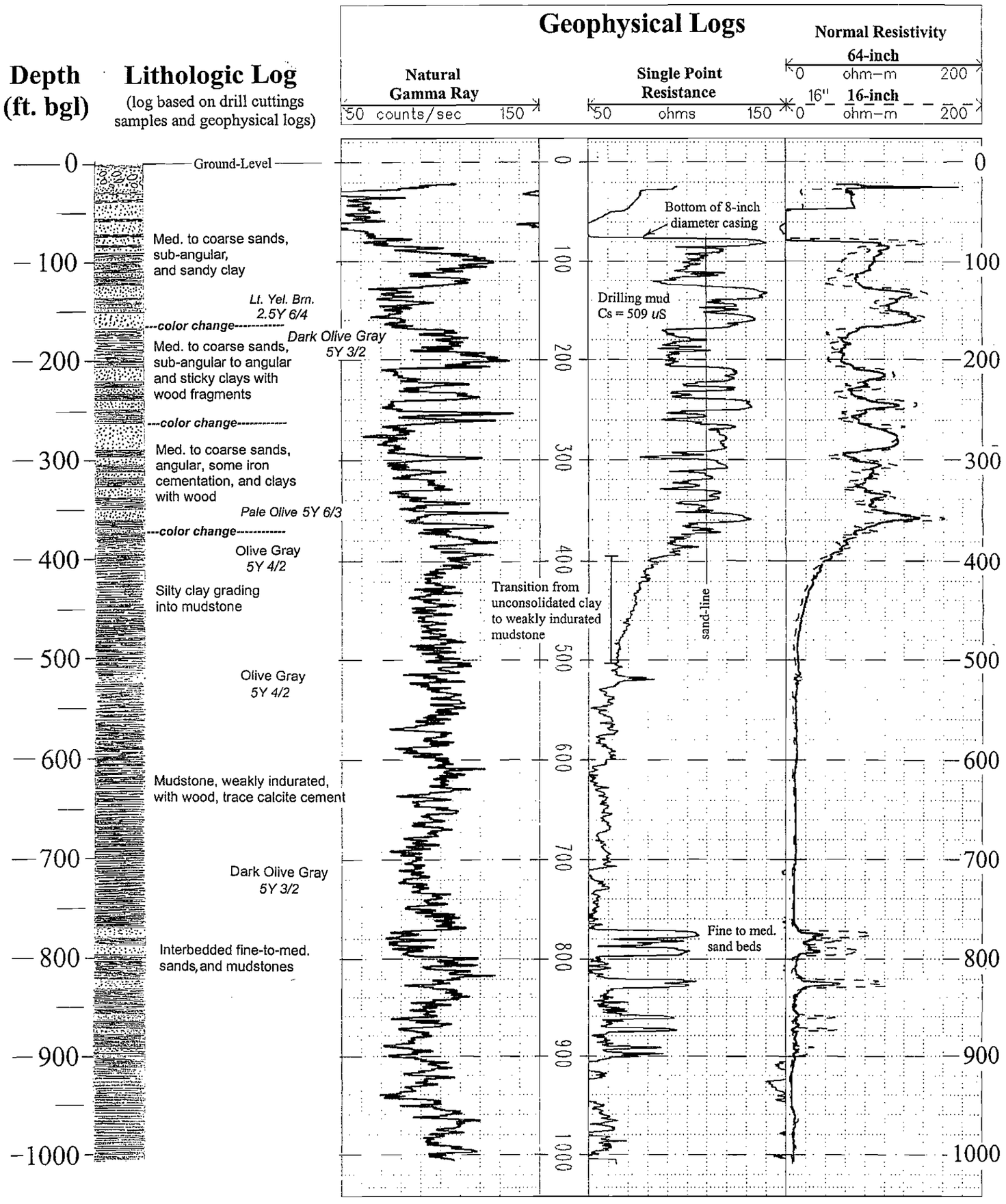
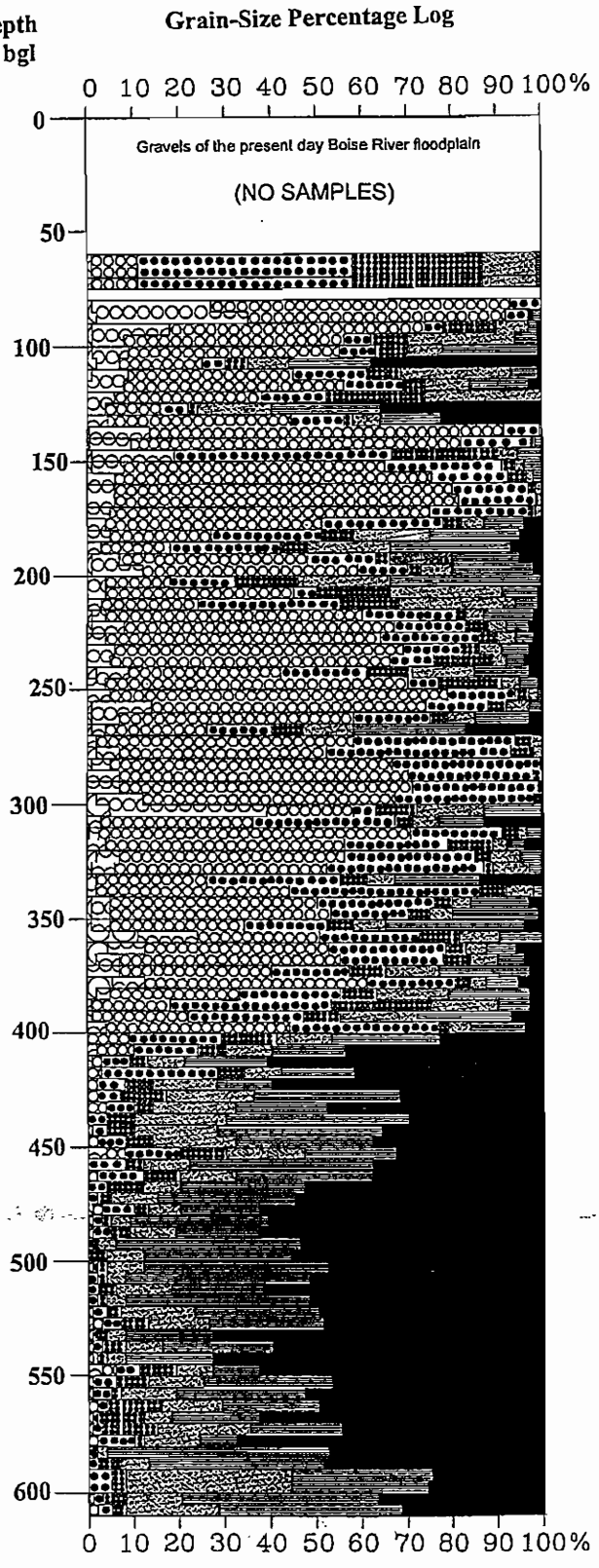
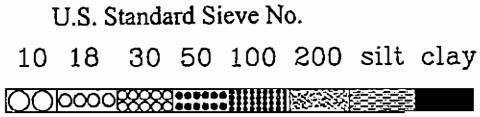


Figure 3. Geophysical logs and lithologic log of the TVHP #1 test-well. Geophysical logs were run in open mud-filled hole by UWID Geosciences on 11/22/96.

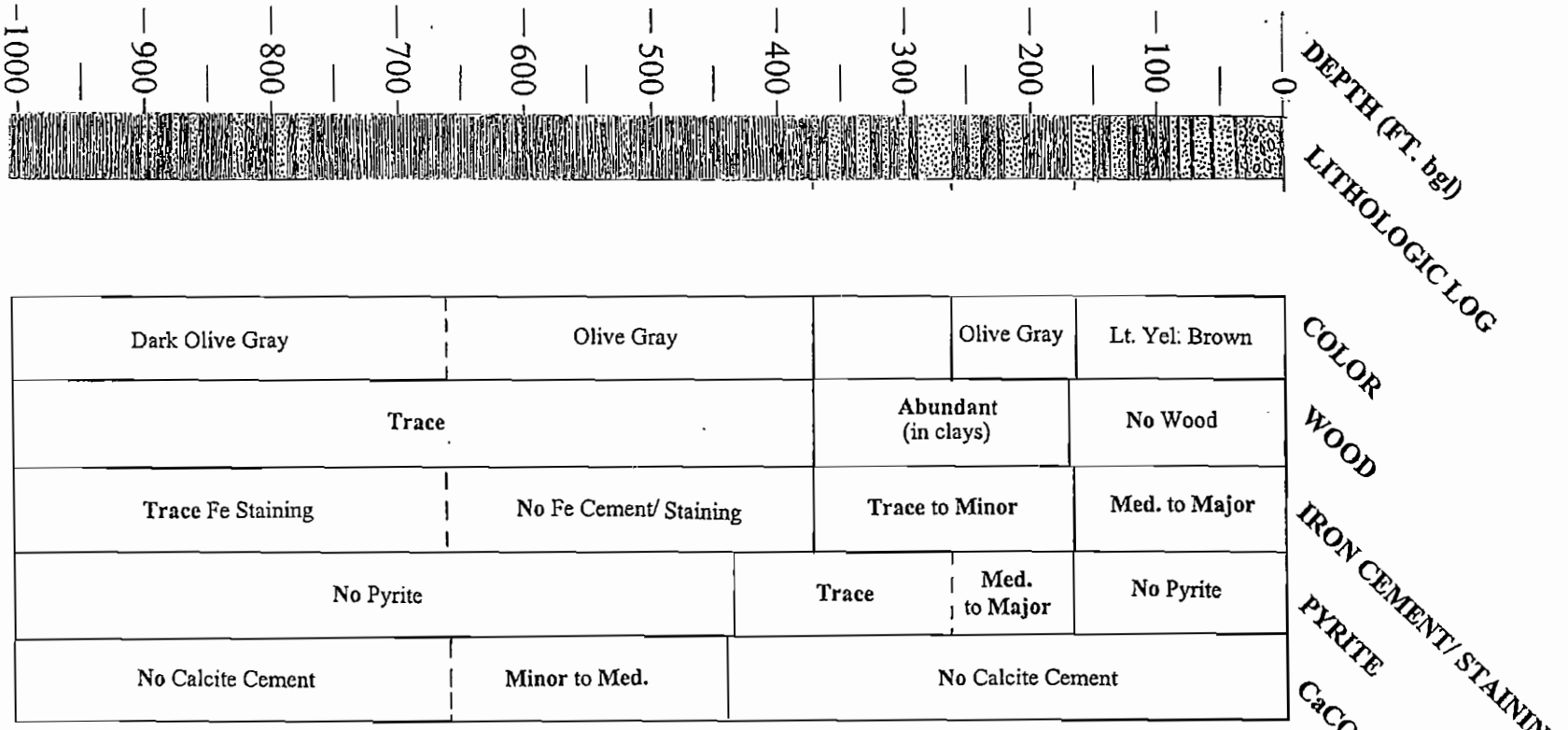




CUTTINGS RETAINED ON SIEVE NO.	GEOLOGIC MATERIAL SIZE RANGE	GRAIN-SIZE RANGE (inches)
#10	> Very Fine Gravel	> 0.079 in.
#18	Very Coarse Sand	0.079 - 0.039
#30	Coarse Sand	0.039 - 0.023
#50	Medium Sand	0.023 – 0.012
#100	Fine Sand	0.012 – 0.006
#200	Fine Sand to Silt	0.006 – 0.003
< #200	Silt/ Clay	< 0.003

Figure 4.

Figure 4. Grain-size percentage log of drill-cuttings from the TVHP #1 test-well. Each five-foot sample interval was wet-washed through a stack of U.S. Standard sieves and the relative percentages retained, by volume,were measured. The silt and clay fractions were estimated by settling the wash-through water, and delineated from one another by setting time in a graduated cylinder. Sieve analysis by Boise State University graduate students Brian Cavanagh and Mike Guilbert of the Department of Geosciences. The log is meant to be an objective representation of grain size distribution with depth, however, recirculated sand, cavings, and the loss of clay and silt particles in the drill-cuttings can affect the log. The log cannot be directly correlated with geophysical logs owing to the cuttings return "lag time".



Explanation:
Major: > 30 % of grains cemented
Medium: > 10 % of grains cemented
Minor: <10 % of grains cemented
Trace: Detectable

Figure 5. Occurrence of reduced wood chips, iron cemented or staining, fine pyrite crystals as cement, and calcite cement on sand grains in the TVHP #1 test well samples.

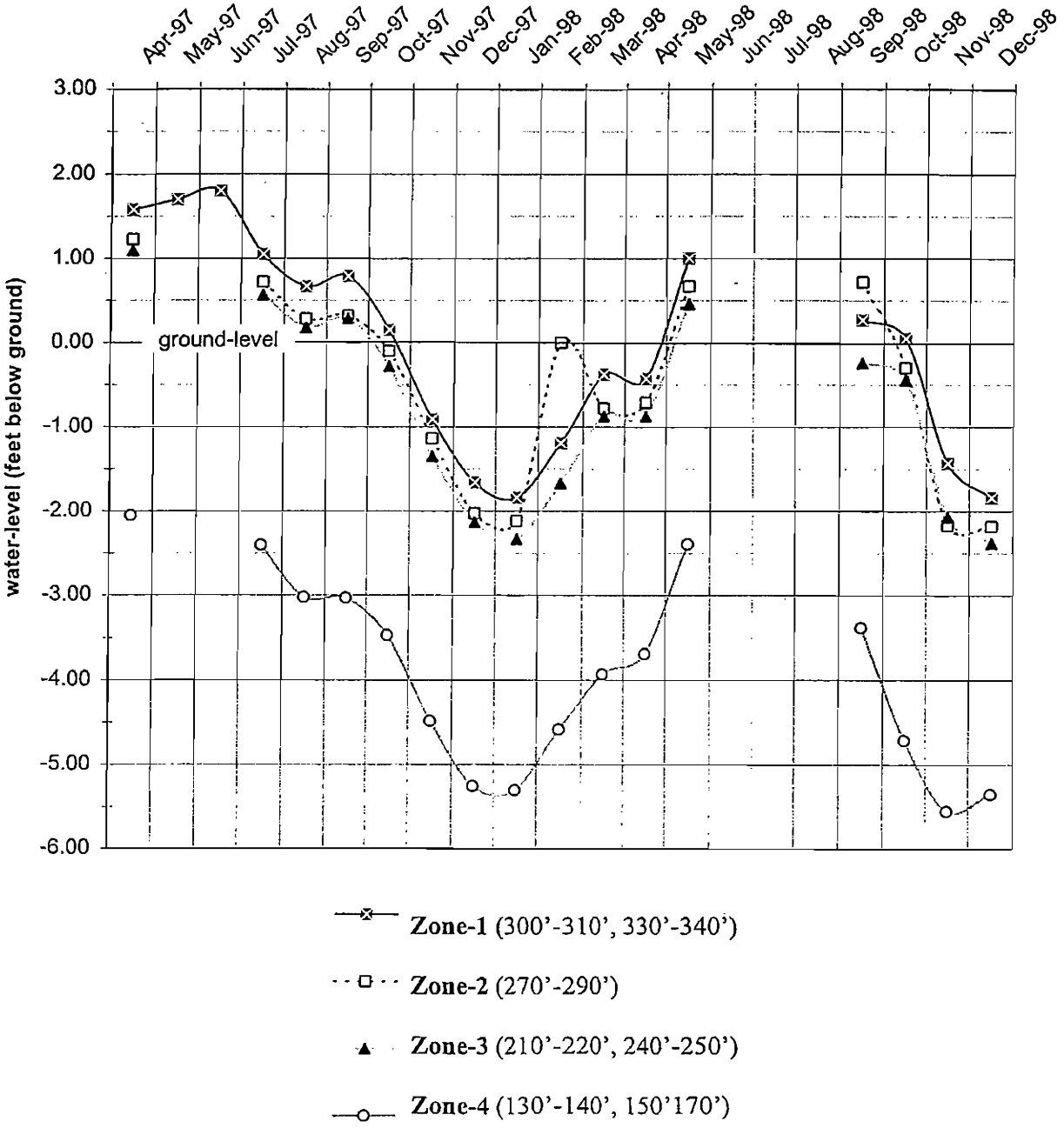


Figure 6. Hydrograph of monthly water-level measurements of the TVHP #1 test-well piezometers. Measurements were taking near the beginning of each month, except June through August 1998, when land owners prevented access.

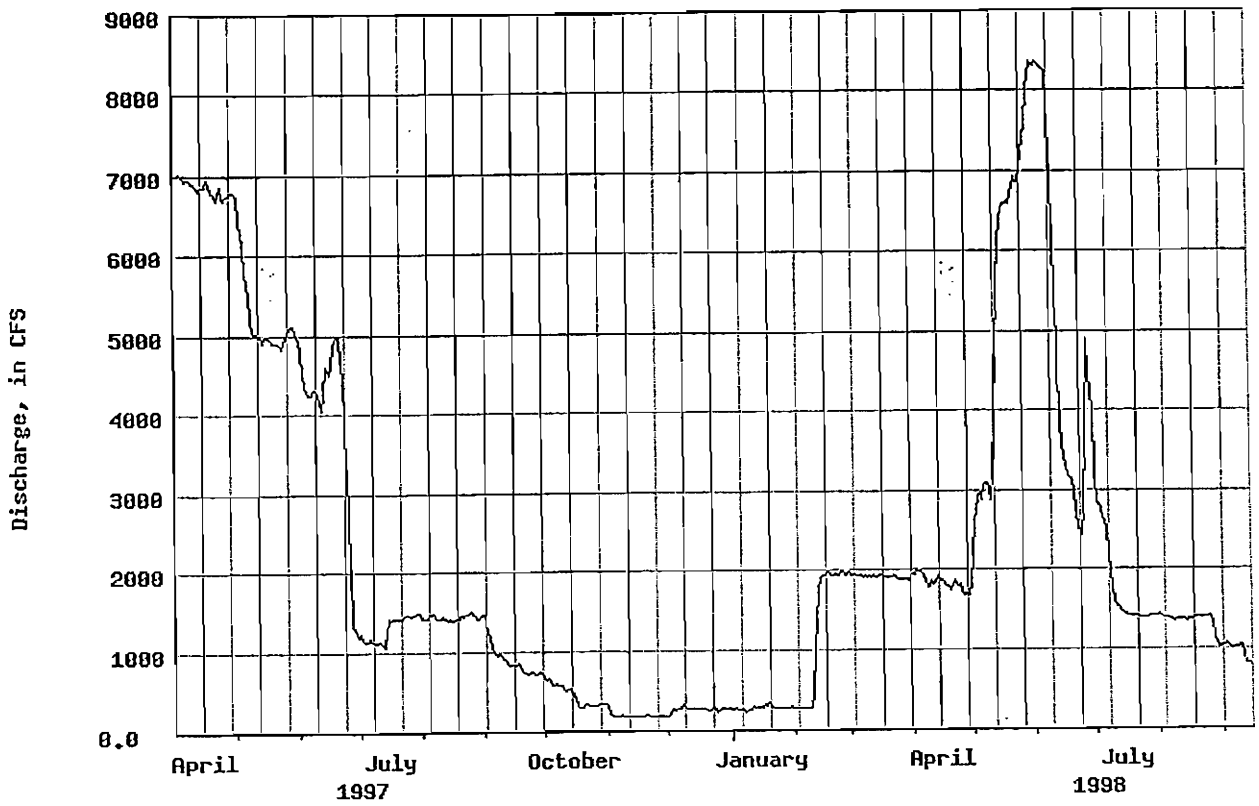
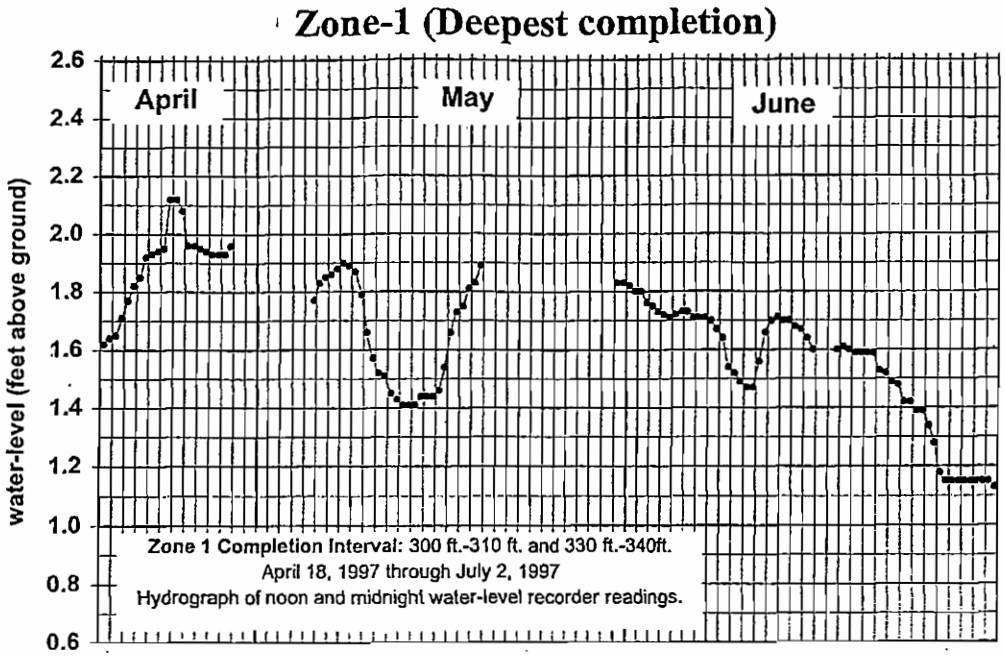


Figure 7. Flow rate of the Boise River at USGS streamflow gauging station number 13206000, located at the Glenwood Bridge, 2.2 miles southeast of the Treasure Valley Hydrologic Project #1 test-well (USGS data). Flow rate in the Boise River corresponds to hydrograph based on monthly water-levels measured in the TVHP #1 test-well over the same time period (see Figure 8).



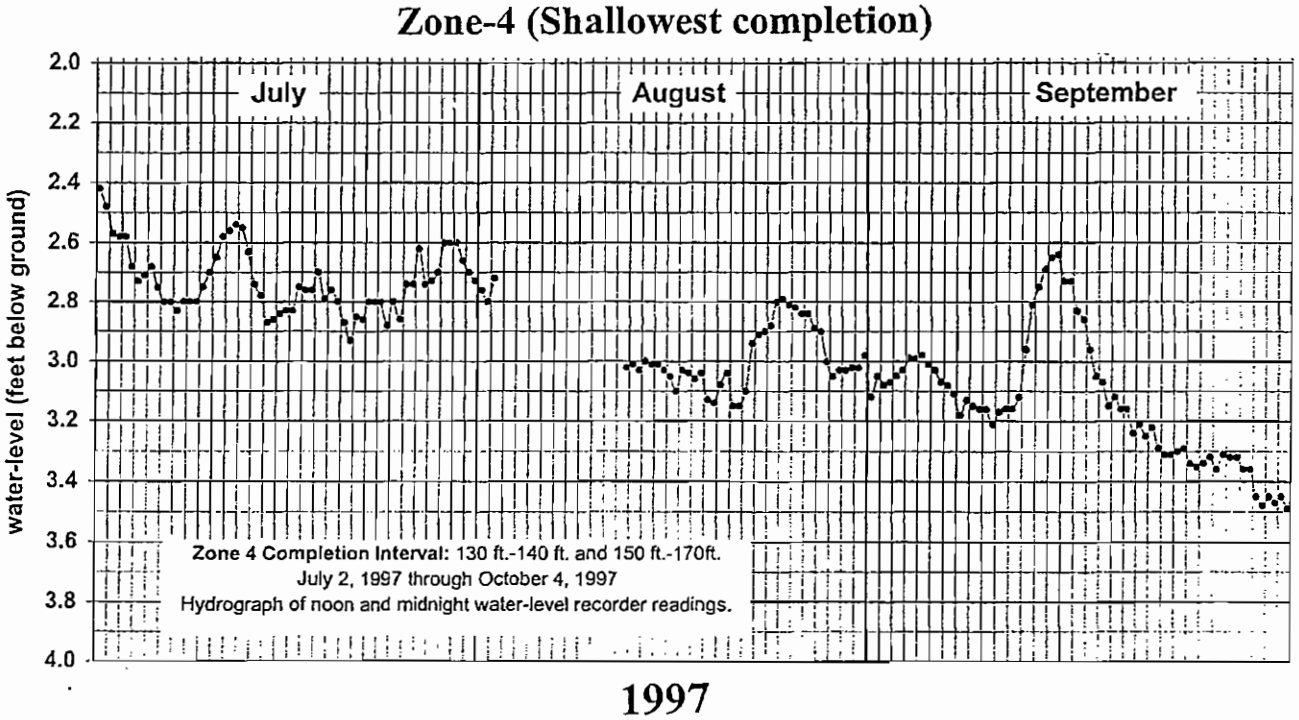


Figure 8. Hydrograph of water-levels for the deepest and shallowest of the four piezometer completion zones in the TVHP #1 test-well , showing the relatively small-scale fluctuations which are probably responses to changes in barometric pressure.

APPENDIX A

WELL DRILLER'S REPORT
to the
Idaho Department of Water Resources

(note: sketch turned in with driller's report is UWID's proposed construction plan which is different from UWID's as-built diagram of this report.)

Form 238-7
3/95

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT
Use Typewriter or Ballpoint Pen

Office Use Only
Inspected by _____
Twp____ Rge____ Sec____
____1/4 ____1/4 ____1/4
Lat: : : Long: : :

1. DRILLING PERMIT NO. 63 - 96 - W - 0709 001
Other IDWR No. _____

2. OWNER:
Name United Water Corp
Address Box 7488
City Boise State ID Zip 83707

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

N / W / E / S

Twp. 4 North ☒ or South ☐
Rge. 1 East ☒ or West ☐
Sec. 14 S/W (10 acres) 1/4 S/W (40 acres) 1/4 ____ (160 acres) 1/4
Gov't Lot ____ County Ada
Lat: : : Long: : :
Address of Well Site State St at Hwy 55
(Pierce Well) City Eagle
(Give at least name of road + Distance to Road or Landmark)

Lt. _____ Blk. _____ Sub. Name _____

4. USE:
☐ Domestic ☐ Municipal ☒ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other _____

5. TYPE OF WORK check all that apply (Replacement etc.)
☐ New Well ☐ Modify ☐ Abandonment ☐ Other _____

6. DRILL METHOD
☐ Air Rotary ☐ Cable ☒ Mud Rotary ☐ Other _____

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
cement				
grout				

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s) _____
Was drive shoe seal tested? ☐ Y ☒ N How? _____

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
2"		sch	80	PVC	☐	☐	☐	☐
2"		sch	80	PVC slotted	☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe _____ Length of Tailpipe _____

9. PERFORATIONS/SCREENS
☐ Perforations Method _____
☐ Screens Screen Type _____

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

STATIC WATER LEVEL OR ARTESIAN PRESSURE:
____ ft. below ground Artesian pressure ____ lb.
Depth flow encountered ____ ft. Describe access port or control devices: _____

11. WELL TESTS:
☐ Pump ☐ Bailer ☐ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes
10"			casing to 76 ft set w/ cable tool rig	
	75	78	clay	
8"	78	85	sand	
	85	86	clay	
	86	92	sand	
	92	112	sand & clay streaks, brn	
	112	116	sand, light olive brn.	
	116	125	clay, yel. brn.	
	125	140	sand, medium, brn	
	140	147	clay, light yel. brn	
	147	168	sand, med. pale yellow	
	168	207	clay, olive brn	
	207	222	sand, med., gry-brn.	
	222	226	sandy clay, olive brn	
	226	235	sand, med. brn.	
	235	241	sandy clay, olive brn.	
	241	250	sand, med. gry-brn.	
	250	264	clay w/ sandy silt in center olive brn	
	264	291	sand, med. light olive brn	
	291	297	clay, yellow brn.	
	297	307	sand, med. light olive brn	
	307	313	clay, yel. brn.	
	313	319	sand, med. light olive brn	
	319	330	clay, yel. brn.	
	330	342	sand, light olive brn.	
	342	345	clay yel. brn	
	345	351	sand silt yel. brn	
	351	354	clay yel. brn	
	354	363	sand med. dark gray brn	
	363	368	clay, dark gray	
	368	374	sand, fine-med dark gry	
	374	771	clay, dark gray	
	771	797	Sand, med w/ clay beds @ 780 and 787'	
	797	820	Clay, dark gray	

Completed Depth 1000' (Measurable)
Date: Started 10/96 Completed 12/96

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Stevens & Sons Firm No 153
Firm Official Ron Stevens Date 12/10/96
and
Supervisor or Operator _____ Date _____
(Signature of Firm Official & Operator)

FORWARD WHITE COPY TO WATER RESOURCES

Form 238-7
3/95

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT
Use Typewriter or Ballpoint Pen

Office Use Only
Inspected by _____
Twp____ Rge____ Sec____
____1/4 ____1/4 ____1/4
Lat: : : Long: : :

1. DRILLING PERMIT NO. 63 - 96 - W - 0709 001
Other IDWR No. _____

2. OWNER:
Name United Water Corp
Address Box 7488
City Boise State ID Zip 83707

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

N / W / E / S

Twp. 4 North ☒ or South ☐
Rge. 1 East ☒ or West ☐
Sec. 14, S/W 1/4 (10 acres) S/W 1/4 (40 acres) ____ 1/4 (160 acres)
Gov't Lot ____ County Ada
Lat: : : Long: : :
Address of Well Site State St at Hwy 55
(Pierce Well) City Eagle
(Give at least name of road + Distance to Road or Landmark)

Lt. _____ Blk. _____ Sub. Name _____

4. USE:
☐ Domestic ☐ Municipal ☒ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other _____

5. TYPE OF WORK check all that apply (Replacement etc.)
☒ New Well ☐ Modify ☐ Abandonment ☐ Other _____

6. DRILL METHOD
☐ Air Rotary ☐ Cable ☒ Mud Rotary ☐ Other _____

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
cement				
grout				

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s) _____
Was drive shoe seal tested? ☐ Y ☐ N How? _____

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
2"		sch	80	PVC	☐	☐	☐	☐
2"		sch	80	PVC slotted	☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe _____ Length of Tailpipe _____

9. PERFORATIONS/SCREENS
☐ Perforations Method _____
☐ Screens Screen Type _____

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
_____ ft. below ground Artesian pressure _____ lb.
Depth flow encountered _____ ft. Describe access port or control devices: _____

11. WELL TESTS:
☐ Pump ☐ Bailer ☐ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time

Water Temp. _____ Bottom hole temp. _____
Water Quality test or comments: _____
Depth first Water Encountered _____

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Wa Yes
	820	830	Sand, med. gray	
	830	858	Clay, dk. gray	
	858	863	Sand, fine-med, gray	
	863	871	Clay, dark gray	
	871	876	Sand, fine-med gray	
	876	891	Clay, dark gray	
	891	893	Sand, fine-med, gray	
	893	897	Clay, gray	
	897	901	Sand, Fine, gray	
	901	1005	Clay, dark gray	

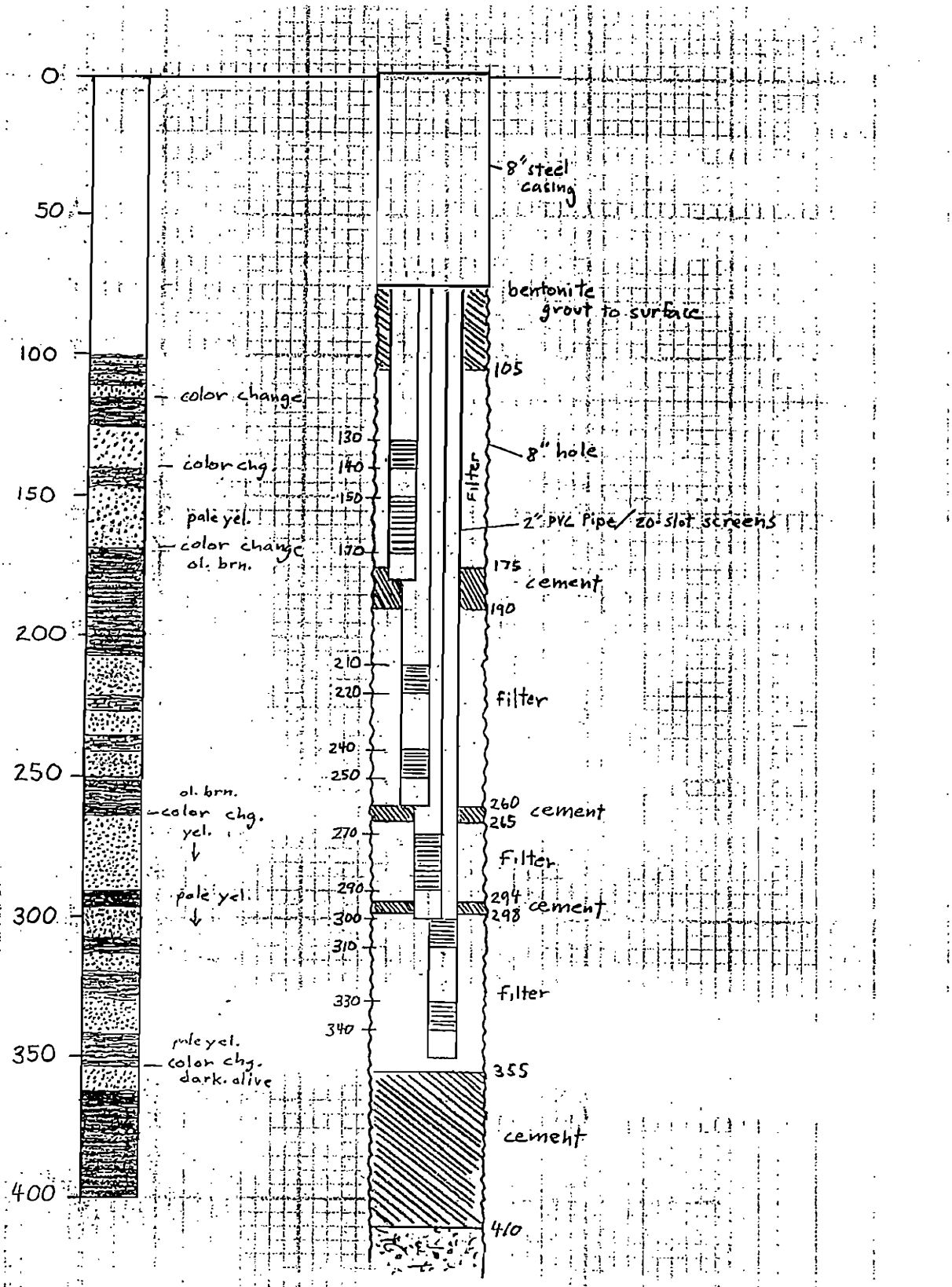
RECEIVED
MAR 13 1997
WATER RESOURCES
WESTERN REGION

Completed Depth 1000' (Measurable)
Date: Started 10/96 Completed 12/96

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Stevens & Sons Firm No. 153
Firm Official Ron Stevens Date 12/10/96
and
Supervisor or Operator _____ Date _____
(Signature of Firm Official & Operator)

FORWARD WHITE COPY TO WATER RESOURCES


0
50
100
150
200
250
300
350
400
8" steel casing
bentonite grout to surface
105
8" hole
color change
130
color chg.
140
150
pale yel.
2" PVC Pipe / 20 slot screens
color change
ol. brn.
170
175
cement
190
200
210
220
filter
240
250
ol. brn.
color chg.
yel.
260
265
cement
270
Filter
pale yel.
290
294
298
cement
300
310
filter
330
340
pale yel.
color chg.
dark. olive
355
cement
410
Filter

APPENDIX B

LABORATORY REPORTS OF WATER QUALITY

ALCHEM LABORATORIES

Alchem Laboratories, Inc.
104 West 31st Street
Boise, Idaho 83714
Phone (208) 336-1172
FAX (208) 336-7124
Water, Waste Water and Soil Analysis

LABORATORY REPORT

UNITED WATER
P. O. BOX 7488
BOISE, IDAHO 83707-1488

ATTENTION: ED SQUIRES
SOURCE -: ZONE #4 / STATE ST. TEST WELL shallow ; 130-140', 150'-170'

DATE COLLECTED - - -12/13/96
TIME COLLECTED - - -14:00
DATE RECEIVED - - - 12/13/96
DATE REPORTED - - - 12/23/96
SUBMITTED : ALLRED

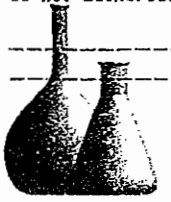
LAB SAMPLE NUMBER - 18075

Results reported unless noted: (Chemistry Analysis as mg/l) (Bacteria as organisms/100 ml)

ANALYSIS	RESULTS	DATE ANALYZED	ANALYST
ALKALINITY	139.0	12/19/96	JD
CALCIUM	37.5	12/17/96	PM
CHLORIDE	3.20	12/13/96	CB
CONDUCTIVITY (umhos/cm)	299.0	12/13/96	GC
CORROSIVITY	-0.33*	12/23/96	CB
FLUORIDE	0.33	12/18/96	JD
HARDNESS	111.0	12/17/96	PM
IRON	0.03	12/17/96	PM
IRON (DISS.)	0.01	12/17/96	PM
MAGNESIUM	4.16	12/17/96	PM
MANGANESE	0.01	12/17/96	PM
MANGANESE (DISS.)	0.01	12/17/96	PM
NITRATE as N	<0.10	12/13/96	CB
POTASSIUM	2.17	12/20/96	SQ
SILICA	28.7	12/16/96	SQ
SODIUM	24.9	12/16/96	SQ
SULFATE	10.2	12/13/96	CB
SULFIDE	<0.05	12/13/96	JD
TEMPERATURE	12.8o C	12/13/96	JA
TOTAL DISS. SOLIDS	248.0	12/17/96	NH
TOTAL PHOSPHORUS as P	0.05	12/17/96	JD
pH (SU)	7.70	12/13/96	GC

COMMENTS: FIELD pH = 7.36 @ 12.8o C
CORROSIVITY: THE WATER IS MODERATELY AGGRESSIVE.

This report for the exclusive use of the client(s) to whom it is addressed. Its disclosure to others for use in advertising is not authorized. These results refer only to the specific sample tested and no interpretation is intended or implied.



Suzanne Howell, Laboratory Manager

ALCHEM LABORATORIES

Alchem Laboratories, Inc.
104 West 31st Street
Boise, Idaho 83714
Phone (208) 336-1172
FAX (208) 336-7124
Water, Waste Water and Soil Analysis

LABORATORY REPORT

UNITED WATER
P.O. BOX 7488
BOISE, IDAHO 83707-1488

ATTENTION: ED SQUIRES
SOURCE -: ZONE #3 / STATE ST. TEST WELL
(210'-220' 240'-250')

DATE COLLECTED - - -12/13/96
TIME COLLECTED - - -13:00
DATE RECEIVED - - - 12/13/96
DATE REPORTED - - - 12/23/96
SUBMITTED : ALLRED

LAB SAMPLE NUMBER - 18074

Results reported unless noted: (Chemistry Analysis as mg/l) (Bacteria as organisms/100 ml)

ANALYSIS	RESULTS	DATE ANALYZED	ANALYST
ALKALINITY	132.0	12/19/96	JD
CALCIUM	39.6	12/17/96	PM
CHLORIDE	2.63	12/13/96	CB
CONDUCTIVITY (umhos/cm)	313.0	12/13/96	GC
CORROSIVITY	-0.35*	12/23/96	CB
FLUORIDE	0.37	12/18/96	JD
HARDNESS	129.0	12/17/96	PM
IRON	0.63	12/17/96	PM
IRON (DISS.)	0.57	12/17/96	PM
MAGNESIUM	7.22	12/17/96	PM
MANGANESE	0.06	12/17/96	PM
MANGANESE (DISS.)	0.05	12/17/96	PM
NITRATE as N	(0.10	12/13/96	CB
POTASSIUM	2.55	12/20/96	SQ
SILICA	31.5	12/16/96	SQ
SODIUM	20.3	12/16/96	SQ
SULFATE	22.5	12/13/96	CB
SULFIDE	(0.05	12/13/96	JD
TEMPERATURE	13.1o C	12/13/96	JA
TOTAL DISS. SOLIDS	173.0	12/17/96	NH
TOTAL PHOSPHORUS as P	0.04	12/17/96	JD
pH (SU)	7.65	12/13/96	GC

COMMENTS: FIELD pH = 7.18 @ 13.1o C
CORROSIVITY: THE WATER IS MODERATELY AGGRESSIVE.

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Suzanne Howell, Laboratory Manager

ALCHEM LABORATORIES

Alchem Laboratories, Inc.
104 West 31st Street
Boise, Idaho 83714
Phone (208) 336-1172
FAX (208) 336-7124
Water, Waste Water and Soil Analysis

LABORATORY REPORT

UNITED WATER
P.O. BOX 7488
BOISE, IDAHO 83707-1488

ATTENTION: ED SQUIRES
SOURCE -: ZONE #2 / STATE ST. TEST WELL (270'-290')

DATE COLLECTED - - -12/13/96
TIME COLLECTED - - -12:00
DATE RECEIVED - - - 12/13/96
DATE REPORTED - - - 12/23/96
SUBMITTED : ALLRED

LAB SAMPLE NUMBER - 18073

Results reported unless noted: (Chemistry Analysis as mg/l) (Bacteria as organisms/100 ml)

ANALYSIS	RESULTS	DATE ANALYZED	ANALYST
ALKALINITY	101.0	12/19/96	JD
CALCIUM	28.1	12/17/96	PM
CHLORIDE	1.73	12/13/96	CB
CONDUCTIVITY (umhos/cm)	224.0	12/13/96	GC
CORROSIVITY	-0.54*	12/23/96	CB
FLUORIDE	0.36	12/18/96	JD
HARDNESS	86.4	12/17/96	PM
IRON	0.05	12/17/96	PM
IRON (DISS.)	0.01	12/17/96	PM
MAGNESIUM	3.94	12/17/96	PM
MANGANESE	0.04	12/17/96	PM
MANGANESE (DISS.)	0.04	12/17/96	PM
NITRATE as N	<0.10	12/13/96	CB
POTASSIUM	2.07	12/20/96	SQ
SILICA	33.6	12/16/96	SQ
SODIUM	15.2	12/16/96	SQ
SULFATE	11.4	12/13/96	CB
SULFIDE	<0.05	12/13/96	JD
TEMPERATURE	14.1o C	12/13/96	JA
TOTAL DISS. SOLIDS	188.0	12/17/96	NH
TOTAL PHOSPHORUS as P	0.03	12/17/96	JD
pH (SU)	7.70	12/13/96	GC

COMMENTS: FIELD pH = 7.42 @ 14.1o C
CORROSIVITY: THE WATER IS MODERATELY AGGRESSIVE.

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Suzanne Howell, Laboratory Manager

ALCHEM LABORATORIES

Alchem Laboratories, Inc.
104 West 31st Street
Boise, Idaho 83714
Phone (208) 336-1172
FAX (208) 336-7124

Water, Waste Water and Soil Analysis

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DEC 2 6 1996
UNITED WATER

LABORATORY REPORT

UNITED WATER
P.O. BOX 7488
BOISE, IDAHO 83707-1488

ATTENTION: ED SQUIRES
SOURCE -: ZONE #1 / STATE ST. TEST WELL
(300-310', 330-340')

DATE COLLECTED - - -12/13/96
TIME COLLECTED - - -11:00
DATE RECEIVED - - - 12/13/96
DATE REPORTED - - - 12/23/96
SUBMITTED : ALLRED

LAB SAMPLE NUMBER - 18072

Results reported unless noted: (Chemistry Analysis as mg/l) (Bacteria as organisms/100 ml)

ANALYSIS	RESULTS	DATE ANALYZED	ANALYST
ALKALINITY	112.0	12/19/96	JD
CALCIUM	28.9	12/17/96	PM
CHLORIDE	2.05	12/13/96	CB
CONDUCTIVITY (umhos/cm)	260.0	12/13/96	GC
CORROSIVITY	-0.87*	12/23/96	CB
FLUORIDE	0.34	12/18/96	JD
HARDNESS	90.9	12/17/96	PM
IRON	0.06	12/17/96	PM
IRON (DISS.)	0.02	12/17/96	PM
MAGNESIUM	4.54	12/17/96	PM
MANGANESE	0.03	12/17/96	PM
MANGANESE (DISS.)	0.03	12/17/96	PM
NITRATE as N	0.13	12/13/96	CB
POTASSIUM	2.00	12/20/96	SQ
SILICA	32.5	12/16/96	SQ
SODIUM	17.3	12/16/96	SQ
SULFATE	14.4	12/13/96	CB
SULFIDE	(0.05	12/13/96	JD
TEMPERATURE	15.0o C	12/13/96	JA
TOTAL DISS. SOLIDS	218.0	12/17/96	NH
TOTAL PHOSPHORUS as P	0.04	12/17/96	JD
pH (SU)	7.30	12/13/96	GC

COMMENTS: FIELD pH = 7.03 @ 15.0o C
CORROSIVITY: THE WATER IS MODERATELY AGGRESSIVE.

This report for the exclusive use of the client(s) to whom it is addressed. Its disclosure to others for use in advertising is not authorized. These results refer only to the specific sample tested and no interpretation is intended or implied.

Suzanne Howell, Laboratory Manager

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628561

Attn. ED SQUIRES

UNITED WATER
8248 W VICTORY RD
BOISE ID,

P.O.# 4034

Time of Collection: **14:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/19/96**

Submitted by:

Source of Sample: ZONE 4

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
IRON, DISSOLVED			<0.05	mg/L		EPA 200.7	12/18/96	DDB
MANGANESE DISSOLVED			<0.05	mg/L		EPA 200.7	12/18/96	DDB

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628560

Attn. ED SQUIRES

UNITED WATER
8248 W VICTORY RD
BOISE ID,

P.O.# **4034**

Time of Collection: **13:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/19/96**

Submitted by:

Source of Sample: **ZONE 3**

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
IRON, DISSOLVED			0.45	mg/L		EPA 200.7	12/18/96	DDB
MANGANESE DISSOLVED			0.05	mg/L		EPA 200.7	12/18/96	DDB

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628559

Attn. ED SQUIRES

P.O.# 4034

UNITED WATER
8248 W VICTORY RD
BOISE ID,

Time of Collection: 12:00
Date of Collection: 12/13/96

Date Received: 12/13/96
Date Reported: 12/19/96

Submitted by:

Source of Sample: ZONE 2

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
IRON, DISSOLVED			<0.05	mg/L		EPA 200.7	12/18/96	DDB
MANGANESE DISSOLVED			<0.05	mg/L		EPA 200.7	12/18/96	DDB

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628558

Attn. ED SQUIRES

UNITED WATER
8248 W VICTORY RD
BOISE ID,

P.O.# **4034**

Time of Collection: **11:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/19/96**

Submitted by:

Source of Sample: ZONE 1

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
IRON, DISSOLVED			<0.05	mg/L		EPA 200.7	12/18/96	DDB
MANGANESE DISSOLVED			<0.05	mg/L		EPA 200.7	12/18/96	DDB

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628557

Attn. ED SQUIRES

P.O.# 4034

UNITED WATER
8248 W VICTORY RD
BOISE ID,

Time of Collection: **14:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/30/96**

Submitted by:

Source of Sample: **STATE ST TEST WELL ZONE #4** 130'-140'
shallowest 150-170'

Lab Comment: FIELD PH 7.36 TEMP 12.8c

*VOC SCAN:

BENZENE	<0.5	ug/L
VINYL CHLORIDE	<0.5	ug/L
CARBON TETRACHLORIDE	<0.5	ug/L
1,2-DICHLOROETHANE	<0.5	ug/L
TRICHLOROETHENE	<0.5	ug/L
1,4-DICHLOROBENZENE	<0.5	ug/L
1,1-DICHLOROETHENE	<0.5	ug/L
1,1,1-TRICHLOROETHANE	<0.5	ug/L
CHLOROFORM	<0.5	ug/L
BROMODICHLOROMETHANE	<0.5	ug/L
DIBROMOCHLOROMETHANE	<0.5	ug/L
BROMOFORM	<0.5	ug/L
trans-1,2-DICHLOROETHENE	<0.5	ug/L
CHLOROBENZENE	<0.5	ug/L
1,3-DICHLOROBENZENE	<0.5	ug/L
DICHLOROMETHANE	<0.5	ug/L
cis-1,2-DICHLOROETHENE	<0.5	ug/L
1,2-DICHLOROBENZENE	<0.5	ug/L
DIBROMOMETHANE	<0.5	ug/L
1,1-DICHLOROPROPENE	<0.5	ug/L
TETRACHLOROETHENE	<0.5	ug/L
TOLUENE	<0.5	ug/L
p-XYLENE	<0.5	ug/L
o-XYLENE	<0.5	ug/L
m-XYLENE	<0.5	ug/L
1,1-DICHLOROETHANE	<0.5	ug/L
1,2-DICHLOROPROPANE	<0.5	ug/L
1,1,2,2-TETRACHLOROETHANE	<0.5	ug/L
ETHYLBENZENE	<0.5	ug/L
1,3-DICHLOROPROPANE	<0.5	ug/L
STYRENE	<0.5	ug/L
CHLOROMETHANE	<0.5	ug/L
BROMOMETHANE	<0.5	ug/L
1,2,3-TRICHLOROPROPANE	<0.5	ug/L
1,1,1,2-TETRACHLOROETHANE	<0.5	ug/L
CHLOROETHANE	<0.5	ug/L
1,1,2-TRICHLOROETHANE	<0.5	ug/L
2,2-DICHLOROPROPANE	<0.5	ug/L
2-CHLOROTOLUENE	<0.5	ug/L
4-CHLOROTOLUENE	<0.5	ug/L

(continued)

BROMOBENZENE	<0.5	ug/L
1,3-DICHLOROPROPENE	<0.5	ug/L
1,2,4-TRICHLOROBENZENE	<0.5	ug/L

** WATER WAS MODERATELY AGGRESSIVE.

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
CHLORIDE	1017		3	mg/L	1.0	EPA 300.0	12/23/96	JAL
FLUORIDE DIRECT	1025	4.0	0.75	mg/L	0.05	SM 4500F-C	12/22/96	KAI
NITRATE N	1040	10.0	<0.10	mg/L	0.10	EPA 300.0	12/23/96	JAL
SODIUM	1052		24.2	mg/L	0.10	EPA 200.7	12/19/96	DDB
SULFATE	1055		11	mg/L	1.0	EPA 300.0	12/23/96	JAL
CALCIUM	1016		33.3	mg/L	0.10	EPA 200.7	12/19/96	DDB
IRON	1028		<0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
POTASSIUM	1042		1.64	mg/L	0.10	EPA 200.7	12/19/96	DDB
MAGNESIUM	1031		3.62	mg/L	0.10	EPA 200.7	12/19/96	DDB
MANGANESE	1032		<0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
SILICON			14.3	mg/L		EPA 200.7	12/19/96	DDB
ALKALINITY	1927		143	mg/L		EPA 310.1	12/19/96	JH
CONDUCTIVITY	1926		294	umhos	2.0	EPA 120.1	12/13/96	MBM
CORROSIVITY	1997		-0.7	**		LANGELIER	12/27/96	DMB
SULFIDE	1027		0.19	mg/L		EPA 376.1	12/30/96	MDM
HARDNESS	1915		108	mg/L	2.0	SM 2340	12/19/96	JH
PHOSPHATE P, TOTAL			0.08	mg/L	0.05	EPA 365.4	12/19/96	JAL
TOTAL DISSOLVED SOLIDS	1930		188	mg/L	1.0	EPA 160.1	12/18/96	MS
PH	1925		8.0	S.U.		EPA 150.1	12/13/96	MBM
VOC			* SCAN	ug/L		EPA 502.2	12/14/96	DMB

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628556

Attn. ED SQUIRES

P.O.# 4034

UNITED WATER
8248 W VICTORY RD
BOISE ID,

Time of Collection: **13:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/30/96**

Submitted by:

Source of Sample: **STATE ST TEST WELL ZONE #3** 210-220' 240-250'

Lab Comment: FIELD PH 7.18 TEMP 13.1c

*VOC SCAN:

BENZENE	<0.5	ug/L
VINYL CHLORIDE	<0.5	ug/L
CARBON TETRACHLORIDE	<0.5	ug/L
1,2-DICHLOROETHANE	<0.5	ug/L
TRICHLOROETHENE	<0.5	ug/L
1,4-DICHLOROBENZENE	<0.5	ug/L
1,1-DICHLOROETHENE	<0.5	ug/L
1,1,1-TRICHLOROETHANE	<0.5	ug/L
CHLOROFORM	<0.5	ug/L
BROMODICHLOROMETHANE	<0.5	ug/L
DIBROMOCHLOROMETHANE	<0.5	ug/L
BROMOFORM	<0.5	ug/L
trans-1,2-DICHLOROETHENE	<0.5	ug/L
CHLOROBENZENE	<0.5	ug/L
1,3-DICHLOROBENZENE	<0.5	ug/L
DICHLOROMETHANE	<0.5	ug/L
cis-1,2-DICHLOROETHENE	<0.5	ug/L
1,2-DICHLOROBENZENE	<0.5	ug/L
DIBROMOMETHANE	<0.5	ug/L
1,1-DICHLOROPROPENE	<0.5	ug/L
TETRACHLOROETHENE	<0.5	ug/L
TOLUENE	<0.5	ug/L
p-XYLENE	<0.5	ug/L
o-XYLENE	<0.5	ug/L
m-XYLENE	<0.5	ug/L
1,1-DICHLOROETHANE	<0.5	ug/L
1,2-DICHLOROPROPANE	<0.5	ug/L
1,1,2,2-TETRACHLOROETHANE	<0.5	ug/L
ETHYLBENZENE	<0.5	ug/L
1,3-DICHLOROPROPANE	<0.5	ug/L
STYRENE	<0.5	ug/L
CHLOROMETHANE	<0.5	ug/L
BROMOMETHANE	<0.5	ug/L
1,2,3-TRICHLOROPROPANE	<0.5	ug/L
1,1,1,2-TETRACHLOROETHANE	<0.5	ug/L
CHLOROETHANE	<0.5	ug/L
1,1,2-TRICHLOROETHANE	<0.5	ug/L
2,2-DICHLOROPROPANE	<0.5	ug/L
2-CHLOROTOLUENE	<0.5	ug/L
4-CHLOROTOLUENE	<0.5	ug/L

(continued)

BROMOBENZENE	<0.5	ug/L
1,3-DICHLOROPROPENE	<0.5	ug/L
1,2,4-TRICHLOROBENZENE	<0.5	ug/L

** WATER WAS MODERATELY AGGRESSIVE.

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
CHLORIDE	1017		3	mg/L	1.0	EPA 300.0	12/23/96	JAL
FLUORIDE DIRECT	1025	4.0	0.78	mg/L	0.05	SM 4500F-C	12/22/96	KAI
NITRATE N	1040	10.0	<0.10	mg/L	0.10	EPA 300.0	12/23/96	JAL
SODIUM	1052		19.4	mg/L	0.10	EPA 200.7	12/19/96	DDB
SULFATE	1055		22	mg/L	1.0	EPA 300.0	12/23/96	JAL
CALCIUM	1016		35.1	mg/L	0.10	EPA 200.7	12/19/96	DDB
IRON	1028		0.50	mg/L	0.05	EPA 200.7	12/18/96	DDB
POTASSIUM	1042		2.06	mg/L	0.10	EPA 200.7	12/19/96	DDB
MAGNESIUM	1031		6.55	mg/L	0.10	EPA 200.7	12/19/96	DDB
MANGANESE	1032		0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
SILICON			15.4	mg/L x 2.139 = 32.9 silica		EPA 200.7	12/19/96	DDB
ALKALINITY	1927		138	mg/L		EPA 310.1	12/19/96	JH
CONDUCTIVITY	1926		305	umhos	2.0	EPA 120.1	12/13/96	MBM
CORROSIVITY	1997		-0.8 **			LANGELIER	12/27/96	DMB
SULFIDE	1027		0.16	mg/L		EPA 376.1	12/30/96	MDM
HARDNESS	1915		125	mg/L	2.0	SM 2340	12/19/96	JH
PHOSPHATE P, TOTAL			0.06	mg/L	0.05	EPA 365.4	12/19/96	JAL
TOTAL DISSOLVED SOLIDS	1930		200	mg/L	1.0	EPA 160.1	12/18/96	MS
PH	1925		7.9	S.U.		EPA 150.1	12/13/96	MBM
VOC			* SCAN	ug/L		EPA 502.2	12/14/96	DMB

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628555

Attn. ED SQUIRES

UNITED WATER
8248 W VICTORY RD
BOISE ID,

P.O.# 4034

Time of Collection: **12:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/30/96**

Submitted by:

Source of Sample: **STATE ST TEST WELL ZONE #2** Middle zone 270'-290'

Lab Comment: FIELD PH 7.42 TEMP 14.1c

*VOC SCAN:

BENZENE	<0.5	ug/L
VINYL CHLORIDE	<0.5	ug/L
CARBON TETRACHLORIDE	<0.5	ug/L
1,2-DICHLOROETHANE	<0.5	ug/L
TRICHLOROETHENE	<0.5	ug/L
1,4-DICHLOROBENZENE	<0.5	ug/L
1,1-DICHLOROETHENE	<0.5	ug/L
1,1,1-TRICHLOROETHANE	<0.5	ug/L
CHLOROFORM	<0.5	ug/L
BROMODICHLOROMETHANE	<0.5	ug/L
DIBROMOCHLOROMETHANE	<0.5	ug/L
BROMOFORM	<0.5	ug/L
trans-1,2-DICHLOROETHENE	<0.5	ug/L
CHLOROBENZENE	<0.5	ug/L
1,3-DICHLOROBENZENE	<0.5	ug/L
DICHLOROMETHANE	<0.5	ug/L
cis-1,2-DICHLOROETHENE	<0.5	ug/L
1,2-DICHLOROBENZENE	<0.5	ug/L
DIBROMOMETHANE	<0.5	ug/L
1,1-DICHLOROPROPENE	<0.5	ug/L
TETRACHLOROETHENE	<0.5	ug/L
TOLUENE	<0.5	ug/L
p-XYLENE	<0.5	ug/L
o-XYLENE	<0.5	ug/L
m-XYLENE	<0.5	ug/L
1,1-DICHLOROETHANE	<0.5	ug/L
1,2-DICHLOROPROPANE	<0.5	ug/L
1,1,2,2-TETRACHLOROETHANE	<0.5	ug/L
ETHYLBENZENE	<0.5	ug/L
1,3-DICHLOROPROPANE	<0.5	ug/L
STYRENE	<0.5	ug/L
CHLOROMETHANE	<0.5	ug/L
BROMOMETHANE	<0.5	ug/L
1,2,3-TRICHLOROPROPANE	<0.5	ug/L
1,1,1,2-TETRACHLOROETHANE	<0.5	ug/L
CHLOROETHANE	<0.5	ug/L
1,1,2-TRICHLOROETHANE	<0.5	ug/L
2,2-DICHLOROPROPANE	<0.5	ug/L
2-CHLOROTOLUENE	<0.5	ug/L
4-CHLOROTOLUENE	<0.5	ug/L

(continued)

zone 2
compl. 270-290'

BROMOBENZENE	<0.5	ug/L
1,3-DICHLOROPROPENE	<0.5	ug/L
1,2,4-TRICHLOROBENZENE	<0.5	ug/L

** WATER WAS MODERATELY AGGRESSIVE.

Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
CHLORIDE	1017		2	mg/L	1.0	EPA 300.0	12/23/96	JAL
FLUORIDE DIRECT	1025	4.0	0.66	mg/L	0.05	SM 4500F-C	12/22/96	KAI
NITRATE N	1040	10.0	<0.10	mg/L	0.10	EPA 300.0	12/23/96	JAL
SODIUM	1052		14.2	mg/L	0.10	EPA 200.7	12/19/96	DDB
SULFATE	1055		12	mg/L	1.0	EPA 300.0	12/23/96	JAL
CALCIUM	1016		25.8	mg/L	0.10	EPA 200.7	12/19/96	DDB
IRON	1028		<0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
POTASSIUM	1042		1.63	mg/L	0.10	EPA 200.7	12/19/96	DDB
MAGNESIUM	1031		3.70	mg/L	0.10	EPA 200.7	12/19/96	DDB
MANGANESE	1032		<0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
SILICON			15.7	mg/L		EPA 200.7	12/19/96	DDB
			Silica ≈ 33.58 (SiO_2)					
ALKALINITY	1927		103	mg/L		EPA 310.1	12/19/96	JH
CONDUCTIVITY	1926		237	umhos	2.0	EPA 120.1	12/13/96	MBM
CORROSIVITY	1997		-0.8 **			LANGELIER	12/27/96	DMB
SULFIDE	1027		0.23	mg/L		EPA 376.1	12/30/96	MDM
HARDNESS	1915		93.7	mg/L	2.0	SM 2340	12/19/96	JH
PHOSPHATE P, TOTAL			0.07	mg/L	0.05	EPA 365.4	12/19/96	JAL
TOTAL DISSOLVED SOLIDS	1930		164	mg/L	1.0	EPA 160.1	12/18/96	MS
PH	1925		8.1	S.U.		EPA 150.1	12/13/96	MBM
VOC			* SCAN	ug/L		EPA 502.2	12/14/96	DMB

RECEIVED

DEC 3 1 1996

UNITED WATER

ANALYTICAL LABORATORIES, INC.
1804 N. 33rd Street
Boise, Idaho 83703
Phone # (208) 342-5515

LABORATORY ANALYSIS REPORT
SAMPLE NUMBER - 9628554

Attn. ED SQUIRES

UNITED WATER
8248 W VICTORY RD
BOISE ID,

P.O.# 4034

Time of Collection: **11:00**
Date of Collection: **12/13/96**

Date Received: **12/13/96**
Date Reported: **12/30/96**

Submitted by:

Source of Sample: **STATE ST TEST WELL ZONE #1** Deepest

Lab Comment: FIELD PH 7.03 TEMP 15.0c

*VOC SCAN:

BENZENE	<0.5	ug/L
VINYL CHLORIDE	<0.5	ug/L
CARBON TETRACHLORIDE	<0.5	ug/L
1,2-DICHLOROETHANE	<0.5	ug/L
TRICHLOROETHENE	<0.5	ug/L
1,4-DICHLOROBENZENE	<0.5	ug/L
1,1-DICHLOROETHENE	<0.5	ug/L
1,1,1-TRICHLOROETHANE	<0.5	ug/L
CHLOROFORM	<0.5	ug/L
BROMODICHLOROMETHANE	<0.5	ug/L
DIBROMOCHLOROMETHANE	<0.5	ug/L
BROMOFORM	<0.5	ug/L
trans-1,2-DICHLOROETHENE	<0.5	ug/L
CHLOROBENZENE	<0.5	ug/L
1,3-DICHLOROBENZENE	<0.5	ug/L
DICHLOROMETHANE	<0.5	ug/L
cis-1,2-DICHLOROETHENE	<0.5	ug/L
1,2-DICHLOROBENZENE	<0.5	ug/L
DIBROMOMETHANE	<0.5	ug/L
1,1-DICHLOROPROPENE	<0.5	ug/L
TETRACHLOROETHENE	<0.5	ug/L
TOLUENE	<0.5	ug/L
p-XYLENE	<0.5	ug/L
o-XYLENE	<0.5	ug/L
m-XYLENE	<0.5	ug/L
1,1-DICHLOROETHANE	<0.5	ug/L
1,2-DICHLOROPROPANE	<0.5	ug/L
1,1,2,2-TETRACHLOROETHANE	<0.5	ug/L
ETHYLBENZENE	<0.5	ug/L
1,3-DICHLOROPROPANE	<0.5	ug/L
STYRENE	<0.5	ug/L
CHLOROMETHANE	<0.5	ug/L
BROMOMETHANE	<0.5	ug/L
1,2,3-TRICHLOROPROPANE	<0.5	ug/L
1,1,1,2-TETRACHLOROETHANE	<0.5	ug/L
CHLOROETHANE	<0.5	ug/L
1,1,2-TRICHLOROETHANE	<0.5	ug/L
2,2-DICHLOROPROPANE	<0.5	ug/L
2-CHLOROTOLUENE	<0.5	ug/L
4-CHLOROTOLUENE	<0.5	ug/L

(continued)

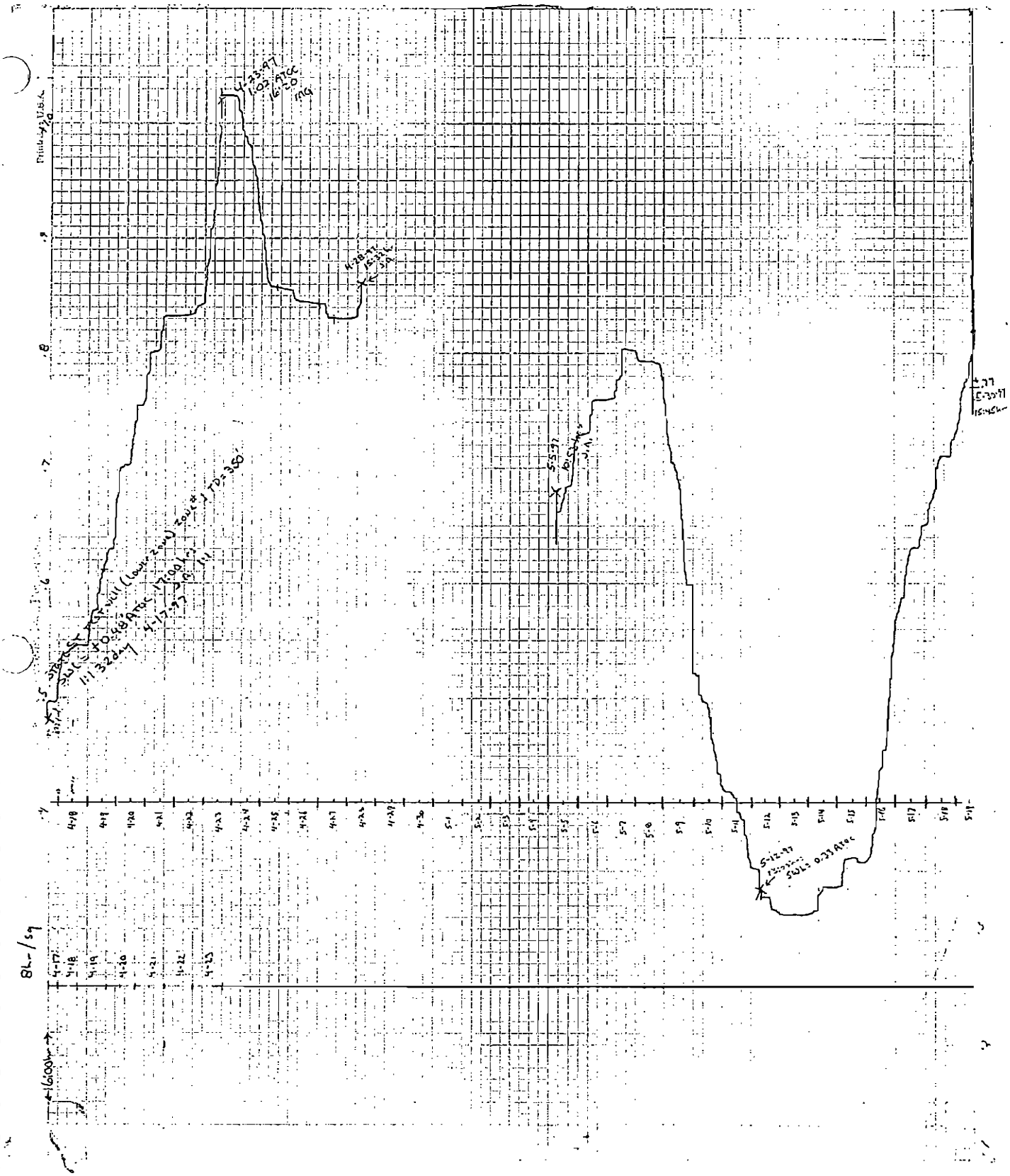
BROMOBENZENE	<0.5	ug/L
1,3-DICHLOROPROPENE	<0.5	ug/L
1,2,4-TRICHLOROBENZENE	<0.5	ug/L

** WATER WAS MODERATELY AGGRESSIVE.

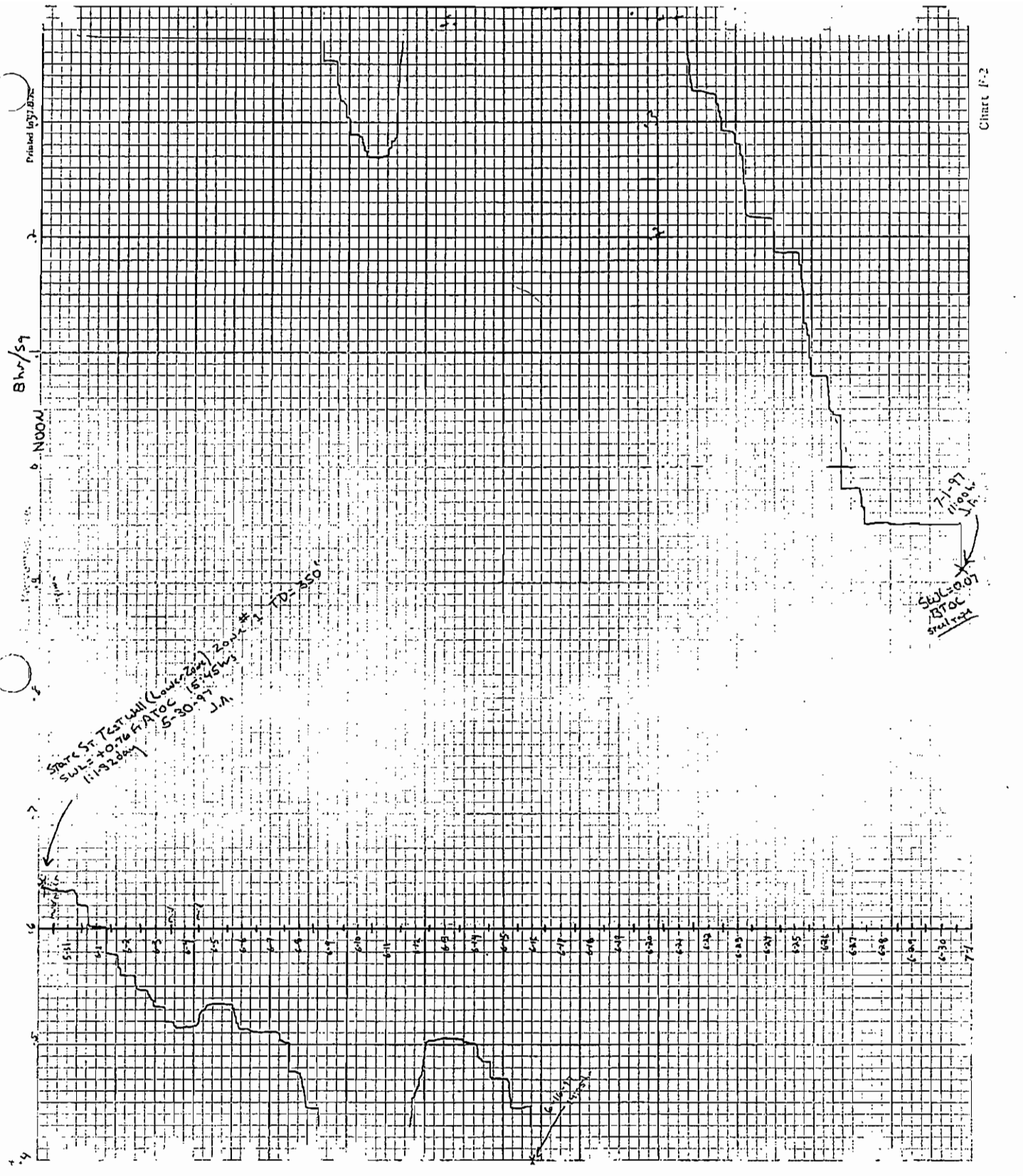
Test Requested	FRDS #	MCL	Analysis Result	Unit	MDL	Method	Date Completed	Analyst Initials
CHLORIDE	1017		2	mg/L	1.0	EPA 300.0	12/23/96	JAL
FLUORIDE DIRECT	1025	4.0	0.57	mg/L	0.05	SM 4500F-C	12/22/96	KAI
NITRATE N	1040	10.0	0.16	mg/L	0.10	EPA 300.0	12/23/96	JAL
SODIUM	1052		15.8	mg/L	0.10	EPA 200.7	12/19/96	DDB
SULFATE	1055		14	mg/L	1.0	EPA 300.0	12/23/96	JAL
CALCIUM	1016		29.2	mg/L	0.10	EPA 200.7	12/19/96	DDB
IRON	1028		<0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
POTASSIUM	1042		1.58	mg/L	0.10	EPA 200.7	12/19/96	DDB
MAGNESIUM	1031		4.58	mg/L	0.10	EPA 200.7	12/19/96	DDB
MANGANESE	1032		<0.05	mg/L	0.05	EPA 200.7	12/18/96	DDB
SILICON ⇒ Si			14.6	mg/L		EPA 200.7	12/19/96	DDB
			x 2.139 = 29.9 (SiO_2) Silica					
ALKALINITY	1927		114	mg/L		EPA 310.1	12/19/96	JH
CONDUCTIVITY	1926		255	umhos	2.0	EPA 120.1	12/13/96	MBM
CORROSIVITY	1997		-1.1	**		LANGELIER	12/27/96	DMB
SULFIDE	1027		0.07	mg/L		EPA 376.1	12/30/96	MDM
HARDNESS	1915		99.9	mg/L	2.0	SM 2340	12/19/96	JH
PHOSPHATE P, TOTAL			0.07	mg/L	0.05	EPA 365.4	12/19/96	JAL
TOTAL DISSOLVED SOLIDS	1930		182	mg/L	1.0	EPA 160.1	12/18/96	MS
pH	1925		7.6	S.U.		EPA 150.1	12/13/96	MBM
VOC			* SCAN	ug/L		EPA 502.2	12/14/96	DMB

APPENDIX C

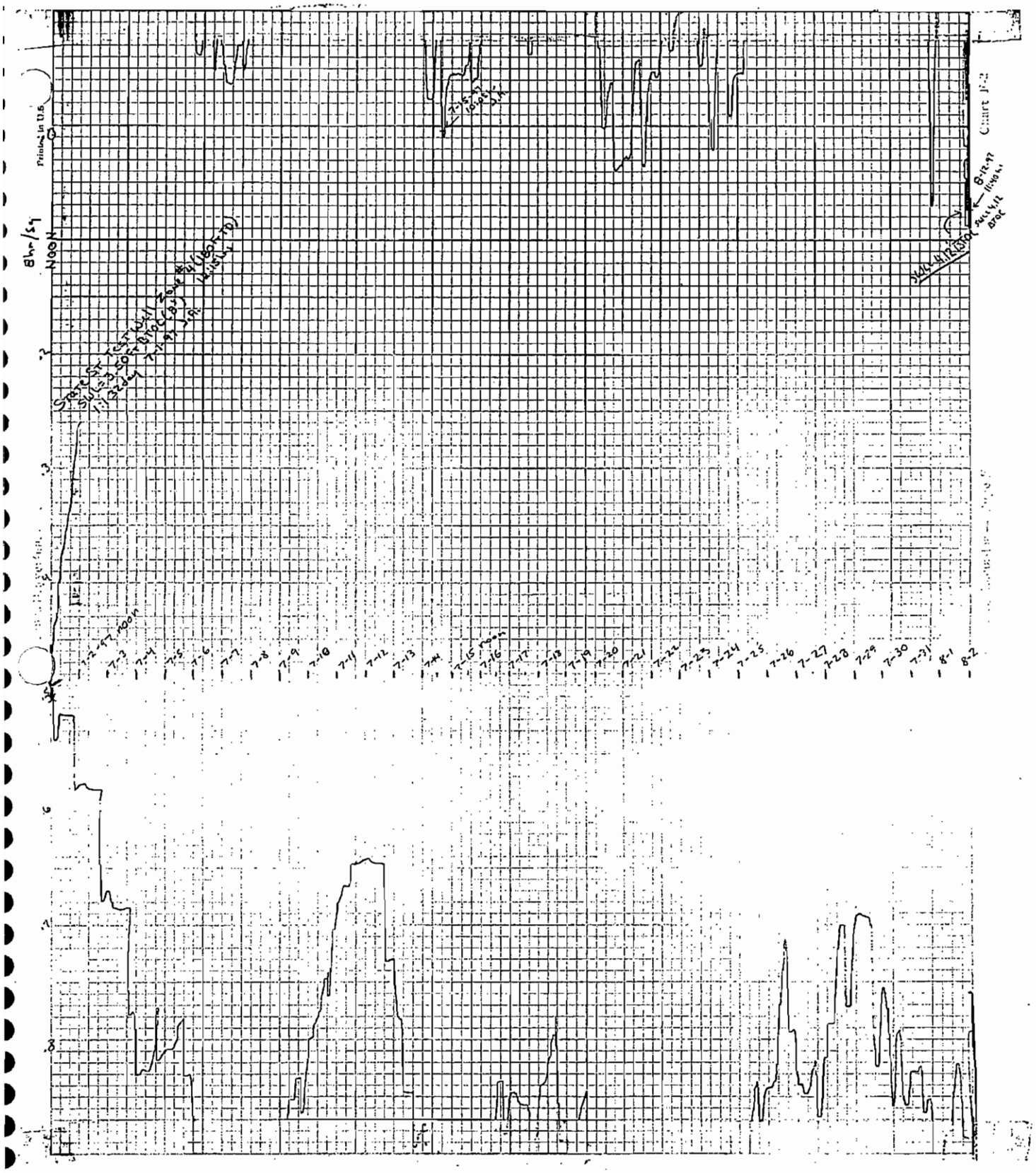
CHARTS FROM WATER-LEVEL RECORDERS



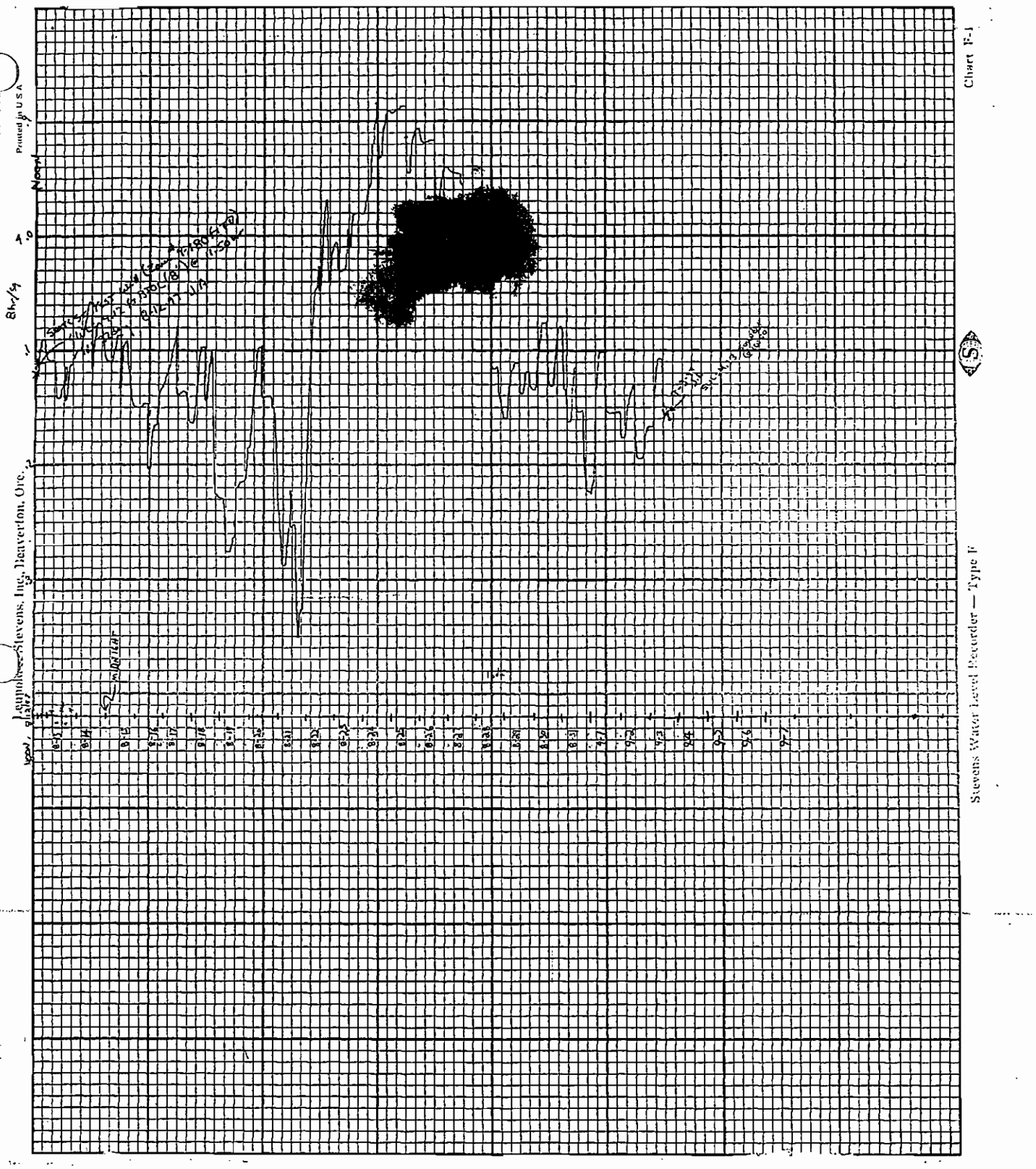
Zone #1 piezometer 4/17/97 to 5/1/97



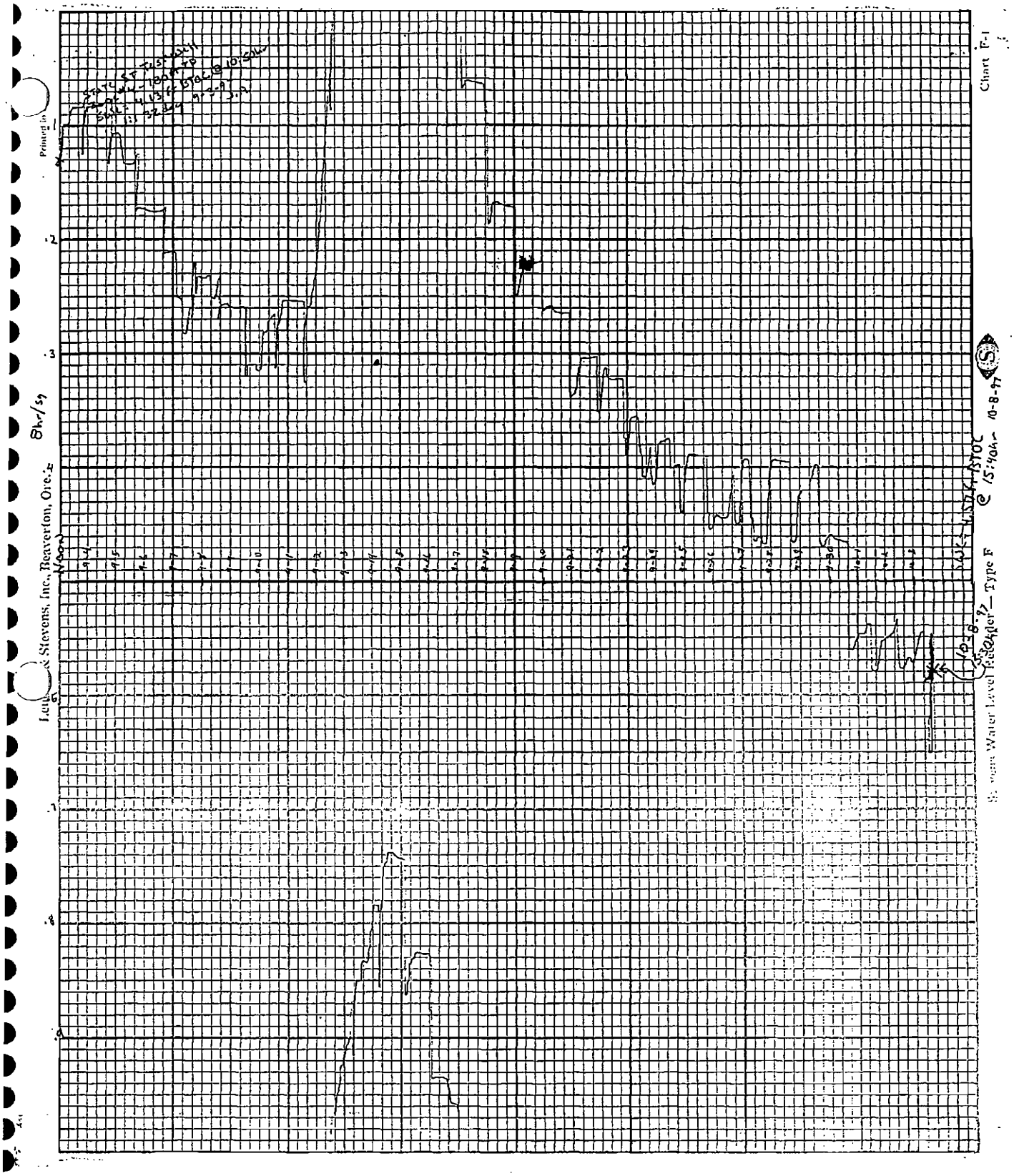
Zone #1 piezometer: 5/30/97 to 7/1/97



Zone #4 piezometer: 7/1/97 to 8/2/97



Zone #4 piezometer: 8/12/97 to 9/3/97



Zone #4 piezometer: 9/3/97 to 10/8/97

33K

Treasure Valley Hydrologic Project #2 Monitoring Well

11/2/1999

Well Construction

Depth (ft. bgl)

0 — 100 — 200 — 300 — 400 — 500 — 600 — 700 — 800 — 900 — 1000

- 12-inch diameter X 375-inch wall steel well casing
- caved river gravels and slabby basalt
- 22-inch drilled hole to 84-feet
- 3/8-inch washed granitic pea-gravel
- #8-#16 sieve "Bird Seed" brand graded silica filter sand
- "Johnson" schedule 80 2-inch, flush-joint PVC "V-wire" 20-slot, well screen
- 12-inch diameter reverse-rotary drilled hole
- 3/8-to-5/8-inch bentonite chips from the "Teague" pits at Adrian, Oregon
- "Johnson" schedule 80 2-inch, flush-joint PVC pipe
- 3/8-inch washed granitic pea-gravel
- #8-#16 sieve "Bird Seed" brand graded silica filter sand
- 3/8-to-5/8-inch bentonite chips from the "Teague" pits at Adrian, Oregon
- cavings
- total depth =1010 ft

Zone 8 · Zone 7 · Zone 6 · Zone 5 · Zone 4 · Zone 3 · Zone 2 · Zone 1

Vertical Scale: 1" = 100'
Horizontal Scale: .1" = 1"

Drilling Contractor: Riverside, Inc - Jeff "Newt" Hash & Justin Cleaver driller's
Geophysical Logging: United Water Idaho, Inc - Roger Dittus and Ed Squires operators
Well Design and Geotechnical: Ed Squires, Hydro Logic, & Brian Cavanagh, BSU
Construction Oversight: Boise State University, Geosciences - Brian Cavanagh,
Project Management: Hal Anderson, IDWR & Ben Weymouth/Gordon Law, City of Caldwell

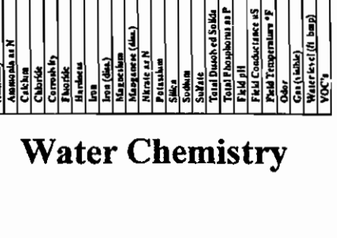
Lithology

- 0 — *massive basalt*
- *highly fractured basalt*
- *unconsolidated river terrace gravels* — -100
- *"sticky" clay*
- *interbedded medium sands and "sticky" cohesive clays* — -200
- *interbedded sequences of "sticky" clay and fine-to-medium sands* — 300
- oxidized sediments (pale yellow-to-tan)
- 400
- 450
- reduced sediments (greenish gray-to-dark-gray)
- 500 — *fine micaceous sand*
- *top of cemented mudstone section*
- *siltstone* — -600
- 700 — *massive indurated mudstone with thin lenses of fine-to-medium sands*
- *wood* — 800
- 900 — *very fine sand*
- *wood*
- 1000

Geophysics

- Caliper inches 0 — 20
- 64" Resistivity 0 ohm-meters 200
- 16" Resistivity 0 ohm-meters 200
- H20 Temperature 65 Degrees F 75
- NaturalGammaRay 0 counts/sec 150
- PointResistance 100 ohms 300
- *bottom of basalt*
- *bottom of 12-inch casing*
- 100 — 200 — 300 — 400 — 500 — 600 — 700 — 800 — 900 — 1000
- BHT=71.5°F

Wellhead Configuration



Water Chemistry

Parameter (mg/l)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
Alkalinity			73.2	60.6	64.8	75.2	359.0	
Ammonia as N			0.33	0.04	0.04	0.06	0.03	
Calcium			10.4	9.84	10.7	18.9	62.3	
Chloride			2.41	2.80	3.06	9.83	13.5	
Corrosivity			-0.35	-0.62	-0.69	-0.3	0.15	
Fluoride			0.57	0.42	0.44	0.43	0.36	
Hardness			28.9	30.2	32.9	60.9	199.8	
Iron			<0.01	<0.01	<0.01	<0.01	<0.01	
Iron (diss.)			<0.01	<0.01	<0.01	<0.01	<0.01	
Magnesium			0.73	1.38	1.53	3.33	10.5	
Manganese (diss.)			0.05	<0.01	<0.01	<0.01	<0.01	
Nitrate as N			<0.10	0.16	0.27	0.49	4.55	
Potassium			1.38	1.45	1.52	1.81	3.19	
Silica			32.3	24.6	27.0	26.6	30.1	
Sodium			23.5	17.4	18.1	23.3	74.5	
Sulfate			7.07	7.29	8.01	21.2	64.6	6.668
Total Dissolved Solids	6.167	6.170	6.133	6.229	6.176	6.179	6.538	6.668
Total Phosphorus as P			0.030	0.037	0.066	0.031	0.037	
Field pH			8.38	8.15	8.04	8.08	7.48	8.15
Field Conductance uS	332	336	383	369	376	348	747	656
Field Temperature °F	62.45		66.0	64	61.5	62	61.5	68.8
Odor	H2S	H2S	H2S	no	no	no	no	no
Gas (Vublle)			no	no	no	no	no	no
Water level (ft bmp)	40.42	39.38	61.37	73.15	73.16	74.04	74.54	74.45
VOC's			N/D	N/D	N/D	N/D	N/D	N/D

Geophysical logs run in an open, water filled borehole on 10/1/99

ES/BC
11-99

33L

SCANLAN ENGINEERING
Groundwater and Environmental Engineering

July 28, 2001

Elizabeth Cody
City of Boise
Public Works Department
P.O. Box 500
Boise, ID 83701-0500

Subject: Final Report on the Quarry View Park Well Project

Dear Liz:

The Quarry View Park Well reconstruction project was completed in June of this year. The work consisted of converting the existing irrigation well into a two-level observation well.

Stevens and Sons Well Drilling was the drilling contractor. Well construction work began in February and continued intermittently into early April. Piezometer development and site repair were completed in early June.

The original irrigation well construction consisted of a 10-inch surface casing to 45 feet, 8-inch well casing to 498 feet, and 6-inch perforated liner from 486 to 857 feet. The inside of the liner was filled with sand and debris to approximately 700 feet. Gravel pack material had been added outside the 6-inch liner from the surface through a gravel make-up pipe extending into the annular space between the 8-inch and 10-inch casings. The water-bearing zone of the well was believed to be primarily from 600 to 700 feet. Background information regarding well construction and history are provided in my work plan letter to you that was dated March 28, 2000.

The initial work plan contemplated pulling the liner and casing from the borehole, and installing three piezometer pipes at depths of 800 to 850, 650 to 700, and 200 to 260 feet. However, the contractor was only able to pull the liner approximately 90 feet above the bottom of the borehole, and was unable to pull the 8-inch casing. Furthermore, it was apparent that the borehole annulus behind the 8-inch casing was open. The open annulus made the ability to isolate the uppermost proposed piezometer (200 to 260 feet) questionable. Therefore, only the two deep piezometers were eventually installed.

The work was completed as follows.

1. The first step was to bail out approximately 150 feet of fill material from inside the liner. Several days of drilling and bailing were required to accomplish this work due to a significant quantity of debris. The debris included a lost geophysical tool, metallic objects such as chunks of rebar and cast iron, and numerous large pieces of gravel in the upper 50 feet of so of the fill. It is appears that the well had been open at one time and that vandals had thrown

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Boise, Idaho 83706

Telephone (208) 383-4140
Facsimile (208) 383-4156

many of these materials into the well. Most of the fill below 750 feet consisted of fine-grained sand and silt.

2. After the well was bailed down to approximately 850 feet, the contractor speared the 6-inch liner and attempted to extract it from the well. However, the liner was pulled up only 90 feet before becoming stuck. Significant amounts of gravel pack material came into the borehole when the liner was pulled. These materials were bailed out.

3. A decision was made to leave the liner in place, cut the 8-inch casing above the liner by perforating around the pipe with a Mills Knife, and then pull the 8-inch casing from the well. However, the contractor was unsuccessful in cutting the 8-inch casing in two attempts. He indicated that the Mills Knife would perforate the pipe on the first few cuts, but as more of the pipe was cut, the pipe would simply bend into the open annulus. The contractor then perforated the liner from 216 to 260 feet for grouting purposes.

4. The lower piezometer was installed to 848 feet. The lower piezometer is constructed of 2-inch steel pipe that is torch-perforated from 813 to 848 feet.

5. Pea-gravel (¼-inch minus) was poured from the surface and tagged at 805 feet.

6. Bentonite chips (850 lbs) were poured from the surface and tagged from 805 to 770 feet.

7. Pea-gravel was poured from the surface and tagged at 700 feet.

8. The upper piezometer was installed to approximately 700 feet. The piezometer is constructed of 2-inch steel pipe that is torch-perforated from 600 to 700 feet.

9. Pea-gravel was poured from the surface and tagged at 544 feet.

10. Bentonite grout was used to seal from the top of the gravel pack to surface on April 5. The grout was pumped from the bottom up through tremie pipe using a positive displacement pump. The grout was installed in stages, so that the tremie pipe was raised as the grout pumping rate slowed due to high pressure.

11. The top of the 8-inch casing was sealed with a steel plate with penetrations for the two piezometer pipes. The taller piezometer pipe (0.76 of stickup above the steel plate) is the lower (deep) piezometer. The steel plate is the measuring point for water level measurements.

12. The work site was repaired during April and May. The repair work included rebuilding the well/pump vault (but to a lower level) and landscape repair.

13. The piezometer pipes were developed by air-lift pumping on June 7. The upper piezometer produced approximately 20 gpm when blowing through 168 feet of 1-inch pipe. The lower piezometer produced only 1 gpm when blowing through 168 feet of 1-inch pipe.

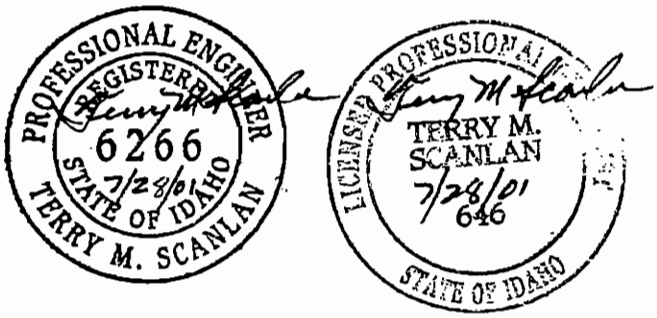
I measured water levels of 36.49 feet in the deep piezometer and 36.64 feet in the shallow piezometer on July 20, 2001. The measurements are depth to water below the steel plate.

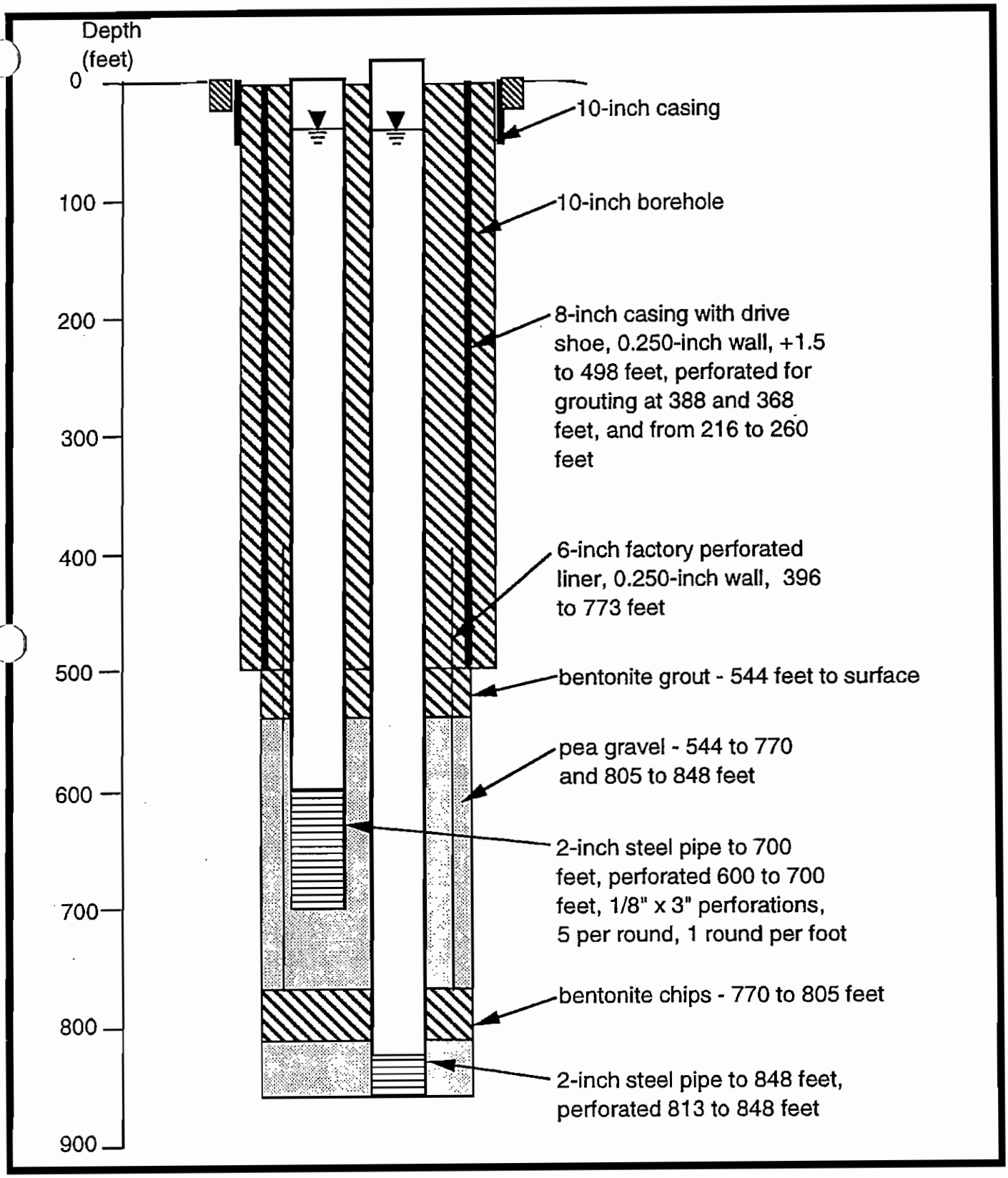
A schematic diagram of the completed well is enclosed, along with photographs of construction materials and the completed well head. Please contact me with any questions.

Sincerely,

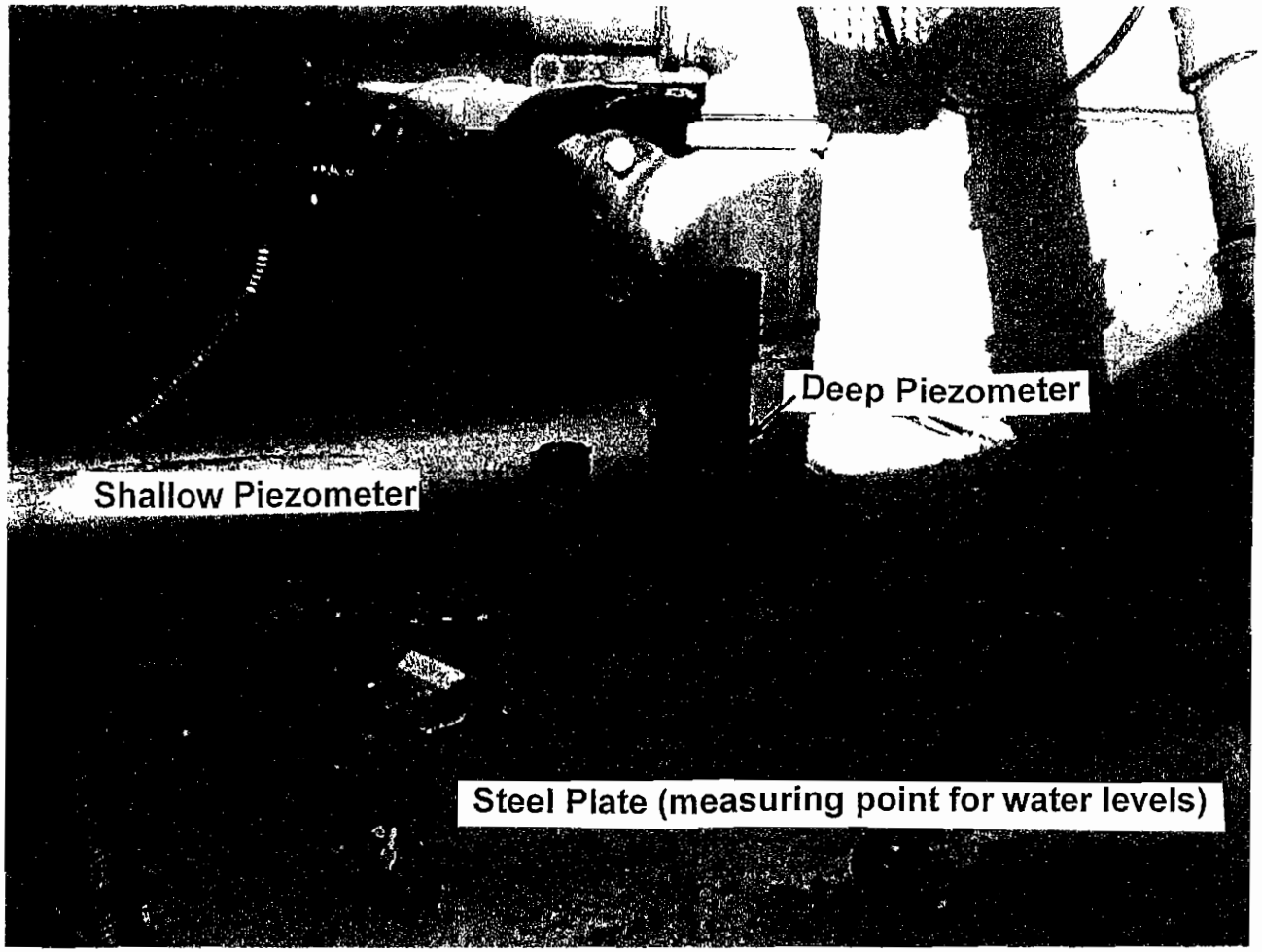
Terry M. Scanlan, P.E., P.G.

Cc: Paul Castelin
Christian Petrich

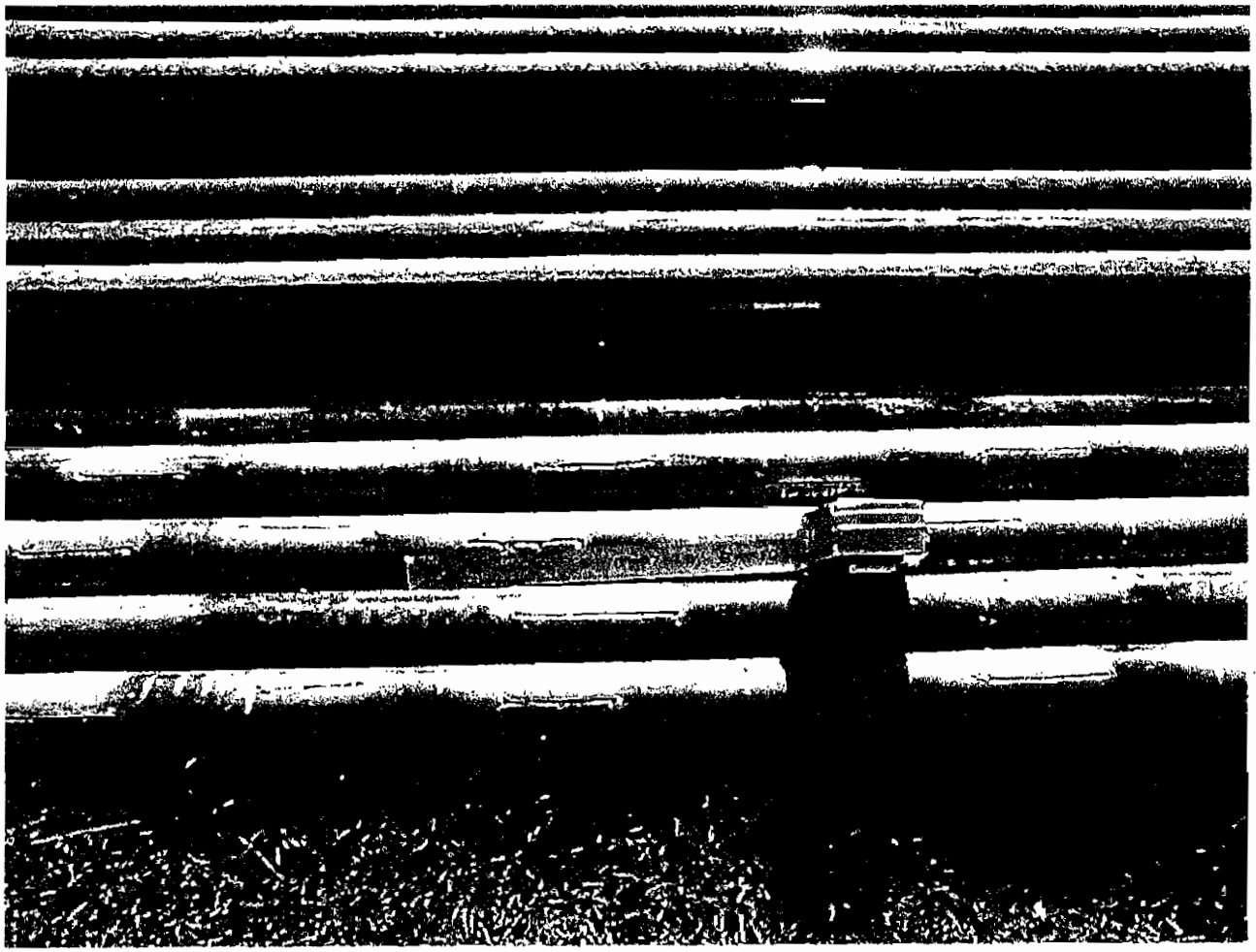




As-Built Diagram - Quarry View Park Well - June 2001



Completed Well Head



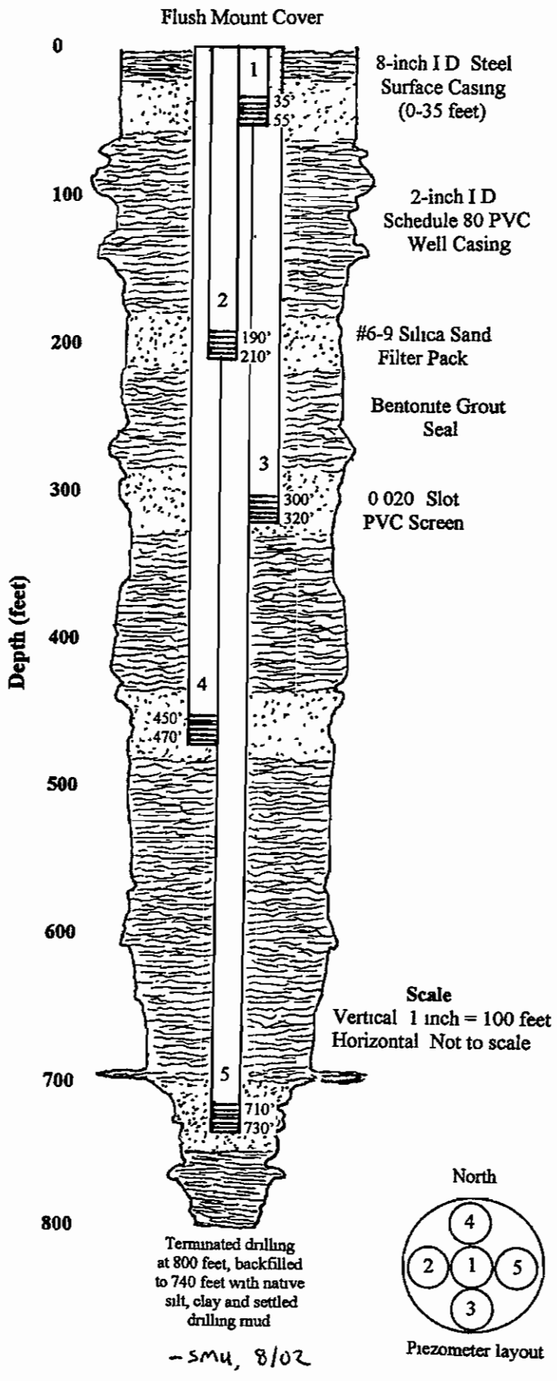
2-inch Torch Perforated and Blank Pipe

Gravel Pack Material in Dump Truck
(pipe to the right is tremie pipe)

33M

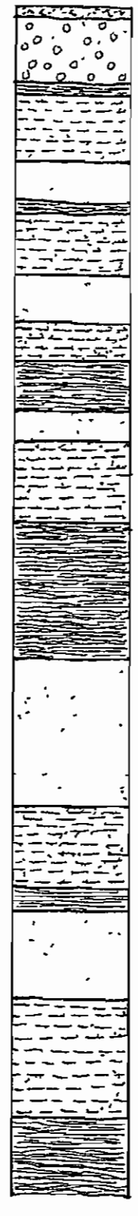
Municipal Park Monitoring Well (TVHP #4)

Well Construction Details



Lithologic Log

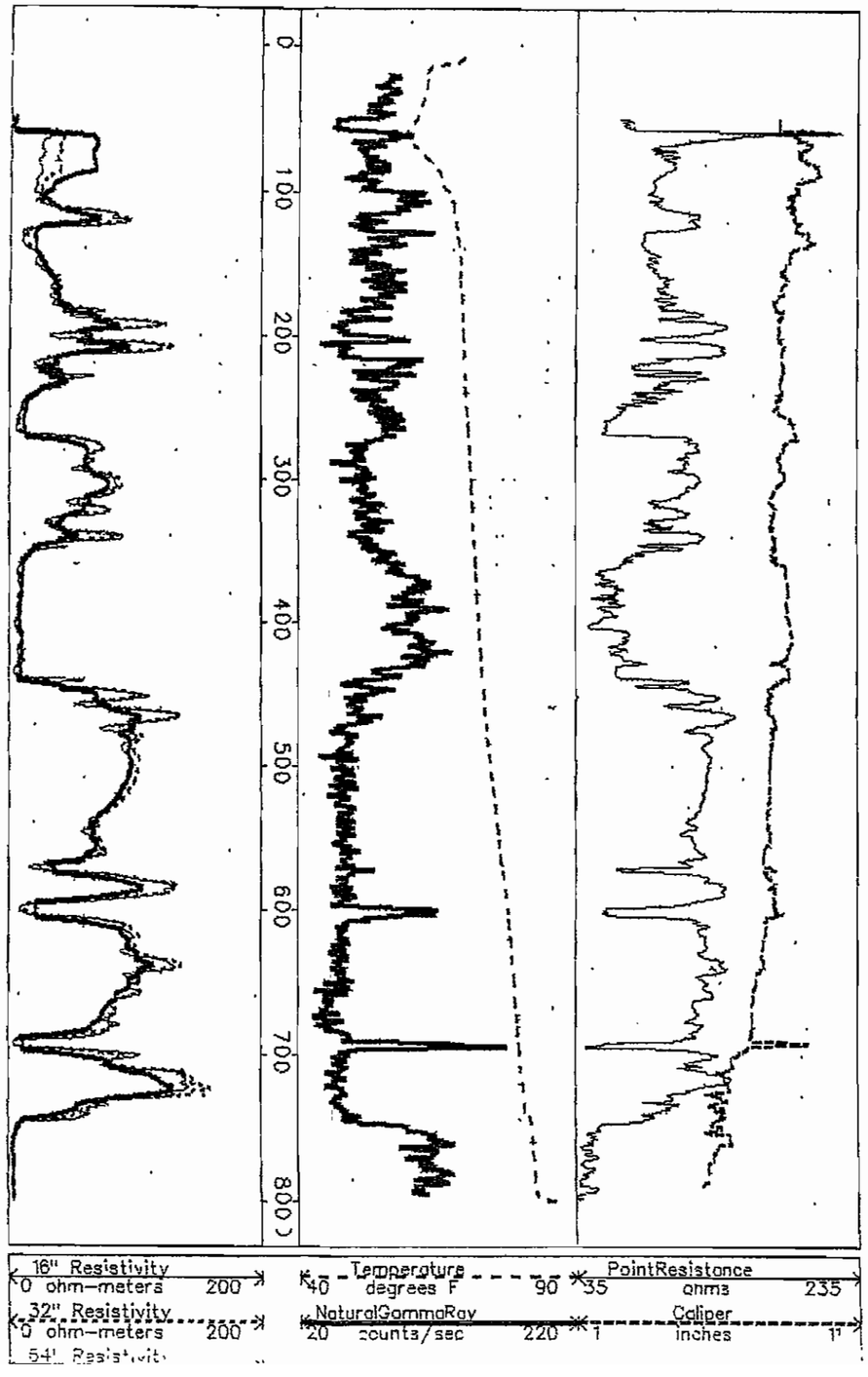
0 – 8	Topsoil/fill/sand and gravel; grayish brown (2 5Y 5/2)
8 – 55	Sand with gravel, light brownish gray (2 5Y 6/2); Possibly cemented at 37 - 38 feet, then >H_2O
55 – 60	V fine sand (yellowish-brown, 10YR 5/4) interbedded with clay (dark gray, 5Y 4/4) "Brown clay" in driller's report
60 – 105	Fine to coarse sand with clay, gray (5Y 6/1), Fast drilling (60 feet/hour)
105 – 130	Fine to coarse sand, light olive-gray (5Y 6/2)
130 – 140	Clay, v dark gray (10YR 3/1); some wood fragments,
140 – 180	Sandy clay, fine to medium, greenish-gray (5GY 5/1)
180 – 215	Sand, interbedded fine to coarse, olive-gray (5Y 5/2)
215 – 240	Sandy clay, v dark gray (5Y 3/1 – 4/1)
240 – 270	Clay, v dark gray (5Y 4/1)
270 – 295	Sand, fine to coarse; olive-gray (5Y 5/2)
295 – 345	Sand, fine to coarse, interbedded with clay, dark gray (5Y 5/1) Fast drilling (averaging 90 feet/hour from 330 – 530 feet)
345 – 440	Clay; dark gray (10YR 4/1)
440 – 540	Sand, fine to coarse, dark gray (5Y 4/1)
540 – 595	Sand, fine to coarse, interbedded with some clay, dark gray (5Y 4/1), Slower drilling (30 feet/hour)
595 – 610	Clay/sandy clay, dark gray (5Y 4/1)
610 – 670	Sand, fine to coarse, dark gray (5Y 4/1) Slow drilling (35 feet/hour), Caliper log suggests evidence of bit wear
670 – 750	Sand, sandy clay, possible sandstone/mudstone, dark gray (5Y 4/1); very slow drilling (less than 20 feet/hour)
750 – 800	Clay; dark gray (5Y 4/1)



Drilled by Stevens and Son Well Drilling, Inc
- Started drilling 6/18/02, well completed on 7/29/02
- Cable tool rig 0-59 feet, mud rotary 59-800 feet

Geophysical logging by L Pearson, Hydro Logic, Inc
- Well logged on 6/27/02

Geophysical Logs



33N

TREASURE VALLEY HYDROLOGIC PROJECT

Geological and Geophysical Framework of the Treasure Valley

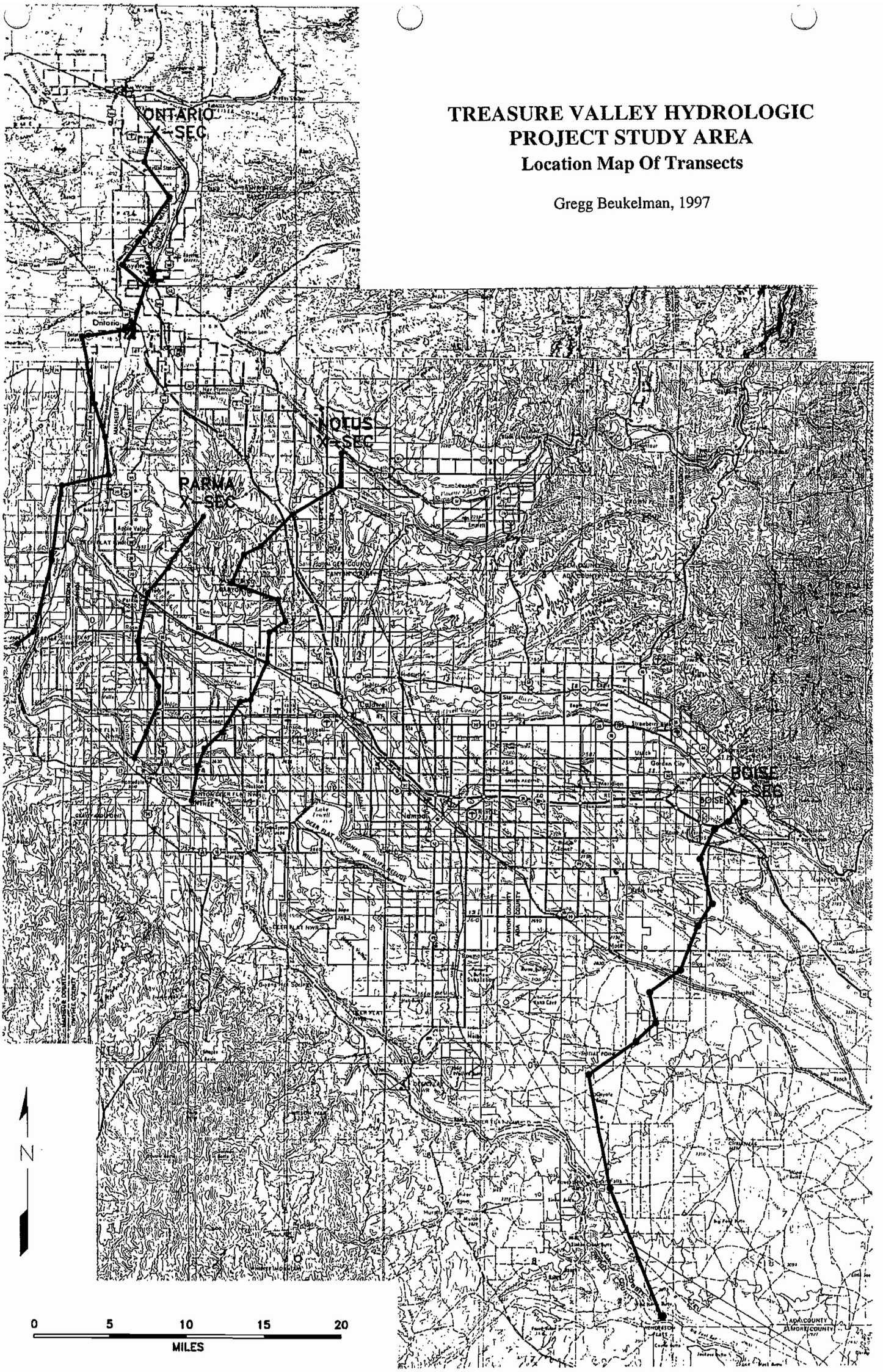
Reports on the Ontario, Parma, Notus and Boise Cross Sections

Gregg Beukelman, 1997

TREASURE VALLEY HYDROLOGIC PROJECT STUDY AREA

Location Map Of Transects

Gregg Beukelman, 1997



Cross section of the Treasure Valley in the Ontario area for the TVHP (Treasure Valley Hydrologic Project):
Notes on Geology of the Ontario area, Payette and Canyon Counties, Idaho and Malheur County, Oregon

by Gregg Beukelman
Department of Geosciences, Boise State University
Boise, Idaho 83725
tele: 208-385-1631, fax 385-4061, email: gbeukelm@trex.idbsu.edu

June 14, 1997

Introduction

The report and enclosed data are a preliminary compilation of information along a transect extending NNE-SSW from just south of the town of Weiser, southwest to the Adrian, Oregon area (Figs. 1a and 1b). The intent of this report is to show the nature of the Late Cenozoic stratified sediments in the upper portion of the western Snake River Plain near it's western extent (Figs. 2a, b, and c). Included for each well along the transect are the well owner, Land Office Grid coordinates, surface elevation (± 10 feet), and diagrams of well construction and lithology (attached). Lithologies, taken from well drillers' reports on record at the Idaho Department of Water Resources and the Boise office of the U. S. Geological Survey for the wells completed in Idaho and the Oregon Water Resources Department for those in Oregon, are plotted in detail where distinctive units of lithologic or hydrogeologic significance are well documented by the driller. Individual drillers' reports are attached to the report should the user wish more detail. Also included is a geologic cross section drawn to show correlatable distinctive lithologic and hydrogeologic boundaries encountered in each well. A 1:100,000 map of the area Fig. 1) is included showing the route of the transect (A-A'), individual well owners and surface geology taken from: Ferns and others, (1993), Othberg and Stanford (1992), Brooks, McIntyre, and Walker (1976), and Savage (1961).

Methods

The cross section included is a graphical presentation of subsurface lithologies based on water well drillers reports and deep exploration wells. Wells along the transect were selected to ensure maximum section coverage. Water well drillers reports were obtained from the Idaho Department of Water Resources for the wells in Idaho and from the Oregon Water Resources Department by means of their Internet-based Grid program for the wells in Oregon. For each well included in the profile (1:24,000 horizontal) the stratigraphic section and well construction, as reported in the drillers logs, were plotted at a vertical scale of 1:1,200 (see attached sheets) and the well completion data noted. Correlations were made at this scale and all data digitized and reduced to produce the cross section in figure 2. Accuracy of all elevations is probably ± 10 feet. No attempt has been made to correlate the upper contact of the lacustrine claystone because of very sparse data. However this contact occurs at about 1300-ft. elevation in the Rube Bolles #1 deep exploration well and about 1700-ft. elevation in the Kiesel Estates well based on a marked decrease in the electrical resistivity signature.

Structure

The structural nature of this area of the plain is inferred to be a normal fault-bounded graben. Faults are thought to be older structures owing to their lack of surface expression and the absence of offset in Pleistocene gravels and overlying Bonneville Flood deposits. Evidence of a major south facing fault near the southern end of the transect includes an approximate 120 ft. offset of the boundary between the overlying brown sediments and the blue sediments below. Additionally, two gravel units that occur at about 2100-ft. elevation in the Brown well are faulted against a monotonous clay in the City of Adrian well (fig. 2a). A small graben occurs in the vicinity of the confluence of the Snake River and the Payette River. This structure is evinced by an offset of the blue-brown sediment boundary (about 110 ft.). Another small graben (offset of less than 40 ft.) occurs near the north end of this transect (fig. 2c). None of these structures has been mapped on any existing surface geologic map and are here based almost exclusively on offset of the blue-brown sediment boundary. Although some of the recognized offset is likely the result of downwarping of sediments during diagenesis, the overall horizontal nature of the blue-brown boundary (0.03° between Malheur Experimental Station well and the American Fine Foods well) suggests that downwarping has been complicated by faulting.

Stratigraphy

The sedimentary section contains Late Cenozoic fluvial and lacustrine deposits and an interbedded basalt units. Basalt is not noted in any of the water wells and can be seen only in the Kiesel Estates well where the first occurrence is at -1600 ft. and in the Ore-Ida well where the first occurrence is at -2450 ft. and the basalt basement is at -6050 ft. (Minus signs indicate elevation below sea level). Surficial deposits include modern flood plain deposits, Bonneville Flood slackwater fine sediments, gravels of Pleistocene age, and older Tertiary age sediments. A typical stratigraphy in the upper potion of the section includes gravels overlain by up to 40 feet of sands and clays. Beneath the gravels is a complex sequence of interfingering gravels, sands, and clays that are interpreted to represent fluvial and shallow lacustrine deposits. This section contains an upper portion in which sediments are commonly some shade of brown, tan, or yellow and a deeper portion having sediments that are described as blue or grey in drillers logs. North of the fault that occurs near the southern extent of the transect, the boundary between these color-defined units is at 2230-ft ± 50 ft elevation except within the graben near the Snake River (1970-ft in the Mills well). The brown-colored unit is up to 130 feet thick beneath the uplands northeast the Snake River, but has apparently been mostly removed by erosion near the Snake River.

The nature of this brown-blue boundary is not well understood but is believed to reflect differences in depositional environment. The blue colored sediments are thought to be an indication of a chemically reducing depositional environment characteristic of lake deposits. The brown colors are more likely caused by oxidation of iron-bearing minerals under unsaturated conditions. Thus, these sediments are thought to represent alluvial, fluvial, and lake margin deposits which would be more apt to be oxidized. Alternatively, it is also possible that recharge by oxygenated waters percolating through reduced (blue) iron minerals may oxidize formerly blue-gray colored deposits. Groundwater that is high in dissolved iron can be associated with the oxidation of reduced iron minerals at a contact between oxidizing and reducing conditions. In

the area of this transect and others completed across the western Snake River Plain, evidence such as the uniform elevation of the contact suggests that this brown-blue contact is the result of original diagenesis. Therefore, this oxidation/reduction contact may well be useful for geologic interpretation of depositional environments.

North of the major fault in the Adrian area, the deeper part of the sedimentary section is composed of over 4000 feet of monotonous lacustrine claystone. The upper contact of this section is at 1700-ft or 1400-ft elevations as interpreted from the electrical resistivity logs of the Kiesel Estates and Rube Bolles #1 deep exploration wells respectively. This upper contact of this unit is the top of the pro-delta mudstone facies interpreted by Wood (1997). The geometry of the upper contact of this claystone cannot be determined from this cross section as only the deep exploration wells penetrate it. Included within the claystone near its base are several interbedded basaltic flows and tuffs.

Hydrogeology

The static water level in wells along this transect vary only 100 feet in elevation. All of the wells along this transect are completed in the upper portion of the blue sediments and behave as confined of semiconfined. Discharge from wells ranges from 10-55 gpm in the southernmost four wells with a general increase in those to the north (90-500 gpm) with two exceptions. The Roberts Farm well was drilled to a depth of about 400 ft. and is dry and the Mills well adjacent to the Snake River drilled to about 520 ft. and producing 8-10 gpm.

References

Brooks, H.C., McIntyre, J.R., and Walker, G.W., 1976, Geology of the Oregon part of the Baker 1° by 2° quadrangle, State of Oregon, Department of Geology and Mineral Resources.

Ferns, M.L., and Brooks, H.C., 1993, Geologic map of the Vale 30X60 minute quadrangle, Malheur county, Oregon and Owyhee county, Idaho, State of Oregon, Department of Geology and Mineral Resources.

Idaho Department of Transportation, 1994, 30 X 60 minute series topographic maps of Boise and Weiser, Idaho, scale 1:100,000.

U. S. Geological Survey, 1993, 30X60 minute series topographic maps of Vale, Idaho-Oregon and Brogan, Idaho-Oregon, scale 1:100,000.

Idaho Department of Water Resources, 1997, microfiche file of drillers reports, Orchard Street Office.

Oregon Water Resources Department, 1997, Files of drillers reports via Internet Grid program.

Othberg, K.L., and Sanford, L.R., 1992, Geologic map of the Boise Valley and adjoining area, western Snake River Plain, Idaho: Idaho Geological Survey, Geologic Map Series, scale 1:100,000.

Savage, C.N., 1961, Geology and Mineral Resources of Gem and Payette counties, County report no. 4, State of Idaho, Idaho Bureau of Mines and Geology.

Wood, S.H., 1997, Structural contour map of the top of Miocene basalt basement rocks, western Snake River Plain, Idaho: Report for Idaho Department of Water Resources (2 sheets, 1:100,000).

Figures and enclosures

Figure 1a & b	Map (1:100,000) showing cross section transect, wells used in cross section, surficial geology, and location of deep exploration wells.
Figure 2a, b, and c	Cross section of geology and hydrogeology across the western Snake River Plain in the Ontario, Oregon area.
Figure 2d	Legend for cross section
Attached	Fifteen panels of wells used in cross section showing lithology, well construction, and completion data.
Attached	Drillers reports of selected wells.

FIGURE 1a

ONTARIO CROSS SECTION LOCATION MAP

Surficial geology from: (1) Ferns and others, (1993), (2) Othberg and Stanford (1992). (3) Brooks, McIntyre, and Walker (1976), and (4) Savage (1961). Existing geologic mapping is incomplete southeast of Ontario, Oregon.

ADOPTED MAP UNITS

Qa	Alluvium of Boise, Payette, and Snake Rivers (1,2,3)
Qfe	Fluviatile and eolian sediments (4)
Qsbf	Fluviatile sand, gravel, and silt (Holocene to upper Pleistocene)(1)
Qbfg	Gravel of Bonneville Flood-scoured Boise Terrace and Boise Floodplain (2)
Qwfg	Gravel of the Bonneville Flood- scoured Whitney Terrace (2)
Qas	Terrace gravels and alluvial-fan deposits (Holocene? And Pleistocene) (1)
Qcn	Caldwell-Nampa sediments (4)
Qwig	Sandy silt of the Bonneville Flood slack water (2)
Qwgs	Sandy silt of Bonneville Flood slack water (2)
Tst	Tuffaceous sedimentary rocks (3)

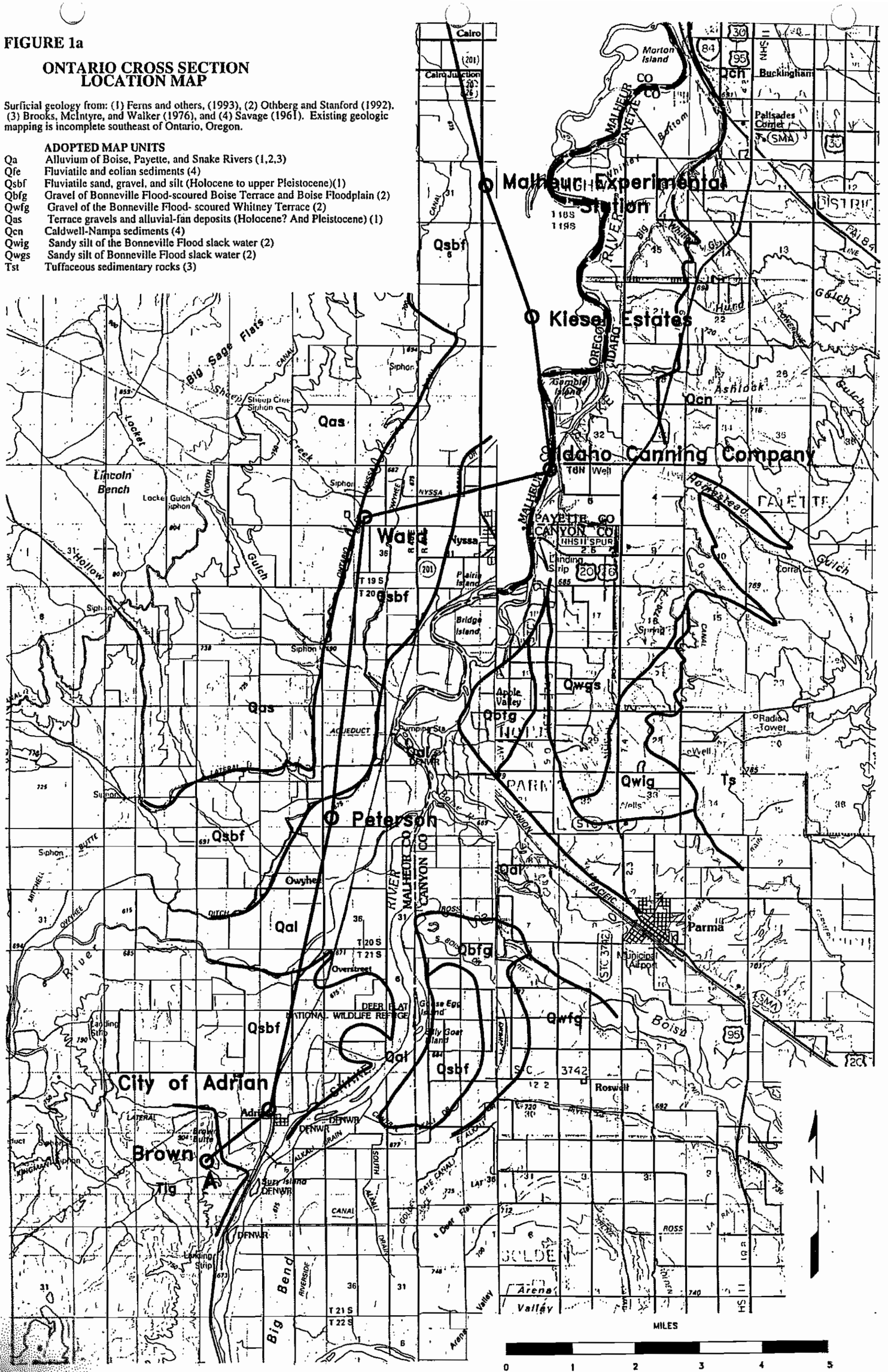


FIGURE 1b

ONTARIO CROSS SECTION LOCATION MAP

Surficial geology from: (1) Ferns and others, (1993), (2) Othberg and Stanford (1992), (3) Brooks, McIntyre, and Walker (1976), and (4) Savage (1961). Existing geologic mapping is incomplete southeast of Ontario, Oregon.

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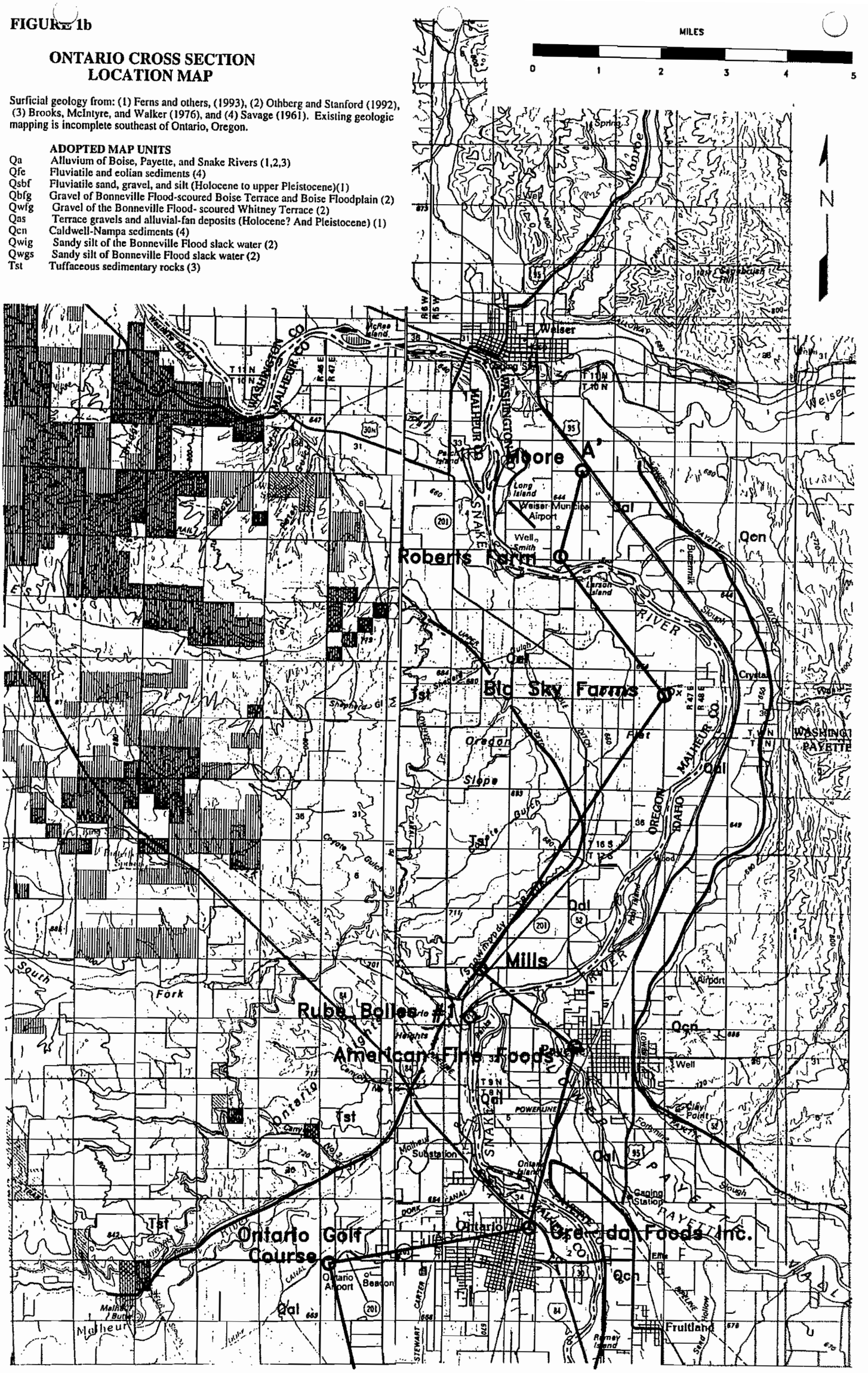


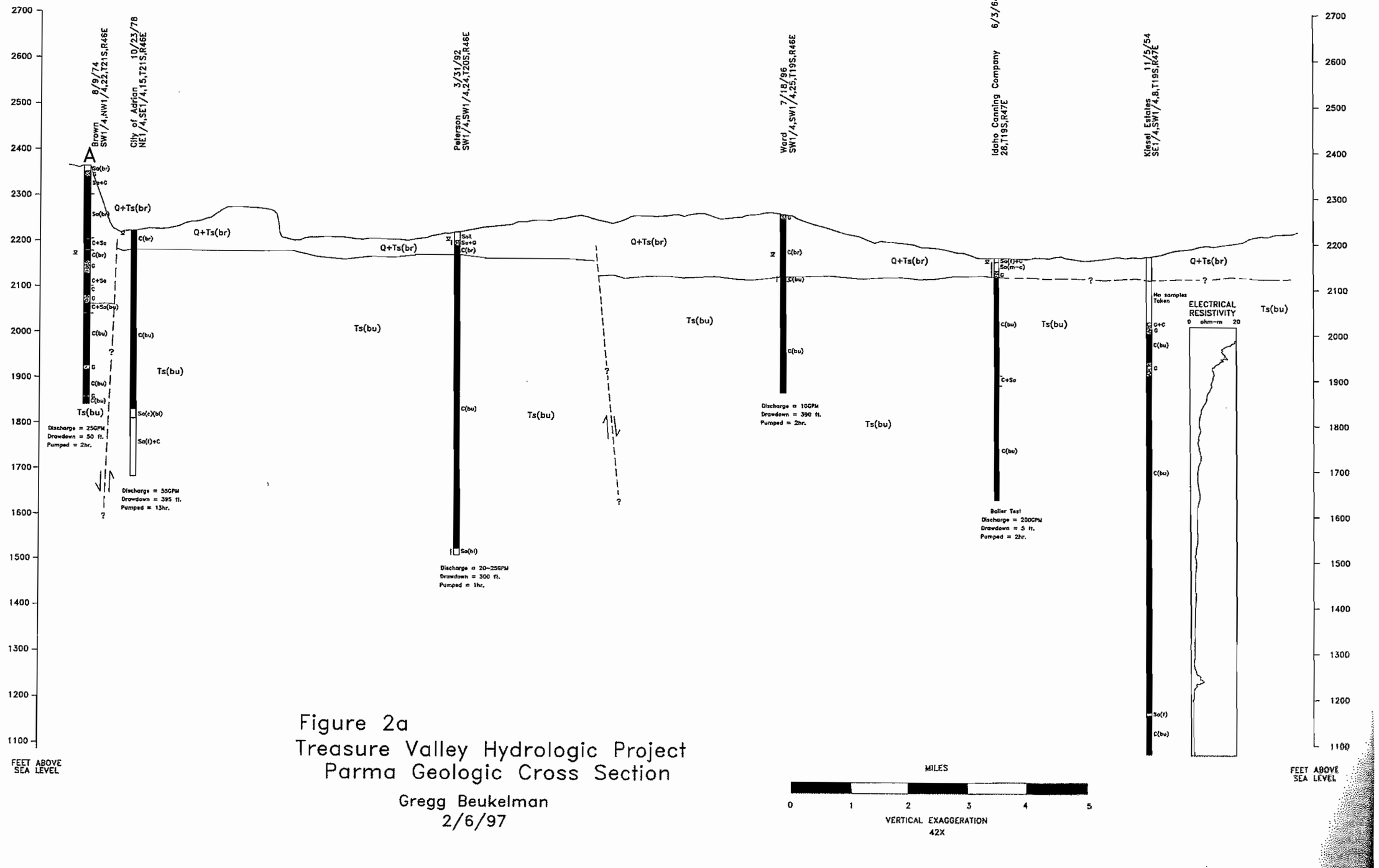


Figure 2a
Treasure Valley Hydrologic Project
Parma Geologic Cross Section

Gregg Beukelman
2/6/97

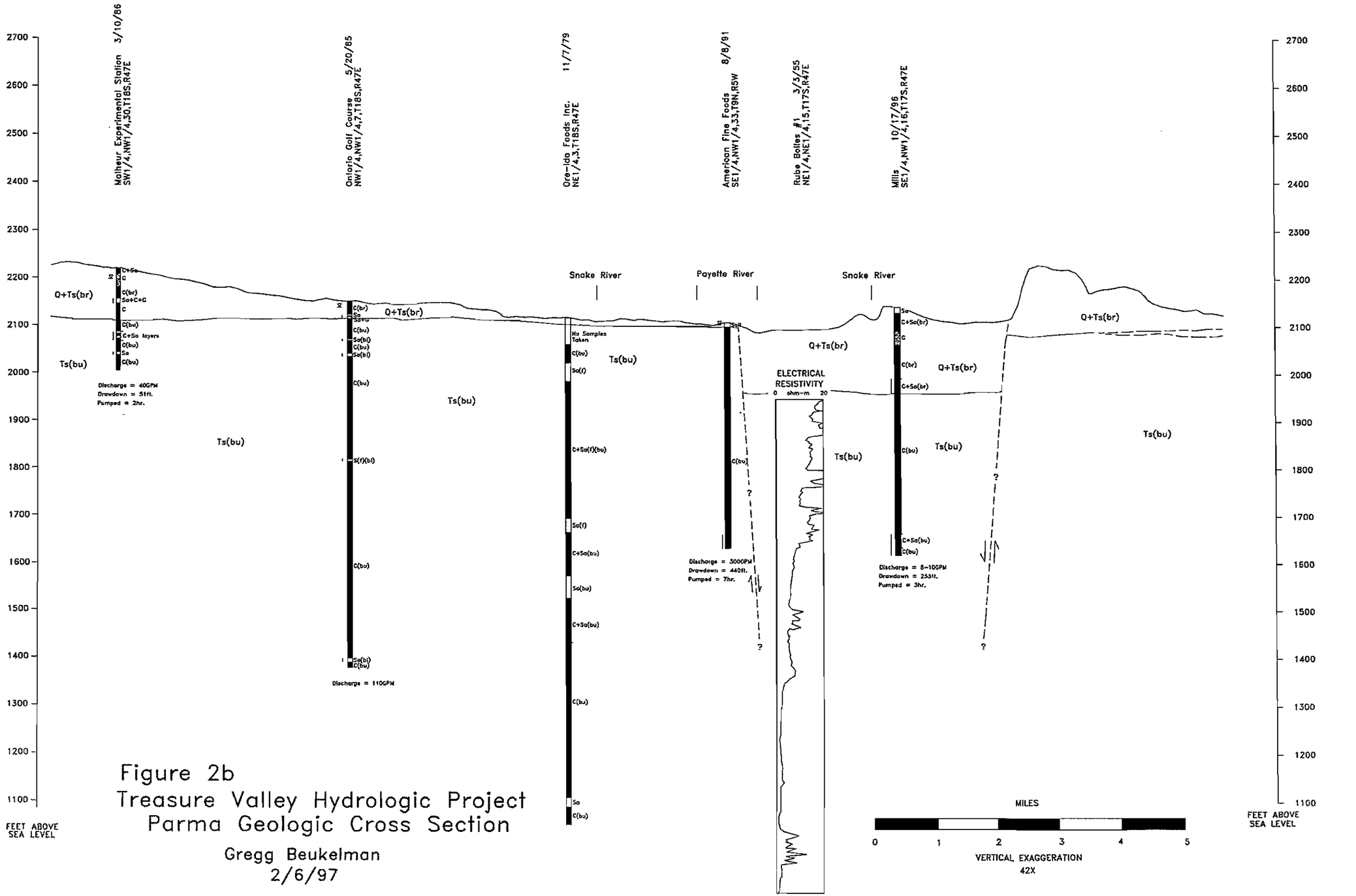


Figure 2b
Treasure Valley Hydrologic Project
Parma Geologic Cross Section

Gregg Beukelman
2/6/97

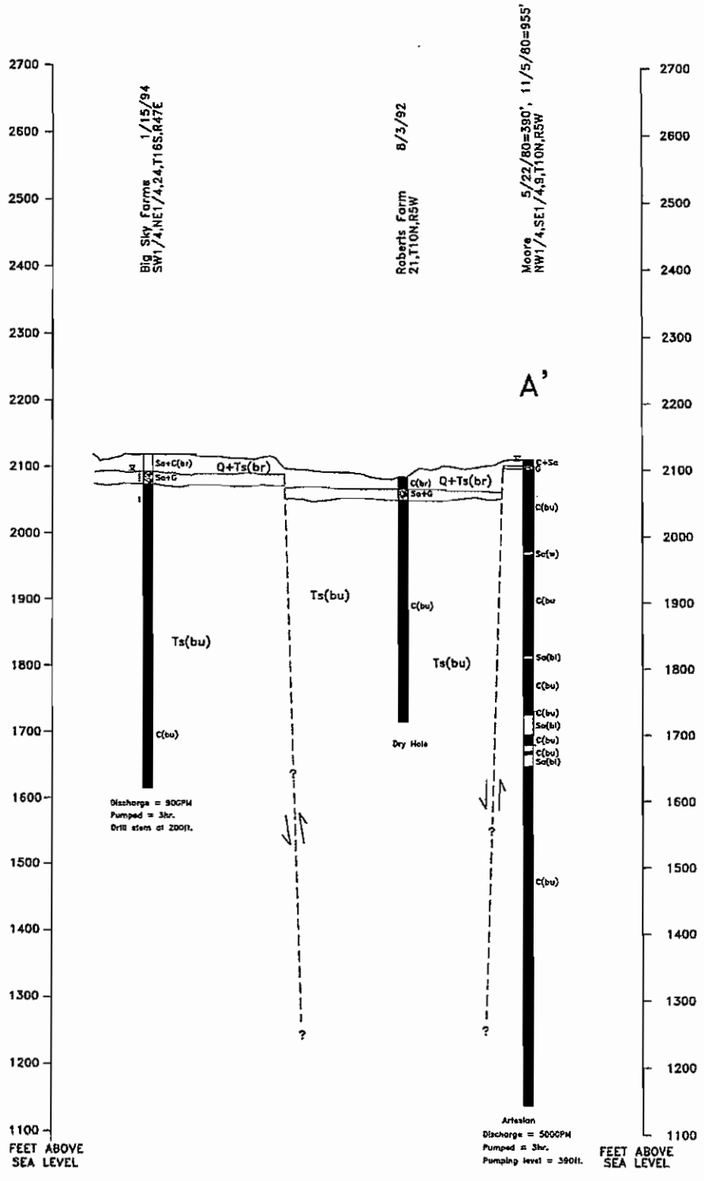


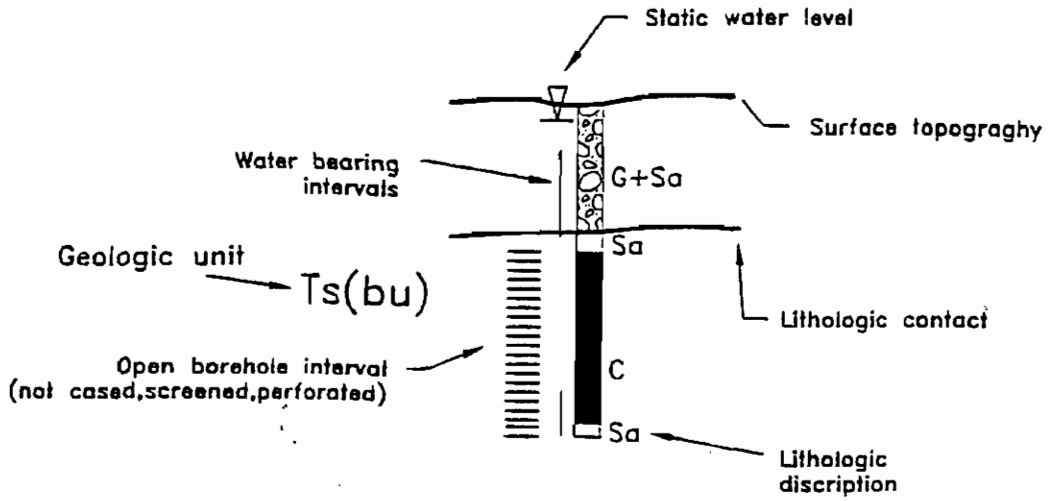
Figure 2c
Treasure Valley Hydrologic Project
Parma Geologic Cross Section

Gregg Beukelman
2/6/97

FIGURE 2d

CROSS SECTION LEGEND

Diagram of Typical Well Interval



GEOLOGIC Units (After: (1) Ferns and others, (1993), (2) Othberg and Stanford (1992), (3) Brooks, McIntyre, and Walker (1976), and (4) Savage (1961).

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Qwig	Sandy silt of the Bonneville Flood slack water (2)
Qwgs	Sandy silt of Bonneville Flood slack water (2)
Tst	Tuffaceous sedimentary rocks (3)

WELL LITHOLOGIC ABBREVIATIONS

G	Gravel
Sa(c,m,f)	Sand (coarse, medium, fine)
C	Clay

When two sediment sizes are combined (C+Sa) the first sediment is the most abundant.

Color modifiers: Brown (Br), White (W), and Blue (Bu) are included for Tertiary sediments.

Form 238-7
1/78

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name Ray Moore
2000 North 22nd Ave
Address Pasco, Washington 99301
Owner's Permit No. _____

2. NATURE OF WORK

☒ New well ☐ Deepened ☐ Replacement
☐ Abandoned (describe method of abandoning) _____

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☒ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other looking for hot water (specify type)

4. METHOD DRILLED

☒ Rotary ☒ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other _____

5. WELL CONSTRUCTION

Casing schedule: ☒ Steel ☐ Concrete ☐ Other _____

Thickness	Diameter	From	To
250 inches	6 inches	1 feet	32 feet
_____ inches	_____ inches	_____ feet	_____ feet
_____ inches	_____ inches	_____ feet	_____ feet
_____ inches	_____ inches	_____ feet	_____ feet

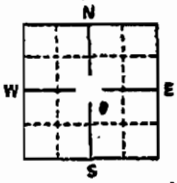
Was casing drive shoe used? ☒ Yes ☐ No
Was a packer or seal used? ☐ Yes ☒ No
Perforated? ☐ Yes ☒ No
How perforated? ☐ Factory ☐ Knife ☐ Torch
Size of perforation _____ inches by _____ inches

Number		From	To
_____	perforations	_____ feet	_____ feet
_____	perforations	_____ feet	_____ feet
_____	perforations	_____ feet	_____ feet

Well screen installed? ☐ Yes ☒ No
Manufacturer's name _____
Type _____ Model No. _____
Diameter ___ Slot size ___ Set from _____ feet to _____ feet
Diameter ___ Slot size ___ Set from _____ feet to _____ feet
Gravel packed? ☐ Yes ☒ No ☐ Size of gravel _____
Placed from _____ feet to _____ feet
Surface seal depth 20 Material used in seal: ☐ Cement grout ☒ Puddling clay ☐ Well cuttings
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☒ Overbore to seal depth
Method of joining casing: ☐ Threaded ☒ Welded ☐ Solvent Weld
☐ Cemented between strata
Describe access port _____

6. LOCATION OF WELL

Sketch map location must agree with written location.



Subdivision Name _____
Lot No. _____ Block No. _____
County Washington
NW ¼ SE ¼ Sec. 9 , T. 10N N/S, R. 5W E/W.

7. WATER LEVEL

Static water level 0 feet below land surface.
Flowing? ☒ Yes ☐ No G.P.M. flow _____
Artesian closed-in pressure 1 p.s.i.
Controlled by: ☐ Valve ☒ Cap ☐ Plug
Temperature 68°F. Quality good

8. WELL TEST DATA

☐ Pump ☐ Bailer ☒ Air ☐ Other _____

Discharge G.P.M.	Pumping Level	Hours Pumped
500	390	1

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
12	0	3	top soil		
12	3	12	sandy clay		
12	12	15	sand		
12	15	27	gravel		
6	27	160	blue clay		
6	160	161	white sand	*	
6	161	307	blue clay		
6	307	308	black sand	*	
6	308	390	blue clay		
6	390	400	black sand	*	
			put in tempory bentonite seal he wants to case and go deeper		

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JUN 17 1980
Department of Water Resources
Western Regional Office

Work started 5/20/80 finished 5/22/80

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name DALLAS DRILLING Firm No. 224
Address Payette, Idaho Date 5/28/80
Signed by (Firm Official) Dallas T. Goff
and
(Operator) Johnny T. Goff

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Form 238-7
1/78

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name Ray Moore
2000 N 22nd Ave.
Address Pasco, Washington 99301
Owner's Permit No. _____

2. NATURE OF WORK

☐ New well ☒ Deepened ☐ Replacement
☐ Abandoned (describe method of abandoning) _____

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☒ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other _____ (specify type)

4. METHOD DRILLED

☒ Rotary ☒ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other _____

5. WELL CONSTRUCTION

Casing schedule: ☒ Steel ☐ Concrete ☐ Other _____

Thickness	Diameter	From	To
250 inches	6 inches +	1 feet	669 feet
258 inches	8 inches	1 feet	40 feet
_____ inches	_____ inches	_____ feet	_____ feet
_____ inches	_____ inches	_____ feet	_____ feet

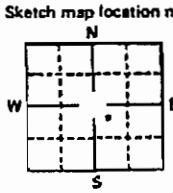
Was casing drive shoe used? ☒ Yes ☐ No
Was a packer or seal used? ☐ Yes ☒ No
Perforated? ☐ Yes ☒ No
How perforated? ☐ Factory ☐ Knife ☐ Torch
Size of perforation _____ inches by _____ inches

Number	From	To
_____ perforations	_____ feet	_____ feet
_____ perforations	_____ feet	_____ feet
_____ perforations	_____ feet	_____ feet

Well screen installed? ☐ Yes ☒ No
Manufacturer's name _____
Type _____ Model No. _____
Diameter ___ Slot size ___ Set from ___ feet to ___ feet
Diameter ___ Slot size ___ Set from ___ feet to ___ feet
Gravel packed? ☐ Yes ☒ No ☐ Size of gravel _____
Placed from _____ feet to _____ feet
Surface seal depth 40 Material used in seal: ☒ Cement grout ☐ Puddling clay ☐ Well cuttings
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☒ Overbore to seal depth
Method of joining casing: ☐ Threaded ☒ Welded ☐ Solvent Weld ☐ Cemented between strata
Describe access port _____

6. LOCATION OF WELL

Sketch map location must agree with written location.



Subdivision Name _____
Lot No. ___ Block No. ___
County Washington
NW ¼ SE ¼ Sec. 9, T. 10N N/S, R. 5W E/W.

7. WATER LEVEL

Static water level 0 feet below land surface.
Flowing? ☐ Yes ☒ No G.P.M. flow ___
Artesian closed-in pressure _____ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature 80 °F. Quality good with gas

8. WELL TEST DATA

☐ Pump ☐ Bailer ☒ Air ☐ Other _____

Discharge G.P.M.	Pumping Level	Hours Pumped
10	950	2.

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
			In addition to Ray Moore		
6	395	400	blue clay		
6	400	405	sand stone		
6	405	430	black/white heaving sand	x	
6	430	445	blue clay		
6	445	451	black sand flowing heaving		
6	451	454	blue clay		
6	454	478	black sand heaving		
6	478	578	blue sticky clay		
6	578	579	black sand		
6	579	633	hard blue shale caving		
6	633	955	blue shale hard		

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DEC 19 1980
Department of Water Resources
Western Regional Office

DEC 24 1980
Water Resources

10. Work started 10/17/80 finished 11/5/80

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name DALLAS DRILLING Firm No. 224
Address Payette, Idaho Date 12/15/80
Signed by (Firm Official) Johnny J Dall
and
(Operator) Johnny J Dall

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER
Name Roberts Farm (Sid and Brad Roberts)
Address 1467 Larsen Rd. Weiser Id. 83672
Drilling Permit No. 67-92-10006 (well 1)
Water Right Permit No.

2. NATURE OF WORK (check)
☒ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase
☐ Abandoned (describe abandonment procedures such as materials, plug depths, etc. in lithologic log)

3. PROPOSED USE
☒ Domestic ☐ Irrigation ☐ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other (specify type)

4. METHOD DRILLED
☒ Rotary ☒ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other

5. WELL CONSTRUCTION
Casing schedule: ☒ Steel ☐ Concrete ☐ Other

Thickness	Diameter	From	To
.250"	6" inches	+2 feet	40 feet
	inches	feet	feet
	inches	feet	feet
	inches	feet	feet

Was casing drive shoe used? ☒ Yes ☐ No
Was a packer or seal used? ☐ Yes ☒ No
Perforated? ☐ Yes ☒ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation inches by inches

Number	perforations	From feet	To feet
	perforations	feet	feet
	perforations	feet	feet

Well screen installed? ☐ Yes ☒ No
Manufacturer's name Model No.
Type Set from feet to feet
Diameter Slot size Set from feet to feet
Gravel packed? ☐ Yes ☒ No Size of gravel
Placed from feet to feet
Surface seal depth 38 Material used in seal? ☐ Cement grout
☒ Bentonite ☐ Puddling clay ☐
Sealing procedure used: ☐ Slurry pit ☒ Tamp, surface casing
☒ Overbore to seal depth
Method of joining casing: ☐ Threaded ☒ Welded ☐ Solvent Weld
☐ Cemented between strata
Describe access port

6. LOCATION OF WELL 1463 Larsen RD
Sketch map location must agree with written location.
Subdivision Name 92045
Govt. Lt. 2
Lot No. x, 62, 38 Block No. x, 72, 419
County Washington
¼ ¼ Sec. 21 T. 10 ☐ S ☒ N R. 5 ☐ E ☒ W

7. WATER LEVEL
Static water level Dry feet below land surface.
Flowing? ☐ Yes ☒ No G.P.M. flow
Artesian closed-in pressure p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature: °F. Quality
Describe artesian or temperature zones below

8. WELL TEST DATA
☐ Pump ☐ Bailer ☒ Air ☐ Other

Discharge G.P.M.	Pumping Level	Hours Pumped
0	365	1

9. LITHOLOGIC LOG

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
10	0	15	Brown Clay		
10	15	30	Sand and Gravel		
10	30	38	Blue Clay		
6	38	365	Blue Clay		

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Department of Water Resources
Western Regional Office
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OCT 26 1992 OCT 01 1992
Department of Water Resources Department of Water Resources

10. Work started 8-01-92 finished 8-03-92

11. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.
Dallas Drilling and
Firm Name Pump Co., Inc. Firm No. 445
505 So. 18th St.
Address Payette Id. 83661 Date 9-29-92
Signed by (Firm Official)
and
(Operator)

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STATE OF OREGON
WATER WELL REPORT
(as required by ORS 537.765)

MALA 3006

RECEIVED
MAR 18 1994
WATER RESOURCES DEPT.
SALEM, OREGON

165/47E/24ac

(START CARD) # 18568

(1) OWNER: Well Number 18568
Name Big Sky Farms Inc.
Address 3270 E. 7th St.
City Wieser State Ida Zip 83672

(2) TYPE OF WORK:
☒ New Well ☐ Deepen ☐ Recondition ☐ Abandon

(3) DRILL METHOD:
☒ Rotary Air ☒ Rotary Mud ☐ Cable
☐ Other

(4) PROPOSED USE:
☐ Domestic ☐ Community ☐ Industrial ☒ Irrigation
☐ Thermal ☐ Injection ☐ Other Irrig test.

(5) BORE HOLE CONSTRUCTION:
Special Construction approval ☐ Yes ☒ No Depth of Completed Well 500 ft.
Explosives used ☐ Yes ☒ No Type Amount

HOLE Diameter	From	To	SEAL Material	From	To	Amount sacks or pounds
16	0	56	C-grout	0	56	36
9	56	500				

How was seal placed: Method ☐ A ☒ B ☐ C ☐ D ☐ E
☐ Other
Backfill placed from ft. to ft. Material
Gravel placed from ft. to ft. Size of gravel

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:	12	+1	56	250	☒	☐	☒	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
Liner: No					☐	☐	☐	☐
					☐	☐	☐	☐

Final location of shoe(s) 56 ft.

(7) PERFORATIONS/SCREENS: NO
☐ Perforations Method
☐ Screens Type Material

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐
						☐	☐

(8) WELL TESTS: Minimum testing time is 1 hour
☐ Pump ☐ Bailer ☒ Air ☐ Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
90		200	1 hr.

Temperature of Water 57° Depth Artesian Flow Found NO
Was a water analysis done? NO ☐ Yes By whom
Did any strata contain water not suitable for intended use? NO ☐ Too little
☐ Salty ☐ Muddy ☐ Odor ☐ Colored ☐ Other
Depth of strata:

(9) LOCATION OF WELL by legal description:
County Malheur Latitude Longitude
Township 16 N or S Range 47 E or W WM.
Section 24 SW ¼ NE ¼
Tax Lot 2401 Lot Block Subdivision
Street Address of Well (or nearest address) Lon Sing Rd
Ontario Ore 97914

(10) STATIC WATER LEVEL:
21 ft. below land surface. Date 1-15-94
Artesian pressure lb. per square inch. Date

(11) WATER BEARING ZONES:
Depth at which water was first found 22

From	To	Estimated Flow Rate	SWL
22	42	150 gpl	21
64	67	90	21

(12) WELL LOG:
Ground elevation 0

Material	From	To	SWL
Sandy Clay Brown	0	22	21
Sand & Large boulders	22	42	21
Blue Clay	42	64	0
Fractured Blue Claystone	64	67	21
Blue Claystone &	67	500	0
siltstone similar &			
Consistent formation			

Date started 12-25-93 Completed 1-15-94

(unbonded) Water Well Constructor Certification:
I certify that the work I performed on the construction, alteration, or abandonment of this well is in compliance with Oregon well construction standards. Materials used and information reported above are true to my best knowledge and belief.

Signed Frank Bailey WWC Number 789
Date 1-20-94

(bonded) Water Well Constructor Certification:
I accept responsibility for the construction, alteration, or abandonment work performed on this well during the construction dates reported above. All work performed during this time is in compliance with Oregon well construction standards. This report is true to the best of my knowledge and belief.

Signed Frank Bailey WWC Number 789
Date 1-20-94

ORIGINAL & FIRST COPY - WATER RESOURCES DEPARTMENT SECOND COPY - CONSTRUCTOR THIRD COPY - CUSTOMER 9809C 10/91

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NOV 21 1996

WATER RESOURCES DEPT.
SALEM, OREGON

MALH 50397

STATE OF OREGON WATER SUPPLY WELL REPORT
(as required by ORS 537.765)

WELL I.D.# _____ (START CARD) # 94824

Instructions for completing this report are on the last page of this form.

(1) OWNER: Well Number L06852
Name Max Mills
Address 1141 SW 3 Ave
City Ontario State OR Zip 97914

(2) TYPE OF WORK
☒ New Well ☐ Deepening ☐ Alteration (repair/recondition) ☐ Abandonment

(3) DRILL METHOD:
☐ Rotary Air ☐ Rotary Mud ☒ Cable ☐ Auger
☐ Other

(4) PROPOSED USE:
☒ Domestic ☐ Community ☐ Industrial ☐ Irrigation
☐ Thermal ☐ Injection ☐ Livestock ☐ Other

(5) BORE HOLE CONSTRUCTION:
Special Construction approval ☐ Yes ☒ No Depth of Completed Well 520 ft.
Explosives used ☐ Yes ☒ No Type _____ Amount _____

HOLE Diameter	From	To	SEAL Material	From	To	Sacks or pounds
12	0	[illegible]	Cement			
	0	83	grout	10	83	36
8	+1	520	Bentonite	0	10	7

How was seal placed: Method ☐ A ☐ B ☒ C ☐ D ☐ E
☒ Other Bentonite was dry from surface
Backfill placed from _____ ft. to _____ ft. Material _____
Gravel placed from _____ ft. to _____ ft. Size of gravel _____

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:	8	+1	84	.250	☒	☐	☒	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
Liner:					☐	☐	☐	☐
					☐	☐	☐	☐

Final location of shoe(s) 84 ft

(7) PERFORATIONS/SCREENS:
☐ Perforations Method _____
☐ Screens Type _____ Material _____

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐
						☐	☐

(8) WELL TESTS: Minimum testing time is 1 hour

☐ Pump ☒ Bailer ☐ Air ☐ Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
8-10	253 ft		1 hr.
			3 hrs

Temperature of water 63° Depth Artesian Flow Found _____
Was a water analysis done? ☐ Yes By whom _____
Did any strata contain water not suitable for intended use? ☐ Too little
☐ Salty ☐ Muddy ☐ Odor ☐ Colored ☐ Other _____
Depth of strata: _____

(9) LOCATION OF WELL by legal description:
County Malheur Latitude _____ Longitude _____
Township 17 S ☒ or S Range 47 E E or W W.M.
Section 16 SE 1/4 NW 1/4
Tax Lot 5102 Lot _____ Block _____ Subdivision _____
Street Address of Well (or nearest address) Highline Rd. Hwy 201

(10) STATIC WATER LEVEL:
147 ft. below land surface. Date 10-17-96
Artesian pressure _____ lb. per square inch. Date _____

(11) WATER BEARING ZONES:
Depth at which water was first found 150 ft

From	To	Estimated Flow Rate	SWL
150 ft	182	1-2 GPM	147 ft
475	505	8-10 GPM	147

(12) WELL LOG:
Ground Elevation _____

Material	From	To	SWL
Sandy Soil	0	8	
Hardpan	8	12	
Sandy Brn clay	12	49	
Gravel	49	79	
Brn clay	79	150	
Brn Sandy clay	150	182	147
Hard Brn clay	182	189	
Blue clay	189	385	
Hard Blue clay	385	387	
Blue clay	387	475	
Grey Sandy clay	475	505	147
Grey clay	505	520	147

Date started 9-23-96 Completed 10-18-96

(unbonded) Water Well Constructor Certification:
I certify that the work I performed on the construction, alteration, or abandonment of this well is in compliance with Oregon water supply well construction standards. Materials used and information reported above are true to the best of my knowledge and belief.
WWC Number _____
Signed _____ Date _____

(bonded) Water Well Constructor Certification:
I accept responsibility for the construction, alteration, or abandonment work performed on this well during the construction dates reported above. All work performed during this time is in compliance with Oregon water supply well construction standards. This report is true to the best of my knowledge and belief.
WWC Number 1485
Signed Jon M Fyfe Date 11-14-96

ORIGINAL & FIRST COPY-WATER RESOURCES DEPARTMENT SECOND COPY-CONSTRUCTOR THIRD COPY-CUSTOMER

Form 238-7
8/90

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

#2

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER
Name American Fine Foods
Address 25 North 6th St Jerome Id
Drilling Permit No. GS-91-40-014
Water Right Permit No. _____

2. NATURE OF WORK
☑ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase
☐ Abandoned (describe abandonment procedures such as materials, plug depths, etc. in lithologic log)

3. PROPOSED USE TEST WELL #2
☐ Domestic ☐ Irrigation ☑ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other _____ (specify type)

4. METHOD DRILLED
☑ Rotary ☐ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other _____

5. WELL CONSTRUCTION
Casing schedule: ☑ Steel ☐ Concrete ☐ Other _____

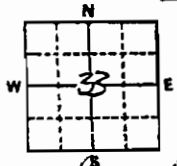
Thickness	Diameter	From	To
.250 inches	8 inches +	1 feet	24 feet
_____ inches	_____ inches	_____ feet	_____ feet
_____ inches	_____ inches	_____ feet	_____ feet
_____ inches	_____ inches	_____ feet	_____ feet

Was casing drive shoe used? ☑ Yes ☐ No
Was a packer or seal used? ☐ Yes ☑ No
Perforated? ☐ Yes ☑ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation _____ inches by _____ inches

Number	From	To
_____ perforations	_____ feet	_____ feet
_____ perforations	_____ feet	_____ feet
_____ perforations	_____ feet	_____ feet

Well screen installed? ☐ Yes ☑ No
Manufacturer's name _____
Type _____ Model No. _____
Diameter ___ Slot size ___ Set from _____ feet to _____ feet
Diameter ___ Slot size ___ Set from _____ feet to _____ feet
Gravel packed? ☐ Yes ☑ No ☐ Size of gravel _____
Placed from _____ feet to _____ feet
Surface seal depth 18 Material used in seal: ☐ Cement grout ☑ Bentonite ☐ Puddling clay ☐ _____
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☑ Overbore to seal depth
Method of joining casing: ☐ Threaded ☑ Welded ☐ Solvent Weld ☐ Cemented between strata
Describe access port 1" plug

6. LOCATION OF WELL
Sketch map location must agree with written location.



Subdivision Name _____
Lot No. _____ Block No. _____
County Jerome
SE ¼ NW ¼ Sec. 33 , T. 9 N ☒ S ☐ R. 15 E ☐ W ☒

7. WATER LEVEL
Static water level ~2~ feet below land surface.
Flowing? ☐ Yes ☐ No G.P.M. flow _____
Artesian closed-in pressure _____ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature 62 °F. Quality Fair grassy
Describe artesian or temperature zones below

8. WELL TEST DATA
☐ Pump ☐ Bailer ☑ Air ☐ Other _____

Discharge G.P.M.	Pumping Level	Hours Pumped
300	440	7

9. LITHOLOGIC LOG

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
12	0	11	Brown Soil		✓
12	11	16	Blue Clay		✓
12	16	18	Blue Clay		✓
8	18	455	Blue Clay		✓
8	455	470	Broken Sandstone & Sand	✓	

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OCT 25 1991
Department of Water Resources
Western Regional Office

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DEC 04 1991
Department of Water Resources

10. Work started 30 Apr 8-91 finished _____

11. DRILLERS CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.
Firm Name Frank Shelley Firm No. 326
Address 940 N 19th Ave Payette Date _____
Signed by (Firm Official) Frank Shelley
and
(Operator) Frank Shelley

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

WATER WELL REPORT
STATE OF OREGON

RECEIVED
MAY 30 1985
WATER RESOURCES DEPT
SALEM, OREGON

Malh 1499

State Well No. 18S/47E-7bb

State Permit No.

(1) OWNER:
Name ONTARIO GOLF COURSE
Address P O BOX 24
City ONTARIO State OREGON

(2) TYPE OF WORK (check):
New Well XX Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary Air XX Driven ☐
Rotary Mud ☐ Dug ☐
Cable ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation XX Test Well ☐ Other ☐
Thermal: Withdrawal ☐ Reinjection ☐

(5) CASING INSTALLED: Steel XX Threaded ☐ Plastic ☐ Welded XX
8" Diam. from 2 ft. to 10 ft. Gauge 250
" Diam. from ft. to ft. Gauge

LINER INSTALLED:
" Diam. from ft. to ft. Gauge

(6) PERFORATIONS: Perforated? XX Yes ☐ No
Type of perforator used TORCH
Size of perforations 3/16 in. by 5 in.
150 perforations from 30 ft. to 45 ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes XX No
Manufacturer's Name
Type Model No.
Diam. Slot Size Set from ft. to ft.
Diam. Slot Size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? XX Yes ☐ No If yes, by whom? DALLAS DRILLING
Yield: 110g.p.m. gal/min. with ft. drawdown after hrs.
(PUMP TEST)
Air test 100+ gal/min. with drill stem at ft. hrs.
Bailer test gal/min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water 58 Depth artesian flow encountered ft.

(9) CONSTRUCTION: Special standards: Yes ☐ No ☐
Well seal—Material used CEMENT
Well sealed from land surface to 18 ft.
Diameter of well bore to bottom of seal 14 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal 12 + 5% bentonite sacks
How was cement grout placed? pumped through 1" grout pipe
Was pump installed? NO Type HP Depth ft.
Was a drive shoe used? ☐ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☐ No
Type of Water? depth of strata
Method of sealing strata off
Was well gravel packed? XX Yes ☐ No Size of gravel: 3/8
Gravel placed from 25 ft. to 40 ft.

(10) LOCATION OF WELL:
County MALHEUR Driller's well number
NW ¼ NW ¼ Section 7 T. 18 S R. 47E W.M.
Tax Lot # Lot Blk Subdivision
Address at well location:

(11) WATER LEVEL: Completed well.
Depth at which water was first found 35 ft.
Static level 18 ft. below land surface. Date
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing 8
Depth drilled 220 ft. Depth of completed well 220 ft.
Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
BROWN CLAY	0	30	
SAND	30	33	
SAND GRAVEL	33	40	18
BLUE CLAY	40	80	
BLACK SAND	80	81	18
BLUE CLAY	81	116	
BLACK SAND	116	117	18
BLUE CLAY	117	220	

Work started 5/15 19 85 Completed 5/17 19 85
Date well drilling machine moved off of well 5/17/85 19

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] (Drilling Machine Operator) Date , 19
Drilling Machine Operator's License No.

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name DALLAS DRILLING & PUMP CO., INC. (Person, firm or corporation) (Type or print)
Address 505 So. 18th St. PAYETTE, IDAHO 83661
[Signed] (Water Well Contractor)
Contractor's License No. 682 Date 5/20/85, 19

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the
WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

SP*12658-690

STATE OF OREGON

WATER WELL REPORT

(as required by ORS 537.765)

******NOTICE*****

PLEASE BE ADVISED THIS REPORT IS BEING FILED TO AMEND A PREVIOUSLY FILED WELL REPORT. PLEASE TYPE or PRINT IN INK FILED WITH THE STATE OF OREGON 5/17/85 SAME OWNER, SAME LEGAL DESCRIPTION, SAME DRILLING COMPANY (for official use only)

(1) OWNER:

Name ONTARIO GOLF COURSE - (L. WESTCOTT)

Address P. O. BOX 24

City ONTARIO, OREGON 97914 State

(2) TYPE OF WORK (check):

New Well XX Deepening ☐ Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:

Rotary Air XX Driven ☐

Rotary Mud ☐ Dug ☐

Cable ☐ Bored ☐

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☐

Irrigation ☐ Thermal: ☐ Withdrawal ☐ Reinjection ☐

Other: Piezometric ☐ Grounding ☐ Test ☐

(5) CASING INSTALLED:

Steel Threaded XX ☐ Plastic ☐ Welded XX

8 " Diam. from 2 ft. to 50 ft. Gauge .250

" Diam. from ft. to ft. Gauge

LINER INSTALLED:

Steel Threaded ☐ Plastic ☐ Welded ☐

" Diam. from ft. to ft. Gauge

(6) PERFORATIONS:

Perforated? ☐ Yes ☐ No

Size of perforations in. by in.

perforations from ft. to ft.

SEE PREVIOUS REPORT perforations from ft. to ft.

perforations from ft. to ft.

(7) SCREENS:

Well screen installed? ☐ Yes ☐ No

Manufacturer's Name

Type Model No.

SEE PREVIOUS REPORT Slot Size Set from ft. to ft.

Diam. Slot Size Set from ft. to ft.

(8) WELL TESTS:

Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☐ No If yes, by whom?

Yield: gal./min. with ft. drawdown after hrs.

Air test gal./min. with drill stem at ft. hrs.

Bailer test gal./min. with ft. drawdown after hrs.

Artesian flow g.p.m.

Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:

Special standards: Yes ☐ No ☐

Well seal—Material used

Well sealed from land surface to ft.

Diameter of well bore to bottom of seal in.

Diameter of well bore below seal in.

Amount of sealing material sacks ☐ pounds ☐

How was cement grout placed?

Was pump installed? Type HP Depth ft.

Was a drive shoe used? ☐ Yes ☐ No Plugs Size: location ft.

Did any strata contain unusable water? ☐ Yes ☐ No

Type of Water? depth of strata

Method of sealing strata off

Was well gravel packed? ☐ Yes ☐ No Size of gravel:

Gravel placed from ft. to ft.

(10) LOCATION OF WELL by legal description:

County MALHEUR NW ¼ NW ¼ of Section 7 of

Township 18 South (Township is North or South), Range 47 East (Range is East or West), WM.

Tax Lot Lot Block Subdivision

MAILING ADDRESS OF WELL (or nearest address)

(11) WATER LEVEL of COMPLETED WELL:

Depth at which water was first found ft.

Static level ft. below land surface. Date

Artesian pressure lbs. per square inch. Date

(12) WELL LOG:

Diameter of well below casing

Depth drilled ft. Depth of completed well ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
** THIS FILING IS AN AMENDED WELL REPORT. THE AMENDMENT IS TO SECTION #5. PLEASE NOTICE THE CASING INSTALLED WAS FROM 2ft. TO 50ft. PLEASE AMEND THE ORIGINAL WELL REPORT WHICH READ 10ft. ALL OTHER INFORMATION IS THE SAME AS PREVIOUSLY FILED.			

RECEIVED
JAN 23 1986
WATER RESOURCES DEPT
SALEM, OREGON

Date work started /completed

Date well drilling machine moved off of well 19

(unbonded) Water Well Constructor Certification (if applicable):

This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.

[Signed] Date , 19

(bonded) Water Well Constructor Certification:

Bond 2354454 (number) Issued by: WESTERN SURETY (Surety Company Name)

On behalf of JOHNNY L. GOFF (Type or print name of Water Well Constructor)

DALLAS DRILLING & PUMP CO.

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

(Signed) (Water Well Constructor)

(Dated) 1/14/86

NOTICE TO WATER WELL CONSTRUCTOR
The original and first copy of this report are to be filed with the

WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

SP*46866-690

RECEIVED
JUL 22 1985
WATER RESOURCES DEPT
SALEM, OREGON

WATER WELL REPORT

STATE OF OREGON

1500 Mail

State Well No. 18S/47E-7bb

State Permit No. deep.

****NOTICE****

PLEASE BE ADVISED, THIS REPORT PERTAINS TO THE DEEPENING OF AN EXISTING WELL, REPORT PREVIOUSLY FILED. SAME OWNER. SAME LEGAL. DATE WORK PREV. COMPLETED - 5/17/85. SAME DRILLING COMPANY.

(1) OWNER:

Name ONTARIO GOLF COURSE -(L. WESTCOTT)

Address P. O. BOX 24

City ONTARIO, OREGON 97914 State

(2) TYPE OF WORK (check):

New Well ☐ Deepening XX Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:

Rotary Air XX Driven ☐
Rotary Mud ☐ Dug ☐
Cable ☐ Bored ☐

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☐
Irrigation XX Test Well ☐ Other ☐
Thermal: ☐ Withdrawal ☐ Reinjection ☐

(5) CASING INSTALLED:

Steel ☐ Plastic ☐
Threaded ☐ Welded ☐

EXISTING INFO. "Diam. from ..... ft. to ..... ft. Gauge .....

"Diam. from ..... ft. to ..... ft. Gauge .....

LINER INSTALLED:

"Diam. from ..... ft. to ..... ft. Gauge .....

(6) PERFORATIONS:

Perforated? ☐ Yes ☐ No

Type of perforator used EXISTING INFO.

Size of perforations in. by in.

..... perforations from ..... ft. to ..... ft.

..... perforations from ..... ft. to ..... ft.

..... perforations from ..... ft. to ..... ft.

(7) SCREENS:

Well screen installed? ☐ Yes ☐ No

Manufacturer's Name EXISTING INFO.

Type ..... Model No. .....

Diam. ..... Slot Size ..... Set from ..... ft. to ..... ft.

Diam. ..... Slot Size ..... Set from ..... ft. to ..... ft.

(8) WELL TESTS:

Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☐ No If yes, by whom?

Yield: ..... gal./min. with ..... ft. drawdown after ..... hrs.

" " " " "

Air test ..... gal./min. with ..... drill stem at ..... ft. ..... hrs.

Bailer test ..... gal./min. with ..... ft. drawdown after ..... hrs.

Artesian flow ..... g.p.m.

Temperature of water ..... Depth artesian flow encountered ..... ft.

(9) CONSTRUCTION:

Special standards: Yes ☐ No ☐

Well seal—Material used EXISTING INFO.

Well sealed from land surface to ..... ft.

Diameter of well bore to bottom of seal ..... in.

Diameter of well bore below seal ..... in.

Number of sacks of cement used in well seal ..... sacks

How was cement grout placed? .....

Was pump installed? ..... Type ..... HP ..... Depth ..... ft.

Was a drive shoe used? ☐ Yes ☐ No Plugs ..... Size: location ..... ft.

Did any strata contain unusable water? ☐ Yes ☐ No

Type of Water? ..... depth of strata .....

Method of sealing strata off .....

Was well gravel packed? ☐ Yes ☐ No Size of gravel: .....

Gravel placed from ..... ft. to ..... ft.

(10) LOCATION OF WELL:

County MALHEUR Driller's well number .....

NW ¼ NW ¼ Section 7 T. 18S R. 47E W.M.

Tax Lot # ..... Lot ..... Blk ..... Subdivision .....

Address at well location: .....

(11) WATER LEVEL: Completed well.

Depth at which water was first found EXISTING INFO. ft.

Static level ..... ft. below land surface. Date .....

Artesian pressure ..... lbs. per square inch. Date .....

(12) WELL LOG:

Diameter of well below casing .....

Depth drilled EXISTING INFO Depth of completed well ..... ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
DEEPENING INFO.			
SHALE GREY	220	335	
SAND FINE BLACK	335	336	18'
SHALE GREY	336	750	
SAND FINE BLACK CEMENTED	750	755	18'
SHALE GREY	755	765	

Work started 6/17/85 19 Completed 6/19/85 19

Date well drilling machine moved off of well 6/19/85 19

Drilling Machine Operator's Certification:

This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.

[Signed] ..... (Drilling Machine Operator) Date 19

Drilling Machine Operator's License No. 165

Water Well Contractor's Certification:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Name DALLAS DRILLING & PUMP CO., INC. (Person, firm or corporation) (Type or print)

Address 505 So. 18th St.
PAYETTE, IDAHO 83661

[Signed] ..... (Water Well Contractor)

Contractor's License No. 682 Date 7/11/85 Johnny L. Goff, 19

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the

WATER RESOURCES DEPARTMENT,
SALEM, OREGON 97310
within 30 days from the date of well completion.

SP*12658-690

STATE OF OREGON

WATER WELL REPORT

(as required by ORS 537.765)

RECEIVED
MAY 23 1986
WATER RESOURCES DEPT
SALEM, OREGON

PLEASE TYPE or PRINT IN INK

Ammerman 1723

18s/47E-30bc

(for official use only)

(1) OWNER:

Name: MALHEUR EXPERIMENTAL STATION
Address: RT. 1 BOX 620
City: ONTARIO OREGON 97914 State

(2) TYPE OF WORK (check):

New Well [X] Deepening [ ] Reconditioning [ ] Abandon [ ]
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:

Rotary Air [X] Driven [ ]
Rotary Mud [X] Dug [ ]
Cable [ ] Bored [ ]

(4) PROPOSED USE (check):

Domestic [X] Industrial [ ] Municipal [ ]
Irrigation [ ] Thermal: [ ] Withdrawal [ ] Reinjection [ ]
Other: [X]
Piezometric [ ] Grounding [ ] Test [ ]

(5) CASING INSTALLED:

Steel [X] Threaded [ ] Plastic [ ] Welded [X]

6 in. Diam. from 2 ft. to 134 ft. Gauge .250

" Diam. from ft. to ft. Gauge

LINER INSTALLED:

Steel [ ] Threaded [ ] Plastic [ ] Welded [ ]

" Diam. from ft. to ft. Gauge

(6) PERFORATIONS:

Perforated? [ ] Yes [X] No

Size of perforations in. by in.

perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS:

Well screen installed? [ ] Yes [X] No

Manufacturer's Name
Type Model No.
Diam. Slot Size Set from ft. to ft.
Diam. Slot Size Set from ft. to ft.

(8) WELL TESTS:

Drawdown is amount water level is lowered below static level

Was a pump test made? [X] Yes [ ] No If yes, by whom? DALLAS DRILLING

Yield: 40 gal./min. with 51' ft. drawdown after 2 hrs.

Air test 45 gal./min. with drill stem at 220 ft. 2 hrs.

Bailer test gal./min. with ft. drawdown after hrs.

Artesian flow g.p.m.

Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:

Special standards: Yes [ ] No [X]

Well seal—Material used CEMENT TYPE 1 &11

Well sealed from land surface to 126 ft.

Diameter of well bore to bottom of seal 10 & 11 in.

Diameter of well bore below seal 10 & 126 in.

Amount of sealing material 35 + bentonite sacks [X] pounds [ ]

How was cement grout placed? PUMPED THROUGH 126'
of 1" GROUT PIPE TO LAND SURFACE

Was pump installed? YES Type SUB HP 1½ Depth 109 ft.

Was a drive shoe used? [X] Yes [ ] No Plugs Size: location ft.

Did any strata contain unusable water? [ ] Yes [X] No

Type of Water? depth of strata

Method of sealing strata off

Was well gravel packed? [ ] Yes [X] No Size of gravel:

Gravel placed from ft. to ft.

(10) LOCATION OF WELL by legal description:

County MALHEUR SW¼ NW¼ of Section 30 of
Township 18 South (Township is North or South) Range 47 East (Range is East or West) WM.

Tax Lot Lot Block Subdivision

MAILING ADDRESS OF WELL (or nearest address) SAME AS OWNER ADDRESS

(11) WATER LEVEL of COMPLETED WELL:

Depth at which water was first found 67 ft.
Static level 29 ft. below land surface. Date 3/10/86
Artesian pressure lbs. per square inch. Date

(12) WELL LOG:

Diameter of well below casing 6"
Depth drilled 220 ft. Depth of completed well 220 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
SANDY CLAY	0	15	
DRY CEMENTED GRAVEL	15	40	
BROWN CLAY	40	67	
SAND, SILT, GRAVEL	67	73	30
SILT STONE	73	112	
BLUE CLAY	112	130	
HARD BLUE SHALE	130	136	
BLACK AND GREY SANDSTONE	136	137	30
BLUE SHALE	137	140	
GREY SANDSTONE	140	141	30
BLUE SHALE	141	148	
GREY SANDSTONE	148	150	30
BLUE SHALE	150	175	
GREY SANDSTONE	175	177	30
GREY CLAY	177	220	

Date work started 3/8/86 /completed 3/13/86
Date well drilling machine moved off of well 3/13/86 19

(unbonded) Water Well Constructor Certification (if applicable):

This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.

[Signed] Date , 19

(bonded) Water Well Constructor Certification:

Bond 2354457 (number) Issued by: WESTERN SURETY (Surety Company Name)

On behalf of JOHNNY GOFF (type or print name of Water Well Constructor)

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

(Signed) John L. Goff (Water Well Constructor)

(Dated) 3/28/86

NOTICE TO WATER WELL CONSTRUCTOR
The original and first copy of this report are to be filed with the

WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

SP-46868-690

RECEIVED
JUL 7 1964
STATE ENGINEER
SALEM, OREGON

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the STATE ENGINEER, SALEM, OREGON within 30 days from the date of well completion.

WATER WELL REPORT
STATE OF OREGON
(Please type or print)

19 47-28 29da
Mailed 1974

State Well No. _____
State Permit No. _____

(1) OWNER:
Name Idaho Canning Company
Address Payette Idaho

(2) LOCATION OF WELL:
County Malheur Driller's well number 117
¼ ¼ Section 28 T. 19W R. 5W W.M.
Bearing and distance from section or subdivision corner
Town Lot At Idaho Canning Co. Nyssa Oregon

(3) TYPE OF WORK (check):
New Well ☑ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☑ Other ☐

(5) TYPE OF WELL:
Rotary ☑ Driven ☐
Cable ☐ Jetted ☐
Dug ☐ Bored ☐

(6) CASING INSTALLED:
Threaded ☐ Welded ☐
_____" Diam. from None ft. to _____ ft. Gage _____
_____" Diam. from _____ ft. to _____ ft. Gage _____
_____" Diam. from _____ ft. to _____ ft. Gage _____

(7) PERFORATIONS:
Perforated? ☐ Yes ☐ No
Type of perforator used None
Size of perforations _____ in. by _____ in.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.

(8) SCREENS:
Well screen installed? ☐ Yes ☐ No
Manufacturer's Name None
Type _____ Model No. _____
Diam. _____ Slot size _____ Set from _____ ft. to _____ ft.
Diam. _____ Slot size _____ Set from _____ ft. to _____ ft.

(9) CONSTRUCTION:
Well seal—Material used in seal Bentonite (See Note)
Depth of seal 0-40' ft. Was a packer used? Yes
Diameter of well bore to bottom of seal 9 7/8 in.
Were any loose strata cemented off? ☐ Yes ☐ No Depth _____
Was a drive shoe used? ☐ Yes ☐ No
Was well gravel packed? ☐ Yes ☐ No Size of gravel: _____
Gravel placed from _____ ft. to _____ ft.
Did any strata contain unusable water? ☑ Yes ☐ No
Type of water? Hard depth of strata 15-40
Method of sealing strata off Bentonite

(10) WATER LEVELS:
Static level 9' ft. below land surface Date 6/3/64
Artesian pressure _____ lbs. per square inch Date _____

(11) WELL TESTS:
Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☑ No If yes, by whom?
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
" " " " "
" " " " "
Bailer test 200 gal./min. with 5 ft. drawdown after 1 hrs.
Artesian flow _____ g.p.m. Date _____
Temperature of water 60 Was a chemical analysis made? ☐ Yes ☑ No

(12) WELL LOG:
Diameter of well below casing 9 7/8
Depth drilled 562 ft. Depth of completed well 562 ft.

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
Soil Top	0	5
SAND FINE SILTY	5	15
SAND Med-A COARSE (WATER)	15	30
GRAVEL FINE To Med (Water)	30	40
CLAY Blue	40	255
CLAY Blue STREAK BROWN SAND	255	275
CLAY Blue	275	562
Note		
Hole Filled with BENTONITE FROM		
bottom to 40', Wood plug set at		
40' AND hole Filled with Bentonite		
To SURFACE.		

Work started 5/25 1964 Completed 6/3 1964
Date well drilling machine moved off of well 6/16 1964

(13) PUMP:
Manufacturer's Name _____
Type: _____ H.P. _____

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME Otto Ellsworth
(Person, firm or corporation) (Type or print)
Address P.O. Box 471 Island City, Oregon
Drilling Machine Operator's License No. 282
[Signed] Otto Ellsworth
(Water Well Contractor)
Contractor's License No. 298 Date July 5, 1964

(USE ADDITIONAL SHEETS IF NECESSARY)

MALH 50296

RECEIVED

AUG 26 1996

WATER RESOURCES DEPT.
SALEM, OREGON

STATE OF OREGON WATER WELL REPORT

(as required by ORS 537.765)

(START CARD) # 66463

Instructions for completing this report are on the last page of this form.

(1) OWNER: Well Number

Name Mark Ward

Address P.O. Box 2366

City Nyssa State OR Zip 97913

(2) TYPE OF WORK

☑ New Well ☐ Deepening ☐ Alteration (repair/recondition) ☐ Abandonment

(3) DRILL METHOD:

☑ Rotary Air ☐ Rotary Mud ☐ Cable ☐ Auger

☐ Other

(4) PROPOSED USE:

☑ Domestic ☐ Community ☐ Industrial ☐ Irrigation

☐ Thermal ☐ Injection ☐ Livestock ☐ Other

(5) BORE HOLE CONSTRUCTION:

Special Construction approval ☐ Yes ☑ No Depth of Completed Well 390 ft.

Explosives used ☐ Yes ☑ No Type Amount

HOLE Diameter	From	To	SEAL Material	From	To	Sacks or pounds
10	0	25	Bentonite	0	25	700

How was seal placed: Method ☐ A ☐ B ☑ C ☐ D ☐ E

☑ Other Bentonite

Backfill placed from ft. to ft. Material

Gravel placed from ft. to ft. Size of gravel

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:	6	1	140	.250	☑	☐	☑	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
Liner:					☐	☐	☐	☐
					☐	☐	☐	☐

Final location of shoe(s) 140

(7) PERFORATIONS/SCREENS:

☐ Perforations Method

☐ Screens Type Material

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐
						☐	☐

(8) WELL TESTS: Minimum testing time is 1 hour

☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
~10		390	2hr 1 hr.

Temperature of water 64° Depth Artesian Flow Found

Was a water analysis done? ☐ Yes By whom

Did any strata contain water not suitable for intended use? ☐ Too little

☐ Salty ☐ Muddy ☐ Odor ☐ Colored ☐ Other

Depth of strata:

(9) LOCATION OF WELL by legal description:

County Malheur Latitude Longitude

Township 19 ☐ N or ☑ S Range 46 ☐ E or ☑ W. WM.

Section 25 SW 1/4 SW 1/4

Tax Lot Lot Block Subdivision

Street Address of Well (or nearest address) 3125 Shag Way

(10) STATIC WATER LEVEL:

84 ft. below land surface. Date 7-18-96

Artesian pressure lb. per square inch. Date

(11) WATER BEARING ZONES:

Depth at which water was first found 135

From	To	Estimated Flow Rate	SWL
135	145	~10	84

(12) WELL LOG:

Ground Elevation

Material	From	To	SWL
Cemented Gravel	10	7	
Brown Silty Clay	7	135	
Blue Silt	135	145	84
Blue Clay	145	390	

Date started 7-16-96 Completed 7-18-96

(unbonded) Water Well Constructor Certification:

I certify that the work I performed on the construction, alteration, or abandonment of this well is in compliance with Oregon water supply well construction standards. Materials used and information reported above are true to the best of my knowledge and belief.

WWC Number

Signed Date

(bonded) Water Well Constructor Certification:

I accept responsibility for the construction, alteration, or abandonment work performed on this well during the construction dates reported above. All work performed during this time is in compliance with Oregon water supply well construction standards. This report is true to the best of my knowledge and belief.

WWC Number 682

Signed Date

ORIGINAL & FIRST COPY-WATER RESOURCES DEPARTMENT SECOND COPY-CONSTRUCTOR THIRD COPY-CUSTOMER

MALH 50296

RECEIVED

AUG 26 1996

WATER RESOURCES DEPT.
SALEM, OREGON

STATE OF OREGON
WATER WELL REPORT
(as required by ORS 537.765)

(START CARD) # 66463

Instructions for completing this report are on the last page of this form.

(1) OWNER: Well Number

Name Mark Ward

Address P.O. Box 2366

City Hyssa State OR Zip 97913

(2) TYPE OF WORK

☑ New Well ☐ Deepening ☐ Alteration (repair/recondition) ☐ Abandonment

(3) DRILL METHOD:

☑ Rotary Air ☐ Rotary Mud ☐ Cable ☐ Auger

☐ Other

(4) PROPOSED USE:

☑ Domestic ☐ Community ☐ Industrial ☐ Irrigation

☐ Thermal ☐ Injection ☐ Livestock ☐ Other

(5) BORE HOLE CONSTRUCTION:

Special Construction approval ☐ Yes ☑ No Depth of Completed Well 390 ft.

Explosives used ☐ Yes ☑ No Type Amount

HOLE Diameter	From	To	Material	SEAL From	To	Sacks or pounds
10	0	25	Bentonite	0	25	700

How was seal placed: Method ☐ A ☐ B ☑ C ☐ D ☐ E

☑ Other Bentonite

Backfill placed from ft. to ft. Material

Gravel placed from ft. to ft. Size of gravel

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:	6	1	140	.250	☑	☐	☑	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
Liner:					☐	☐	☐	☐
					☐	☐	☐	☐

Final location of shoe(s) 140

(7) PERFORATIONS/SCREENS:

☐ Perforations Method

☐ Screens Type Material

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐
						☐	☐

(8) WELL TESTS: Minimum testing time is 1 hour

☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
~10		390	2hr/1 hr.

Temperature of water 64° Depth Artesian Flow Found

Was a water analysis done? ☐ Yes By whom

Did any strata contain water not suitable for intended use? ☐ Too little

☐ Salty ☐ Muddy ☐ Odor ☐ Colored ☐ Other

Depth of strata:

(9) LOCATION OF WELL by legal description:

County Malheur Latitude Longitude

Township 19 N or ☑ S Range 46 ☑ E or W. WM.

Section 25 SW 1/4 SW 1/4

Tax Lot Lot Block Subdivision

Street Address of Well (or nearest address) 3125 Shag Way

(10) STATIC WATER LEVEL:

84 ft. below land surface. Date 7-18-96

Artesian pressure lb. per square inch. Date

(11) WATER BEARING ZONES:

Depth at which water was first found 135

From	To	Estimated Flow Rate	SWL
135	145	~10	84

(12) WELL LOG:

Ground Elevation

Material	From	To	SWL
Cemented Gravel	0	7	
Brown Silty Clay	7	135	
Blue Silt	135	145	84
Blue Clay	145	390	

Date started 7-16-96 Completed 7-18-96

(unbonded) Water Well Constructor Certification:

I certify that the work I performed on the construction, alteration, or abandonment of this well is in compliance with Oregon water supply well construction standards. Materials used and information reported above are true to the best of my knowledge and belief.

WWC Number

Signed Date

(bonded) Water Well Constructor Certification:

I accept responsibility for the construction, alteration, or abandonment work performed on this well during the construction dates reported above. All work performed during this time is in compliance with Oregon water supply well construction standards. This report is true to the best of my knowledge and belief.

WWC Number 682

Signed Date

ORIGINAL & FIRST COPY-WATER RESOURCES DEPARTMENT SECOND COPY-CONSTRUCTOR THIRD COPY-CUSTOMER

RECEIVED

APR 29 1992

WATER RESOURCES DEPT
SALEM, OREGON

20S/46E/24cc

(START CARD) # 16036

STATE OF OREGON

WATER WELL REPORT

(as required by ORS 537.765)

MALH 2735

Well Number

(1) OWNER:

Name Alan Peterson

Address 2678 Hwy 201

City Nyssa State OR Zip 97913

(2) TYPE OF WORK:

☒ New Well ☐ Deepen ☐ Recondition ☐ Abandon

(3) DRILL METHOD

☒ Rotary Air ☐ Rotary Mud ☐ Cable

☐ Other

(4) PROPOSED USE:

☒ Domestic ☐ Community ☐ Industrial ☐ Irrigation

☐ Thermal ☐ Injection ☐ Other

(5) BORE HOLE CONSTRUCTION:

Special Construction approval Yes ☐ No ☒ Depth of Completed Well 700 ft.

Explosives used Yes ☐ No ☒ Type Amount

HOLE Diameter	From	To	SEAL Material	From	To	Amount sacks or pounds
10"	0	30	Cement	0	30	12 sacks

How was seal placed: Method ☐ A ☐ B ☐ C ☐ D ☐ E

☒ Other 690-210-340 (1)

Backfill placed from ft. to ft. Material

Gravel placed from ft. to ft. Size of gravel

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:	6"	+1	59	.250	☒	☐	☒	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
Liner:					☐	☐	☐	☐
					☐	☐	☐	☐

Final location of shoe(s) 59'

(7) PERFORATIONS/SCREENS:

☐ Perforations Method

☐ Screens Type Material

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐
						☐	☐
						☐	☐

(8) WELL TESTS: Minimum testing time is 1 hour

☐ Pump ☐ Bailer ☒ Air ☐ Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
20-25		300'	1 hr.

Temperature of water 78 Depth Artesian Flow Found

Was a water analysis done? ☐ Yes By whom

Did any strata contain water not suitable for intended use? ☐ Too little

☐ Salty ☐ Muddy ☐ Odor ☐ Colored ☒ Other Surface water

Depth of strata: 17-30

(9) LOCATION OF WELL by legal description:

County Malheur Latitude ' " Longitude ' "

Township 20 N or (S) Range 46 E or (W) WM.

Section 24 SW ¼ SW ¼

Tax Lot 2700 Lot Block Subdivision

Street Address of Well (or nearest address)

2628 Hwy 201 Nyssa, OR

(10) STATIC WATER LEVEL:

18 ft. below land surface. Date 3-31-92

Artesian pressure lb. per square inch. Date

(11) WATER BEARING ZONES:

Depth at which water was first found 18'

From	To	Estimated Flow Rate	SWL
18	30	30-40	±8
684	700	20-25	18

(12) WELL LOG:

Ground elevation

Material	From	To	SWL
Top soil	0	17	–
Sand & gravel	17	29	18
Brown clay	29	47	–
Blue clay	47	684	–
Black sand	685	700	18

Date started 3-20-92 Completed 3-25-92

(unbonded) Water Well Constructor Certification:

I certify that the work I performed on the construction, alteration, or abandonment of this well is in compliance with Oregon well construction standards. Materials used and information reported above are true to my best knowledge and belief.

WWC Number 1510

Signed Date 4-20-92

(bonded) Water Well Constructor Certification:

I accept responsibility for the construction, alteration, or abandonment work performed on this well during the construction dates reported above. all work performed during this time is in compliance with Oregon well construction standards. This report is true to the best of my knowledge and belief.

WWC Number 1506

Signed Date 4-20-92

ORIGINAL & FIRST COPY - WATER RESOURCES DEPARTMENT SECOND COPY - CONSTRUCTOR THIRD COPY - CUSTOMER 9809C 2/88

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the

WATER RESOURCES DEPARTMENT
SALEM, OREGON 97310
within 30 days from the date of well completion

RECEIVED
NOV 20 1978
WATER RESOURCES DEPT.
SALEM, OREGON

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

State Well No. 21S/46E-15da

State Permit No.

(1) OWNER:
Name Adrian City
Address Adrian Oregon

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☒ Driven ☐
Cable ☐ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☒
Irrigation ☐ Test Well ☐ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☒
8 " Diam. from 0 ft. to 27 ft. Gage .250
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☒ No
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☒ Yes ☐ No If yes, by whom? Page Bros
Yield: 55 gal./min. with 395 ft. drawdown after 13 hrs.
" " " " " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water 76 Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used Cement
Well sealed from land surface to 27 ft.
Diameter of well bore to bottom of seal 12 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal 5 sacks
How was cement grout placed? Pressure grouted

Was a drive shoe used? ☒ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☒ No Size of gravel:
Gravel placed from ft. to ft.

(10) LOCATION OF WELL:
County Malheur Driller's well number
N.E ¼ S.E ¼ Section 15 T. 21 R. 46 W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 388 ft.
Static level 4 ft. below land surface. Date 10-23-78
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing 8
Depth drilled 536 ft. Depth of completed well 536 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
sticky clay	0	42	
Blue shale	42	388	
Coarse black sand	388	408	
Fine sand & shale	408	432	
Fine Sand stone & clay	432	536	

Work started 10-18-78 19 Completed 10-23-78 19
Date well drilling machine moved off of well 10-24-78 19

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] (Drilling Machine Operator) Date 11-2-78 19
Drilling Machine Operator's License No. 65

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name PAGE BROTHERS DRILLING (Person, firm or corporation) (Type or print)
Address RT. 2 BOX 371= VALE, OREGON 97918
[Signed] (Water Well Contractor)
Contractor's License No. 564 Date 11-2-78 19

(USE ADDITIONAL SHEETS IF NECESSARY)

SP*4558-119

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the STATE ENGINEER, SALEM, OREGON 97310 within 30 days from the date of well completion.

2251

RECEIVED
OCT 17 1974
STATE ENGINEER
SALEM, OREGON

WATER WELL REPORT
STATE OF OREGON

State Well No. 21S/46E-22bc
(Please type or print) State Permit No.
(Do not write above this line)

(1) OWNER:
Name Bob Bertram
Address Adrian, Ore.

(2) TYPE OF WORK (check):
New Well ☑ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☑ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☑ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☑
6" Diam. from +1 ft. to 308 ft. Gage .250
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☑ No
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☑ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☑ Yes ☐ No If yes, by whom? Miller
Yield: 25 gal./min. with 50 ft. drawdown after 2 hrs.
" " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used Bentonite
Well sealed from land surface to 20 ft.
Diameter of well bore to bottom of seal 10 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal sacks
Number of sacks of bentonite used in well seal 6 sacks
Brand name of bentonite Baroid Ben Jell #2
Number of pounds of bentonite per 100 gallons of water 65 lbs./100 gals.
Was a drive shoe used? ☑ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☑ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☐ No Size of gravel:
Gravel placed from ft. to ft.

(10) LOCATION OF WELL:
County Malheur Driller's well number
SW ¼ NW ¼ Section 22 T. 21 R. 46 E W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 204 ft.
Static level 196 ft. below land surface. Date 8-9-74
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing 5
Depth drilled 520 ft. Depth of completed well 520 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. *Report each change in position of Static Water Level and indicate principal water-bearing strata.*

MATERIAL	From	To	SWL
Brown Sand	0	18	
Red Gravel & Clay Brown	18	28	
Sand & Red Gravel	28	93	
Red Fine Sand	93	130	
Brown Sand & Stone	130	160	
Brown Sandy Clay	160	189	
Brown Clay	189	204	✓
Red Gravel	204	237	
Brown Sandy Clay	237	271	
Blue Clay	271	284	
Brown Sandy Clay	284	306	
Blue Clay Sandy	306	315	
Blue Clay	315	405	
Blue Clay	405	438	
Red Gravel	438	442	
Blue Clay	442	469	
Blue Clay	469	504	
Red Gravel	504	505	
Blue Clay	505	520	

Work started 7-31 19 74 Completed 9-12 19 74
Date well drilling machine moved off of well 9-12 19 74

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Lee D Mallon (Drilling Machine Operator) Date Sept 30, 1974
Drilling Machine Operator's License No. 101

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name HAROLD HARTLING (Person, firm or corporation) (Type or print)
Address BOX 124 ONTARIO ORE.
[Signed] Harold E. Hartling (Water Well Contractor)
Contractor's License No. 273 Date Sept 30, 1974

(USE ADDITIONAL SHEETS IF NECESSARY)

SP-46456-119

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the STATE ENGINEER, SALEM, OREGON 97310 within 30 days from the date of well completion.

Mally 2251

RECEIVED
OCT 17 1974
STATE ENGINEER
SALEM, OREGON

WATER WELL REPORT
STATE OF OREGON

State Well No. 21S/4E-22bc
(Please type or print) State Permit No.
(Do not write above this line)

(1) OWNER:
Name Bob [illegible] Brown
Address Aumsville Ore.

(2) TYPE OF WORK (check):
New Well ☑ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☑ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☑ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐

(5) CASING INSTALLED:
Threaded ☐ Welded ☑
6" Diam. from +1 ft. to 308 ft. Gage .250
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS:
Perforated? ☐ Yes ☑ No
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS:
Well screen installed? ☐ Yes ☑ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS:
Drawdown is amount water level is lowered below static level
Was a pump test made? ☑ Yes ☐ No If yes, by whom? Miller
Yield: 25 gal./min. with 35 ft. drawdown after 2 hrs.
" gal./min. with ft. drawdown after hrs.
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used Bentonite
Well sealed from land surface to 20 ft.
Diameter of well bore to bottom of seal 10 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal sacks
Number of sacks of bentonite used in well seal 6 sacks
Brand name of bentonite Baroid Ben-Tell #2
Number of pounds of bentonite per 100 gallons of water 65 lbs./100 gals.
Was a drive shoe used? ☑ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☑ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☐ No Size of gravel:
Gravel placed from ft. to ft.

(10) LOCATION OF WELL:
County Marion Driller's well number
SW ¼ NW ¼ Section 22 T. 7S R. 4E W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 204 ft.
Static level 191 ft. below land surface. Date 8-9-74
Artesian pressure lbs. per square inch. Date

(12) WELL LOG:
Diameter of well below casing 8"
Depth drilled 520 ft. Depth of completed well 520 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
Brown sand	0	18	
Pea Gravel & Clay Brown	18	28	
Sand & Pea Gravel	28	93	
Fine brown sand	93	130	
Brown sand & Stone	130	160	
Brown sandy Clay	160	189	
Brown Clay	189	204	✓
Pea Gravel	204	233	
Brown sandy Clay	233	271	
Blue Clay &	271	284	
Brown sandy Clay	284	306	
Blue Clay Sandy	306	318	
Blue Clay	318	405	
Blue Clay	405	438	
Pea Gravel	438	442	
Blue Clay	442	469	
Blue Clay	469	504	
Pea Gravel	504	505	
Blue Clay	505	520	

Work started 7-31 19 74 Completed 9-12 19 74
Date well drilling machine moved off of well 9-12 19 74

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Lee L Miller Date Sept 30, 1974
(Drilling Machine Operator)
Drilling Machine Operator's License No. 101

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name HAROLD HARTLING
(Person, firm or corporation) (Type or print)
Address BOX 124 ONTARIO ORE.
[Signed] Harold E. Hartling
(Water Well Contractor)
Contractor's License No. 273 Date Sept 30, 1974

(USE ADDITIONAL SHEETS IF NECESSARY)

SP-46656-119

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the STATE ENGINEER, SALEM, OREGON 97310 within 30 days from the date of well completion.

2251

WATER WELL REPORT
STATE OF OREGON

RECEIVED
OCT 17 1974
STATE ENGINEER
SALEM, OREGON

(Please type or print) (Do not write above this line)

State Well No. 21S/46E-22bc
State Permit No.

(1) OWNER:
Name BOB [illegible]
Address [illegible]

(2) TYPE OF WORK (check):
New Well ☑ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☑ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☑ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐

(5) CASING INSTALLED:
Threaded ☐ Welded ☑
6" Diam. from +1 ft. to 308 ft. Gage .250
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS:
Perforated? ☐ Yes ☑ No
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS:
Well screen installed? ☐ Yes ☑ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS:
Drawdown is amount water level is lowered below static level
Was a pump test made? ☑ Yes ☐ No If yes, by whom? Miller
Yield: 25 gal./min. with 30 ft. drawdown after 2 hrs.
gal./min. with ft. drawdown after hrs.
Baller test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used Cement
Well sealed from land surface to 20 ft.
Diameter of well bore to bottom of seal 10 in.
Diameter of well bore below seal 6 in.
Number of sacks of cement used in well seal sacks
Number of sacks of bentonite used in well seal 6 sacks
Brand name of bentonite Baroid Ben Gel #2
Number of pounds of bentonite per 100 gallons of water 6.5 lbs./100 gals.
Was a drive shoe used? ☑ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☑ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☐ No Size of gravel:
Gravel placed from ft. to ft.

(10) LOCATION OF WELL:
County Malheur Driller's well number
SW ¼ NW ¼ Section 22 T. 21 R. 46 E W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 204 ft.
Static level 191 ft. below land surface. Date 8-9-74
Artesian pressure lbs. per square inch. Date

(12) WELL LOG:
Diameter of well below casing 5
Depth drilled 520 ft. Depth of completed well 520 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
Brown sand	0	18	
Rock Gravel & Clay Brown	18	28	
Sand & Rock Gravel	28	93	
Rock Brown Sand	93	130	
Brown sand Stone	130	160	
Brown Sandy Clay	160	189	
Brown Clay	189	204	✓
Rock Gravel	204	232	
Brown Sandy Clay	232	271	
Blue Clay	271	284	
Brown Sandy Clay	284	306	
Blue Clay Sandy	306	318	
Blue Clay	318	405	
Blue Clay	405	438	
Rock Gravel	438	442	
Blue Clay	442	469	
Blue Clay	469	504	
Rock Gravel	504	505	
Blue Clay	505	520	

Work started 7-31 1974 Completed 9-12 1974
Date well drilling machine moved off of well 9-12 1974

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] [illegible] Date Sept 30, 1974
(Drilling Machine Operator)
Drilling Machine Operator's License No. 101

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name HAROLD HARTLING
(Person, firm or corporation) (Type or print)
Address BOX 24 ONTARIO ORE.
[Signed] Harold E. Hartling
(Water Well Contractor)
Contractor's License No. 223 Date Sept 30, 1974

(USE ADDITIONAL SHEETS IF NECESSARY)

SP-46696-119

Cross section of the Treasure Valley in the Parma area for the TVHP (Treasure Valley Hydrologic Project):
Notes on Geology of the Parma area, Payette, Canyon and Owyhee Counties, Idaho

by Gregg Beukelman
Department of Geosciences, Boise State University
Boise, Idaho 83725
tele: 208-385-1631, fax 385-4061, email: gbeukelm@trex.idbsu.edu

February 8, 1997

Introduction

The report and enclosed data are a preliminary compilation of information along a transect extending NE-SW in the Parma area, to show the nature of the Late Cenozoic stratified sediments in the upper portion (~ 1000 feet) of the western Snake River Plain (Fig. 2). Included for each well along the transect are the well owner, Land Office Grid coordinates, surface elevation (± 10 feet), and diagrams of well construction and lithology. Lithology, taken from well drillers' reports on record at the Idaho Department of Water Resources and the U. S. Geological Survey, is plotted in detail where distinctive units of lithologic or hydrogeologic significance are well documented by the driller. Individual drillers' reports are attached to the report should the user wish more detail. Also included is a geologic cross section drawn to show correlatable distinctive lithologic and hydrogeologic boundaries encountered in each well. A 1:100,000 map of the area is included showing the route of the transect (A-A'), individual well owners and surface geology (taken from Othberg and Stanford, 1992).

Methods

The cross section included is a graphical presentation of subsurface lithologies based on water well drillers reports and data from a single deep exploration well (Highland L & L). Wells along a NE-SW transect were selected to ensure maximum section coverage and U. S. Geological Survey monitoring wells were included where possible. For each well included in the profile (1:24,000 horizontal) the stratigraphic section and well construction, as reported in the drillers logs, were plotted at a vertical scale of 1:1,200 (attached sheets). Correlations were made at this scale and all data digitized and reduced to produce the cross section in figure 2. Accuracy of all elevations is probably ± 10 feet. Elevations of the contacts at the top of the lacustrine claystone (+1340-ft) and the underlying basalt (-1200-ft) are taken from a lithologic log accompanying the drillers report for the Highland L & L exploration well (Minus signs indicate elevation below sea level).

Structure

The structural nature of this area of the plain is inferred to be a normal fault-bounded graben. Faults are thought to be older inactive structures owing to their lack of surface expression and no offset of Pleistocene gravels and overlying Bonneville Flood deposits. Evidence for a major fault north of and adjacent to the Snake River is the rather monotonous

thickness of clay seen in the wells to the south. These sediments have been interpreted by Ekren and others (1981) to be Miocene Poison Creek Formation. Clays of this thickness are not encountered across the fault in the shallow wells to the north but occur only at much greater depth in the Highland L & L well, suggesting a minimum offset of 350 feet. Several other normal faults are interpreted based on offset of a very distinctive color boundary between overlying brown sediments and underlying blue sediments. One such fault occurring south of the Highland L & L well correlates with a similarly north facing normal fault that offsets basalt at depth (basalt at -1200-ft elevation in the Highland L & L well) as interpreted by Wood (1997). Based on the sediment color change boundary, the section appears to have no discernable dip (0.04° to the south between the Obendorf and City of Parma wells).

Stratigraphy

The sedimentary section contains Late Cenozoic fluvial and lacustrine deposits overlying a basement of basalt that varies in elevation along the profile from -1200-ft to -3200-ft. Surficial sediments include modern flood plain deposits, Bonneville Flood slack water fine sediments, gravel deposits of Pleistocene age, and older Tertiary age sediments. Much of the middle portion of the transect is mantled by silts and clays of Bonneville Flood slack water origin. These fine sediments commonly overlie terrace gravels including from youngest to oldest: Gravel of Boise Terrace, Gravel of the Bonneville Flood scoured Whitney Terrace, Gravel of Whitney Terrace, and Gravel of Deer Flat Terrace.

Beneath the surficial sediments occur a complex sequence of interfingering gravels, sands and clays which are interpreted to represent fluvial and shallow lacustrine deposits. This section contains an upper portion in which sediments are commonly some shade of brown and a deeper portion having sediments that are described as blue in drillers logs. The boundary between these color-defined units occurs at 2200-ft ± 50 ft elevation and appears in all well logs. The nature of this type of boundary is not well understood but is believed to reflect differences in depositional environment. The blue colored sediments are thought to be an indication of a chemically reducing depositional environment characteristic of lake deposits. The brown colors are more likely caused by oxidation of iron-bearing minerals under unsaturated conditions. Thus, these sediments are thought to represent alluvial, fluvial, and lake margin deposits which would be more apt to be oxidized. A complication to this interpretation is the effect of recharge by oxygenated waters on reduced (blue) iron minerals. Groundwater that is high in dissolved iron can be associated with the oxidation of reduced iron minerals at a contact between oxidizing and reducing conditions. Evidence in the Parma area, such as the uniform elevation of the contact and its lack of any identifiable deflection in the Boise River or Snake River areas (which might be thought to be recharge sources), suggests that this brown-blue contact is the result of original diagenesis and not greatly affected by later recharge. Therefore, this oxidation/reduction contact may well be useful for geologic interpretation of depositional environments.

North of the major fault in the Snake River area, the deeper part of the sedimentary section is composed of ~ 3000 feet of lacustrine claystone having an upper contact at +1340-ft elevation as recorded in the Highland L & L well. The geometry of the upper contact of this claystone cannot be determined from this cross section as only one well (Highland L & L) penetrates it to any depth. This contact is overlain by the fluvial lacustrine section containing a

significant aquifer section about 1290 feet thick. From water levels in nearby wells (Fig. 2) it appears that its upper 250 feet may be unsaturated. The base of this section, containing sand aquifers, is the top of the pro-delta mudstone facies interpreted by Wood (1994).

Basalt forms a volcanic basement to the sedimentary section. The Highland L & L well penetrates the top of basalt at -1200-ft elevation. Elsewhere along the transect, the topography of the basalt upper contact, as interpreted by Wood (1997) from seismic reflection data, mimics the graben form of the basin. Elevations of the basalt surface range from -2200-ft near the ends of cross section to about -3200-ft beneath the Boise River.

Hydrogeology

The static water level in wells on this transect vary greatly having a range of 180 feet and no easily discernable trends with the exception of a decline in the proximity of the Boise River. Static level in wells completed in the thick Tertiary sediment section north of the Boise Valley range from 2300-ft to 2380-ft elevation. Southward, within the Boise Valley and north of the Boise River, the level drops to about 2200-ft. Between the Boise River and the Snake River static water levels range from 2290-ft to 2340-ft with a trend of decreasing elevation nearer the Boise River. Only one well south of the Snake River is included in the transect so no trend south of the river is evident but the one water level is similar to those north of the river.

Two wells included in this cross section are part of the U.S. Geological Survey monitoring well program. The Skogsburg well (NW1/4,SW1/4,S.35,T6N,R5W) has a static water level of 2308-ft elevation as measured 3/21/96. The drillers found water in a sand and clay layer at a depth of 220-240 ft below the surface but the well is fully cased to its bottom at 322 ft making it likely that most of the water produced by this well is coming from a sand layer at its bottom (2073-ft elevation). The second well included in the monitoring program is the Paulson well (SE1/4,NW1/4,S.10,T4N,R5W) which has a static water level of 2340-ft elevation as measured 3/21/96. The drillers of this well report water in sandy and gravel units at 108'-125', 160'-165', 180'-250', and 300'-306' below land surface. The borehole is cased from the surface to the bottom (2117-ft elevation) with perforations in the bottom three feet making it likely that the principal water producer is a coarse sandy gravel at the bottom six feet of the borehole.

References

Idaho Department of Transportation, 1994, 30 X 60 minute series topographic map of Boise, Idaho, scale 1:100,000.

Idaho Department of Water Resources, 1997 microfiche file of drillers reports, Orchard Street Office.

Othberg, K.L., and Sanford, L.R., 1992, Geologic map of the Boise Valley and adjoining area, western Snake River Plain, Idaho: Idaho Geological Survey, Geologic Map Series, scale 1:100,000.

Ekren, E.B., McIntyre, D.H., and Bennett, E.H., 1981, Geologic map of Owyhee County, Idaho, west of Longitude 116° W: U.S. Geological Survey Miscellaneous Investigations Map I-1256, scale 1:125,000.

U.S. Geological Survey, 1990, Files on wells in observation network, Collins Road Office.

Wood, S.H., 1997, Structural contour map of the top of Miocene basalt basement rocks, western Snake River Plain, Idaho: Report for Idaho Department of Water Resources (2sheets, 1:100,000).

Wood, S.H., 1994, Seismic expression and geological significance of a lacustrine delta in Neogene deposits in the western Snake River Plain, Idaho: American Association of Petroleum Geologists Bulletin, v. 78, no. 1, p. 102-121.

Figures and enclosures

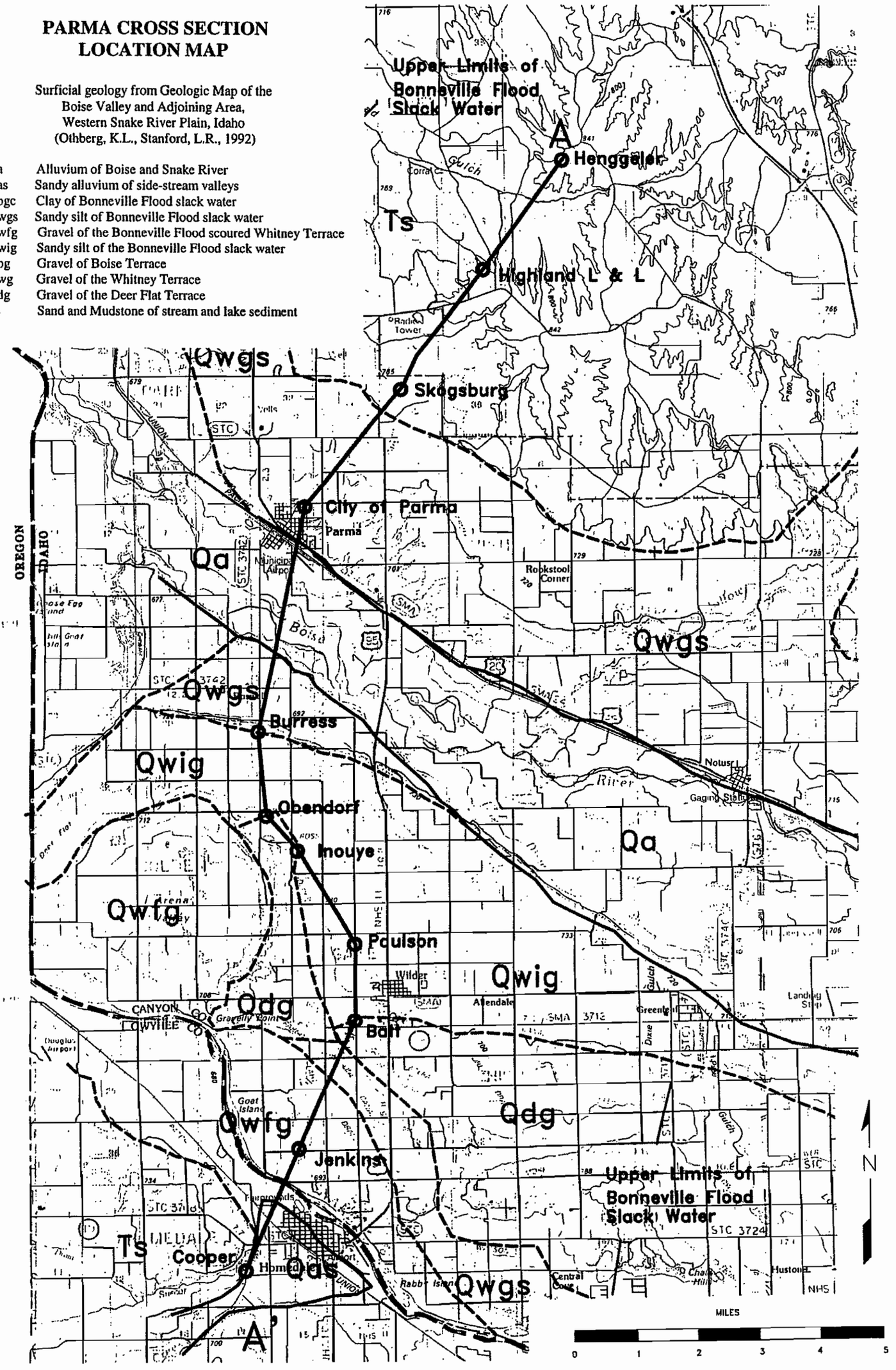
Figure 1	Map (1:100,000) showing cross section transect, wells used in cross section, and surficial geology.
Figure 2	Cross section of geology and hydrogeology across the western Snake River Plain in the Parma, Idaho area.
Figure 2a	Legend for cross section
Attached	Eight panels of wells used in cross section showing lithology and well construction.
Attached	Drillers reports of selected wells.

FIGURE 1

PARMA CROSS SECTION LOCATION MAP

Surficial geology from Geologic Map of the
Boise Valley and Adjoining Area,
Western Snake River Plain, Idaho
(Othberg, K.L., Stanford, L.R., 1992)

Qa	Alluvium of Boise and Snake River
Qas	Sandy alluvium of side-stream valleys
Qbgc	Clay of Bonneville Flood slack water
Qwgs	Sandy silt of Bonneville Flood slack water
Qwfg	Gravel of the Bonneville Flood scoured Whitney Terrace
Qwig	Sandy silt of the Bonneville Flood slack water
Qbg	Gravel of Boise Terrace
Qwg	Gravel of the Whitney Terrace
Qdg	Gravel of the Deer Flat Terrace
Ts	Sand and Mudstone of stream and lake sediment



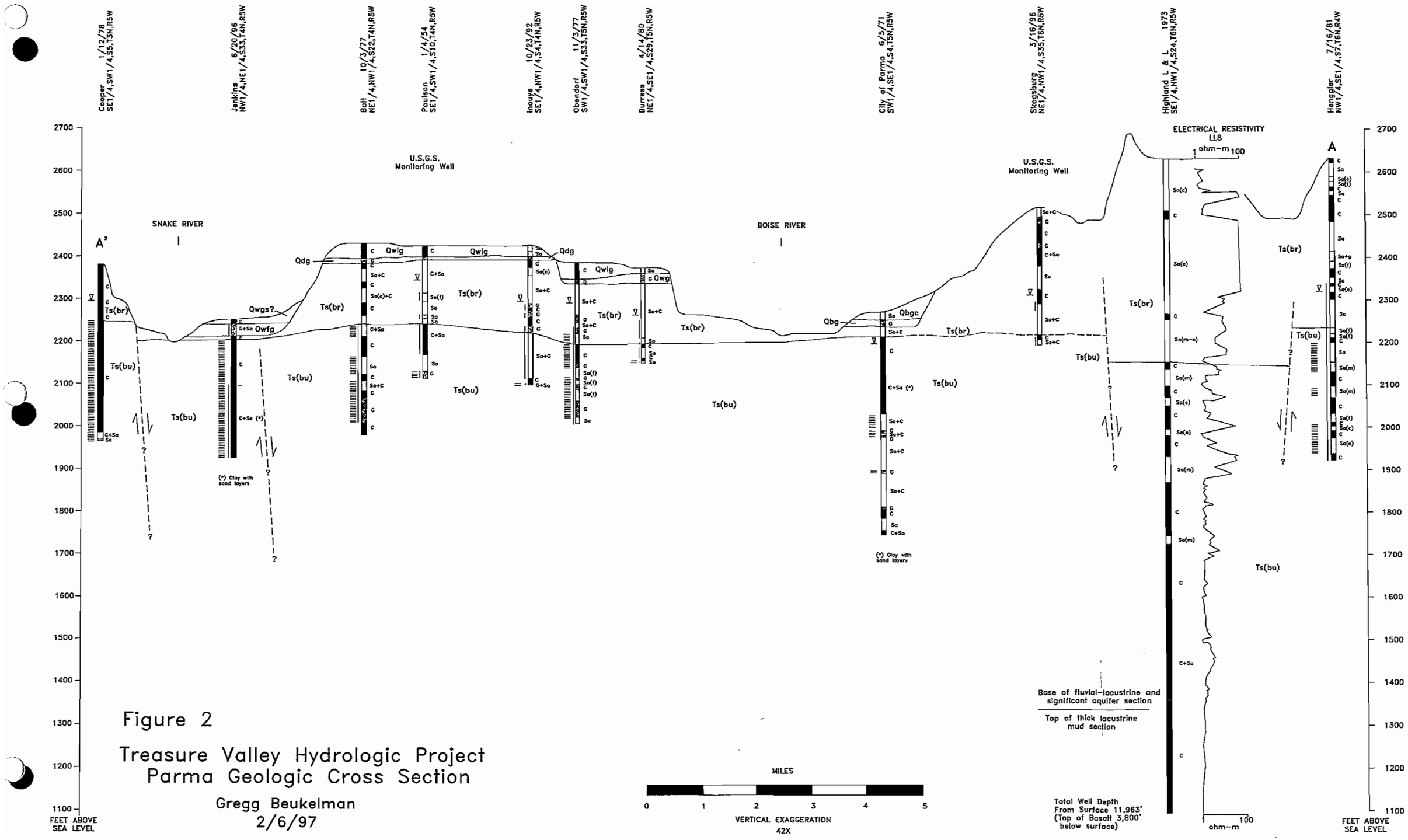


Figure 2

Treasure Valley Hydrologic Project
Parma Geologic Cross Section

Gregg Beukelman
2/6/97

Cross section of the Treasure Valley in the Notus area for the TVHP (Treasure Valley Hydrologic Project):
Notes on Geology of the Notus area, Gem, Payette, Canyon and Owyhee Counties, Idaho

by Gregg Beukelman
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February 18, 1997

Introduction

The report and enclosed data are a preliminary compilation of information along a transect extending NE-SW from the Emmett Valley, southwest near the town of Notus and to the south of the Snake River (Fig. 1). The intent of this report is to show the nature of the Late Cenozoic stratified sediments in the upper portion of the western Snake River Plain (Fig. 2). Included for each well along the transect are the well owner, Land Office Grid coordinates, surface elevation (± 10 feet), and diagrams of well construction and lithology (attached). Lithologies, taken from well drillers' reports on record at the Idaho Department of Water Resources and the Boise office of the U. S. Geological Survey, are plotted in detail where distinctive units of lithologic or hydrogeologic significance are well documented by the driller. Individual drillers' reports are attached to the report should the user wish more detail. Also included is a geologic cross section drawn to show correlatable distinctive lithologic and hydrogeologic boundaries encountered in each well. A 1:100,000 map of the area Fig. 1) is included showing the route of the transect (A-A'), individual well owners and surface geology (taken from Othberg and Stanford, 1992).

Methods

The cross section included is a graphical presentation of subsurface lithologies based on water well drillers reports. Wells along a NE-SW transect were selected to ensure maximum section coverage and U. S. Geological Survey monitoring wells were included where possible. For each well included in the profile (1:24,000 horizontal) the stratigraphic section and well construction, as reported in the drillers logs, were plotted at a vertical scale of 1:1,200 (see attached sheets). Correlations were made at this scale and all data digitized and reduced to produce the cross section in figure 2. Accuracy of all elevations is probably ± 10 feet. Elevations of the contacts at the top of the lacustrine claystone are interpreted from lithologic and electrical resistivity logs for the Oroco Oil Company Richardson #1 and Sundance Oil Company Caldwell Hunter Linning #1-30 deep exploration wells. The elevations for the top of the basement Miocene basalt are taken from a structural contour map of this contact (Wood, 1997).

Structure

The structural nature of this area of the plain is inferred to be a normal fault-bounded graben. Faults are thought to be older structures owing to their lack of surface expression and the absence of offset in Pleistocene gravels and overlying Bonneville Flood deposits. Evidence for a major north facing fault south of the Snake River is the rather monotonous thickness of clay seen in the Lineberger well. Nearby sediments having a similar appearance are mapped by Ekren and others (1981) as Miocene Poison Creek Formation. Thick clay units are not seen as similar elevations in the Asumendi well just across the river to the north suggesting a minimum offset of 400 feet. North of the Snake River, evidence suggests the presence of a five mile wide upthrown block (horst) based in elevations of the clay dominant section. This structure, as identified in the upper stratigraphy of the basin, correlates with a topographic high on the surface of the basement basalt (Wood, 1997). Several other normal faults, all having offsets less than 120 feet, are interpreted based on offset of a very distinctive color boundary between overlying brown sediments and underlying blue sediments. A south facing fault just north of the Lane well correlates spatially with a fault seen in the Miocene basalts but in the sediments appears to have an opposite sense of displacement. The north facing normal fault just north of the Gottesch well and along the southern margin of the Emmett Valley correlates well with the northwest extension of a similarly facing basement fault (Wood, 1997). Based on the sediment color change boundary, the section appears to have no discernable dip along the NE-SW oriented line of section (0.04° between the Frisby and Gottesch wells).

Stratigraphy

The sedimentary section contains Late Cenozoic fluvial and lacustrine deposits and an interbedded basalt unit overlying a basement of basalt that varies in elevation along the profile from -2000-ft to -3200-ft (Minus signs indicate elevation below sea level). Surficial deposits include modern flood plain deposits, Bonneville Flood slack water fine sediments, gravels of Pleistocene age, and older Tertiary age sediments. Low lying portions of the profile adjacent to the Boise and Snake River courses are mantled by sediments of Bonneville Flood slack water origin. There are typically silts and clays and commonly overlie terrace gravels including from youngest to oldest: Gravel of Boise Terrace, Gravel of Whitney Terrace, Gravel of the Wilder Terrace, and Gravel of Deer Flat Terrace. In the Emmett Valley a valley bottom gravel may be a modern alluvial deposit (Qal) of the Payette River or part of a older terrace with correlation to the Boise Terrace. A thin (approximately 10 feet) perched gravel occurring in the Gottesch well at 2390-ft elevation may also be a remnant of a Pleistocene terrace.

Beneath the surficial sediments is a complex sequence of interfingering lenses of gravels, sands, and clays which are interpreted to represent fluvial and shallow lacustrine deposits. This section contains an upper portion in which sediments are commonly some shade of brown, tan, or yellow and a deeper portion having sediments that are described as blue in drillers logs. The boundary between these color-defined units occurs at 2250-ft ± 75 ft elevation and appears in most well logs. The brown-colored unit is up to 300 feet thick beneath the uplands north and south of the Boise River, but has apparently been mostly removed by erosion by the Boise River Valley beneath the lowlands. The nature of this type of boundary is not well understood but is believed to reflect differences in depositional environment. The blue colored sediments are

thought to be an indication of a chemically reducing depositional environment characteristic of lake deposits. The brown colors are more likely caused by oxidation of iron-bearing minerals under unsaturated conditions. Thus, these sediments are thought to represent alluvial, fluvial, and lake margin deposits which would be more apt to be oxidized. Alternatively, it is also possible that recharge by oxygenated waters percolating through reduced (blue) iron minerals may oxidize formerly blue-gray colored deposits. Groundwater that is high in dissolved iron can be associated with the oxidation of reduced iron minerals at a contact between oxidizing and reducing conditions. Evidence in the area of the transect, such as the uniform elevation of the contact and its lack of any identifiable deflection near either the Boise River or Snake River (areas which might be thought to be recharge sources), suggests that this brown-blue contact is the result of original diagenesis and not greatly affected by later recharge. Therefore, this oxidation/reduction contact may well be useful for geologic interpretation of depositional environments.

North of the major fault in the Snake River area, the deeper part of the sedimentary section is composed of about 2800 feet of lacustrine claystone. The upper contact of this section is at 620-ft or 815-ft elevations as interpreted from the electrical resistivity logs of the Richardson #1 and Caldwell Hunter Linning #1-30 deep exploration wells respectively. The geometry of the upper contact of this claystone cannot be determined from this cross section as only the deep exploration wells penetrate it. Included within the claystone section is an approximately 400 foot thick volcanic unit of interbedded basaltic flows and tuffs. This basalt can be seen on seismic reflection data (Lariat Exploration-BB2 line) and in the Caldwell Hunter Sinning #1-30 well where its top is penetrated at -1000-ft elevation. The claystone section is overlain by a fluvial-lacustrine section containing a significant aquifer section a minimum of 900 feet thick. Beneath the uplands north of the Snake River the base of this section, containing sand aquifers, is the top of the pro-delta mudstone facies interpreted by Wood (1997).

Basalt forms a volcanic basement to the sedimentary section. Although no wells along the transect penetrates the top of the basalt, seismic reflection data from the Lariat Exploration-BB2 line suggest that its upper contact is at about -2400-ft elevation in the area of the Pioneer Irrigation well. Elsewhere along the profile, the topography of the upper contact of the basalt, as interpreted by Wood (1997) from seismic reflection data, mimics the graben form of the basin with the exception of the topographic high between the Snake River and the Boise River. Elevations of the basalt surface range from -2000-ft near the southern end of the cross section to about -3200-ft farther to the northeast.

Hydrogeology

With two exceptions, the static water level in wells along this transect vary only 130 feet in elevation. One exception is the Asumendi well located adjacent to the Snake River having a static water level of 2190-ft and the other is the Hillard well in the highlands between the Boise River drainage and the Payette River drainage that has a water level of 2580-ft. The Woods well in the Emmett Valley was completed into a thick section of clay to an elevation of 1940-ft and is flowing artesian. Most of the wells between the Emmett Valley and the Boise River are completed in the alluvial, fluvial, and shallow lacustrine section and behave as unconfined of semiconfined. Between the Boise River flood plain and the Snake River the static water level is

rather consistent, ranging from 2390-ft to 2340-ft elevation with a trend of decreasing elevation nearer both water courses. Only one well south of the Snake River is included in the transect so no trend south of the river has been studied, but the one water level is about 125 feet lower than the others north of the river.

Five wells included in the cross section are part of the U. S. Geological Survey monitoring well program:

The Pioneer Irrigation well (SE1/4, NW1/4, S22, T4N, R4W) has a static water level of 2340-ft as measured on 9/19/96. The well is cased for the upper 65 feet if its total 132 foot depth making it likely that water is from a sand at 2220-ft elevation. This sand unit is behaves as a semiconfined aquifer.

The Clement well (SW1/4, NW1/4, S36, T5N, R4W) has a water level of 2340-ft as measured on 3/21/96 and the upper 125 feet of its total 146 foot depth is cased. A sand unit at 2228-ft is the likely source of the water and is acting as a semiconfined aquifer.

The Copp well located in the NE1/4, NW1/4, S24, T5N, R4W is completed to a depth of 448 feet in the upper alluvial, fluvial, and lacustine sediments. Its static water level is at 2373-ft elevation and is cased a total of 420 feet with screened intervals that allow sand lenses to supply water.

The Hanson Livestock Co. well (NW1/4, NE1/4, S16, T5N, R4W) is completed to a depth of 333 feet and is cased its entire depth. Perforations in the bottom 70 feet and a gravel pack likely allow for supply of water by a higher unit (2250-ft) which behaves as an unconfined aquifer.

The Lane well (NE1/4, SW1/4, S35, T6N, R4W) penetrates the upper section of alluvial, fluvial, and lacustrine deposits to a depth of 362 feet. The sediments in the lowest 70 feet of the borehole are all water bearing but the well is cased its entire depth making it likely that the sand unit at 2265-ft elevation is the primary water source.

References

Idaho Department of Transportation, 1994, 30 X 60 minute series topographic map of Boise, Idaho, scale 1:100,000.

Idaho Department of Water Resources, 1997 microfiche file of drillers reports, Orchard Street Office.

Othberg, K.L., and Sanford, L.R., 1992, Geologic map of the Boise Valley and adjoining area, western Snake River Plain, Idaho: Idaho Geological Survey, Geologic Map Series, scale 1:100,000.

Ekren, E.B., McIntyre, D.H., and Bennett, E.H., 1981, Geologic map of Owyhee County, Idaho, west of Longitude 116° W: U.S. Geological Survey Miscellaneous Investigations Map I-1256, scale 1:125,000.

U.S. Geological Survey, 1990, Files on wells in observation network, Collins Road Office.

Wood, S.H., 1997, Structural contour map of the top of Miocene basalt basement rocks, western Snake River Plain, Idaho: Report for Idaho Department of Water Resources (2 sheets, 1:100,000).

Figures and enclosures

Figure 1 Map (1:100,000) showing cross section transect, wells used in cross section, surficial geology, location of deep exploration wells, and seismic reflection line.

Figure 2a & b Cross section of geology and hydrogeology across the western Snake River Plain in the Notus, Idaho area.

Figure 2a Legend for cross section

Attached Eleven panels of wells used in cross section showing lithology and well construction.

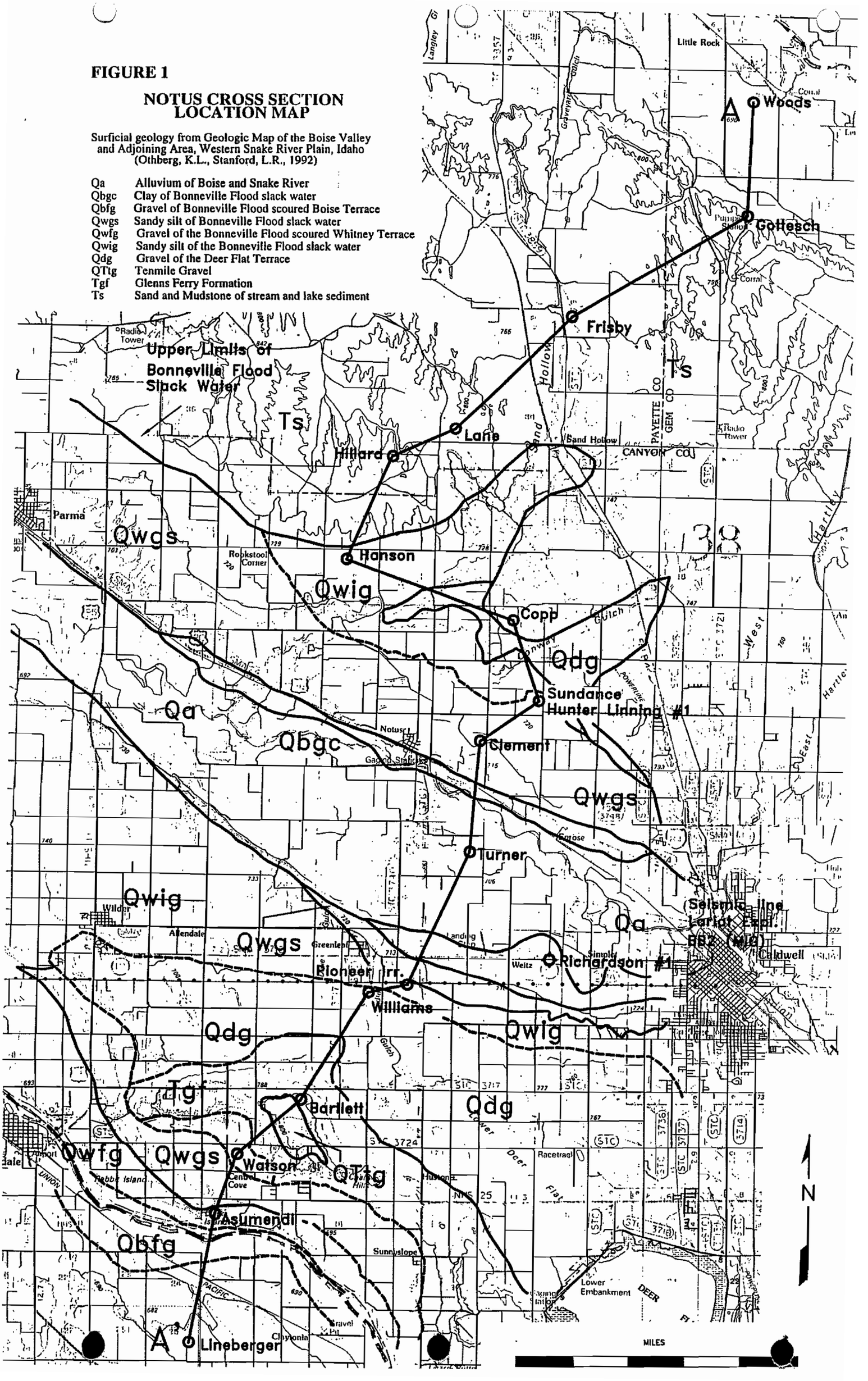
Attached Drillers reports of selected wells.

FIGURE 1

NOTUS CROSS SECTION LOCATION MAP

Surficial geology from Geologic Map of the Boise Valley and Adjoining Area, Western Snake River Plain, Idaho (Othberg, K.L., Stanford, L.R., 1992)

Qa	Alluvium of Boise and Snake River
Qbgc	Clay of Bonneville Flood slack water
Qbfg	Gravel of Bonneville Flood scoured Boise Terrace
Qwgs	Sandy silt of Bonneville Flood slack water
Qwfg	Gravel of the Bonneville Flood scoured Whitney Terrace
Qwig	Sandy silt of the Bonneville Flood slack water
Qdg	Gravel of the Deer Flat Terrace
QTtg	Tenmile Gravel
Tgf	Glenns Ferry Formation
Ts	Sand and Mudstone of stream and lake sediment



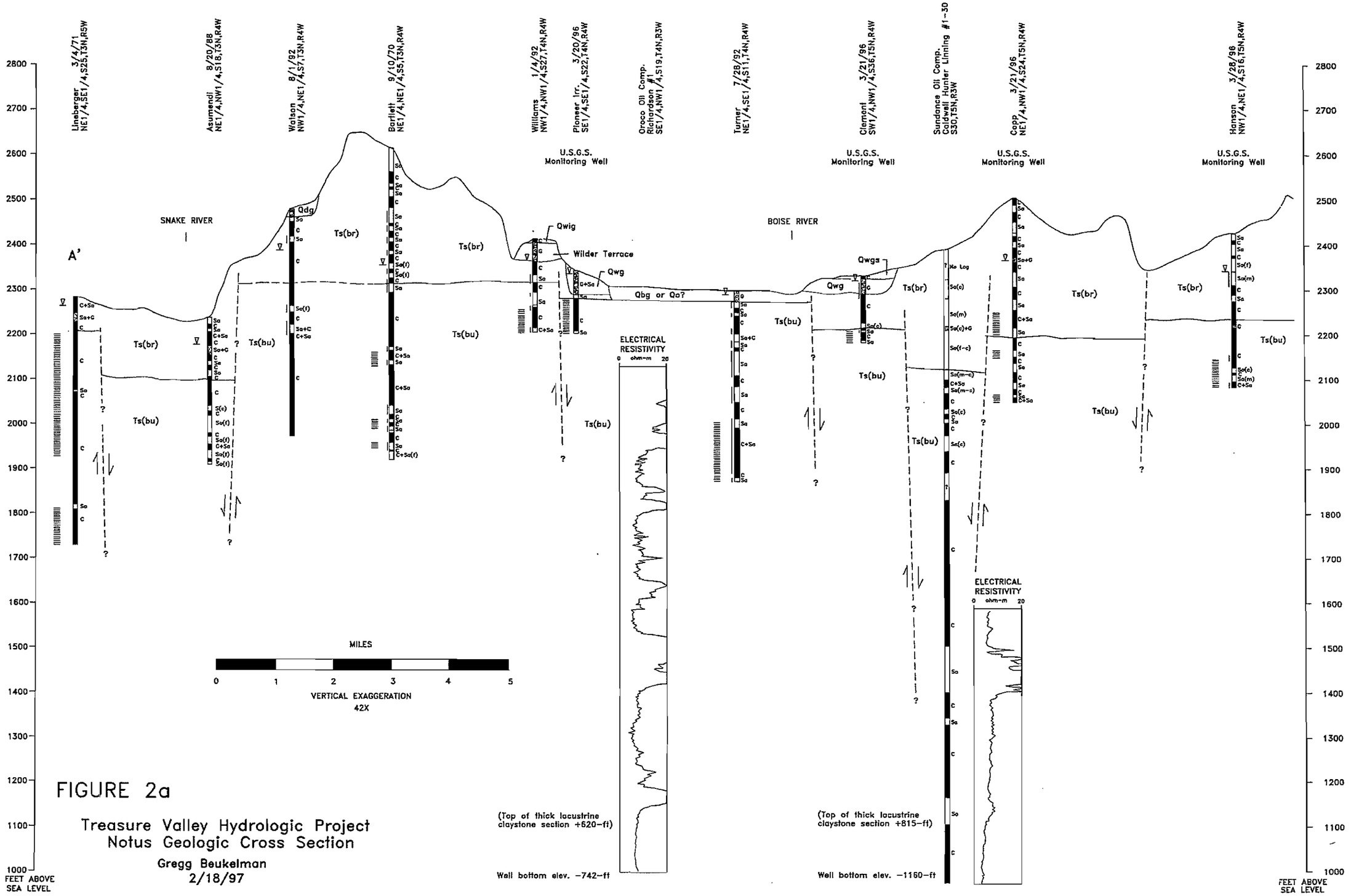


FIGURE 2a

Treasure Valley Hydrologic Project
Notus Geologic Cross Section

Gregg Beukelman
2/18/97

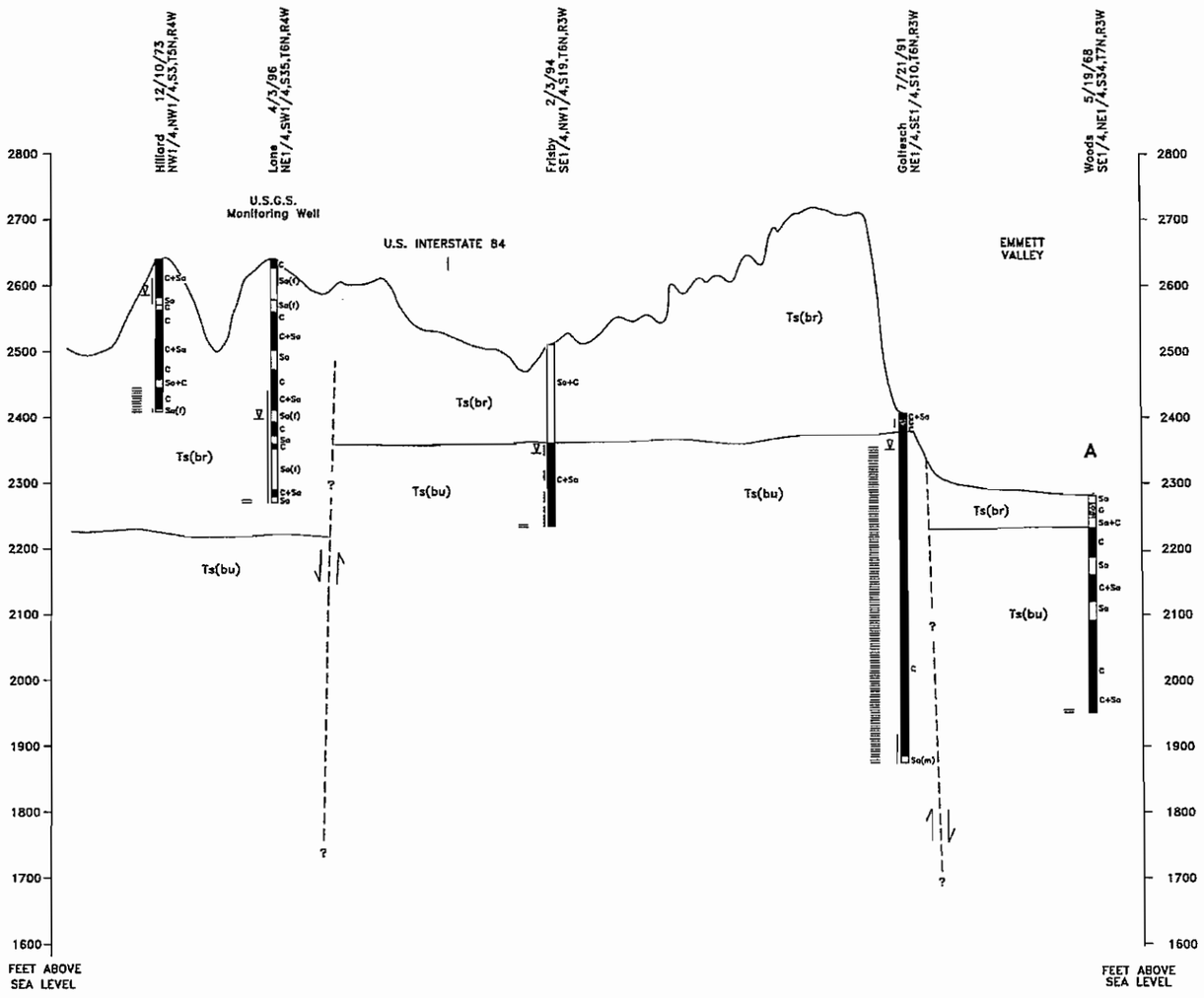
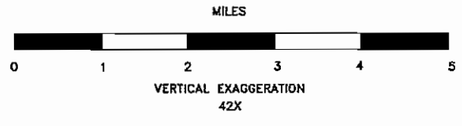


FIGURE 2b



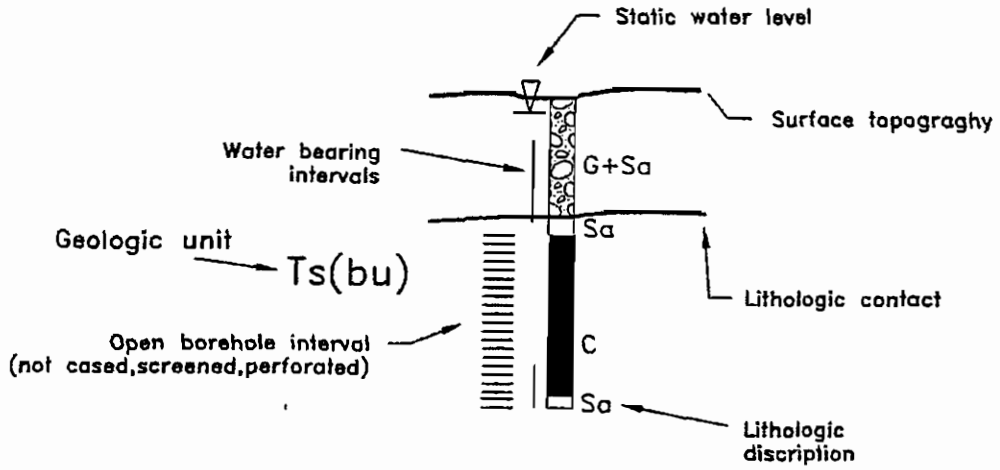
Treasure Valley Hydrologic Project
Notus Geologic Cross Section

Gregg Beukelman
2/18/97

FIGURE 2C

CROSS SECTION LEGEND

Diagram of Typical Well Interval



GEOLOGIC Units (After Othberg and Stanford, 1992)

Qa	Alluvium of Boise and Snake River
Qas	Sandy alluvium of side-stream valleys
Qbgc	Clay of Bonneville Flood slack water
Qwgs	Sandy silt of Bonneville Flood slack water
Qwfg	Gravel of the Bonneville Flood scoured Whitney Terrace
Qwig	Sandy silt of the Bonneville Flood slack water
Qbg	Gravel of the Boise Terrace
Qwg	Gravel of the Whitney Terrace
Tdg	Gravel of the Deer Flat Terrace
Ts	Sand and Mudstone of stream and lake sediment

WELL LITHOLOGIC ABBREVIATIONS

G	Gravel
Sa(c,m,f)	Sand (coarse, medium, fine)
C	Clay

When two sediment sizes are combined (C+Sa) the first sediment is the most abundant.

Color modifiers: Brown (Br) and Blue (Bu) are included for Tertiary sediments

USE INFORMATION
DARK PRINT

State of Idaho
Department of Water Resources

WELL DRILLER'S REPORT

Send the original and first copy to the Department of Water Resources within 60 days after completion of well. Retain the second copy for your records.

1. WELL OWNER (Copy)

Name [illegible]

Address [illegible]

Owner's Permit No. _____

2. WATER USER

Section No. [illegible] 1/4 of 1/4 of Twp. [illegible] N., Rge. [illegible] E.W.M.

Canyon [illegible] Basin [illegible]

Area to be irrigated _____ acres

Construction: ☐ New ☐ Deepened ☐ Other

3. NATURE OF WORK

☒ New well ☐ Deepened ☐ Replacement

☐ Abandoned (Describe method of abandonment)

_____

4. PROPOSED USE

☒ Domestic ☐ Irrigation ☐ Test ☐ Other (specify type)

☐ Municipal ☐ Industrial ☒ Stock ☐ Waste Disposal or Injection

5. WATER QUALITY

☐ Potable ☐ Other

6. WELL TEST DATA

☐ Pump ☒ Bailer ☐ Other

Drawdown (ft.)	Time (hours)	Recovery (ft.)
[illegible]	[illegible]	[illegible]

7. GEOLOGIC LOG

From	To	Material
[illegible]	[illegible]	[illegible]

8. WELL CONSTRUCTION

Was any casing driven below surface? ☐ Yes ☐ No

Was a packer or seal used? ☐ Yes ☐ No

Perforated? ☐ Yes ☐ No

Type perforator used ☐ Factory ☐ Cable ☐ Torch

Size of perforations _____ inches by _____ inches

Number of perforations	From (ft.)	To (ft.)
_____	_____	_____
_____	_____	_____
_____	_____	_____

Was well gravel packed? ☐ Yes ☐ No

Well gravel size _____

Top packer: _____ Depth _____

Bottom packer: _____ Depth _____

Type: _____ Model No. _____

Diameter _____ Slot No. _____ Set from _____ feet to _____ feet

Diameter _____ Slot No. _____ Set from _____ feet to _____ feet

Was a screen used? ☐ Yes ☐ No Size of gravel _____

Placed from _____ feet to _____ feet

Surface seal depth 18" Material used to seal ☐ Cement grout

☒ Puddling clay ☐ Well cuttings

Sealing procedure used ☐ Slurry pit ☐ Temporary surface casing

☒ Compacted in place ☐ Other

9. LOCATION OF WELL

Sketch map location and give nearest town and direction

[illegible]

Lot No. _____ Block No. _____

County [illegible]

SE ¼ of SW ¼ Sec. 5 T. 2 [illegible]

10. REMARKS OR ADDITIONAL INFORMATION

Work started [illegible] Completed [illegible]

Driller's Certification

The well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Name [illegible]

Signed: [illegible]

Date [illegible]

USE ADDITIONAL SHEETS IF NECESSARY

FORWARD THE WHITE COPY TO THE DEPARTMENT

FORWARD THE WHITE COPY TO THE DEPARTMENT

DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

G-442

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name Fred Batt (Wilder Non Co.)

Address Rt. 1, Wilder, Idaho 83676

Owner's Permit No. 63-8953

2. NATURE OF WORK

☒ New well ☐ Deepened ☐ Replacement

☐ Abandoned (describe method of abandoning)

3. PROPOSED USE

☐ Domestic ☒ Irrigation ☐ Test ☐ Other (specify type)

☐ Municipal ☐ Industrial ☐ Stock ☐ Waste Disposal or Injection

4. METHOD DRILLED

☐ Cable ☒ Rotary ☐ Dug ☐ Other

5. WELL CONSTRUCTION

Diameter of hole 28 inches Total depth 444 feet

Casing schedule: ☒ Steel ☐ Concrete

Thickness		Diameter		From		To	
.250	inches	16	inches	2	feet	200	feet
.250	inches	16	inches	220	feet	260	feet
.250	inches	16	inches	300	feet	325	feet
.250	inches	16	inches	420	feet	430	feet
	inches		inches		feet		feet

Was casing drive shoe used? ☐ Yes ☒ No

Was a packer or seal used? ☐ Yes ☒ No

Perforated? ☐ Yes ☒ No

How perforated? ☐ Factory ☐ Knife ☐ Torch

Size of perforation ____ inches by ____ inches

Number		From		To	
	perforations		feet		feet
	perforations		feet		feet
	perforations		feet		feet

Well screen installed? ☒ Yes ☐ No

Manufacturer's name Roscoe Moss

Type ____ Model No. ____

Diameter 16 Slot size 80 Set from 200 feet to 220 feet

Diameter 16 Slot size 80 Set from 325 feet to 430 feet

Gravel packed? ☒ Yes ☐ No Size of gravel 1/8 minus

Placed from 30 feet to 444 feet

Surface seal depth 30' Material used in seal: ☐ Cement grout ☒ Puddling clay ☐ Well cuttings

Sealing procedure used: ☐ Slurry pit ☐ Temporary surface casing ☒ Overbore to seal depth

6. LOCATION OF WELL

Sketch map location must agree with written location.

63

N / W / E / S

Subdivision Name ____

Lot No. ____ Block No. ____

County Canyon

NE ¼ NW ¼ Sec. 22, T. 4 N/S, R. 5 E/W

7. WATER LEVEL

Static water level ____ feet below land surface.

Flowing? ☐ Yes ☐ No G.P.M. flow ____

Temperature ____ °F. Quality ____

Artesian closed-in pressure ____ p.s.i.

Controlled by: ☐ Valve ☐ Cap ☐ Plug

8. WELL TEST DATA

☐ Pump ☐ Bailer ☐ Other

Discharge G.P.M.	Drawdown	Hours Pumped

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
28	0	10	Topsoil		
	10	39	Hardpan		
	39	50	Sand, Gravel, Rock		
	50	60	Clay		
	60	64	Sand & Pea Gravel		
	64	79	Fine Sand		
	79	99	Sand & Clay Mixed		
	99	105	Clay		
	105	117	Sand & Pea Gravel w/some Clay		
	117	120	Clay		
	120	124	Sand & Pea Gravel		
	124	140	Sand, Small Gravel & Clay mixed		
	140	149	Clay		
	149	189	Sand & Pea Gravel w/some Clay		
	189	202	Blue Clay w/ some Sand		
	202	214	Blue Sand & Pea Gravel		
	214	261	Gray Clay w/some Sand		
	261	284	Fine to Med. Blue Sand		
	284	301	Coarse Sand & Pea Gravel		
	301	320	Clay		
	320	331	Sand & Clay mixed		
	331	338	Fine to Coarse Sand & Pea Gravel		
	338	358	Clay w/some Sand		
	358	419	Coarse Sand & Small Gravel		
	419	434	Clay		
	434	444	Clay & Shale		

10.

Work started 9-27-77 finished 10-3-77

11. DRILLERS CERTIFICATION

Firm Name Pete Cope Drilling Co. Inc. Firm No. 111

Address 10566 K-Bar-T Drive Boise, Idaho 83705 Date 10-12-77

Signed by (Firm Official) [signature]

and

(Operator) [signature]

USE ADDITIONAL SHEETS IF NECESSARY – FORWARD THE WHITE COPY TO THE DEPARTMENT

G-423

Form 238-7
3/96

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

Use Typewriter or Ballpoint Pen

Office Use Only
Inspected by _____
Twp ____ Rge ____ Sec ____
____1/4 ____1/4 ____1/4
Lat: : : Long: : :

1. DRILLING PERMIT NO. 63-96-W-0394-000
Other IDWR No. _____

2. OWNER:
Name Ralph Jenkins
Address 26757 upper Pleasant Rd
City Wilder State Idaho 83676

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

N / W / E / S

Twp. 4 North ☒ or South ☐
Rge. 5 East ☐ or West ☒
Sec. 33 1/4 NW 1/4 NW 1/4
Gov't Lot ____ County Canyon
Lat: ____ Long: ____
Address of Well Site 26757 upper Pleasant Rd City Wilder
Lot ____ Blk ____ Sub. Name ____

4. USE: ☒ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation ☐ Thermal ☐ Injection ☐ Other ____

5. TYPE OF WORK check all that apply: ☒ New Well ☐ Modify ☐ Abandonment ☐ Other (Replacement, etc.) ____

6. DRILL METHOD: ☐ Air Rotary ☐ Cable ☐ Mud Rotary ☐ Other ____

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
Bentonite	0	18½	400	Pour

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s) 58
Was drive shoe seal tested? ☒ Y ☐ N How? Air

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
6"	+2	58	250	Steel	☒	☐	☒	☐
					☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe ____ Length of Tailpipe ____

9. PERFORATIONS/SCREENS
☐ Perforations Method ____
☐ Screens Screen Type ____

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
20 ft. below ground Artesian pressure ____ lb.
Depth flow encountered 150-320 ft. Describe access port or control devices: CAP

11. WELL TESTS: ☐ Pump ☐ Bailer ☒ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
80	300	300	1hr

Water Temp. 58 Bottom hole temp. 60
Water Quality test or comments: ____
Depth first Water Encountered 18

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks (Lithology, Water Quality & Temperature)	Water Y	Water N
10	0	2	Top Soil		
	2	4	Hard "		
	4	10	Sandy Clay		
	10	18	Sand & Gravel	X	
6	18	34	" " " with Water	X	
	34	42	Brn Clay		
	42	150	Blue Shale		
	150	320	Blue Shale & Sand		
			Water Sand Zone	X	
			@ 200 ft. 15 Gal min		
			@ 320 ft. 80 " "		

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WESTERN REGION

Completed Depth 320 (Measurable)
Date Started 6-19-96 Completed 6-20-96

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Treasure Valley Drilling Firm No. 710
Firm Official _____ Date 6-20-96
and
Supervisor or Operator _____ Date 6-20-96
(Sign once if Firm Official & Operator)

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330

Stratigraphic Studies of the Boise (Idaho) Aquifer System Using Borehole Geophysical Logs With Emphasis on Facies Identification of Sand Aquifers

Report to the Treasure Valley Hydrologic Study
Idaho Department of Water Resources

By

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January 8, 2001

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Introduction

The cold-water aquifer system beneath the City of Boise is composed of sandy sediments interbedded with claystone and mudstone that were deposited near the shores of lakes which filled the western Snake River Plain during the late Miocene and Pliocene epochs (10 to 1.7 million years ago) (Figures 1and 2). The sand layers are the deposits of stream channels, beach sands winnowed by wave action, deltas built out into the lake, and possibly density-flows across the lake bottom from collapse of parts of the delta shelf. These depositional environments do not produce broadly distributed sand layers. Instead the sand layers are typically restricted in their horizontal and vertical continuity by interbedded mudstone or lateral termination into mudstone. The difficulty here lies with correlation of sand layers and determination of their shapes. Important is to predict whether sand layers found in wells have some sort of hydraulic connection, and which are not interconnected. By analogy to modern sedimentary environments and subsurface studies by others, our goal is to obtain at least a partial understanding of the three-dimensional geometrical shapes of sand aquifers.

Structural downwarping coupled with normal faulting along the margins of the plain further complicates deciphering the stratigraphic section. For example, a 4-degree dip of strata (370 feet per mile), results in strata identified in one well, being 370 feet deeper in a well one mile away in the down dip direction (Figure 2). Stratigraphic offset along down-to-basin normal faults (up to 800 feet of vertical throw on some faults) pose additional complexity, because in the older strata, faulting was contemporaneous with deposition.

For this report, we have compiled available geophysical logs (natural gamma, single-point resistance, or normal-resistivity logs at a scale of 1 inch equals 200 feet for the wells shown in Figure 3. Most of the logs are owned by United Water Idaho, Inc. and we have been permitted to use other data by the City of Boise, Micron Technology, and the Idaho Department of Transportation. On many of the United Water Idaho (UWID) wells, drill cuttings were examined by geologists, and the grain size of sands are known. On other wells, the driller's descriptions are the only record of lithology, and the grain-size of sands is not consistently reported. We explain our attempts to correlate geologic strata and identify depositional facies for the line of wells from Claremont Subdivision (end of 8th Street in the foothills) to the Cassia Street well, and for the line of wells from " Hill 3431" above Stewart Gulch in the foothills to the McMillan well of west Boise. Correlation from the Micron Technology plant area to Cassia Street are still preliminary, and not included. Correlation from Idaho Street well to the Bethyl Street well and west to the St. Lukes well (at east Meridian) is currently being evaluated using seismic reflection data acquired by the Boise State University CGISS group this summer of 2000.

Methods

Facies interpretations of geophysical logs are discussed in Rider (1996), Berg (1986); and Galloway and Hobday (1996); however, examples from lacustrine basins are few. Most of the examples from Rider's interpretations (shown in Figure 4) are from marine environments; however, his examples of a channel-point bar, delta-border progradation, transgressive shelf, and prograding shelf are probably applicable to the lacustrine setting. The study of the Pliocene lacustrine Ridge Basin in California by Link and Osborne (1978) is helpful, because they interpret logs of a mouth bar complex overlying a delta

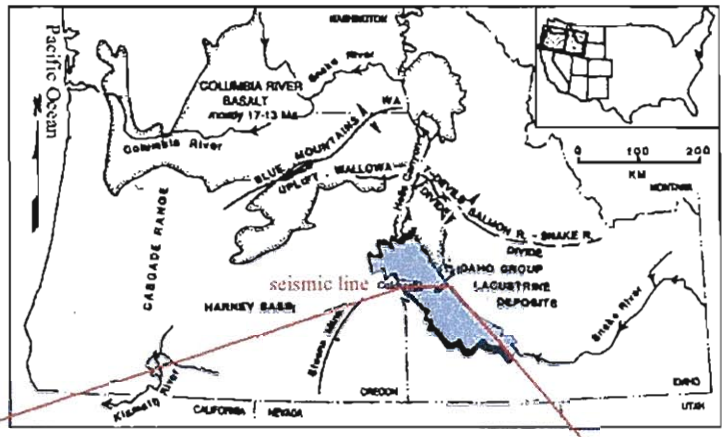


Figure 1. Location of Neogene Lake Idaho deposits in the northwest United States (from Wood, 1994)

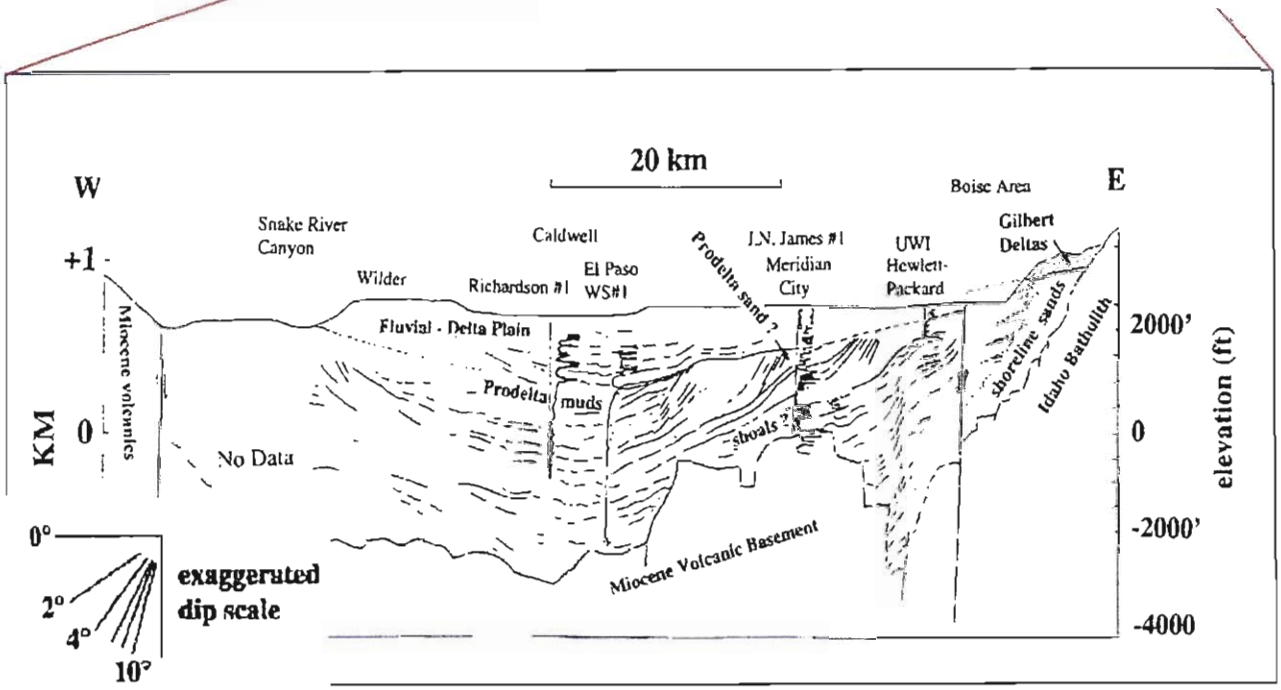


Figure 2. Interpreted cross-section from seismic lines across the western Snake River Plain, showing the geometry of strata that reflect seismic waves within lake and stream deposits and the resistivity response of borehole geophysical logs of deep wells. Drawn from petroleum industry seismic reflections lines which were focused on the deeper strata and did not image the strata shallower than 700 ft depth (i.e., the main cold-water aquifer section).

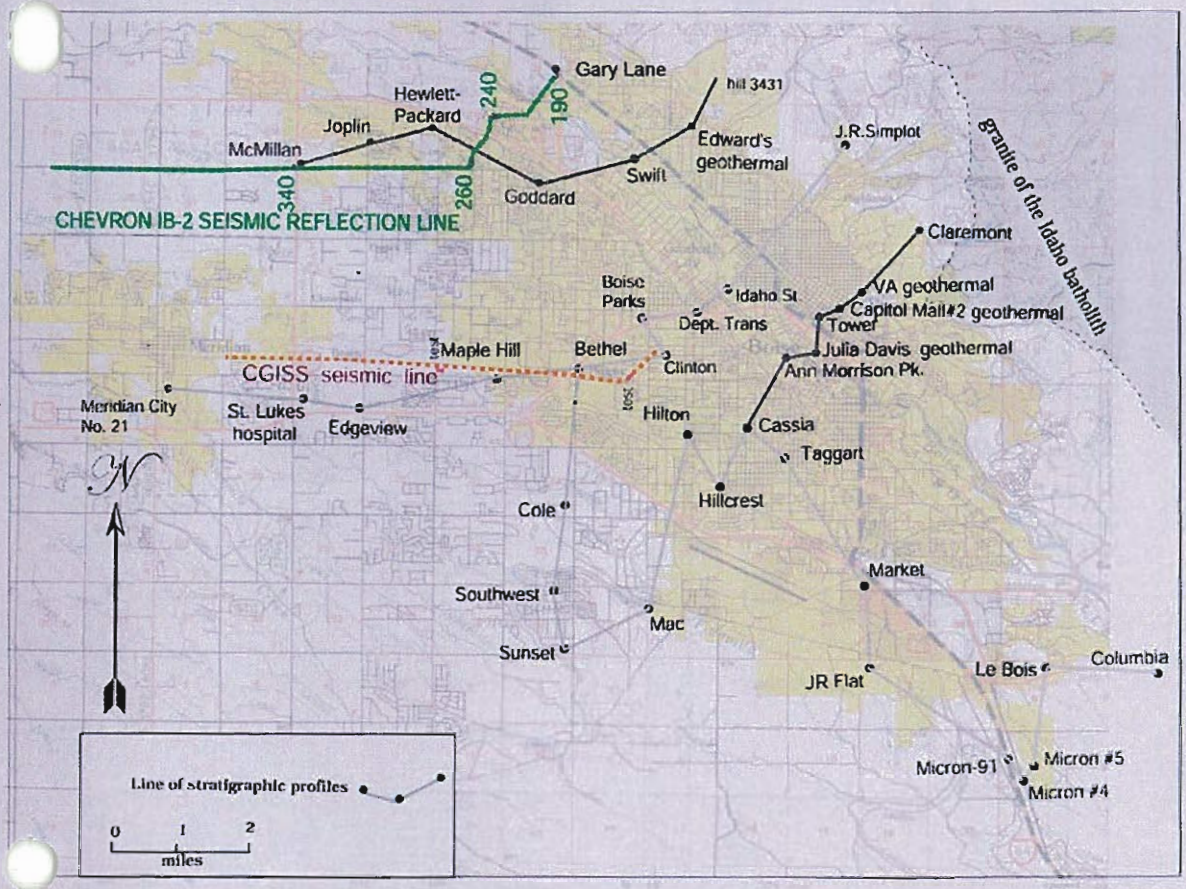


Figure 3. Map showing deep wells in the Boise area and locations of seismic lines. Profiles of Figures 9 and 10 are highlighted lines.

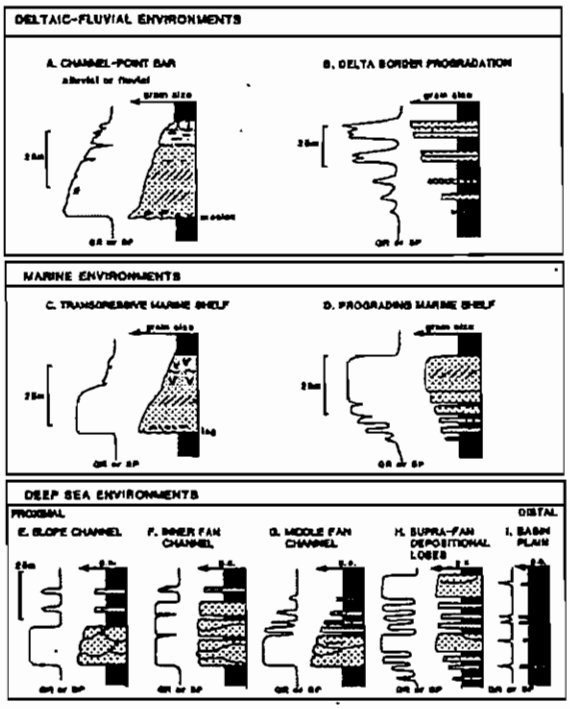


Figure 4. Idealized well log shapes (gamma or SP, or mirror image of resistivity) for sedimentary facies (From Rider, 1996).

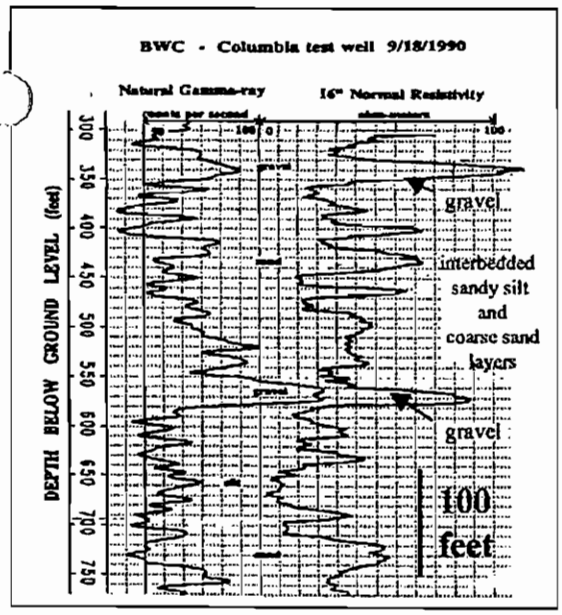


Figure 5. Geophysical log character of the mixed alluvial-fan - braided-stream facies beneath southeast Boise. Gravel layers are typically 20 feet thick and have higher radioactivity (high counts/sec on the natural gamma log) on account of a large percentage of cobbles of high-potassium porphyritic felsite. Gravels show a tendency to be more silty upwards (fining of matrix upward), and have abrupt bases ical of channels. Sands are typically 20 feet thick h abrubt bases and fining upward. Silty beds show spiky" character on the natural gamma log. (From Squires and others, 1992).

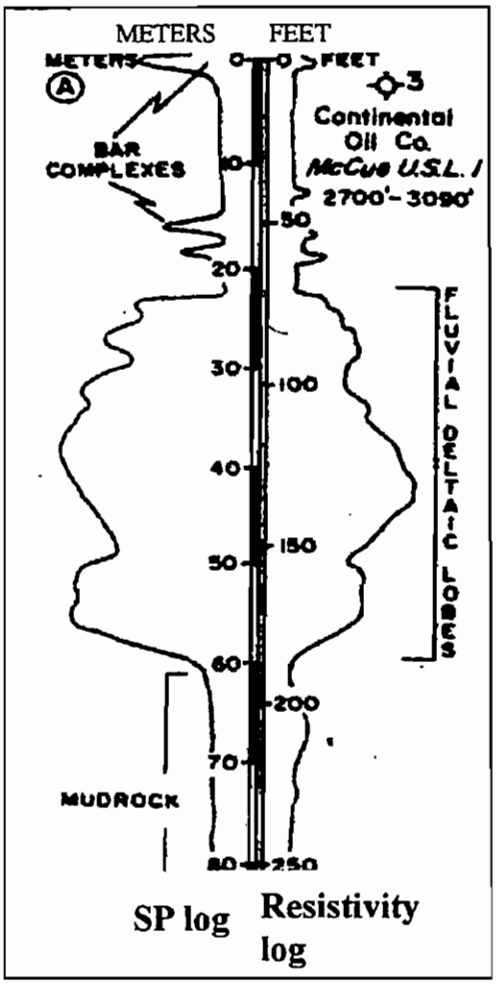


Figure 6. SP and resistivity log of lacustrine prodelta mudrock overlain by delta sand lobes, overlain by a mouth-bar complex: Ridge-Basin, California (from Link and Osborne, 1978).

1)**Funnel-shaped logs, over 20 to 100 m vertical extent,** overlain by abruptly more resistive sands, and correlative over 10's of km. These are interpreted as prodelta coarsening upward mud sequences overlain by channel sands.

2)**Funnel-shaped logs, of 5 to 20 m vertical extent,** and repeated in the section. Several to 10 or more units are repeated over intervals of 30 to 100 m. Units are rarely correlative over a few km. Sands generally medium-grained. These are interpreted as stacked mouth bars of streams entering the lake, or as beach sands.

3) **Monotonous low resistivity, and irregular medium gamma** activity, over vertical extents of 30 to 400 or more meters, interpreted as muds deposited in the open lake environment.

4) **Thin bell shaped units, less than 3 m thick,** and enclosed by thick muds, are interpreted as fining upward density-flow sands, and generally made up of fine well-sorted sand.

5) **Bell-shaped logs, with abrupt bases, 7 to 40 m in vertical extent.** Sands are typically coarse, and some have gravel at base. These are interpreted as fluvial channels, and rarely correlative over a few km.

6) **Spikey logs, with resistive units 3 to 7 m,** and low resistance units typically 3 m in vertical extent. 7 m units with abrupt bases, and high gamma. These are interpreted as alluvial fan deposits, with high-gamma rhyolite gravel with abrupt bases, and alternating silt and muddy sand layers none of which can be individually correlated.

Figure 7. Useful electric and natural gamma-ray signatures of depositional facies in Lake Idaho sediments (from Wood and others, 2000)

lobe (Figure 6). Studies by Ainsworth and others (1999), Flint and others (1988, 1989) of Miocene lake sediments in Thailand illustrate the continuity of bars and other lacustrine sands. They found mouth-bar sands to be coarsening upward (funnel-shaped logs), fine-grained sands with a sheet geometry of variable thickness. Individual sheets of mouth-bar sands, vary in thickness from 0.5 to 5 meters,and could be traced for a distances up to 5 km. Their studies of a Thailand oil field was for wells about 1 km apart accompanied by a 3D-seismic survey, a set of data far more detailed than that usually available in water resource studies.

The shapes of logs we have found useful in interpreting facies in the sedimentary section beneath Boise are summarized in Figure 7. Squires and others (1992) identified the log character of mixed alluvial-fan-and-braided-stream facies in the southeast Boise area (Figure 5).

The great value of borehole-geophysical logs is their ability to detect sand and gravel aquifers, and distinguish aquifers from low permeability mudstone, siltstone, and clay. The best log is one that measures electrical resisitivity in an open, uncased hole full of water or drilling mud (the 16 or 64-inch normal log, or induction logs). This log shows high resistivity in a fresh-water-filled clean sand or gravel aquifer, but the response is greatly reduced by low-resistivity (high-conductance, > 400 μS) groundwater in the aquifer. The single-point resistance log gives a similar response to resistivity in the sand and mudstone section and is equally useful, though not quantitative. Electrical resistivity logs have low values in silt and clay bearing sediments, thereby distinguishing them from aquifer sands and gravels. Natural gamma logs are generally useful, but their similar response in silt-clay and gravels with cobbles of high potassium content make an ambiguous interpretation of gravel or clay, unless accompanied by a resistivity or resistance log.

Background Geology and Problems

In the past, aquifers were typically named for the geologic formations in which they occurred. However, the variety of depositional environments of the lake-stream systems and the changing environments with fluctuating lake levels tells us that the sand units are complex. In previous reports on the western plain (Whitehead, 1992), the aquifer systems are associated with a set of geologic formations originally defined by Malde and Powers (1962). The stratigraphic order and characteristic lithology of the formations is a useful framework, because the changing lithology in some cases can be attributed to basin-wide geologic events or progressions of similar depositional environments across parts of the basin. However, it is unlikely that these formation units reliably relate to hydraulic connectivity of aquifers. In the areas Malde and Powers had geologically mapped, they found a general sequence of granitic rocks overlain by rhyolite, overlain by basalt, overlain by lake and stream sediments. They recognized an early set of lake and stream deposits that had been tilted, faulted and beveled off by erosion which they called the Chalk Hills Formation. Their concept of the Banbury Basalt beneath the Chalk Hills Formation is misleading, because we now know that many local basalt fields erupted during the time lake and stream sediments were accumulating in the basin (Wood and Clemens, in press). The Poison Creek Formation was originally identified on the south side of the plain as sediments dominated by one or several layers of 1-to-7-meter-thick fluvial or coarse-grained delta sand at or near the base of the lake and stream section.

These sands are discontinuous, and the Poison Creek Formation is best regarded as just a al sand facies of the Chalk Hills Formation (Wood and Clemens, in press). The basis the top of the Chalk Hills Formation is well established as an unconformity with slight angularity on the south side of the western plain. On the south side, it is overlain by beach gravel and in places shoreline carbonate oolitic sands. On the north side of the plain, we have searched for such a straight-forward contact of a widespread angular unconformity overlain by the oolites or gravel, but have it only in one locality in the Boise foothills (discussed later in this section), and are uncertain of its occurrence in the subsurface, as discussed later in this report.

In the Boise foothills and in the subsurface are several gravel and coarse-sand occurrences indicating stream deposition or beach gravel over lake-bed muds. This can result from streams flowing out over the exposed mud surface as the lake lowers. These layers can also result from beach sand facies being spread as waves work the shoreline of a rising lake. We are looking for criteria to identify both situations, but the relationships in outcrop and on the well logs are not yet obvious to us. The gravel and coarse sand layers occur at several horizons within the mudstones, but we are still uncertain of the correlation of many of these layers.

Carbonate oolitic sands lenses occur in a 400-ft thick section of shoreline sands in the foothills which Burnham and Wood (in press) have always considered a part of their definition of the Terteling Springs Formation. The oolite bearing section varies greatly in thickness, and appears to be absent in places. The oolites were deposited as shoreline sand beaches and bars, and therefore occur only as lenses within the sediments. The oolite lithology appears to be a unique lithology associated with lake level rise (Wood and Clemens, in press; Repenning and others, 1994, p. 54). In the subsurface beneath Boise, oolite sands have been documented in the UWID'S Cassia, Taggert, and Cole er wells (locations of these wells is shown on Figure 3) at a relatively shallow depth (<300 ft), and above elevation 2500 ft.

Oolite sand also occurs in the Veterans Administration (VA) Reinjection Well, at a depth of 450-ft deep at elevation 2,300 feet. We mention this here, because the oolite layer is only 90 feet above the basalt of Aldape Heights which Clemens and Wood (1993) have dated by K-Ar as 9.4 million years old. The oolite sand occurrence here is not well understood. Because oolite in the VA well is only 90 feet above the basalt, it may be that most of the Chalk Hills sediments were eroded from this locality near the edge of the foothills, and oolite of the Terteling Springs Formation transgressed over the basalt surface. It is unlikely that the oolite in the VA well is a carbonate facies within the older Chalk Hills Formation, because nowhere else in the basin has carbonate sediment been found in the Chalk Hills Formation. The oolite layer in the VA well has probably been faulted down at least two hundred feet deeper than occurrences in the 3 UWID wells of west central Boise, suggesting a graben structure near the edge of the foothills.

We believe the sediments containing lenses of shoreline oolites to be a transgressive sequence over an unconformity at the top of the Chalk Hills Formation. An angular unconformity is mapped at the base of the oolite in Stewart Gulch (NW ¼, sec. 22, T. 4 N., R. 2 E.), but elsewhere in the foothills the contact appears to be conformable.

Overlying the oolite-bearing section in the western Boise foothill outcrops, is the "Pierce Park Sand", a 150-to-250- foot-thick layer of coarse sand. This thick sand represents a large "Gilbert-type" delta system. Where the oolite section is absent, the

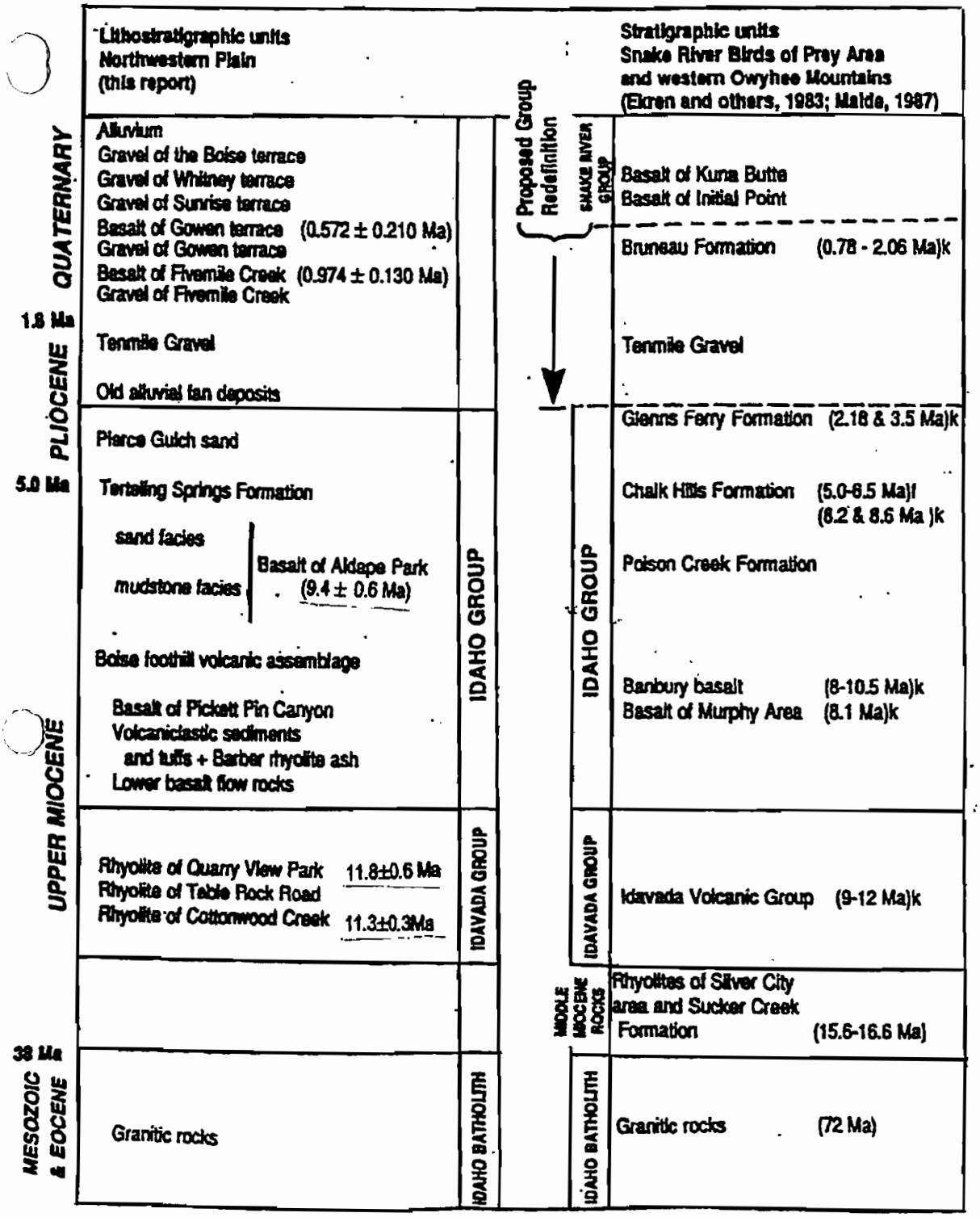


Figure 8. Stratigraphic names in the western Snake River Plain: Comparison of stratigraphic units of the Boise area (from Burnham and Wood, in press) to units mapped on the south side of the plain by other workers.

Pierce Park Sand conformably overlies mudstone. The reason the coarse sand directly overlies mudstone is because the delta prograded basinward over muds of the deep-lake deposits. The delta apparently formed as the level of Lake Idaho began lowering after it reached its spill point into Hells Canyon, probably in the early Pliocene (about 4 or 5 million years ago).

For the first time, in this study, we attempt to correlate the main features mapped in the Boise foothills with the subsurface sedimentary sequence in water wells beneath the city. We make an assumption that the oolite sequence is a singular occurrence in the stratigraphic record. We allow that gravel occurrences in the subsurface could be channel gravel, beach gravel, or river-terrace gravel, and that all gravel occurrences require a beach or a stream environment for deposition. The occurrence of an angular unconformity is not generally detectable in geophysical logs or the sequence of drill cuttings. Logs that detect dip (dip meter, resistivity borehole imager, or acoustic televiewer) have not been run in the Boise area water wells. To detect dip and angular unconformities, the configuration on high-resultion seismic reflection is also useful.

Discussion of the NE-W section from Claremont Subdivision Well to Cassia Street Well (Figure 9)

The dip of the deeper section between the Capitol Mall #2 well and the Julia Davis Well may be as much as 11° to the southwest as determined by a seismic reflection survey by Liberty (1998). The deeper sediments are a mudstone sequence more than 800 feet thick, shown on the borehole geophysical log of the Julia Davis well. Overlying the mudstone, between elevations 2,100 and 2,280 feet, is a sequence of stacked, coarse sand layers, each one 25 to 70 feet thick. Each of the upper 4 sand layers shows a coarsening-upward log signature. The log character of this sand sequence is similar to that shown in the Ridge Basin, California study by Link and Osborne (1978) as a delta-front bar complex (Figure 6). Similar beds occur near the bottom of the Ann Morrison Park well between elevation 2,000 and 2,200 foot elevation.

The overall funnel shape of the Cassia Street logs indicates a fine and medium sand delta above the silty mud at 2,100 foot elevation. These delta sands appear to correlate to sands in the Ann Morrison Park Well, but the funnel-shaped log signature is not as prominent in this well. That correlation implies an apparent dip of about 1.4° in the southwest direction between these two wells, which seems too low a dip, in view of deeper strata dipping in excess of 10 degrees in southwest direction. Another possibility is correlation of the Ann Morrison Park well sands to the deepest sands of the Cassia Street well.

Gravel occurs at the bottom of the Cassia Well at elevation 1,700 feet, but that part of the section was not geophysically logged. No other wells drilled gravel at that depth. The gravel indicates either a gravel beach deposit or a stream channel deposit. The gravel was deposited about 4 miles basinward from the basin margin indicating that the lake environment was not at this locality at the time of deposition: this locality was either a stream bed or a shoreline.

The major sand section of these wells is below an unconformity marked by an upper gravel, generally occurring in wells between elevation 2,400 and 2,550 feet (line colored pink on Figure 9). In the next paragraph we discuss evidence interpreting this

unconformity as the top of the Chalk Hills Formation. The deeper sand section in these wells on the north side of the Boise River all appear to be good aquifers down to at least 1,600 elevation; however, temperatures approaching 85°F below that level may preclude development for cold-water supply.

The unconformity is marked by a prominent gravel bed about 30 feet thick in the Cassia Well at elevation 2, 550 feet. This gravel correlates with gravel in the Ann Morrison Park Well and with the Julia Davis well. This gravel horizon is shown with a pink line in Figure 9. Cavanagh (2000, p. 68-72) discovered from examination of well cuttings and Carbon-13 isotopic analysis of carbonate that a soil caliche had developed in this gravel layer. This discovery shows that the lake had receded from this area at one time, and a soil formed upon a river-terrace gravel, or perhaps an abandoned beach gravel. Above this gravel, in the Cassia well, a 30-ft thick carbonate oolite sand containing gastropod fossils occurs as a coarsening upward layer at a depth of 110 feet (elevation about 2,670 ft.) These features are taken as evidence that rising lake water transgressed over this gravel and and laid down the upper 200 to 300 feet of mostly near-shore lake sediment of these wells. It is uncertain whether the erosional unconformity is in the Capitol Mall#2 well. It may warrant re-examination of the cuttings to see if it can be identified. No obvious correlative gravel is reported from that well or the recently drilled Tower well, suggesting that this gravel horizon was not deposited to the northeast, or has since been eroded by the downcutting of the Boise River Valley.

Gravel of the active floodplain of the Boise River is about 60 feet thick in the downtown Boise area of these wells, and so is the terrace gravel that mantles the Whitney Bench. The bases of both river gravels are shown in Figure 9 by a yellow line.

Although we do not have a good geochronology of the lake deposits beneath Boise, the major geologic events can be tentatively correlated with the proposed, albeit hypothetical lake history proposed by Wood and Clemens (in press). In this correlation, none of the deposits shown in the section of Figure 9 would be correlated with the Glenns Ferry Formation. The very thick sediment section beneath the transgressive sequence would be regarded as the Chalk Hills Formation. The overlying sequence would be the Terteling Springs Formation. To the north of here (Swift Well to McMillan Well) is a delta sequence that appears to correlate with the Pierce Park sand. The Pierce Park sand is believed to be correlative in time with the declining lake level and the Glenns Ferry Formation.

Discussion of E-W section from Swift Well to the McMillan Well (Figure 10)

The two Swift-well sand aquifers appear to correlate with the Hewlett-Packard well, almost straight across; however, the Chevron Seismic data shows the lower sand in Swift to have an apparent west dip of about 2°, and to lie at least 300 feet below the bottom of the Hewlett Packard well (Figure 10). Well-log character of the deeper aquifer sand in the Swift Well has an abrubt base, typical of a channel sand, and the grain size is medium-fine sand. That lower aquifer appears to correlate with the bottom sand aquifer in the Goddard well. However, information on that bottom aquifer in the Goddard well is limited to the 1968 driller's description (see Squires and others, 1992, p. 94). It is problematic that no major sand units occur in the up-faulted foothills section to the northeast, either in outcrop or in wells, that might correlate with the lower Swift well

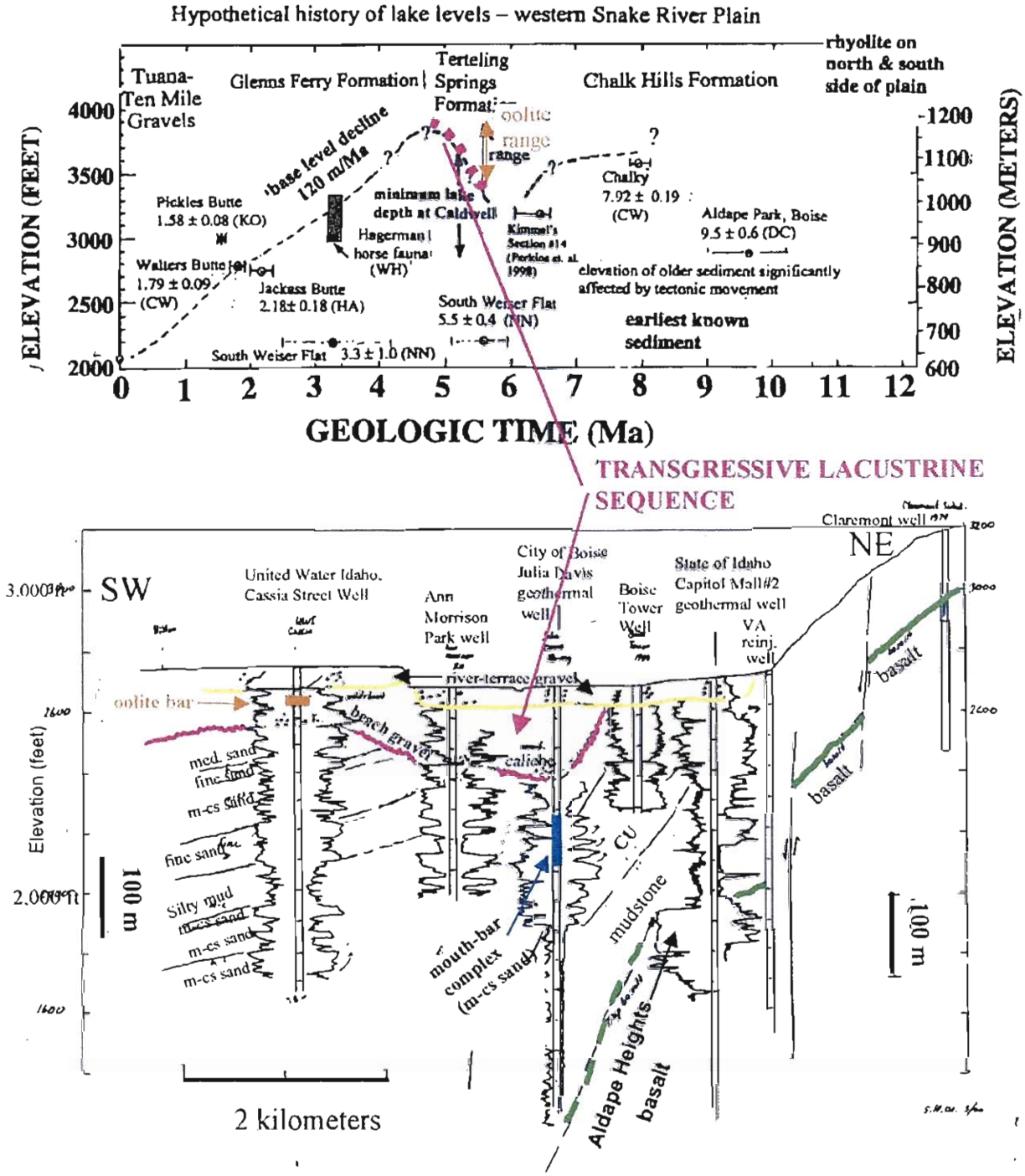
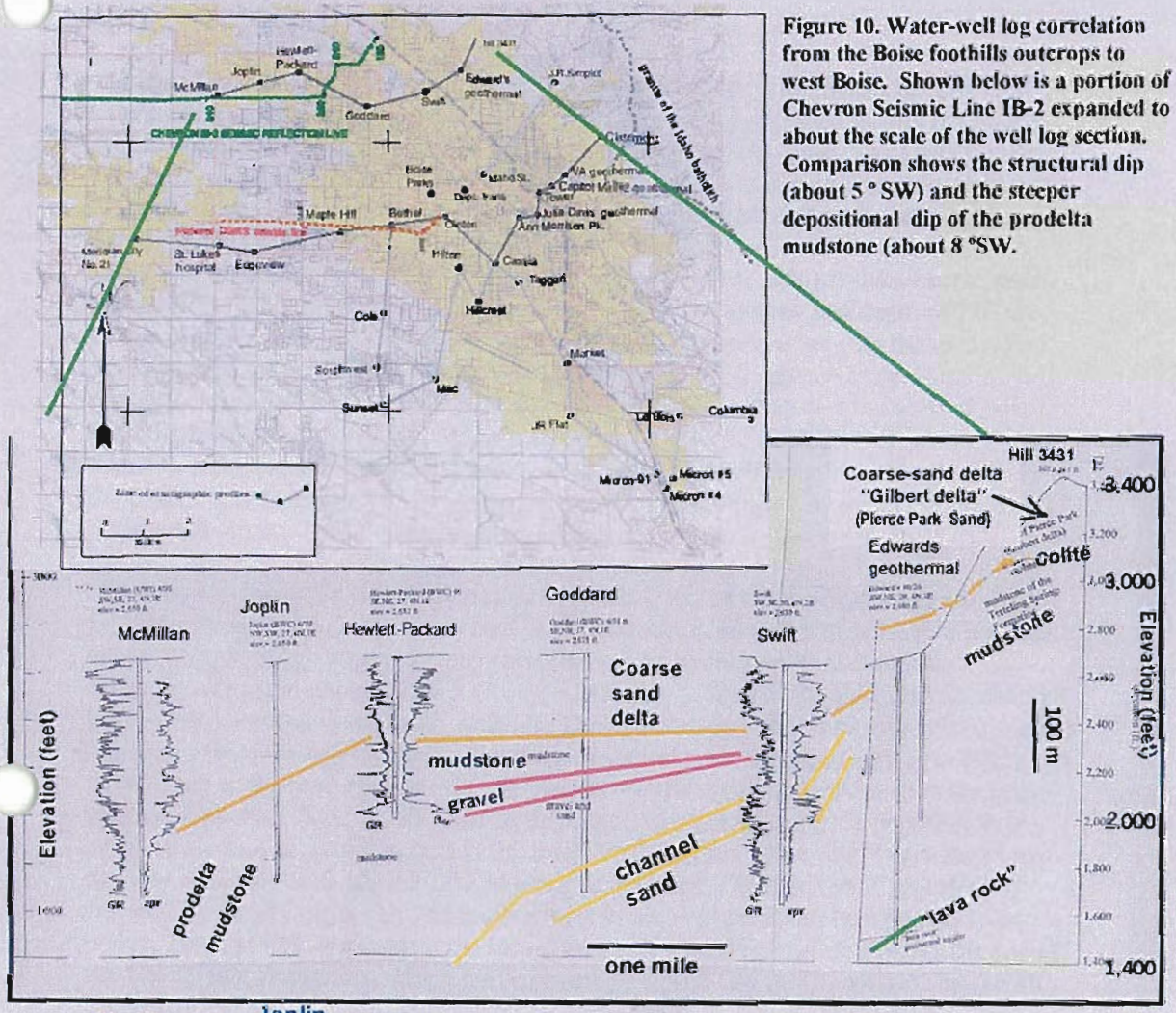


Figure 9. Correlation of strata in wells in a section from the Boise foothills (Claremont well, Boise Heights) to the Cassia Street Well. Basalt of Aldape Heights (9.5 Ma) shown in green. Mouth-bar complex of a sand delta deposited over mudstone shown in blue at the Julia Davis well. CU refers to coarsening upward sand layers, shown by small arrows. Dark pink line is an unconformity at about 2,400-ft elevation, indicated by Carbon-13 isotope analysis of caliche in the Julia Davis Well by Cavanagh (2000, p. 68-72). The unconformity surface is identified by occurrence of gravel in other wells, and is interpreted as the top of the Chalk Hills Formation. Sediment above the unconformity contains oolite, and is interpreted to be a part of the Terteling Springs Formation. Quaternary-aged terrace gravel shown in yellow. Hypothetical lake history corresponding to deposits is from Wood and Clemens (in press).



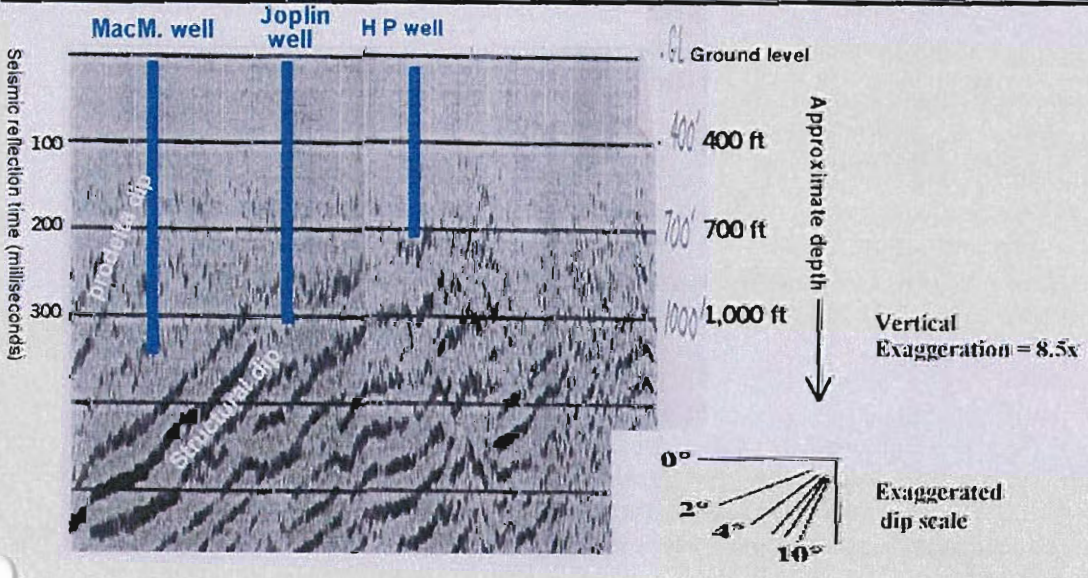


Figure 10. Water-well log correlation from the Boise foothills outcrops to west Boise. Shown below is a portion of Chevron Seismic Line IB-2 expanded to about the scale of the well log section. Comparison shows the structural dip (about 5 ° SW) and the steeper depositional dip of the prodelta mudstone (about 8 °SW.

aquifer. The nearby deep wells in the foothills (Hillside Jr. High, Quail Hollow Golf Course, and wells on the Terteling Stewart-Gulch properties) drilled mostly mudstone according to driller's logs. Possibly the section containing the lower Swift well aquifer sand has been eroded from the upthrown fault block, and for that reason it does not occur in the foothills. Alternatively the lower sand may be a channel deposit that simply was not deposited to the northeast.

One and one-half miles to the northwest of the Swift well, an 80-ft-thick coarse sand occurs in the UWID Gary Lane well below 350 feet of mudstone at a depth of 740 feet. In this well, the grain size is mostly 0.5 to 2 mm, and much coarser than the medium-fine sand reported for the lower Swift well aquifer. Otherwise, it appears to be a similar and possibly correlative sand. Three and one-half miles to the northwest of the Swift well is the Treasure Valley Hydrologic Project Monitoring Well #1 (TVHP#!) in which several medium-fine-grained sand beds occur beneath 300 feet of mudstone at a depth of 770 feet. Individual beds are 2 to 10 feet thick, and the sandy sequence is 120 feet thick (Dittus and others, 1997). Grain-size and depth are similar to the lower Swift well aquifer. The TVHP#1 well was not completed below 340 feet, so the hydraulic connection to the other two wells cannot be studied. All of these occurrences are probably along strike and indicate sand about 700 feet deep and 300 feet beneath a thick mudstone unit, suggesting they may correlate and be hydraulically connected.

Gravel occurs at about 2,100-ft elevation near the bottom of the Hewlett Packard well, but it does not occur in the Swift well. The Hewlett Packard well is situated about 6 miles basinward from the basin margin, therefore the gravel must represent a river or beach out in the basin at the time of deposition. Its absence in the foothills, requires that the gravel was not deposited there, or has been eroded from the section nearer the foothills. It is problematic that no gravel occurs in the Swift Well, but the "pink line" is projected east to show where an unconformity might occur in that well. "Red-colored" gravel is reported by the driller at a corresponding level in the Goddard well (see Squires and others, 1992, p. 94). We suspect the gravel in the Hewlett Packard well marks the top of the Chalk Hills Formation, which we represent by a pink line on the section (Figure 10). The mudstone above the gravel is tentatively correlated with the Terteling Springs Formation, deposited by the rising transgressive lake water. That mudstone, changes upward to the prodelta mud of a delta prograding basinward, discussed in the next paragraph.

In the foothills, and in all wells on the section depicted in Figure 10 is a clear signature of a delta prograding into the Basin. The delta signature on the logs the a funnel shape of side-by-side gamma and resistivity logs (Figure 4 B and D) seen in the Swift and Hewlett Packard wells above 2,350-ft elevation, and in the McMillan well above 1,900-ft elevation. The sand thickness and depth increase progressively to the west. The delta sand is coarse in the foothills, and the driller reported coarse sand in the depth interval 153 to 280 feet in the McMillan well.

Because this is the uppermost delta in the lacustrine sequence, we correlate it to the Pierce Park sand that crops out in the upper part of the foothills section west of Crane Creek. In the foothills, this unit is mostly foreset beds of coarse sand typical of the "Gilbert-type" of delta. Some foreset bed sets are 60 feet thick, and the sand unit as a whole is up to 250 feet thick in the foothills (Burnham and Wood, in press). This delta is then correlated by Wood and Clemens (in press) to the history of Lake Idaho. Since it is

the uppermost major delta in the section its deposition over mudstone, is explained as a prograding sand delta in response to the slow lowering of lake levels after Lake Idaho spilled over into Hells Canyon. In the lake history context, this uppermost delta should correspond to the upper part of the Glenns Ferry Formation of Malde and Powers (1962) and Reppening and others (1994) which crops out south and southeast of the Boise area along the Snake River

We feel fairly certain that there is a "long term" hydraulic connection in the sands of the upper delta sequence (Figure 10); however, local lenses of mudstone in that section may prevent short-term detection of well-drawdown responses. It may take months to decades for large drawdowns to propagate through this seemingly continuous section of interbedded sand and thin muds.

Other older sand deltas surely occur in the lacustrine section. For example in Figure 9, the lower sands in the upper 800 feet in the Julia Davis well are mouth-bar sands of a delta sequence over mudstone. However because this section is steeply dipping, this delta is much older than the upper 800 foot section of the McMillan well (Figure 10). In our interpretation the delta sands in the Julia Davis well are part of the much older Chalk Hills Formation.

Comments on structure

We did not re-interpret the structure along the two cross-sections; however the framework published by Squires and others (1992, their Figure 11) generally concurs with observations in this study. They show the Eagle-west Boise fault with 800 feet of offset between the Swift well and Goddard well using data available to them at that time. The 800-ft offset they show is the offset of the volcanic basement. The fault does not necessarily offset of the upper section. The aquifer section below 2000-ft elevation (about 700 ft deep) may be offset, but the Eagle-west Boise fault does not appear to significantly offset the upper delta sequence.

Squires and others (1992) also show the "foothills fault zone", just northeast of the Swift well. In our Figure 10, the base of the upper delta is shown as offset by 300 feet with respect to the foothills outcrops, however this elevation shift could also be due to tilting without significant faulting. It is likely that a major fault or fault system occurs between the Swift well and the Edwards geothermal well and that this fault offsets the deeper section. Lava rock is reported by the driller at elevation 1,500 ft in the 1926 well (Idaho Supreme Court Records, *Silkey vs. Teigs,* 1931) showing that the "volcanic basement is relatively shallow here (Figure 10). None of these geothermal wells have been logged by borehole geophysics, and we do not know whether the geothermal aquifer in this area is basalt or rhyolite.

Conclusions

In this study we have identified gravel layers, oolite beds, thick mudstone sequences, and thick delta sequences that appear to correlate with regional concepts of fluvial and lacustrine deposition as outlined by Wood and Clemens (in press). We are still uncertain how many gravel layers are in the section; however, occurrence of gravel layers out in the basin, several miles basinward from the basin margin is an indication that the lake level lowered several times and streams flowed over exposed lake beds and delivered gravel

away from the uplands. Some gravel may be beach gravel, and some may be channel or remnant terrace gravel; however, it had to be originally delivered to the site by a stream.

Our best evidence that a lake transgressed over the gravel is the occurrence of oolite sands in the shallow section of the Cassia, Taggert, and Cole wells (Figure 3 and 9). This section shown in Figure 9 also indicates that there may be topographic relief upon the tilted and eroded older section. This is also our best evidence that the sedimentary sequences shown in this profile (Figure 9) correlate to the Chalk Hills Formation and the overlying Terteling Springs Formation. We also conclude that the Pierce Park sand (correlative with the upper Glenns Ferry Formation) is absent from the section shown in Figure 9, but the Pierce Park Sand is the same sand as the upper delta sequence in the Swift, Hewlett-Packard, and McMillan wells shown in Figure 10.

Deeper sedimentary strata comprising the aquifer system have been tilted basinward (to the southwest, 2 to 11 degrees. The deeper strata are offset by faulting, but the amount of offset is known only where seismic data is available. The extent to which shallow parts of the aquifer system are faulted and tilted has not been determined, because the available petroleum-industry data was not focused on the shallow section (<600 feet) (see seismic section in Figure 10).

Eventually, the aquifer geometry can be determined accurately using high-resolution seismic reflection methods and continued diligence in obtaining borehole geophysical logs and cuttings examination of drilled water wells. We hope that this study provides a framework for future study.

Ackowledgements

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33P

Contribution to the Treasure Valley Hydrologic Project - 1997

STRUCTURE CONTOUR MAP OF THE BASE OF QUATERNARY BASALT

Murphy and west part of Mountain Home Map Sheets, Idaho

By

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August, 1997

Scale = 1:100,000

Contour Interval = 100 feet

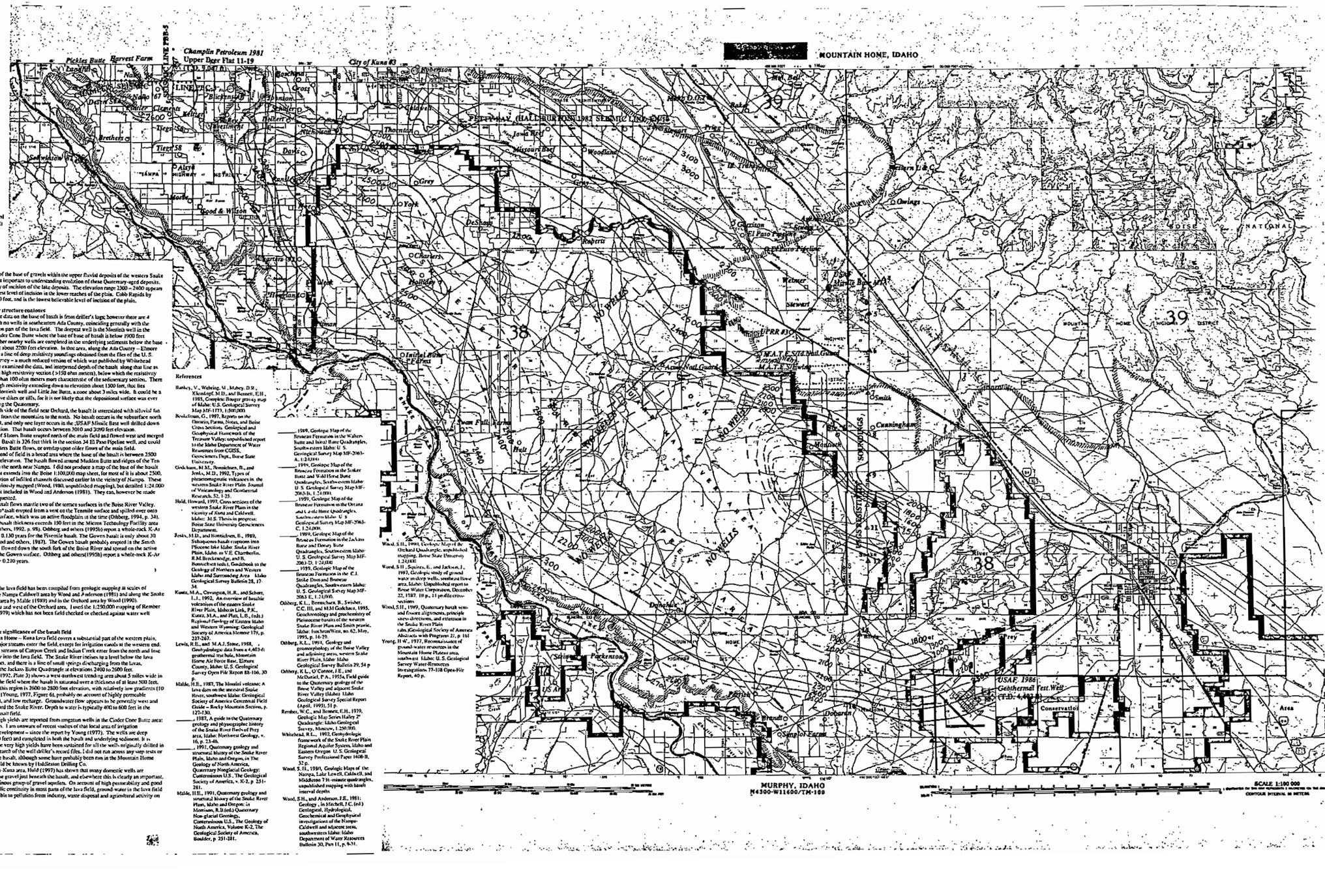
Contours are dashed where uncertain for lack of control wells

Elevations in feet with respect to sea level

UPRR #3 ○ = deep water well used for control

Δ 15 = vertical electrical-resistivity-sounding point (unpublished data of R.L. Bisdorf (USGS), 1983 referenced by Whitehead (1992)

= mapped geologic contact of the basalt field


MOUNTAIN HOME, IDAHO
Champlin Petroleum 1981
Upper Dace Flat 11-19
City of Kuna #3
Pickles Butte
Harvest Farm
SNAKE RIVER PLAIN
FEDERAL AV (HALLIBURTON) 1982 SEISMIC LINE
Swan Falls
Kuna
Nampa
Caldwell
Parma
Notus
Boise
Mountain Home
Glenns Ferry
Bruneau
Grand View
Owyhee
Jordan Valley
Rockies
Cretaceous
Tertiary
Quaternary
Basalt
Sediments
Water Table
Fault
Anticline
Syncline
Thrust
Normal
Strike-slip
Oblique
Unconformity
Intrusive
Extrusive
Metamorphic
Sedimentary
Igneous
Volcanic
Plutonic
Batholith
Stock
Dike
Sill
Lava Flow
Pyroclastic
Ash
Tuff
Breccia
Conglomerate
Sandstone
Shale
Limestone
Coal
Oil
Gas
Uranium
Phosphate
Geothermal
Hot Springs
Earthquake
Epicenter
Focus
Seismograph
Richter
Magnitude
Intensity
Mercalli
Modified Mercalli
Peak Acceleration
Peak Velocity
Peak Displacement
Response Spectrum
Fourier Spectrum
Power Spectrum
Autocorrelation
Cross-correlation
Convolution
Deconvolution
Filter
Low-pass
High-pass
Band-pass
Band-reject
Notch
Comb
Boxcar
Triangular
Gaussian
Hamming
Hanning
Kaiser
Bessel
Chebyshev
Butterworth
Elliptic
Cauer
Parks-McClellan
Remez
Exchange
Algorithm
Iteration
Convergence
Divergence
Stability
Instability
Oscillation
Damping
Resonance
Antiresonance
Impedance
Admittance
Reactance
Susceptance
Conductance
Resistance
Capacitance
Inductance
Transformer
Rectifier
Amplifier
Oscillator
Modulator
Demodulator
Multiplexer
Demultiplexer
Encoder
Decoder
Transmitter
Receiver
Transceiver
Antenna
Waveguide
Coaxial Cable
Fiber Optic
Satellite
Orbit
Geostationary
Polar
Inclined
Elliptical
Circular
Parabolic
Hyperbolic
Escape Velocity
Gravity
Magnetic
Electric
Electromagnetic
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
Cosmic Ray
Particle
Wave
Quantum
Relativity
Time
Space
Energy
Mass
Momentum
Force
Pressure
Temperature
Entropy
Enthalpy
Heat
Work
Power
Efficiency
Thermodynamics
Statistics
Probability
Uncertainty
Information
Entropy
Redundancy
Compression
Encryption
Decryption
Hash
Checksum
Parity
Error Correction
Error Detection
Handshake
Protocol
Network
Internet
Ethernet
Token Ring
FDDI
ATM
SONET
TCP/IP
UDP
IP
ICMP
ARP
RARP
DNS
SMTP
POP
IMAP
MIME
HTTP
FTP
Telnet
SSH
SSL
TLS
VPN
Firewall
Router
Switch
Hub
Bridge
Gateway
Modem
DSL
Cable
Dial-up
Wireless
Bluetooth
Wi-Fi
WiMAX
LTE
3G
4G
5G
GPS
GLONASS
Galileo
Beidou
Inertial Navigation
Gyroscope
Accelerometer
Magnetometer
Barometer
Altimeter
Thermometer
Hygrometer
Anemometer
Rain Gauge
Seismometer
Tiltmeter
Strainmeter
Extensometer
Creepmeter
Piezometer
Lysimeter
Tensiometer
Soil Moisture
Evapotranspiration
Precipitation
Runoff
Infiltration
Percolation
Groundwater
Aquifer
Aquitard
Confining Layer
Recharge
Discharge
Hydraulic Head
Hydraulic Conductivity
Transmissivity
Storativity
Specific Yield
Specific Storage
Darcy's Law
Theis
Thiem
Dupuit
Boussinesq
Richards
Green-Ampt
Horton
Curve Number
Unit Hydrograph
Rational Method
Manning's Equation
Chezy
Weir
Orifice
Venturi
Parshall
Flume
Culvert
Spillway
Dam
Levee
Reservoir
Detention
Retention
Wetland
Riparian
Floodplain
Channel
Stream
River
Lake
Ocean
Estuary
Delta
Watershed
Basin
Divide
Gauge
Datum
Benchmark
Survey
Triangulation
Trilateration
Traverse
Leveling
Bathymetry
Sounding
Tide
Current
Wave
Swell
Fetch
Wind
Storm
Hurricane
Typhoon
Cyclone
Anticyclone
Front
Jet Stream
Coriolis
Ekman
Geostrophic
Thermocline
Halocline
Pycnocline
Upwelling
Downwelling
Gyre
Thermohaline
Salinity
Density
Buoyancy
Stratification
Mixing
Diffusion
Advection
Dispersion
Turbulence
Laminar
Reynolds
Boundary Layer
Viscosity
Surface Tension
Capillarity
Wetting
Drying
Hysteresis
Contact Angle
Interface
Phase
Solid
Liquid
Gas
Plasma
Sublimation
Deposition
Condensation
Evaporation
Boiling
Freezing
Melting
Triple Point
Critical Point
Latent Heat
Specific Heat
Thermal Conductivity
Thermal Expansion
Thermal Stress
Fatigue
Creep
Yield
Ultimate
Elastic
Plastic
Brittle
Ductile
Hardness
Toughness
Impact
Shear
Tensile
Compressive
Bending
Torsion
Buckling
Fracture
Crack
Dislocation
Grain
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Elastomer
Thermoplastic
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Resin
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Dye
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Paper
Wood
Steel
Aluminum
Copper
Concrete
Asphalt
Glass
Ceramic
Rubber
Plastic
Foam
Insulation
Roofing
Flooring
Drywall
Plaster
Brick
Mortar
Grout
Rebar
Prestressed
Post-tensioned
Reinforced
Masonry
Timber
Steel Frame
Concrete Frame
Shear Wall
Moment Frame
Braced Frame
Tilt-up
Precast
Cast-in-place
Foundation
Footing
Slab
Pile
Caisson
Retaining Wall
Basement
Crawl Space
Slab-on-grade
Roof
Truss
Rafter
Joist
Beam
Column
Girder
Header
Sill
Stud
Sheathing
Siding
Window
Door
Skylight
Gutter
Downspout
Flashing
Vapor Barrier
Air Barrier
Weatherstripping
Caulking
Sealant
Gasket
Fastener
Bolt
Nut
Washer
Screw
Nail
Rivet
Weld
Solder
Braze
Glue
Tape
Clamp
Jig
Fixture
Tool
Machine
Lathe
Mill
Drill
Grinder
Saw
Router
Sander
Planer
Jointer
Shaper
Press
Brake
Shear
Punch
Die
Mold
Casting
Forging
Extrusion
Rolling
Drawing
Stamping
Machining
Turning
Boring
Facing
Threading
Knurling
Tapping
Reaming
Honing
Lapping
Polishing
Grinding
Milling
Drilling
Sawing
Cutting
Welding
Soldering
Brazing
Gluing
Taping
Clamping
Jigging
Fixturing
Tooling

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Contribution to the Treasure Valley Hydrologic Project -1997

STRUCTURE CONTOUR MAP OF TOP OF THE MUDSTONE FACIES, Western Snake River Plain, Idaho

By
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Boise Map Sheet, Idaho: Scale = 1:100,000
Elevations in feet with respect to sea level
Contour Interval = 100 feet (contours dashed where uncertain for lack of control wells)

Doty '79 ○ = deep water well used for control, giving name of owner listed on driller's log, and date of completion.

Ormco Oil and Gas Cleveland #1 (T.D. 4038 ft) ⟡ = deep petroleum or geothermal exploration well, giving operator, lease name, and total depth

▨ = edge of sedimentary basin

⟋ = approximate trace where contact is at the surface (i.e. the contact between the fluvial-deltaic section and the underlying mudstone skylights in the Snake River Canyon)

Introduction

The most important hydrogeologic facies boundary encompassed in the western plain is the contact of the fluvial-deltaic section overlying a thick section of predelta and deep-lake mud facies that fills the western plain. It is recognized in every exploration well west of 116° 20' E deeper than 2000 feet (Figure 1). Few or perhaps no water supply wells have drilled through the contact in this area, so adequate transmissivity usually occurs when the first 300 to 1200 feet. E[illegible] 116° 30' E the mudstone facies becomes increasingly more[illegible]. Furthermore, the northeast margin of the basin has[illegible]ified or is less compacted -- so that the contact is[illegible]d to the east and grades eastward into an[illegible]ntinuous zone as suggested by Squires and others (1992, p 29). Although an angular discordance of a few degrees may occur at the unconformity, it has not been recognized in wells. In many areas there may be no discordance, but I believe study may show coarser sediments over fine deeper water facies in an underlier.

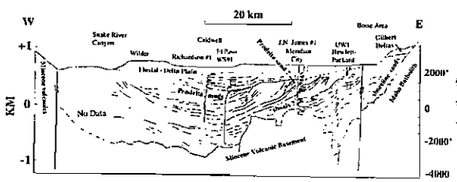

Figure 1. East-west cross-section of the western Snake River Plain showing configuration of strata interpreted from seismic reflections (Chevron Seismic Line 1B-2 and Lariat Exploration Seismic Line BB21 and showing location of sand aquifer systems identified by geophysical logs of deep wells. Resistivity logs are shown for 4 wells. Excursions on log trace to the right indicates sand aquifers, and low resistivity values to the left indicates clayey muds of low permeability. Vertical scale is greatly exaggerated, so that the inclination of strata is incorrectly shown as being steep, whereas in reality the inclination from horizontal (dip of strata) is everywhere less than 6 degrees.

Data used for structure contours

The electric logs from deep petroleum and geothermal wells clearly show the vertical facies change from a predominantly mudstone section upward to sands of river deltas and fluvial systems (Wood, 1994). The contact can be reliably picked from the geophysical logs of 9 deep wells on the Boise 1:100,000 sheet and at the 1630 feet in the Rube Bottles #1 well near Payette (illustrated on the Ontario cross section by Bendixsen (1997)). The key to identification of the contact is the subtle upward coarsening of the mudstone, and then an abrupt change to sand, feature shown by Wood (1993) to be characteristic of the pro-delta facies. The contact can be identified from the cleanform character of seismic reflections of the prodelta facies using high-resolution seismic profiling; however, only parts of Chevron 1B-2, and Intermountain Gas Corp seismic data have been processed to resolve the shallow section (shallower than 1200 feet). Long-offset seismic spreads on all but the Intermountain Gas data published by Wood (1993) precludes resolution of the section shallower than 1000 feet.

It is reasonable to assume that the contact conforms with seismic reflections, but on most lines it occurs too shallow to be resolved. On the other Chevron lines, the Champlin, Ames hole, and Lariat Exploration data the shallowest reflection have been interpreted, and their configuration extrapolated upward to tie to the depths of the coal set in the wells (known as construction of a "phantom horizon" in seismic interpretation methodology). Seismic lines to the "phantom horizon" representing the mudstone contact were converted to depth using a velocity of 6150 feet/second. This velocity is based upon the only reliable sonic logs for the shallow section in the basin: the Higgerson Well, 4 miles west of Meridian and the Highland 1, & 1 well 5 miles south of Parma. Sonic log of the Highland 1 & 1 (the water saturated section below 300 feet) indicates a velocity of 5830 ft/sec for sediments in the upper 1000 feet. The Higgerson sonic log indicates a velocity of 6100 feet/second for the upper 1000 feet -- such was decided to use 6000 feet/second for all of the data. A velocity of 7000 ft/second used for some current lines in processing by Chevron and Lariat worked for low resolution data but is incorrect and too high a value. Chevron used a 2500 foot datum, and Lariat a 3200 foot datum. I was able to tie the lines by adding 50 milliseconds time to the Lariat data. Processing parameters of the Ames hole and Champlin data are unknown, but it one simultaneously tied to Chevron data by adding a constant to the reflection time.

The water well locations posted on map are those in close vicinity prepared by Bendixsen (1997) and *HLAS* (1993) for this project. Few if any of these water wells penetrate the contact because drillers seldom continue through more than 100 feet of mudstone, if they can make a well in the previously drilled section. However on the margins of the plain, it appears some wells penetrate the contact.

The outcropping well in the Canyon County Pickles Butte Landfill (PB-3) record through the contact at elevation 2245 (Hold, 1997, Profile II). Exposures along the Snake River Canyon southeast of Marsing and the western detachment by Repenning and others (1995) indicate that the contact is exposed in the canyon at this area. On the northwest side of the plain, along Willow Creek, about 4 miles north of Star the Little Cattle Company well drilled over 50 feet of mudstone at elevation 2000 feet. Three miles to the northwest, the Land-well drilled 350 feet of "blue-gray clay" below elevation 2340 feet.

Structure contours north of 43°45' (i.e. Parma - New Plymouth area) are based upon 4 widely spaced wells and are not controlled by seismic data. Donation of three proprietary seismic lines covering that area have been requested from Amoco Production Company (Denver and Houston offices), but at the time of writing the request has not been acted upon.

Little information is available on the elevation of the contact in the Murphy quadrangle and Mountain Home area of the Treasure Valley Hydrologic Project. Much of the area is covered with Quaternary basalt (Wood, 1997c) and there are few deep wells. Therefore a map was not produced for the mudstone contact in that area. I have received sample parts (to reconsider for data purchase*) of a Petty Ray (Halliburton) seismic line, run in 1982 between Mora and Black Creek Reservoir. The seismic data indicate a thick sedimentary section, perhaps 7000 feet thick, dipping gently to the west - and the data presently could be purchased and reprocessed for information on the upper aquifer section.

In the deepest well (Mountain Home Air Force Base) the sedimentary section between depth 535 ft and 1825 feet is now likely the lacustrine section (Lewis and Stone, 1981). Lithology was uncommonly logged, but a record section may still be available from the USGS for remedy. The gamma log shows an abrupt increase in counts at 1440 feet, which might be the top of the mudstone, and part of the section was logged as calcareous clay and silt. That geometry contact would correspond to an elevation of 1581 feet. The Cunningham well, 6 miles southeast of Orchard drilled beneath the Quaternary basalt into 250 feet of sand - sediment. Its surface elevation 1820 feet, but is apparently still in the fluvial section. The HSAP Lincoln well 2 miles northeast of Orchard drilled 1240 feet through materials described mostly as silt and shale, but sand units occur throughout the section also to elevation 2100 feet.

Exposures of the Glenns Ferry Formation along the Snake River Canyon of the Murphy area have not been mapped in a detail adequate to identify facies units, but many shale-dominant exposures are of sandy sediments, without a clear boundary of a mudstone unit.

Hydrogeologic Significance

The section of fluvial-deltaic facies above the mudstone contact is typically 800 to 1500 feet thick, and contains the major sand aquifers for water supplies from the western plain. Exception is in the City of Boise area, where some of the deep wells are surely producing from below the unconformity, from sands equivalent in age to the mudstone facies.

Other workers have searched without convincing results for stratigraphic lithologic boundaries, and broadly distributed "blue clay" units within the fluvial-deltaic section. I think it unlikely that such broadly distributed units of low permeability exist in the section. Some mudstone-fine bedrock clay and silt layers can be traced within the fluvial-deltaic section for several miles but are regionally limited as it likely that over a broad region there is some vertical connectivity in the section - although some local aquifers do contain unusual water chemistry (T-E Squires, personal communication) indicating some degree of local isolation by aquitards.

Individual lacustrine mudstone units can be many hundreds of feet thick, locally separated by thin fine sand units, probably of downward flow origin. It is not known whether these units occur in some places up to 50 feet of thin interbedded sand and mud are local occurrences, or whether they extend for many miles. The lithology of the mudstone varies from a calcareous claystone to clayey silt and has low permeability. I have used the collective term mudstone for these clayey units because they have a broad spectrum of fractions in addition to silt-sized clay and silt. Fifteen laboratory measurements of saturated hydraulic conductivity of samples from Chevron and Squires were made for studies of the Pickles Butte landfill (Canyon County) and the City Butte Landfill (Payette County) and reported by Holliday Engineering (1993). Twelve of these measurements are between 10^{-6} to 3×10^{-7} cm/s while the remainder varied from 10^{-5} to 1.9×10^{-6} cm/s; therefore a value of the order of 10^{-7} cm/s seems appropriate for the upper part of the mudstone unit, which is utterly several miles of magnitude lower than most of the overlying fluvial deltaic section.

Structural relief on the upper mudstone contact

The contact is broadly downwarped toward the middle of the western Snake River basin, being about elevation 2500 feet on the margins, and about elevation 1200 feet near the center of the basin, seven miles north of Caldwell. Another notiform trending low area is between the cities of Nampa and Caldwell, where the surface is slightly below 1300 feet elevation. Broad downwarping toward the center of the plain probably has exceeded one thousand feet, but much of the relief within the center of the basin may be an account of compaction of sand-rich sediments. The relatively high zone extending from the Meridian area to the Sinclaire Homer-Lineup well, 5 miles northwest of Caldwell, is produced by compaction changes over a subsurface structural high. This has produced relief from 200 to 1000 feet from the high to the adjacent low areas.

Faulting does not appear to have significantly affected the surface. Faulting with displacements less than 100 feet are observed in the mapping or the Ten Mile gravel which overlies the fluvial deltaic section (Wood and Anderson, 1991, p 30). Faulting cannot be resolved on the seismic sections on account of low resolution of the data. Bush Hold (1997) and Bendixsen (1997) referred faults to explain shifts in strata they believe to be consistent, but displacements are probably small, and in some cases alternative explanations (such as channel infilling) may account for the shifts.

Geological Significance of the fluvial deltaic / mudstone contact

This compilation of elevation data on the top contact of the mudstone unit has significantly advanced the understanding of the lacustrine sediments of the western plain. The overlying fluvial-deltaic section is currently regarded by the Glenns Ferry Formation which had previously been studied only southeast of Grandview, and along the Snake River Canyon east to the Hagerman area and reported in many publications referenced in H.E. Malde (1991). My present concept is that Lake Idaho began to overflow into the ancestral Hells Canyon drainage at the beginning of Glenns Ferry time (Wood, 1997a). Gradual downcutting of the new outlet caused a more rapid progradation of deltaic sediment into the basin formerly occupied by deeper parts of Lake Idaho - and this explains the widespread contact between the deep-water mudstone and fluvial-deltaic facies.

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Wood, S.H. and Anderson, J.E., 1981, Geology, in Mitchell, J.C. (ed.) Geological, Hydrological, Geochemical and Geophysical investigations of the Nampa-Caldwell and adjacent areas, southwestern Idaho: Idaho Department of Water Resources Bulletin 30, Part II, p. 9-31.

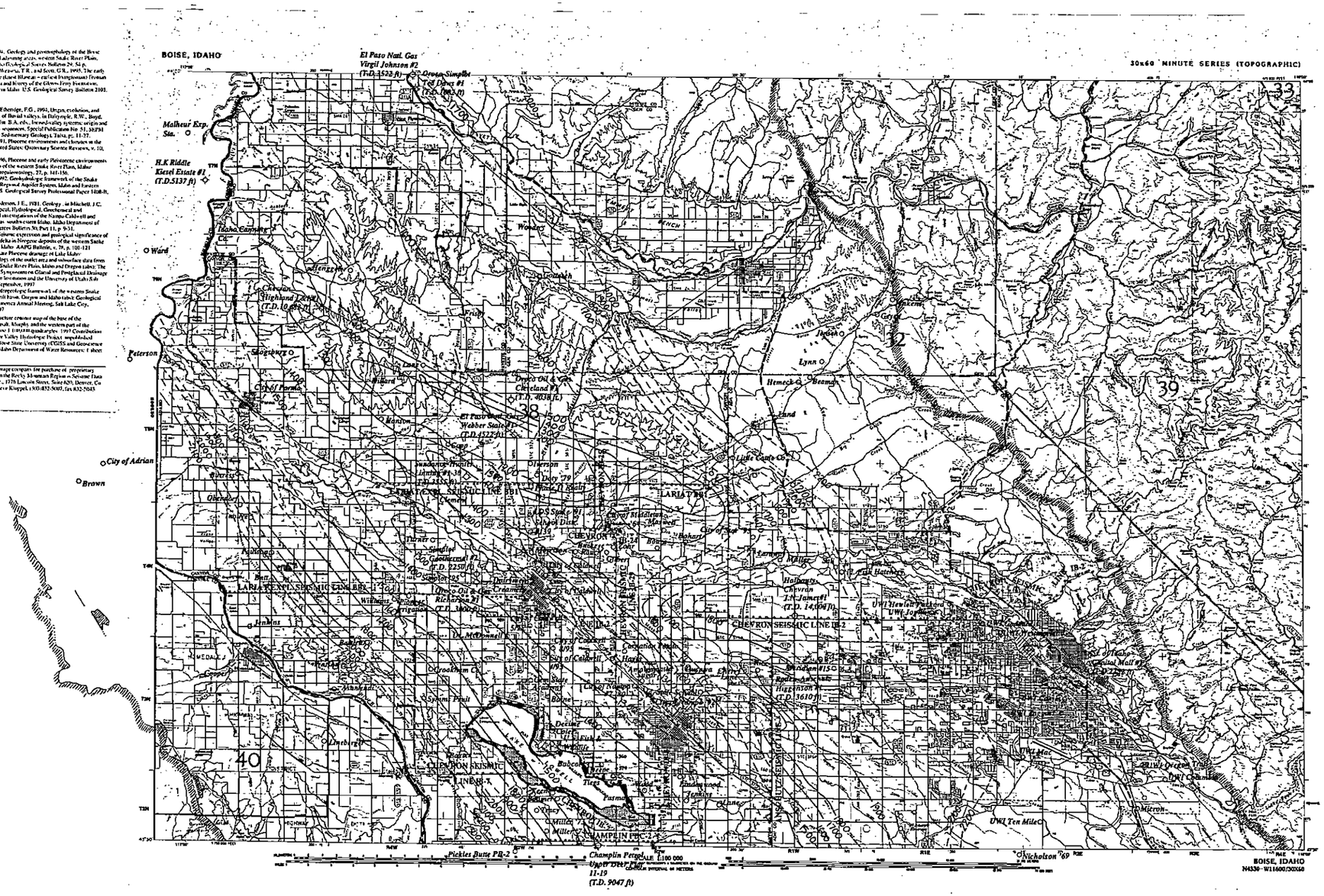
Wood, S.H., 1993, Seismic expression and geological significance of a lacustrine delta in Neogene deposits of the western Snake River Plain, Idaho: AAPG Bulletin, v. 79, p. 181-181

_____ 1997a, Late Pliocene drainage of Lake Idaho: Geomorphology of the outlet area and subsurface data from the western Snake River Plain, Idaho and Oregon (abs): The Great River Symposium on Glacial and Proglacial Drainage (Smithsonian Museum and the University of Utah) 8-6 Lake City, September, 1997

_____1997b, Hydrologic framework of the western Snake River Plain in Ferns, Oregon and Idaho (abs): Geological Society of America Annual Meeting, Salt Lake City, October, 1997

_____ 1997c, Structure contour map of the base of the Quaternary basalt, Murphy and the western part of the Mountain Home 1:100,000 quadrangles: 1997 Contribution to the Treasure Valley Hydrologic Project, unpublished report from Boise State University (CGISS and Geoscience Dept.) to the Idaho Department of Water Resources: 1 sheet with text

*Currently, the Boise Image company for purchase of proprietary seismic data in the Rocky Mountain Region is Seismic Data Exchange Inc., 1776 Lincoln Street, Suite 620, Denver, Co 80203 Rep. Steve Kloppel, 1-800-852-5000, fax 832-7043.


BOISE, IDAHO
30x60 MINUTE SERIES (TOPOGRAPHIC)
El Paso Nat. Gas Virgil Johnson #2 (T.D. 4522 ft)
Sid Owen Simplot Tell Davis #1 (T.D. 7000 ft)
Malheur Exp. Sta.
H.K Riddle Kiesel Estate #1 (T.D.5137 ft)
Ward
Peterson
City of Adrian
Brown
Idaho Canyon Cr.
Henrys L.
Highland Exp. (T.D. 10,000 ft)
Sagehen
Mill Pond
Willard
Ormco Oil & Gas Cleveland #1 (T.D. 4038 ft)
Marsing
El Paso Nat. Gas Webber Stalder #1 (T.D.4527 ft)
Gap
Deer Flat
Diversion
Lake Cascade
Lake Cascade Co.
Lake Fork
Lynn
Hemeck
Beamer
Lund
Banks
Horseshoe Bend
Garden Valley
Crouch
Lowman
Grimes Pass
Idaho City
Placerville
Pine
Featherville
Atlanta
Prairie
Mayfield
Fairfield
Fairfield Mtn.
Mountain Home
Glenns Ferry
Bruneau
Grand View
Owyhee
Jordan Valley
Nyssa
Nampa
Caldwell
Meridian
Boise
Eagle
Star
Middleton
Emmett
Horseshoe Bend
Idaho City
Lowman
Stanley
Challis
Mackay
Arco
Craters of the Moon
Carey
Hailey
Ketchum
Sun Valley
Twin Falls
Jerome
Gooding
Shoshone
Hagerman
Bliss
Wendell
Buhl
Rupert
Burley
Heyburn
Malad City
Oakley
Albion
Burley
Declo
Elba
Almo
Malta
Rockland
Raft River
Yost
Snake River
Salmon River
Payette River
Boise River
Owyhee River
Bruneau River
Weiser River
Malheur River
Jordan Creek
Reynolds Creek
Silver City
Grand View
Bruneau
Mountain Home AFB
Mountain Home
Glenns Ferry
Hammett
Orchard
Kuna
Meridian
Nampa
Caldwell
Parma
New Plymouth
Fruitland
Payette
Weiser
Ontario
Vale
Nyssa
Adrian
Jordan Valley
Owyhee

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33S

GEOLOGIC CROSS SECTION ACROSS THE TREASURE VALLEY, FROM 6 MILES EAST-NORTH-EAST OF STAR TO THE SNAKE RIVER

33T

IDAHO GEOLOGICAL SURVEY
MOSCOW • BOISE • POCATELLO

GEOLOGIC MAP SERIES, SCALE 1:100,000
OTHBERG AND STANFORD

GEOLOGIC MAP OF THE BOISE VALLEY AND ADJOINING AREA, WESTERN SNAKE RIVER PLAIN, IDAHO

BY KURT L. OTHBERG AND LOUDON R. STANFORD

1992

MAP UNITS

SEDIMENTARY

QUATERNARY SEDIMENTS

Alluvium and Colluvium

Deposits of floodplains, alluvial fans, side-stream terraces, and landslides.

Qa — ALLUVIUM OF BOISE AND SNAKE RIVER — Sandy cobble gravel upstream grading to sandy pebble gravel downstream. Mostly channel alluvium of the Boise and Snake rivers. Thickness 6-14 meters (20-46 feet). No pedogenic clay.

Qls — LANDSLIDE DEPOSITS — Highly variable rock and soil masses varying from transported coherent blocks to unsorted, unstratified colluvium, including scar area at the head of the landslide. Derived from slumps, slides, and debris flows. Most slides represent slope failures within basaltic tuff (Tbs) and surface soils of granitic rocks.

Qafg — ALLUVIAL FAN GRAVEL — Sandy pebble and cobble gravel where formed from reworked Terrace Gravel (Qtg) and sand and granule gravel where formed from weathered granite (g). Primarily formed by Pleistocene debris flows and local high-energy streams during times of greater runoff (Pierce and Scott, 1982). Loess 1-2 meters thick discontinuously covers surface of gravel. Patterned ground present. Amount of pedogenic clay and presence of duripans varies.

Qac — SANDY ALLUVIUM OF SIDE-STREAM VALLEYS AND CLUSTERS — Medium to coarse sand interbedded with silty fine sand and silt. Sediment mostly derived from weathered granite and reworked Tertiary sediments. Thickness variable. Minor pedogenic clay and calcium carbonate.

Qafs — SAND OF INCISED ALLUVIAL FANS — Medium to coarse sand interbedded with silty fine sand and silt. Mostly reworked Tertiary sediments deposited in local alluvial fans. Thickness 1-15 meters (3-50 feet). Pedogenic clay 10-20%; duripans locally present.

Qsc — SAND OF DRY CREEK TERRACE — Medium to coarse sand interbedded with silty fine sand and silt. Remnant of ancestral Dry Creek valley. Pedogenic clay 10-20%; duripans locally present.

Qtg — GRAVEL OF ALLUVIAL-FAN REMNANTS — Dark gray, poorly sorted, sandy cobble and pebble gravel. Gravel clasts subangular and subrounded. Thickness 3-6 meters (10-20 feet), stepped only where channel deposits of ancestral Squaw Creek cap remnants of a large alluvial fan in southwestern corner of map.

Bonneville Flood Deposits

Consists primarily of fine-grained sediments of the Bonneville flood slack waters that inundated the Snake River Valley and the lower Boise Valley. Includes gravels deposited in high-energy flood channels. The surface of sediments deposited by the Bonneville Flood show minor accumulations of pedogenic clay and calcium carbonate. Slack-water sediments bury loess and soils of older surfaces.

Qbgs — CLAY OF BONNEVILLE FLOOD SLACK WATER — Light tan silty clay 1-2 meters (3-7 feet) thick. Deposited by slack water of Bonneville Flood upstream from Parma. Buries gravel of Boise terrace.

Qs — SANDY SILT OF BONNEVILLE FLOOD SLACK WATER OVERLYING TERTIARY SEDIMENTS — Thin-bedded tan silt, silty sand, and fine sand 3-6 meters (10-20 feet) thick. Deposited by Bonneville Flood slack water that flooded valleys to 747 meters (2,450 feet) elevation (O'Connor, 1990). Buries gravel of Whitney terrace (Qwg). Erosion surface of fine-grained Tertiary sediments.

Qbfg — GRAVEL OF THE BONNEVILLE FLOOD-SCOURED BOISE TERRACE AND BOISE FLOODPLAIN COMPLEX — Sandy pebble gravel remnants of Boise terrace mostly scoured by late stages of Bonneville Flood. Includes areas of floodplain gravel inadistinguishable from scoured Boise terrace.

Qwgs — SANDY SILT OF BONNEVILLE FLOOD SLACK WATER — Thin-bedded tan silt, silty sand, and fine sand 3-6 meters (10-20 feet) thick. Deposited by Bonneville Flood slack water that flooded valleys to 747 meters (2,450 feet) elevation (O'Connor, 1990). Buries gravel of Whitney terrace (Qwg).

Qwfg — GRAVEL OF THE BONNEVILLE FLOOD-SCOURED WHITNEY TERRACE — Sandy pebble gravel remnants of Whitney terrace scoured by late stages of Bonneville Flood. Includes abandoned flood channels. Loess mostly removed. Local remnants of duripans similar to those on Qwg.

Qwbs — SANDY SILT OF BONNEVILLE FLOOD SLACK WATER — Thin-bedded tan silt, silty sand, and fine sand 3-6 meters (10-20 feet) thick. Deposited by Bonneville Flood slack water that flooded valleys to 747 meters (2,450 feet) elevation (O'Connor, 1990). Extent of slack-water sediment not everywhere coincident with interpreted extent of flood waters. Buries thin loess, duripan, and sandy pebble gravel of Wilder terrace, the third terrace above the floodplain in the western Boise Valley. Gravel thickness 3-8 meters (10-25 feet).

Terrace Gravels

These gravels compose a sequence of terraces of the ancestral Boise River. The characteristic coarse channel gravels were primarily deposited on fine-grained Tertiary sediments cut during valley deepening. The light gray gravel is composed mostly of granitic and felsitic clasts derived from the upper Boise River basin in the central Idaho mountains. Qgg and younger gravels have about a 10% component of Pleistocene basalt clasts mostly derived from the Boise River canyon. Boise Valley units are also used for terrace gravels of the Snake River, but Snake River gravels have a darker color due to a component of gravel clasts derived from the Owyhee Mountains and sources to the southeast. All gravel deposits have imbricated well-rounded clasts, poor sorting, and crude stratification of beds of gravel and lenses of cross-bedded sand. These features suggest deposition in braided channels.

Qwg — GRAVEL OF THE WHITNEY TERRACE — Sandy pebble and cobble gravel. Third terrace above the floodplain. Thickness 3-16 meters (10-45 feet). Mostly mantled with thin loess.

Qbg — GRAVEL OF BOISE FRONT TERRACES, UNDIVIDED — Sandy pebble and cobble gravel with subangular boulders. Thickness 1-6 meters (3-20 feet) thick. Forms terraces along canyons and gulches and on fan divides near the margin of the foothills.

Qwgs — GRAVEL OF WHITNEY TERRACE — Sandy pebble and cobble gravel. Second terrace above floodplain. Thickness 5-24 meters (16-80 feet). Encloses to the east. Mantled with 1-2 meters of loess.

Qbgs — GRAVEL OF SUNRISE TERRACE — Sandy pebble and cobble gravel. Third terrace above the floodplain. Thickness about 13 meters (44 feet). Mostly mantled with 1-2 meters of loess.

Qbgs — GRAVEL OF GOWEN TERRACE — Sandy pebble and cobble gravel. Fourth terrace above the floodplain. Buried by basalt (Qgb) east of Interstate 84. Terrace gravel overlies the gravel and sand of Bonneville Point (Tbg) to the east and fine-grained Tertiary sediments to the west. Mostly mantled by 1-2 meters (3-7 feet) of loess.

Qbg — GRAVEL OF AMITY TERRACE — Sandy pebble and cobble gravel grading at depth to coarse pebbly sand. Seventh terrace above the floodplain. Gravel and sand is about 10 meters (33 feet) thick. Northwest-trending, gentle sloping escarpments suggest faulting of the gravel. Mantled with loess 0.5-2 meters (2-7 feet) thick.

Qbfg — GRAVEL OF DEER FLAT TERRACE — Sandy pebble gravel grading at depth to coarse pebbly sand. Deposited on the fourth terrace above the floodplain in the western Boise Valley. North of Caldwell and Middleton Tertiary sediments are exposed between terrace remnants. Boise River gravels also interfinger with and are replaced northeastward by Willow Creek alluvial fan sand and gravel. Gravel and sand deposit is about 10 meters (33 feet) thick. Mantled with loess 1-4 meters (3-13 feet) thick.

Qwfg — GRAVEL OF DEER FLAT AND PRE-DEER FLAT TERRACES, UNDIVIDED — Sandy pebble and cobble gravel. Alluvial fan deposits of the ancestral Willow Creek interfingering and mixing downstream with channel alluvium of the ancestral Boise River. Deposited on stream-cut surface of fourth and fifth terrace above floodplain. Tertiary sediments are exposed on the crests of ridges. The basalts inundated ancestral valleys and plains. Their resistance to erosion helped preserve the terrace remnants they cap. The early Pleistocene basalt flows diverted the Boise River northward and the Snake River westward.

Tbg — BASALT OF MOFFS CREEK — Single flow of dark gray olivine basalt about 6 meters (20 feet) thick. Fine-grained with abundant microphenocrysts of plagioclase and common microphenocrysts of olivine. Canyon-filling lava erupted from unknown vent in Moffes Creek valley (Howard and others, 1982). Identified in ledges, normally submerged in reservoir near Lucky Peak Dam.

TERTIARY SEDIMENTS

Tps — SAND OF THE PIERCE GULCH FORMATION — Pale yellow-gray arkosic sand overlain by pebble to cobble gravel. Sand includes cross-bedded and ripple-bedded sequences. Named by W.L. Burnham and S.H. Wood (written communication-unpublished manuscript, 1989).

Tg — GLENNS FERRY FORMATION — Greenish gray poorly consolidated siltstone and fine sandstone. Distinct thick beds; indistinct thin bedding. Includes tan sandstones in Dead Horse Canyon.

Tbg — GRAVEL OF BONNEVILLE POINT — Interbedded pebble and cobble gravel, pebble sand, sand and buried soils. Mostly oxidized to yellow-orange grading to reddish-tan near surface. Half of the clasts weathered. Mostly channel alluvium of ancestral Boise River deposited in former valley at mountain front. Thickness about 152 meters (500 feet). Soils have illuvial cores with 50% clay. The upper part of the gravel contains a highly oxidized, partly cemented zone. Several normal faults exposed in gravel pits and road cuts. Patterned ground present with mound relief of 1-2 meters.

Tbg — ALLUVIAL FAN DEPOSIT — Composed of poorly sorted, silty and sandy gravels with subangular cobbles and boulders in crudely stratified layers and lenses; mostly oxidized to a reddish-tan near the surface. Alluvial fan remnants deposited by debris flows and high-energy stream flows locally. Up to 61 meters (200 feet) thick.

Tsj — SAND AND MUDSTONE OF STREAM AND LAKE SEDIMENTS — Medium- to coarse-grained arkosic sand, sandstone, and claystone. Includes interbeds of fine gravel, locally cemented, and sandy siltstone. Structures vary from large-foreset beds of sand to thin-bedded claystone. Undifferentiated unit reflects a variety of stream and lake depositional environments along the northeastern and southwestern margins of the ancestral western Snake River Plain. Includes parts of the Payette, Poison Creek, and Succor Creek Formations, the tuffaceous sediments of Ferns (1989), and the Terreting Springs Formation of W.L. Burnham and S.H. Wood (written communication-unpublished manuscript).

IGNEOUS ROCKS

QUATERNARY BASALTS

Basalt lava flows primarily erupted from three sources during the Pleistocene: the northwest-southeast axis of the western Snake River Plain; Smith Prairie 9 kilometers (6 miles) east of Boise; and the Owyhee Mountains south of Boise. The basalts inundated ancestral valleys and plains. Their resistance to erosion helped preserve the terrace remnants they cap. The early Pleistocene basalt flows diverted the Boise River northward and the Snake River westward.

Qgb — BASALT OF GOWEN TERRACE — Four flows of medium gray olivine basalt. Hand samples and thin sections show sparse phenocrysts of olivine up to 3 millimeters in diameter. Canyon-filling lava probably erupted in Smith Prairie (Howard and others, 1982). Buries gravel of Gowen terrace. Basalt surface capped with about 3 meters (10 feet) of terrace gravel at distal end. Thickness of basalt ranges from about 3 meters (10 feet) near Boise to about 61 meters (200 feet) near Lucky Peak Dam. Mostly mantled with loess 1-2 meters (3-7 feet) thick. Pedogenic clay 35%, duripan (caliche) 0.5-1 meter thick.

Tbl — BASALT OF LUCKY PEAK — Single flow of dark gray to black aphyric very fine-grained basalt. Canyon-filling lava probably erupted in Smith Prairie (Howard and others, 1982). Basalt buries gravel composing fifth terrace above the floodplain. Thickness of basalt about 37 meters (121 feet). Upper surface mostly buried by alluvial fan deposits (Qfg).

Tbk — BASALT OF KUNA BUTTE — Dark gray olivine basalt flow forming irregular topography southeast of Nampa. Common phenocrysts of olivine 1-5 millimeters in diameter. Thickness unknown. Erupted from northwest end of Kuna Butte. Pedogenic clay 10-20%; duripans locally present.

Tbf — BASALT OF FIVEMILE CREEK — One to three flows of medium gray olivine basalt. Thin sections show a cumulophyric texture of a few percent small interlocking olivine grains. Erupted from small vent near headwaters of Fivemile Creek. Basalt buries gravel composing sixth terrace above the floodplain. Thickness ranges from about 3 meters at the west edge of the flow to about 55 meters (180 feet) at the east. Mostly mantled with loess 1-2 meters thick. Pedogenic clay 35%; duripan (caliche) 0.5-1 meter thick. Patterned ground present.

Tbi — BASALT FLOWS OF INDIAN CREEK, UNDIVIDED — Multiple flows of medium to dark gray olivine basalt. Undivided basalts generally aphyric but include flows with small olivine and plagioclase phenocrysts. Erupted from vents south and southeast of the map. Both normal and reversed magnetic polarities. Lavas flowed into and down ancestral Indian Creek and Boise River valleys. Northwest-trending, gently sloping escarpments suggest faulting of the basalt. Mantled with loess 0.5-4 meters thick. Pedogenic clay 35%; duripan (caliche) 1 meter thick.

Tbs — BASALT FLOWS OF INDIAN CREEK BURIED BY LOESS AND STREAM SEDIMENTS — Tan massive silt, light brown stratified clay, silt, and sand, and basalt 6-15 meters (20-50 feet) deep. Location of basalt based on vent and well logs and subcrop mapping by Wood and Anderson (1981). Pedogenic clay 10-20%; duripans locally present.

Tbd — BASALT FLOWS OF UPPER DEER FLAT, UNDIVIDED — Multiple flows of dark gray aphyric olivine basalt. Reversed magnetic polarities. Probably erupted from one or more vents south of the map. Mantled with loess 1-4 meters (3-13 feet) thick. Pedogenic clay in loess 10-20%; calcium carbonate in B horizon. Loess buries duripan (caliche) 1 meter thick formed in the top of the basalt.

Tbv — BASALTIC VENTS, UNDIVIDED — Olivine basalt and basaltic tephra forming dissected cones and volcanic necks near the Snake River.

TERTIARY BASALTS

Tbp — BASALT OF PICKET PIN CANYON — Dark gray basalt flow with a cumulophyric texture of distinctive rosettes of white plagioclase. Position suggests inverted topography of a canyon-filling lava. Maximum thickness is 9 meters (30 feet).

Tbt — TUFF AND VOLCANICLASTIC SEDIMENTS — Brown basaltic tuff and volcaniclastic sediments. Minor beds of arkosic sand, pumice, and rhyolitic ash. Up to 107 meters (350 feet) thick.

Tbv — BASALT VOLCANIC ASSEMBLAGE — Contains several undivided lithologies: (1) thin subaerial lava flows, (2) thin subaqueous and other water-affected subaerial lava flows, and (3) tuff and volcaniclastic sediments. Lava up to 73 meters (240 feet) thick; overlying tuff and volcaniclastic sediments up to 61 meters (200 feet) thick.

Tba — BASALT AND ANDESITE OF GRAVEYARD POINT AREA — Olivine basalt near Graveyard Point and pyroxene andesite breccia south of Graveyard Point (Ferns, 1989).

TERTIARY RHYOLITES

Tpf — RHYOLITE OF THE BOISE FRONT — Pinkish gray porphyritic rhyolite, dark gray sanidine, and gray perlite.

Tjf — JUMP CREEK RHYOLITE — Mostly gray porphyritic rhyolite and quartz latite. Plagioclase phenocrysts up to 15 millimeters. Lava flow or remobilized welded tuff.

Thf — HOTHEAD RHYOLITE — Black glassy rhyolite; light gray where devitrified.

CRETACEOUS GRANITIC ROCKS

Kg — GRANITIC ROCKS OF THE IDAHO BATHOLITH — Light gray biotite granite and granodiorite. Medium to coarse grained and equigranular to porphyritic. Includes pegmatite zones and dikes of rhyolite and basalt.

MAP SYMBOLS

- Contact: approximately located; dashed where inferred
- Fault: approximately located; dashed where inferred; dotted where concealed; ball and bar on downthrown side
- Strike and dip of bedding
- Approximate upper limit of Bonneville flood slack water
- Sand dune fields
- Basalt sampling site

Magnetic Polarities, K/Ar Ages, and $^{87}Sr/^{86}Sr$ Ages of Basalts

Rock Unit	Field Number	Polarity	Latitude	Longitude	Age (Ma) [1 standard error; 2 argon/argon]
Basalt of Moffes Creek	MC3	N	43°31.52'	116°13.59'	6.167 ±0.042 [1]
Basalt of Gowen terrace	GG4	N	43°31.32'	116°14.2'	6.032 ±0.05 [1]
Basalt of Kuna Butte (South Side)	KS	N	43°31.51'	116°13.02'	6.387 ±0.041 [1]
Basalt of Lucky Peak	LP4	N	43°31.05'	116°3.66'	5.864 ±0.74 [2]
Caldwell Loss flow	CLF	R	43°40.31'	116°41.06'	6.709 ±0.092 [1]
Upper Deer Flat loss flow	UDF	R	43°30.29'	116°24.08'	6.322 ±0.04 [1]
Basalt of Fivemile Creek	FM3	N	43°32.67'	116°6.38'	6.074 ±0.036 [1]
Basalt of Fivemile Creek	FM1	N	43°30.27'	116°6.93'	
Basalt of Fivemile Creek	FM2	N	43°31.52'	116°4.40'	
Basalt of Hubbard overlook	HOV1	N	43°31.52'	116°20.20'	1.004 ±0.068 [1]
Mason Creek loss flow	MM	N?	43°31.72'	116°28.23'	1.231 ±0.023 [1]
Black Cat Road loss flow	BC	R	43°31.13'	116°32.13'	
East Nampa loss flow	NES	R	43°36.15'	116°31.72'	1.165 ±0.04 [1]
Ronyon Canal loss flow	RC	R	43°34.09'	116°32.12'	

Potassium-argon and argon-argon analyses provided by the Berkeley Geochronology Center, by virtue of Hurman Dalrymple, University of California, Berkeley, California. Magnetic polarity results from field flangute magnetometer using fine samples per site.

* Stratigraphic relationships indicate that the K-Ar age of the basalt of Locust Grove is too old (Othberg and Burnham, 1990).

Soil data adapted from Colbert (1980), Pierce and others (1973), and the University of Idaho Soil Characterization Laboratory.

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Pitcon, T. W., C. W. Case, J. E. Witty, R. K. Pierce, Jr., G. A. Monroe, H. W. Biggerstaff, G. M. Logan, L. M. Kennaweon, and D. H. Webb, 1972, Soil survey of Canyon area, Idaho: U.S. Department of Agriculture, Soil Conservation Service, 118 p., 39 sheets, scale 1:20,000.

[1] Pedogenic refers to the physical and chemical weathering processes that act upon earth materials at the land surface.

[2] Duripans are white silica- and calcium carbonate-cemented hardpans commonly called caliche.

[3] The Bonneville Flood slackwater sediments that form the surface of Qwfg (gravel of Wilder terrace) bury a duripan about 0.5 meter thick that formed in the top of the gravel.

[4] The surface of Qfg (gravel of Deer Flat terrace) is buried by loess from near Lake Lowell to near Wilder. The thick duripan lies at depths of 1-4 meters (3-12 feet).

LOCATION MAP

Geology field mapping 1985-1990. Funded in part by the U.S. Geological Survey's COGEOMAP program.

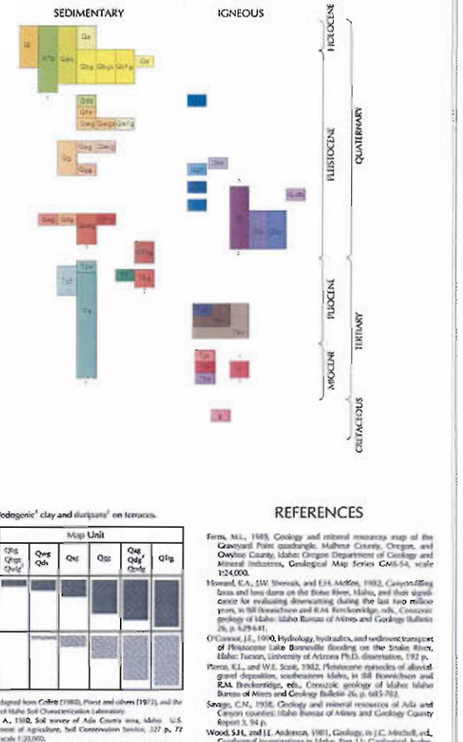
SCALE 1:100,000

KILOMETERS
MILES

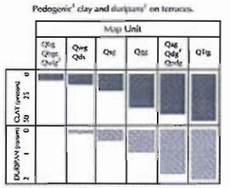
Contour Interval 40 Metres

U.S.G.S. 1:100,000 topographic base
Projection and 10,000-meter grid, zone 11, Universal Transverse Mercator
1927 North American Datum

CORRELATION OF MAP UNITS



Pedogenic[1] clay and duripans[2] on terraces.



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Treasure Valley Seismic Reflection Project - UPRR 2000 Profile

Report Prepared for the Idaho Department of Water Resources

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Technical Report BSU CGISS 01-01
12 April 2001

Treasure Valley Seismic Reflection Project - UPRR 2000 Profile

Lee M. Liberty and Spencer H. Wood
Boise State University

1.0 Summary

We have acquired approximately 12 km of seismic reflection data along the Union Pacific railroad in southwest Boise to help build a hydrostratigraphic model for regional groundwater studies and to better understand the hydrostratigraphic significance of seismic boundaries. High quality continuous reflections appear in the upper 900 m below the subsurface where we find prograding delta and fluvial sediments that influence groundwater flow and capacity. We find numerous faults that can inhibit lateral groundwater flow, a regional unconformity in the upper 150 m, fluvial channels, and reflections from sediments that contain apparent dips to the west of up to 10 degrees in the upper 300 m. By combining regional wells with the seismic stratigraphy, we can help parameterize aquifer capacities and flow directions for groundwater models and optimize placement of future water wells. The dip of many near-surface seismic reflections (1-10 degrees) and the presence of near-vertical faults (>65 degrees) that are often flow boundaries suggest deep water wells within this portion of the Boise basin are in several different dipping sands and that seismic reflection profiles provide critical information to the subsurface setting in the western Snake River Plain.

2.0 Introduction

Mapping stratigraphy and identifying hydraulic connectivity between and within sedimentary units is critical to assessing the groundwater resource. Seismic methods are often used to assist with regional and local groundwater studies because seismic reflection techniques can work at a variety of scales (Liberty et. al, 2001). Also, large-scale permeability changes can occur at lithologic boundaries, and seismic velocity contrasts generally appear at these same boundaries.

The Boise Valley is part of the western Snake River Plain (WSRP), a fault-bounded extensional basin in southwest Idaho and eastern Oregon (Figure 1). The basin contains Neogene and younger fluvial and lacustrine sediments deposited from rising and falling lake levels of relic Lake Idaho (Figure 1). Sand layers and channels were deposited within both shallow and deep-water mudstones (Wood, 1994). These sand units are the principal aquifers for groundwater supply in the valley. The sands are often discontinuous and connectivity between aquifer units is poorly understood. In addition to the complex geometry of the sands, structural downwarping and faulting in the basin further complicate the stratigraphy. For example, a typical 4 degree dip shifts the stratigraphy approximately 70

m between wells spaced 1 km. Water wells rarely extend greater than 200 m depth and are often separated by greater distances. In addition, faults with greater than 200 m of vertical offset are observed in the basin (Wood, 1994; Liberty, 1998), suggesting lithology between water wells may be complex and that each well may record a unique stratigraphic sequence.

The Idaho Department of Water Resources is conducting a major effort to map the groundwater resources within southwest Idaho. To address the problems of mapping complex stratigraphy and structures in the WSRP for groundwater resource assessment, we are compiling existing seismic reflection data and geophysical and lithologic logs to gain a regional understanding of the depositional style of the basin (Figure 2). We have also acquired and processed new seismic reflection data to better understand and map the subsurface stratigraphy at the depths where groundwater resources are economically viable. We have focused this year's effort on the region between southwest Boise and Meridian (Figure 3), where few deep water wells are located and the stratigraphy is too complex to tie major hydrostratigraphic boundaries between wells without additional information. The newly acquired seismic reflection data help correlate lithology and geophysical logs between regional water wells and allows us to better understand the subsurface depositional style in the Boise Basin. This report summarizes the acquisition, processing and initial interpretation of the seismic data that we acquired in the summer of 2000.

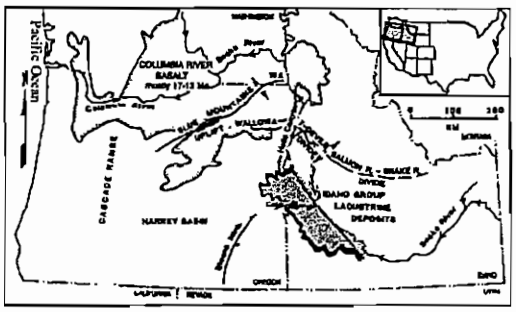


FIGURE 1. Location map of the western Snake River Plain where existing industry seismic reflection data and newly acquired seismic reflection data are being used to characterize the hydrostratigraphic aquifer.

3.0 Basin-scale studies

Interest in the WSRP for petroleum and geothermal resources in the 1970s has yielded several hundred km of seismic reflection data and has provided great insight into the depositional and extensional history of the basin. In particular, a 1972 Chevron USA Vibroseis seismic reflection profile through Boise (Figures 2 and 3) provides a concise picture of the basin structure and stratigraphy of the WSRP. The reflection data show a package of dipping and offset reflections that are typical of an extensional lacustrine basin. Neogene and younger basin sediments appear in nearby wells with a prograding delta sequence that extends up to 1 km below land surface (BLS). Numerous faults cut basin sediments and may extend to the surface or very near surface. The steep dips, large-offset faults, and varying stratigraphy all complicate the groundwater models for the basin, but provide the necessary framework to characterize the groundwater aquifer system. The industry seismic data offer insights into ground water resources by helping to identify major structural boundaries that may inhibit lateral groundwater flow. The data also shed light into the depositional style and sequence of mudstones, silts, and sands that may locally extend to the near-surface (Squires and Wood, 2001). Unfortunately the basin-scale seismic data do not image the upper 300 m BLS (Figure 2b) due to the acquisition design and processing interests, and much of the seismic data are not available for reprocessing to focus the images on near-surface sediment packages. As a result, we have acquired a series of seismic reflection profiles to provide detailed images of the upper km structure and stratigraphy in Boise to map both the cold water aquifer (e. g. , Barrash and Dougherty, 1997; Liberty, 1997; Liberty et al. , 1999) and the underlying geothermal aquifer (Liberty, 1998). The data summarized in this report add to the growing database of seismic data for the valley. Here we combine the seismic data and lithologic and geophysical logs from nearby wells to map hydrostratigraphy below southwest Boise, a region that has not been previously imaged with seismic reflection methods.

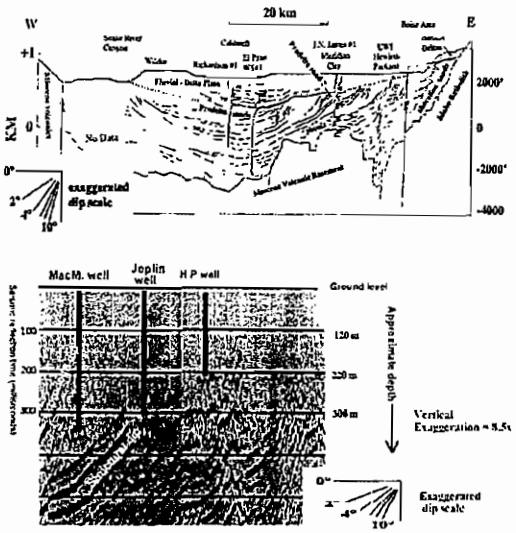


FIGURE 2. (A) Interpreted cross section of Chevron Line IB-2 profile across the western Snake River Plain. (B) A portion of profile IB-2 along the eastern front of the Boise basin. Note the absence of data above 300 m below land surface (figures from Squires and Wood, 2001).

4.0 Union Pacific Railroad Seismic Profiling

4.1 Seismic Reflection Acquisition

In the summer of 2000, we acquired a 10 km seismic reflection profile along the Union Pacific Railroad (UPRR) main line through Boise and an additional 2 km along the north-east-trending spur through southwest Boise (Figure 3). The profile locations provided us

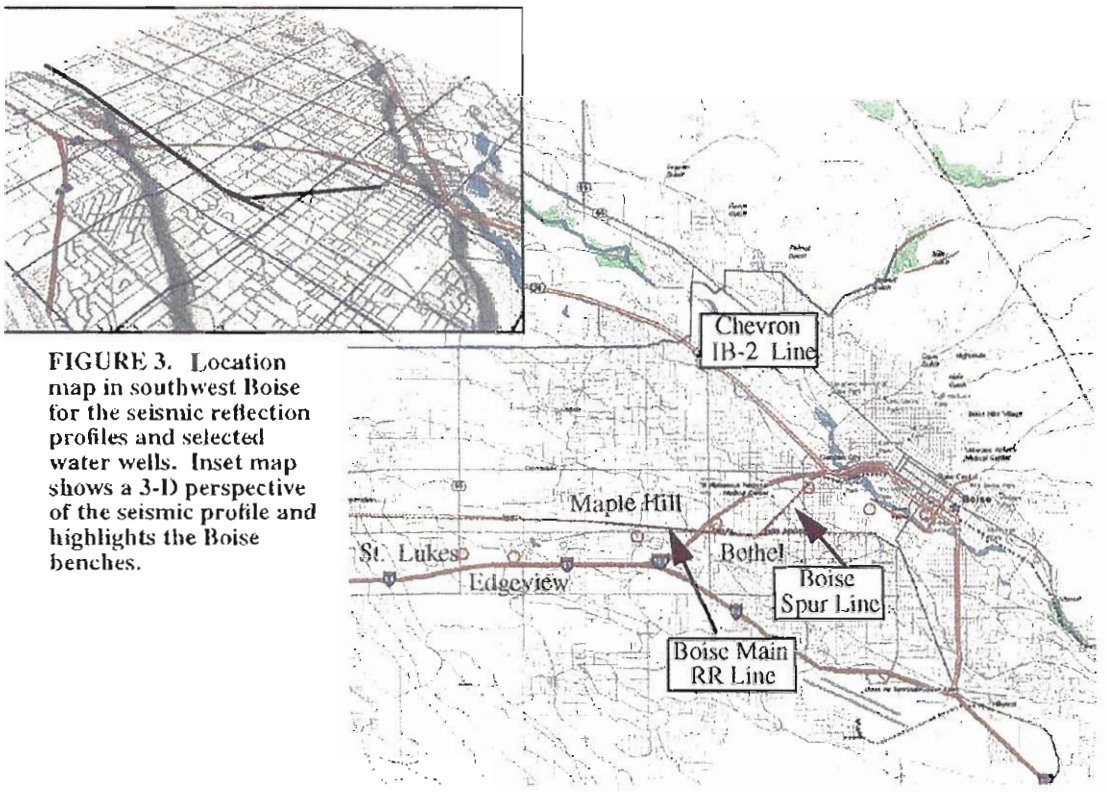
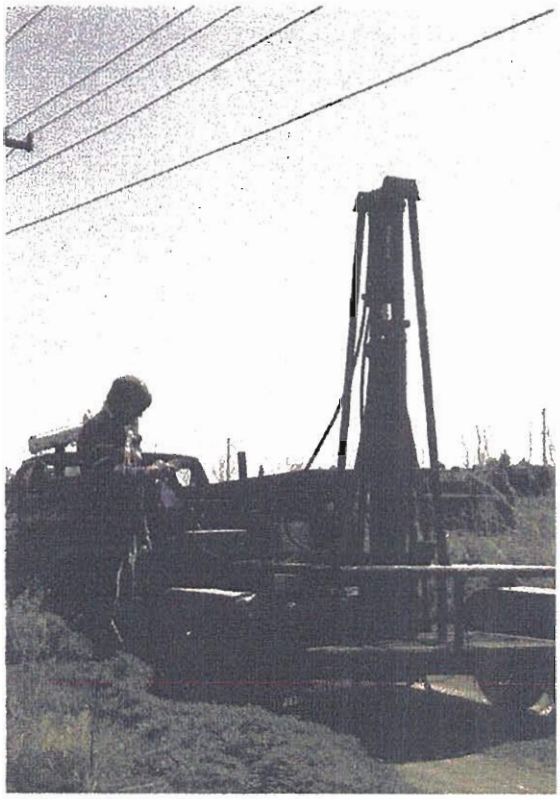


FIGURE 3. Location map in southwest Boise for the seismic reflection profiles and selected water wells. Inset map shows a 3-D perspective of the seismic profile and highlights the Boise benches.

the opportunity to collect straight seismic lines through an urban corridor in southwest Boise. Access for seismic reflection studies can be very challenging through urban areas (e. g. , Liberty, 1998), where either expensive seismic sources (e. g. , vibroseis, air gun, or explosives) are required to overwhelm cultural noise and operate on city streets, or else creative right-of-way access (e. g. , railroad line, irrigation canal lines) must be employed to gain access and to minimize cultural noise. The UPRR line provided this relatively quiet, straight-line access with a single land-access permit.

Railroads are often built up on a level grade to minimize topographic effects for rail traffic. Unfortunately the artificial grade can reduce source and receiver coupling and can also produce significant near-surface lateral velocity contrasts due to varying degrees of compaction. We present a noise test gather in Figure 4 that shows the high-quality of the seismic reflection data on a shot gather record. After initial field tests to optimize acquisition parameters for production seismic work and to test the validity of using the railroad easement for seismic profiling (Liberty and Wood, 2000), we acquired data along the UPRR using a trailer-mounted accelerated weight drop source (Figure 4) designed and built at

Boise State University. We used a 5-m source and receiver station spacing with a 120-channel Geometrics seismograph to produce a 60-fold seismic reflection section (Figure 5a). We used 10-Hz geophones, a 0. 5 ms sample rate, and recorded for 1 second. The



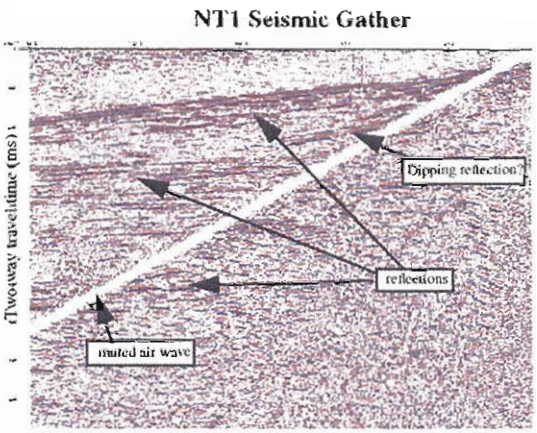


FIGURE 4. (A) The trailer-mounted seismic source used for the seismic reflection project. (B) Annotated shot gather from site NT1 along the downtown railroad spur near Orchard Road. Processing includes f-k and 40-150 Hz spectral whitening filters and air wave mute and shows the data quality of the raw field records.

initial field tests suggested that we could compensate for poor coupling and busy street crossings (up to 5 lanes at 55 m. p. h.) with high fold (redundancy of subsurface mid-points at varying source/receiver offsets) and that we also must pay special attention to static corrections during processing to address the large near-surface lateral velocity changes. In addition, due to excessive noise along portions of the profile, we crossed many busy streets (Table 1) and high noise areas at off hours (evenings and early mornings). A detailed topographic survey with a Topcon total station, coupled with GPS positioning, provided detailed elevation measurements to account for the near-surface static effects. Due to difficulties with access along the spur line, coupled with the poor signal quality from the observed data, only the main railroad profile is presented in this report.

TABLE 1. TVHP Main RailRoad Seismic Line Road Crossings

Location along UPRR	*CDP (internal use)*	Relative Distance (m)
Hartman Road	*4686-4692*	472. 5
canal	*4738-4742*	600
Liberty Street	*4768-4772*	675
Allumbaugh Street	*4928-4934*	1078
Bethel well (projected location)		1700
Cole Road	*5182-5196*	1725
I-80 Overpass	*5240*	1850
Milwaukie Road	*5412-5428*	2300
Benjamin Road	*5638-5646*	2855
Maple Grove Road	*5832-5844*	3345
Maple Hill well (projected location)		3375
Canal	*5898-5912*	3515
Five-mile Road	*6486-6496*	4980
Cloverdale Road	*7138-7146*	6605
Edgeview well (projected location)		6700
St Lukes well (projected location)		8200
Eagle Road	*7794-7806*	8250

4.2 Seismic Processing

We processed the seismic data with Landmark's ProMAX seismic processing software. This software is an oil-industry standard for seismic reflection processing. The basic processing steps are summarized in Table 2. We paid special attention to velocity and static complexities. The high fold and close station spacing enabled us to image detailed structural and stratigraphic information along the length of the UPRR profile.

TABLE 2. Basic processing steps included in the seismic reflection stack

Processing Step	**Comments**
Read raw data	SEGY data from seismograph
Apply geometry	From Topcon total station
Spectral shaping filter	30-150 Hz pass band
Kill bad traces	road crossings, bad channels
Apply Mutes	Ground roll and other coherent noise removal
Apply elevation statics	correct for changes in topography for each source and receiver
Sort to CMP	Place traces in correct spatial position (60 fold)
Normal Moveout Correction	Correct for subsurface velocity variations
Apply residual statics	Correct for near-surface velocity anomalies
CMP Stack	Find the mean of all traces for each common mid-point
F-K migration	Place reflections in the proper spatial position to account for dip

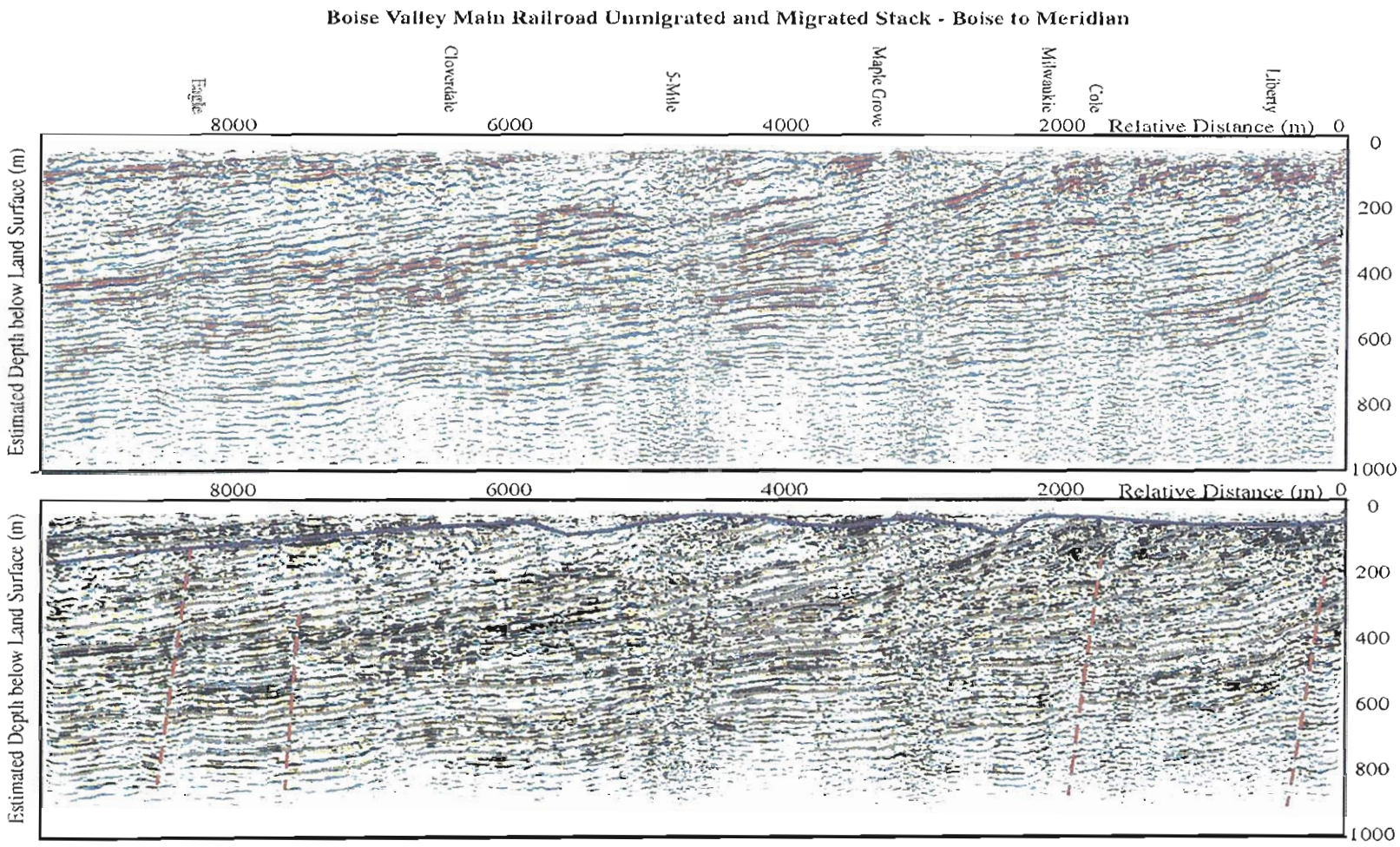


FIGURE 5. Main UPRR unmigrated and migrated seismic reflection profile. Vertical exaggeration ~2:1.

5.0 Discussion

The UPRR seismic data record a similar signature when compared to Chevron Profile IB-2 (Figure 2). However, we recorded reflections from approximately 20 m BLS and extending to upwards of 900 m depth (Figure 5). Although we acquired the seismic profile oblique to the primary dip direction in the basin (but parallel to the Chevron profile), we observe reflections with dips up to 10 degrees and numerous lateral breaks in seismic continuous seismic reflections. High quality data appear along most of the profile with the exception of the Fivemile and Maple Grove road crossings. These were the only two major road intersections that we did not cross at off hours and data quality suffered as a result.

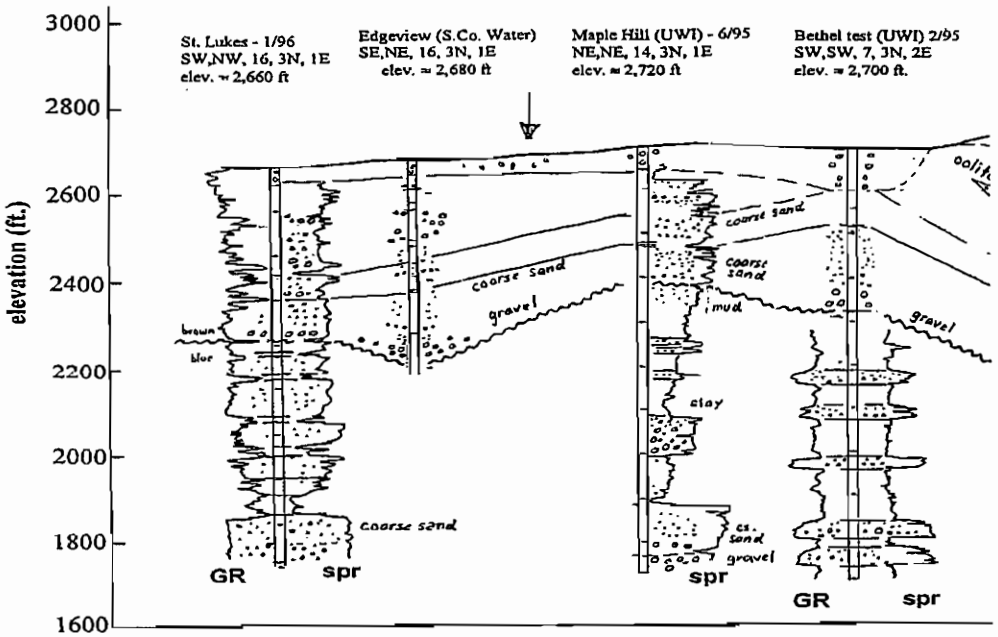


FIGURE 6. Four local wells near the UPRR seismic profile with inferred connection between aquifer units. The coarse-grained and finer-grained sediment contact correlates with the interpreted unconformity on the UPRR seismic section.

We present two views of the UPRR profile in Figure 5. We show the unmigrated seismic profile and the migrated seismic profile. The unmigrated seismic section helps locate faults due to the presence of diffractions (or overlapping reflections) from the edges of reflecting boundaries. The migrated seismic profile places each dipping reflection in the proper spatial position (assuming 2-D structures) and removes the effects of diffractions from abrupt lateral boundaries. We displayed each section in color to easily trace lateral seismic reflection packages. We also overlay black lines for large-amplitude signal on the migrated section to more easily interpret structural and stratigraphic patterns. Depths were calculated by converting sonic (interval) velocity measurements from the nearby

Higginson well to stacking velocities that can directly be applied to observed travel time measurements of seismic reflection data.

The overall pattern of the UPRR profile typifies a prograding delta sequence with basin extension (e. g. , Wood, 1994). Steep dips and fault offsets are common, but the faults do not appear to cut the surface. Reflections can be laterally traced for many km, suggesting that the lacustrine deposits are mappable for great distances and are preserved in-situ. Localized arcuate reflection packages in the upper portion of the section likely represent fluvial channels that have cut the lacustrine sediments (see Figures 7 and 8). These fluvial channels may be good aquifers and should be considered a target for future water wells. Also in the upper portion of the section is a clear unconformity that we inferred from nearby water wells (Figures 3 and 6) prior to seismic acquisition. Locations are projected onto the seismic section on Figures 7 and 8. This unconformity separates reflections from differing dips and represents a change from deep water deposition to shallow water fluvial and lacustrine deposition, as is noted on the geophysical and lithologic wells on Figure 6.

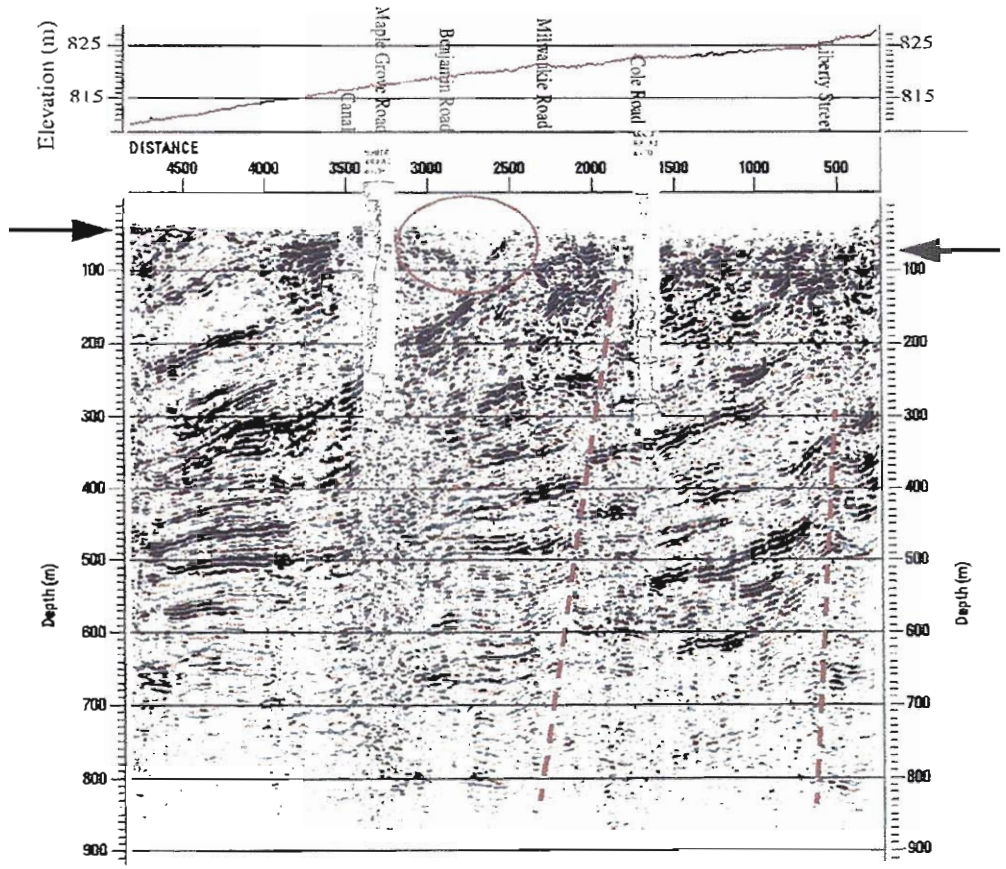


FIGURE 7. Migrated seismic reflection section with nearby well logs (locations on Figure 3) from the eastern portion of the UPRR railroad. Note the presence of faults (red dashed) and an unconformity (bounded by arrows) in the upper 50-100 m BLS with an interpreted sand channel (red circle). The zone above the unconformity correlates with a coarse-grained sand sequence that appears in the two wells. Vertical exaggeration ~4:1.

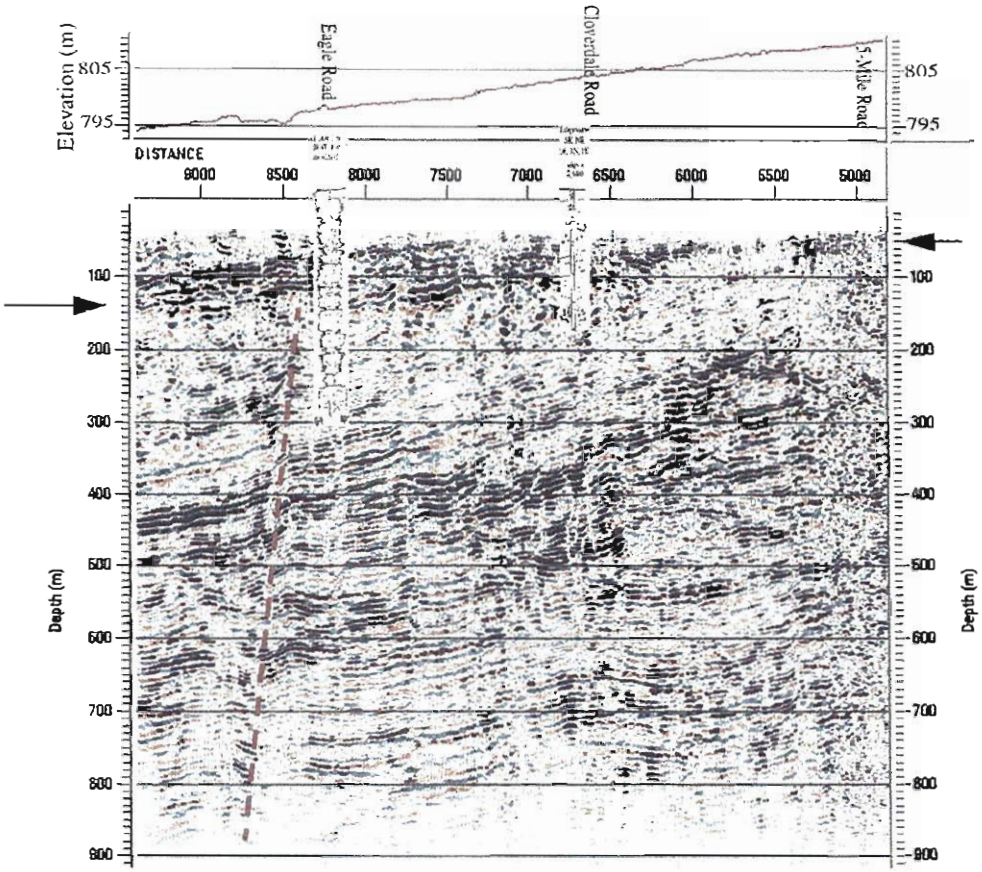


FIGURE 8. Migrated seismic reflection section with nearby well logs (locations on Figure 3) from the western portion of the UPRR railroad. Note the presence of faults (red dashed) and an unconformity (bounded by arrows) in the upper 150 m BLS. The zone above the unconformity correlates with a coarse-grained sand sequence that appears in the two wells. Vertical exaggeration ~4:1.

6.0 Conclusions

We show that seismic reflection methods are well suited for mapping stratigraphy and structure on both a basin scale and aquifer scale to better understand the framework for groundwater flow in the WSRP. We also show that we can map hydrostratigraphic and structural details with the UPRR seismic reflection section and when combined with regional well logs, we can map discrete lithologic sedimentary packages to better understand the depositional history of the sediments beneath Boise. The seismic reflection data show structural and stratigraphic details that well log information cannot solely provide and that the seismic reflection data provide key insights to mapping hydrostratigraphy in the western Snake River Plain.

7.0 Acknowledgments

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TREASURE VALLEY WATER SUMMIT

Treasure Valley's Water Future

Summary of the Treasure Valley Water Summit, January 14-15, 2002

Compiled by:

Community Planning Association of Southwest Idaho
Idaho Department of Water Resources
Idaho Water Resources Research Institute
EnviroIssues, Inc

May 15, 2002

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Executive Summary

Water is a defining element of the Treasure Valley. On January 14 and 15, 2002, more than 300 people participated in the Treasure Valley Water Summit, a community-wide discussion about Treasure Valley water issues. Topics focused on the current state of our water resources, the potential effects of population growth on water resources and strategies for planning a water future. Participants included citizens, elected officials, federal, state and local government scientists, planners and engineers, representatives of agriculture and industry, private developers and legal professionals. In April 2002, the Summit results were presented to valley decision-makers.

Summit speakers and participants identified the issues and recommendations outlined below. In addition to issue-specific recommendations, participants called for strategies that enhance collaboration in all areas of water planning. The next step will be to begin incorporating recommendations in urban planning and water management efforts.

Future Water Supply
Goal: Provide a sustainable supply of high quality water for domestic, commercial, municipal, industrial and irrigation users for the foreseeable future without causing unintended adverse impacts to the basin hydrology.
Recommendations: Use collaborative relationships established in past studies and current planning initiatives to evaluate options for meeting future water needs. Facilitate more efficient and less costly transfer of existing water rights.
Effects of Urbanization
Goal: Manage urbanization to minimize adverse hydrologic impacts to Treasure Valley water resources and uses.
Recommendations: Develop a better understanding of the impacts of urbanization on water resources. Develop policies and requirements for community septic systems and wells, drainage, and landscape watering to protect water resources.
Growth and The Boise River
Goal: Preserve and protect the Boise River and its environs as a multiple-use asset for our communities and future generations. Minimize risk of damage from flooding, with respect for private property rights.
Recommendations: Fund, develop and implement a collaborative multi-objective master plan for the Boise River corridor to address flooding, open space, recreation, habitat and land use in the river corridor. Develop mechanisms to preserve open space and critical sensitive areas in the flood plain to protect flood storage, habitat and wetlands. Improve access to support growing demand for recreation.
Ground and Surface Water Quality
Goal: Protect and improve ground and surface water quality to support domestic, commercial, municipal, industrial, recreation and fish and wildlife uses as required by law and to support present and future water uses.
Recommendations: Expand and improve data collection. Develop and implement local policies and requirements related to storm water management, septic tanks, infill development and protection of drinking water supplies to protect ground and surface water quality. Identify and coordinate funding for implementation. Improve well construction standards and ensure that wells no longer in use are properly abandoned.
Public Outreach and Education
Goal: Provide information in a variety of ways to ensure the public and stakeholders are informed about the importance, character and condition of Treasure Valley water resources and water issues.
Recommendations: Develop and implement a coordinated multi-agency public education and outreach plan to inform key audiences about water issues.

Introduction

Water is a defining element of the Treasure Valley. Adequate amounts of high quality water to meet the needs of irrigation, domestic, commercial, municipal and industrial users, recreation, and fish and wildlife, as well as flows managed to minimize flood risk, are key to our economy and quality of life. What is the current state of our water resources? How will population growth affect water and how will water influence growth?

More than 300 people participated in a community-wide discussion about Treasure Valley water issues on January 14 and 15, 2002 and about 80 people attended a follow-up discussion for decision makers. Participants in the Treasure Valley Water Summit included citizens, elected officials, federal, state and local government scientists, planners and engineers, representatives of agriculture and industry, private developers, and legal professionals. The Summit agenda is included in Appendix A.

The purpose of the Summit was to help participants chart a more informed course for decisions affecting our water future as the Treasure Valley moves into the 21st Century. The summit included:

- An overview of the character, use and condition of water resources;
- Reports on recent technical findings related to ground and surface water;
- Discussions of current and future water supply and management issues and the technical and policy implications of water management options; and
- Identification of priority issues and actions for protecting and enhancing the Boise River.

This report summarizes presentations and participant discussions related to Treasure Valley's water future.

Treasure Valley Growth

Between 1990 and 2000 the Boise metropolitan area, which includes most of Ada County, Caldwell, and Nampa, was the seventh fastest growing metropolitan area in the country. By 2020, population in Ada and Canyon Counties is expected to be around 650,000. The number of households is expected to increase by 52%, from 158,000 in 2000 to 241,000 in 2020. Population growth will inevitably impact water resources in the valley and water resources will influence growth. Recent growth tends to be at higher than comprehensive plan densities outside of impact areas, and equal or lower than comprehensive plan densities inside impact areas. Development outside impact areas means more wells withdrawing water from the shallow aquifer, more individual septic systems and possible changes to aquifer recharge. As development decisions are made, we need to understand how patterns of development will affect our water resources.

Water for domestic, commercial, municipal and industrial uses in the Treasure Valley comes largely from ground water, whether delivered by a public water supplier or withdrawn from a private well. The Idaho Department of Water Resources estimated that in 1998 we used 33.6 billion gallons (103,000 acre-feet[1]) of water for domestic, commercial, municipal and industrial purposes. Water demand is expected to increase between 74 and 93 percent in the next 25 years. That means we need between 76,000 and 96,000 acre-feet of water to satisfy new water demand.

In Idaho, planning and management decisions that affect our water resources are the responsibility of federal, state and local government agencies; special purpose districts for flooding, irrigation, drainage,

[1] An acre-foot is the volume of water that covers one acre (43,560 square feet) one foot deep.

sewer and water; businesses; and individual citizens managing water on their own property. Successful planning for the future requires a collaborative effort among all these groups.

Surface and Ground Water Resources

Treasure Valley is located in the lower part of the Boise River basin, below Lucky Peak Dam. Average annual snow pack for the entire basin is about two million acre-feet of water per year. About one million acre-feet of annual runoff is stored in three reservoirs – Anderson Ranch, Arrowrock and Lucky Peak. The rest is consumptively used or flows out of the basin. The US Bureau of Reclamation, Water District 63, and the US Army Corps of Engineers, manage storage and natural flows for irrigation, flood control, power generation and winter in-stream flows in the Boise River. About 40,000 acre-feet of storage water is released in the summer to augment flows for endangered salmon. The timing and volume of flows varies widely from year to year. Generally, water managers decrease peak flood flows in the spring and increase flows in the summer for irrigation deliveries. Boise River water is distributed throughout the valley by more than 2000 miles of irrigation canals and laterals. Excess irrigation water infiltrates to ground water or returns to the Boise River via drains and natural waterways.

Much of the Treasure Valley is underlain by shallow aquifers (generally less than 250 feet deep), which supply water for rural, domestic, irrigation and some municipal wells. These aquifers are recharged largely by infiltration from flood-irrigated fields and canal seepage. Shallow aquifers are underlain by deeper regional aquifers. Deeper aquifers commonly supply water to irrigation, municipal and some domestic wells ranging in depth from about 300 to over 1,100 feet. In most areas this regional ground water system is separated from shallow aquifers by interbedded clay zones. A geothermal aquifer, which supplies heat for buildings and greenhouses, underlies the deeper cold water system in parts of the valley.

More than 15,000 wells draw about 200,000 acre-feet of water per year from Treasure Valley aquifers. Despite these withdrawals, ground water levels have remained relatively constant in most areas. Two areas – southeast Boise and an area south of Lake Lowell – have experienced substantial declines in deeper aquifers, especially during drought years. Recent decreased pumping in southeast Boise appears to have stabilized ground water levels in that area.

Key Issues and Recommendations

A number of water issues were discussed at the Treasure Valley Water Summit. This section summarizes goals and recommendations for each issue, offered by speakers and participants during the course of the Summit. A more detailed list of recommendations is included in Appendix B. Summaries of speaker presentations are included in Appendix C.

The need for coordination and collaboration was a theme that ran through many of the presentations and recommendations. Speakers and participants alike stressed the need for agency coordination, collaborative problem solving, and meaningful stakeholder involvement in urban and water planning.

Issue 1: Future Water Supply

Goal: Provide a sustainable supply of high quality water for domestic, commercial, municipal, industrial and irrigation users for the foreseeable future without causing unintended adverse impacts to the basin hydrology.

Background

An additional 75,000 to 95,000 acre-feet of water will be needed to supply water for Treasure Valley growth in the next 25 years. While there is enough water in the basin to meet these needs – about 1 million acre-feet leave the basin each year – the water is not always available at the time and location of need. Surface water supply is fully appropriated above Star, most storage water in reservoirs is appropriated for irrigation, and ground water supplies are fully utilized in the eastern part of the basin. Today most municipal water supplies come from the deep aquifer and most individual wells withdraw from the shallow aquifer. Future users will likely need to rely more on surface water.

In much of the basin, the ground water and surface water systems are closely interconnected. The Idaho Department of Water Resources is considering strategies for conjunctive administration of ground and surface water (water rights would be administered without regard to source). This could result in limits on ground water use or mitigation requirements when withdrawals adversely impact a senior surface water right.

Recent multi-agency collaborative studies of future water needs, ground water flow characteristics, water quality, and land use changes have provided valuable new information. These studies provide a sound technical basis for the next stage of water planning.

Recommendations

- Conduct a comprehensive hydrologic, institutional, economic and environmental evaluation of alternatives for meeting future water needs. Evaluate surface water storage (in-stream and off-stream), ground water storage (managed recharge and retrieval), transfer of existing storage and natural flow rights, conservation, recycling and reuse, opportunities to optimize reservoir operations and diversions from the Snake and Payette Rivers.

- Facilitate more efficient and less costly transfers of existing water rights, including broader use of market solutions.

Issue 2: Effects of Urbanization

Goal: Manage urbanization to minimize adverse hydrologic impacts to Treasure Valley water resources and uses.

Background

Most urban development in Treasure Valley is occurring on lands that were formerly irrigated agriculture. Over 100 years of irrigation has changed the Valley's hydrologic system. Ground water recharge from leaking canals and flood irrigation has raised water levels in the shallow aquifer from 10 to over 100 feet in some locations. Natural drainage ways that carried water for only a short time during rain storms and spring runoff have been deepened to provide conveyance for irrigation water and to drain excess ground water from adjacent lands. As these lands urbanize, possible effects include:

- Reduced recharge to shallow aquifers if less water is applied for irrigating landscaped areas;
- Reduced aquifer recharge from canal leakage if lawns are watered with ground water rather than surface water;
- Reduced aquifer recharge due to increasing amount of impervious surfaces;
- Increased flood risks and degraded surface water quality due to increasing impervious surfaces;

- Encroachment on irrigation canals and rights of way, complicating irrigation system operation and maintenance;
- Increased risk of ground water contamination resulting from the proliferation of individual wells and septic systems; and
- New challenges for water appropriation, management and delivery as irrigated lands become urbanized.

Recommendations

- Collect and analyze data to accurately characterize the hydrologic impacts of urbanization.
- Require careful accounting of water use before and after development.
- Use irrigation and gray water for landscape watering to conserve high quality ground water supplies for drinking water.
- Require community wells and community septic systems in higher density developments outside municipal service areas.
- Adopt drainage policies that promote ground water infiltration and improve surface water quality.
- Conduct public education to increase individual stewardship and improve understanding of irrigation system needs.
- Encourage partnerships between communities and irrigation entities to solve challenges resulting from urbanization adjacent to irrigation conveyance systems.

Issue 3: Growth and The Boise River

Goal: Preserve and protect the Boise River and its environs as an important multiple-use asset for our communities and future generations. Minimize risk of damage from flooding, with respect for private property rights.

Background

The Boise River is an enormous asset for the Treasure Valley, supplying water for irrigation and other uses, providing recreation and development opportunities, aesthetic beauty and habitat for fish and wildlife. In 1965, the Boise River was the second most polluted river in Idaho. Twenty years later, the Boise River had become the most recreated river in Idaho. Each summer more than 300,000 people use the river between Barber Park and Eagle, and use is increasing each year. The river is also highly valued for development. As development along the river continues, natural values are impacted, and the risk of flood damage and cost of channel maintenance increases significantly.

The upstream reservoirs have provided a sense of safety resulting in increased development in the floodplain. However the existing storage system can only handle small to medium sized floods. The experiences of other communities show a pattern of development along the river, triggering protection and flood control projects, followed by more development in the river corridor. A typical response is to resort to vegetation management, riprap and channelization to protect property. However, experience elsewhere has shown that flood control projects often fail in a big flood. The impacts of a 100-year flood in the Treasure Valley could be economically devastating.

Recommendations

- Fund development of a multi-agency, multi-objective master plan for the Boise River corridor. Involve landowners, developers, and farmers in planning. The plan should:
  - address access, flooding, land use in the floodplain, open space, recreation, riparian habitat and gravel pit rehabilitation;
  - identify opportunities to reduce risk to citizens from flooding;
  - identify important resources associated with the River (habitat, flood storage areas, etc);
  - develop strategies for protecting important resources and enhancing resources that can be enhanced;
  - involve agencies, landowners, recreation interests and irrigators in developing a multiple use strategy for stream channel management; and
  - complement polices and recommendations in the Idaho Department of Water Resources comprehensive basin water plan.

- Adopt ordinances in individual jurisdictions to implement the plan.

- Use a variety of tools (e.g. conservation easements and setbacks) to preserve open space and critical sensitive areas in the flood plain to protect habitat, flood storage and wetlands. Develop economic incentives for landowners who protect and enhance high priority resources identified in the master plan.

- Improve existing and develop new access areas to support the growing demand for recreation opportunities, with an eye to protecting sensitive resources.

Issue 4: Ground and Surface Water Quality

Goal: Protect and improve ground and surface water quality to support domestic, commercial, municipal, industrial, recreation and fish and wildlife uses as required by law and to support present and future water uses.

Background

The Department of Environmental Quality has determined that sediment and bacteria are present in concentrations that impair beneficial uses in the Boise River and Indian, Blacks, Mason, Fivemile and Tenmile Creeks (bacteria is impairing recreation in all; sediment is impairing aquatic life in the Boise River and Indian Creek). The Department has also found that phosphorus from the Boise River watershed is contributing to impairment of the Snake River and Brownlee Reservoir. Cleanup plans that establish targets and proposed implementation strategies are underway or complete for most of these pollutants. In the Treasure Valley, agriculture and local governments will be responsible for accomplishing most of the pollutant reductions required to meet the targets.

Ground water in the Treasure Valley has been impacted by petroleum from leaking underground storage tanks, industrial solvents, inorganic contaminants from wastewater land application facilities, and nutrients, particularly nitrate, from non-point sources. The Department oversees responsible parties who are compelled to cleanup releases from underground storage tanks, industrial sites and wastewater treatment facilities.

Protecting our high quality water supply is extremely important. Currently about 95% of Treasure Valley drinking water comes from ground water. Large suppliers generally draw water from the deep aquifer and private domestic wells draw from the shallow aquifer. Careful management of potential pollution sources, including land use activities, can protect our water supply for the future. Similarly, proper well construction helps to prevent the introduction of pollutants to aquifers.

Recommendations

Surface Water

- Expand and improve surface water quality data collection. Use data to define attainable goals, better understand factors affecting water quality and evaluate progress.
- Provide coordinated funding, market-based incentives and better information on practices to improve surface water quality.
- Task executive agencies with improving coordination of the implementation of laws and regulations related to surface water quality.
- Develop and implement specific plans for local communities and rural urbanizing areas to reduce sediment and bacteria load to impaired streams.

Ground Water

- Expand and improve ground water quality data collection. Use data to better understand ground water quality trends and problem areas.
- Establish requirements for community septic systems and wells.
- Develop and implement local protection plans for important sources of drinking water (known as wellhead protection or source water assessment plans).
- Develop policies and ordinances that promote infill development to take advantage of public water supply and wastewater treatment facilities.
- Strengthen well construction requirements and oversight, especially for wells that intersect more than one aquifer.

Issue 5: Public Outreach and Education

Goal: Provide appropriate information in a variety of ways to ensure the public and stakeholders are informed about the importance, character and condition of Treasure Valley water resources and water issues.

Background

Many presentations and virtually every discussion group at the Treasure Valley Water Summit noted the need for a more informed public. Key audiences include the homeowners, public officials and decision-makers, stakeholders and the general public. Participants believe these audiences need to be more informed about water supply concerns, conservation, activities that cause pollution, and flood risk, and the effects of urbanization and flood plain development, to name a few. An informed pubic is better able to manage their individual activities and effectively participate in dialogue about public policy decisions.

Recommendations

- Develop a coordinated multi-agency public education and outreach plan to inform key audiences about water issues. Agencies and organizations would agree to take responsibility for specific elements of the plan, consistent with their authorities and interests.

- All governments and organizations should increase their public information and outreach activities consistent with the multi-agency outreach plan.

Strategy for Moving Forward

The next steps will be to develop consensus and mobilize resources for collaborative efforts to address the most important issues and to incorporate recommendations in urban planning and water management efforts. On April 4, 2002 Treasure Valley decision makers met to consider the major recommendations from the Water Summit and identify priority work areas for the near future. Participants in the workshop identified the following priorities:

1. **Develop a collaborative master plan for the Boise River corridor.** The plan should engage a wide group of stakeholders to address river issues associated with growth, with particular emphasis on flooding. The plan should seek multi-objective solutions that address access, flooding, land use in the floodplain, open space, recreation, water quality, riparian habitat and gravel pit rehabilitation.

2. **Develop water management recommendations for local governments based on the best current information.** Our water resources will be managed most effectively if entities making decisions that affect water resources work toward common outcomes. Local governments should be partners with state and federal water management agencies, seeking to impact water resources with a common set of objectives.

3. **Develop a strategy for enhanced collaboration** among entities with water management authorities and interests.

4. **Conduct a comprehensive public information and education campaign** about water issues in the Treasure Valley.

5. **Identify and evaluate long-term management options to meet future water demands.** Recent multi-agency collaborative studies of future water needs, and ground water flow characteristics have provided valuable new information. Build on these efforts and use the Idaho Water Resource Board's current planning process to evaluate the hydrologic, institutional, economic and environmental impacts of alternatives for meeting future water needs. Evaluate surface and underground storage, transfer of existing storage and natural flow rights, conservation, recycling and reuse, opportunities to optimize reservoir operations and diversions from the Snake and Payette Rivers.

Appendix A: Agenda for the Treasure Valley Water Summit, January 14-15, 2002
Appendix B: Key Water Issues and Recommendations from Participant Small Group Discussions
Appendix C: Summary of Speaker Presentations
Appendix D: Recommendations from April 4, 2002 Follow Up Water Summit Meeting