

IN THE MATTER OF PERMITS TO
APPROPRIATE WATER
NOS. 63-34079 & 63-34080,
IN THE NAME OF CHRIS EMMERT

Protestant
Boise Project Board of Control's Hearing
Exhibits
April 6, 2017

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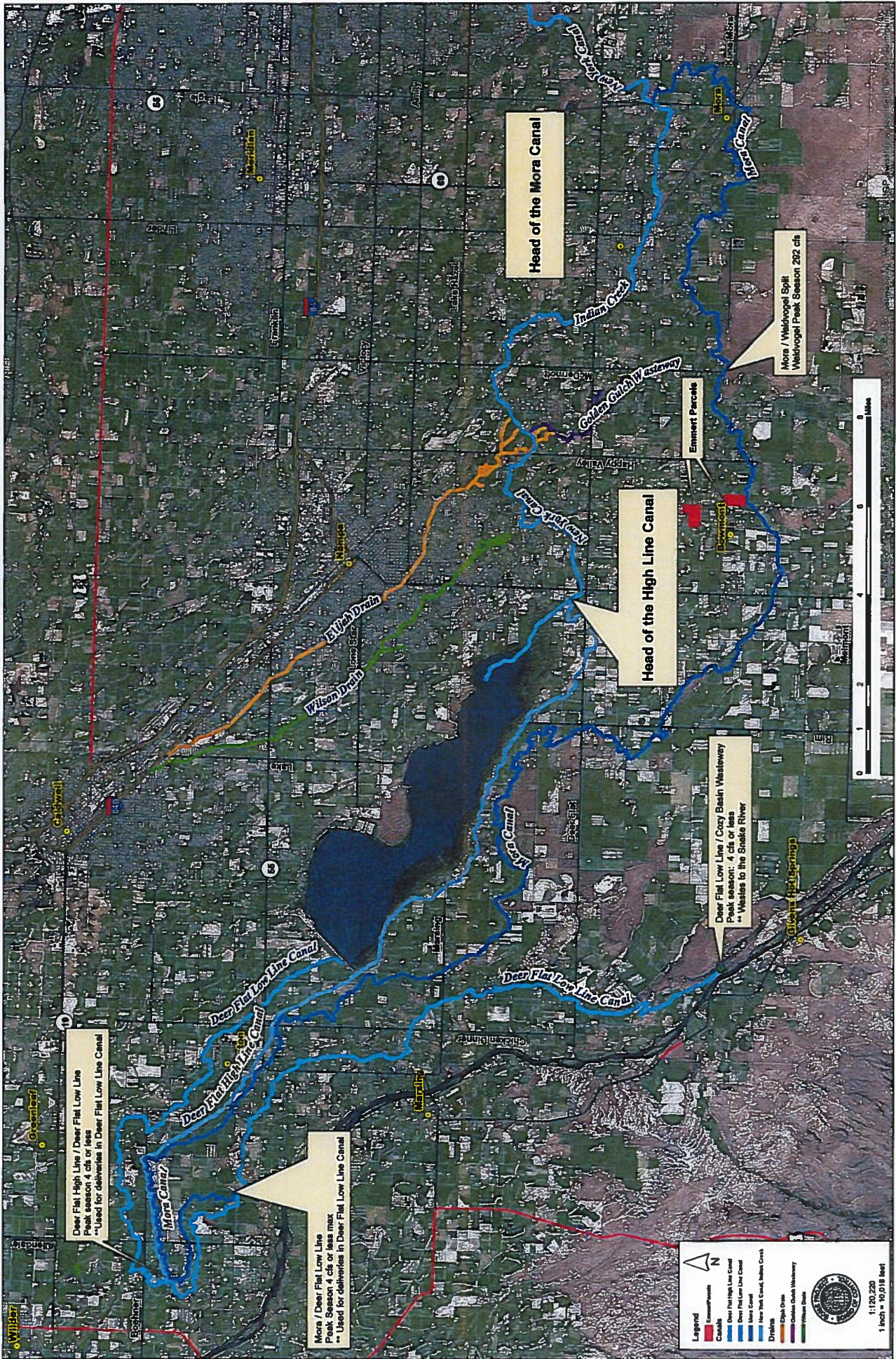
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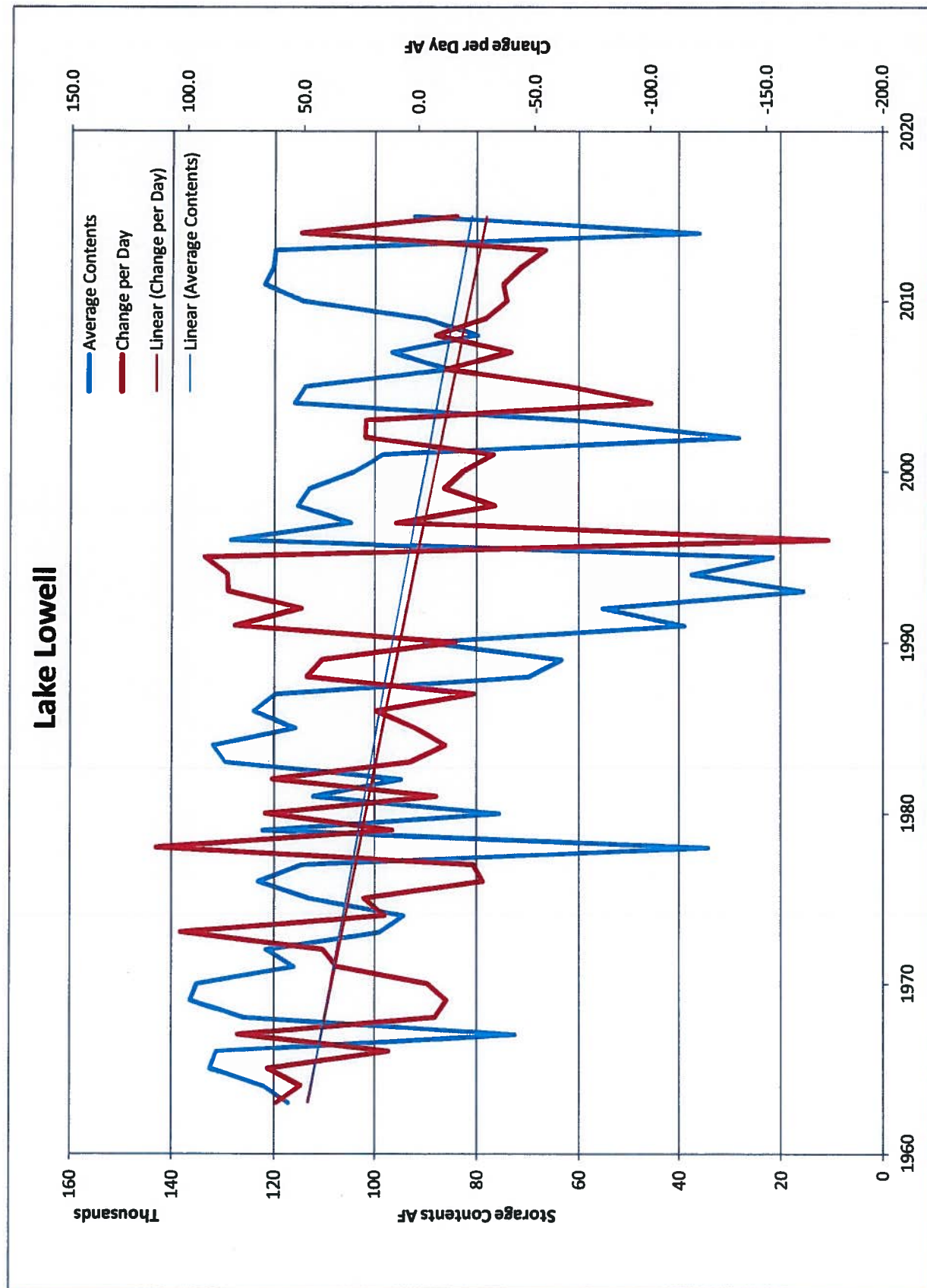
IN THE MATTER OF PERMITS TO APPROPRIATE WATER NOS. 63-34079 & 63-34080, IN THE NAME OF CHRIS EMMERT

Boise Project Board of Control

Exhibit List

Exhibit	Description	Witness	Admitted
101	Chris Emmert Application for Permit No. 63-34079		
102	Boise Project Board of Control's Notice of Protest to Application for Permit No. 63-34079		
103	Chris Emmert Amended Application for Permit No. 63-34080		
104	Boise Project Board of Control's Notice of Protest to Amended Application for Permit No. 63-34080		
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106	Simulation of Increased Ground Water Withdrawals in the Lower Boise River Basin by Christian R. Petrich		
107	Modeling Conjunctive Water Use as a Reciprocal Externality by R. D. Schmidt		
108	Modeling Drain Interactions with Shallow Groundwater in the Boise Valley, using Analytic Elements by R.D. Schmidt		
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110	Conjunctive Hydrologic Modeling Analysis of Proposed New Groundwater Pumping in the Boise Basin South of Lake Lowell by R.D. Schmidt		
111	Average Water Use per Acre Project Wide 1996-2016		
112	Analysis of Hydrologic Impacts of New Groundwater Pumping in the Dry Lake Area of Canyon County, Idaho by R.D. Schmidt		





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

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- Scott Urban (IDWR) provided initial model development assistance and prepared the recharge and withdrawal data for the base-case simulations.
- 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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Simulation Files (CD-ROM)

Simulation SS5e-min (minimum predicted head values)	CD-ROM
Simulation SS5e-max (maximum 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.

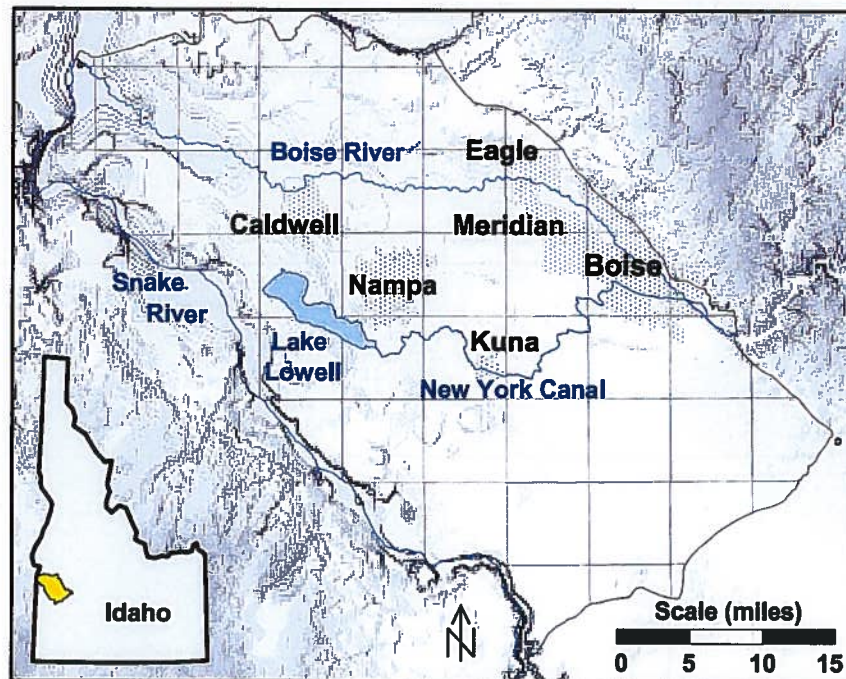


Figure 1-1: The lower Boise River basin and adjoining areas of southwestern Idaho.

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-supplemental¹ 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 water² 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 layers³ 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.

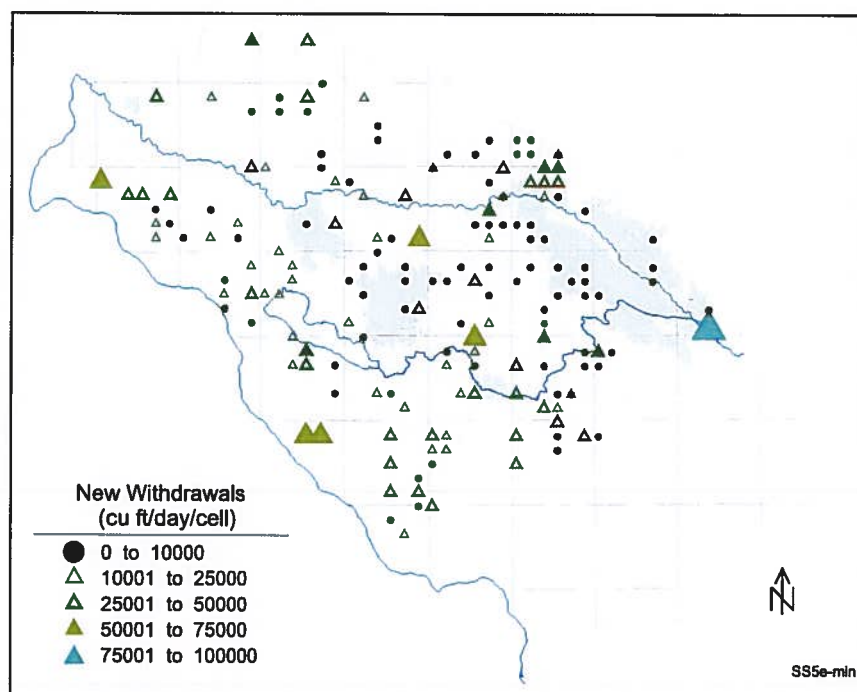


Figure 2-1: Distribution of estimated increased ground water withdrawals, layer 1.

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).

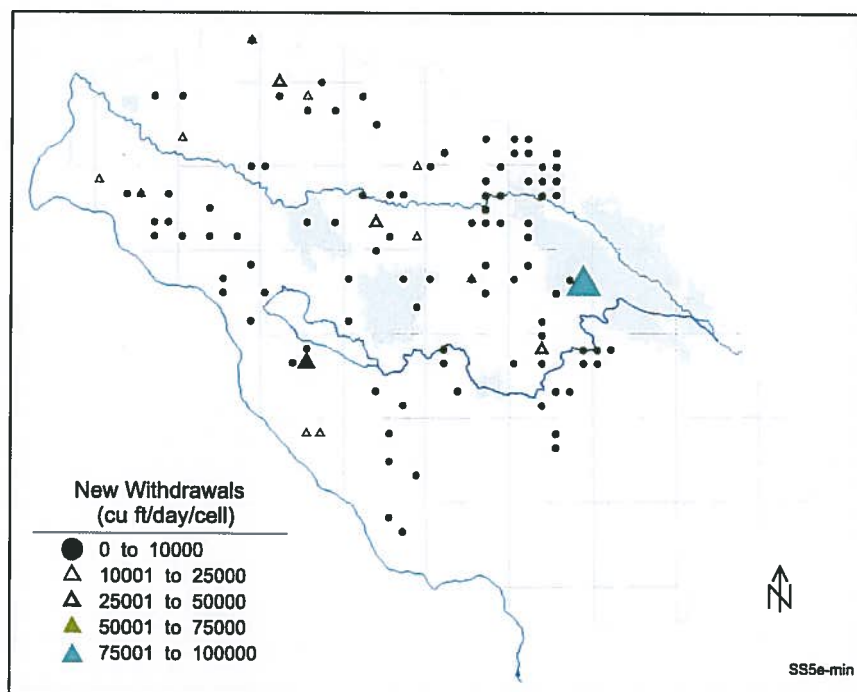


Figure 2-2: Distribution of estimated increased ground water withdrawals, layer 2.

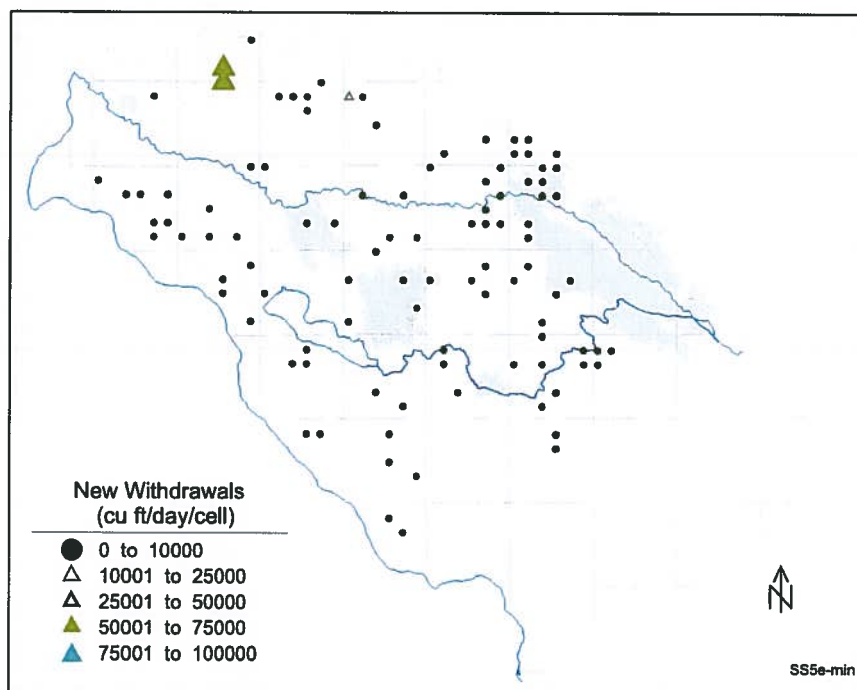


Figure 2-3: Distribution of estimated increased ground water withdrawals, layer 3.

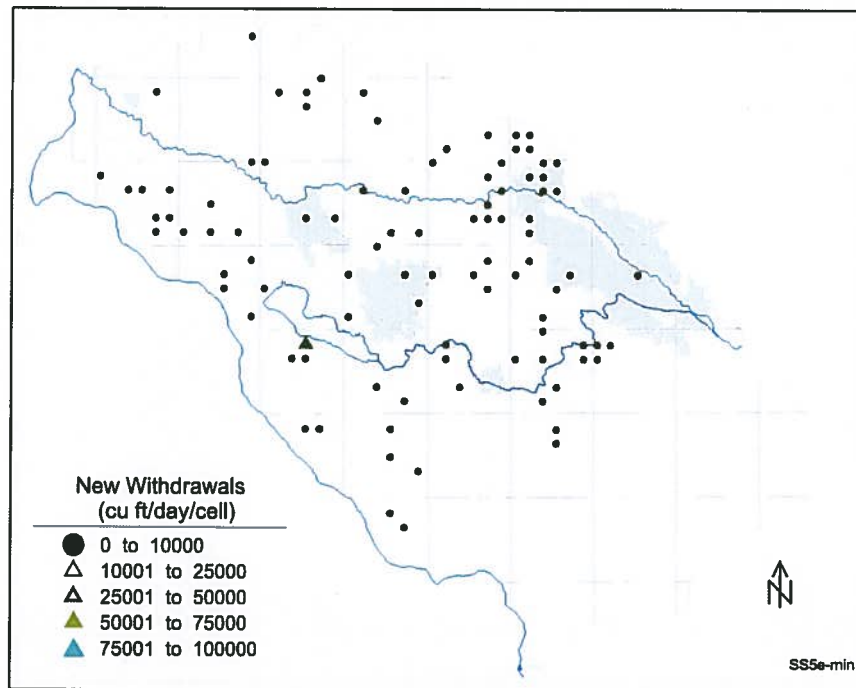


Figure 2-4: Distribution of estimated increased ground water withdrawals, layer 4.

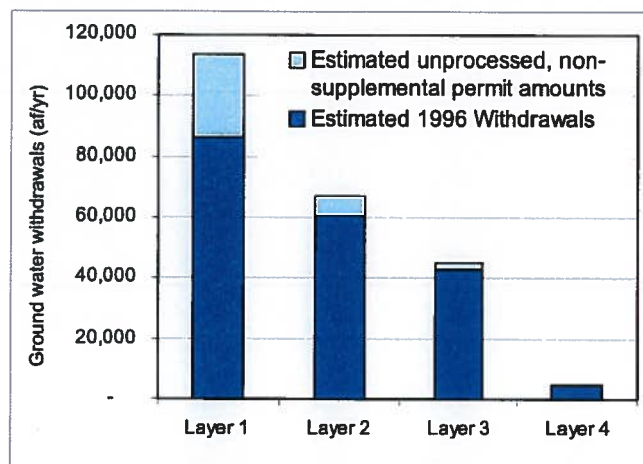


Figure 2-5: Estimated combined 1996 and unprocessed, non-supplemental permit withdrawals.

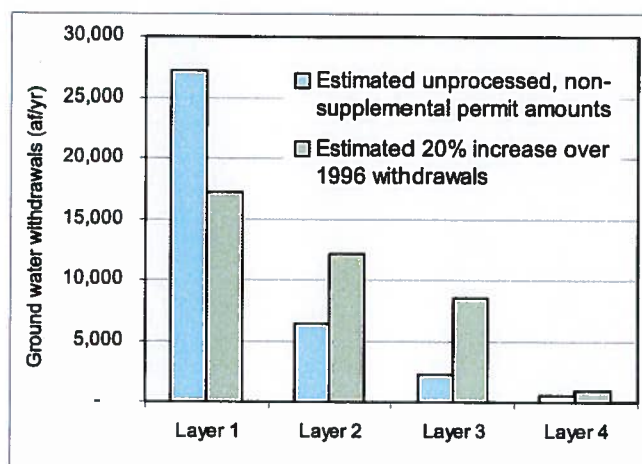


Figure 2-6: Comparison of estimated unprocessed, non-supplemental permit withdrawals and a 20% increase over estimated 1996 withdrawals (Petrich, 2004a).

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 River⁶ and Lake Lowell⁷), 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.

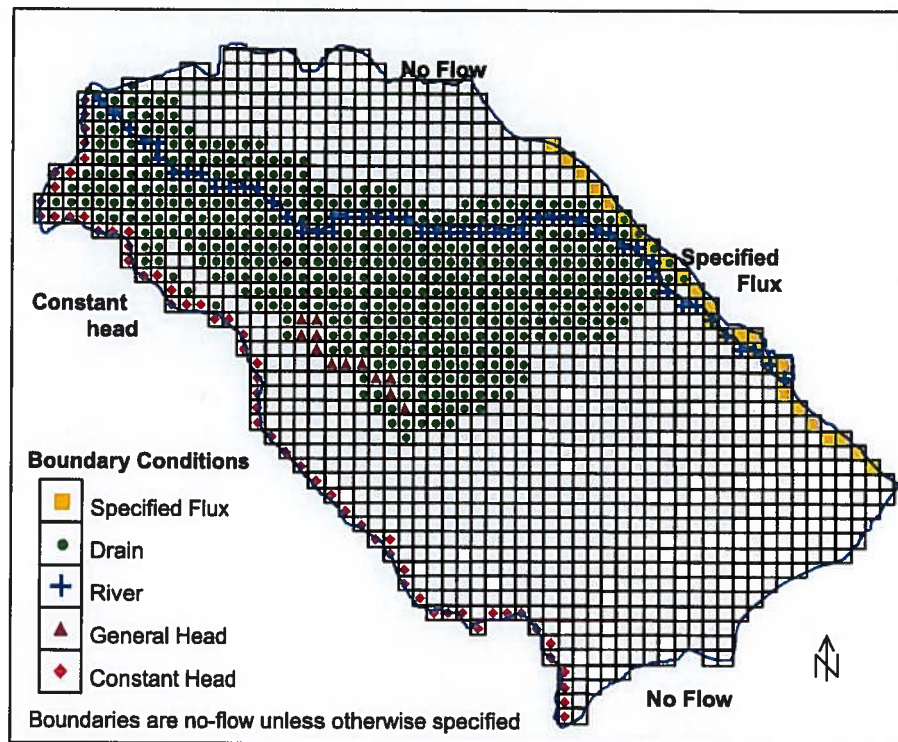


Figure 2-7: Model grid and boundary conditions.

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 point⁸ 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.

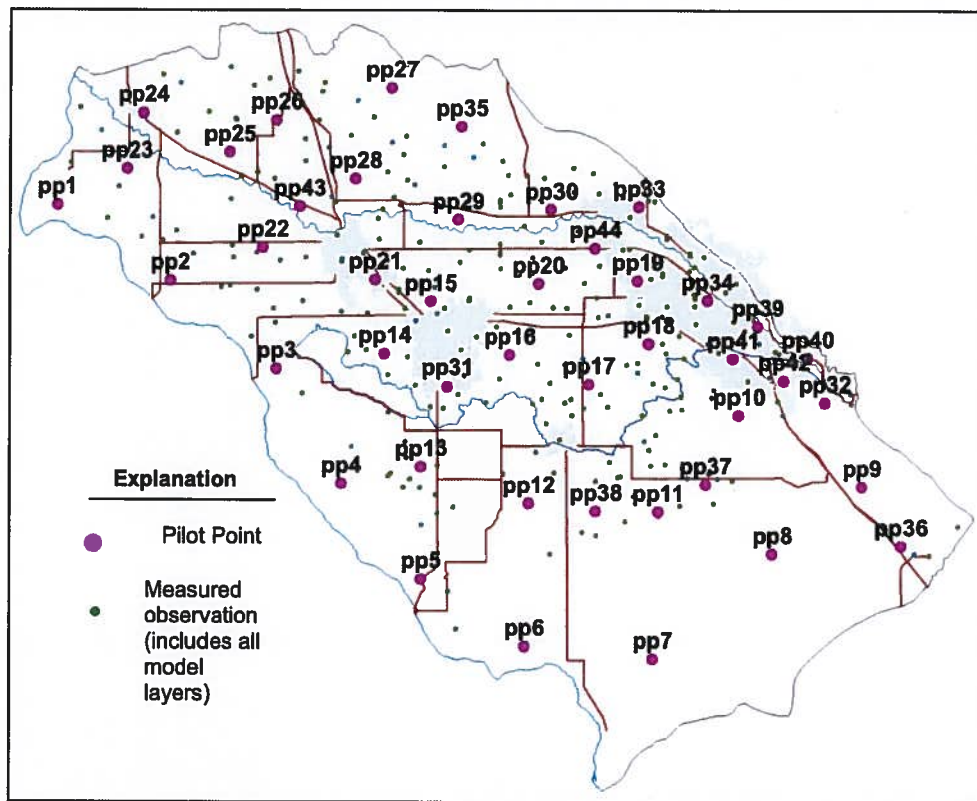


Figure 2-8: Pilot point locations.

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 (Petric, 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 points⁹. 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.

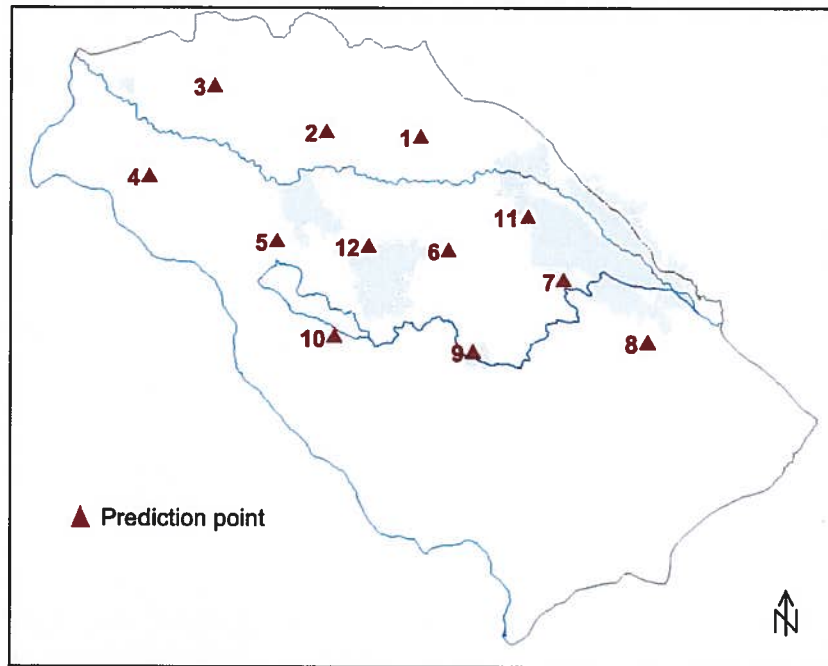


Figure 2-9: Prediction point locations.

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 (<i>see note below</i>)
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, outflows, 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).

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 absolute 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).

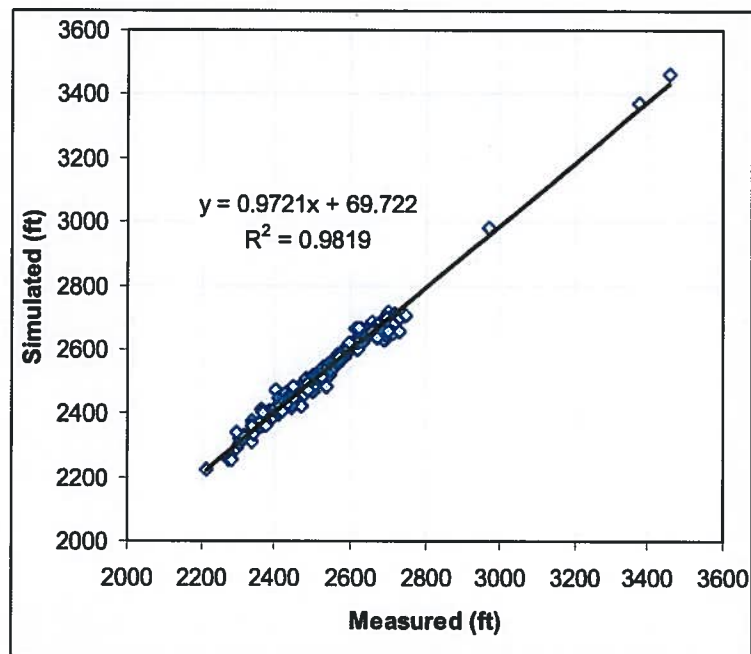


Figure 3-1: Simulated versus measured hydraulic head observations, steady-state hydraulic conditions (base simulation).

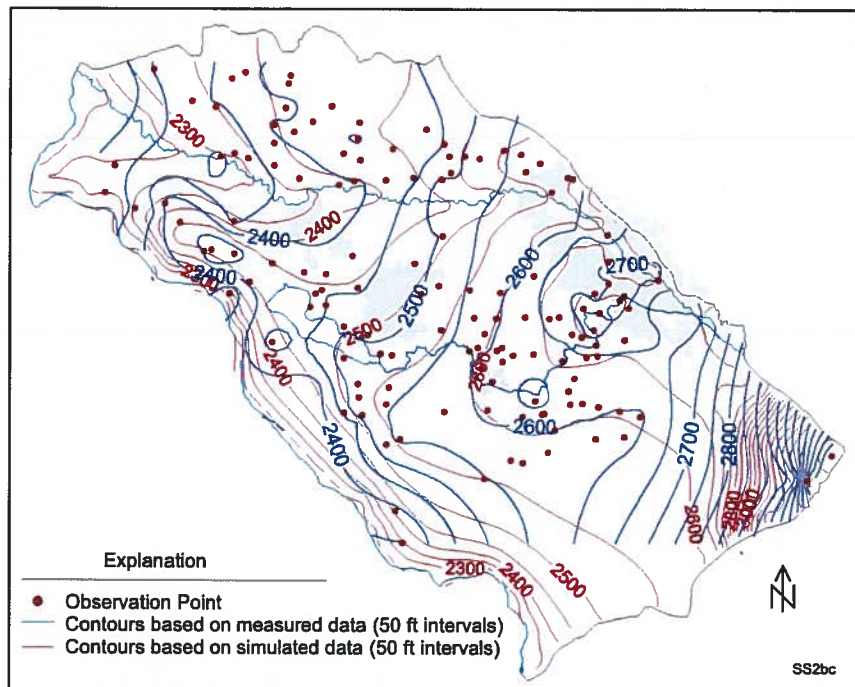


Figure 3-2: Simulated and observed potentiometric contours, layer 1 (base simulation).

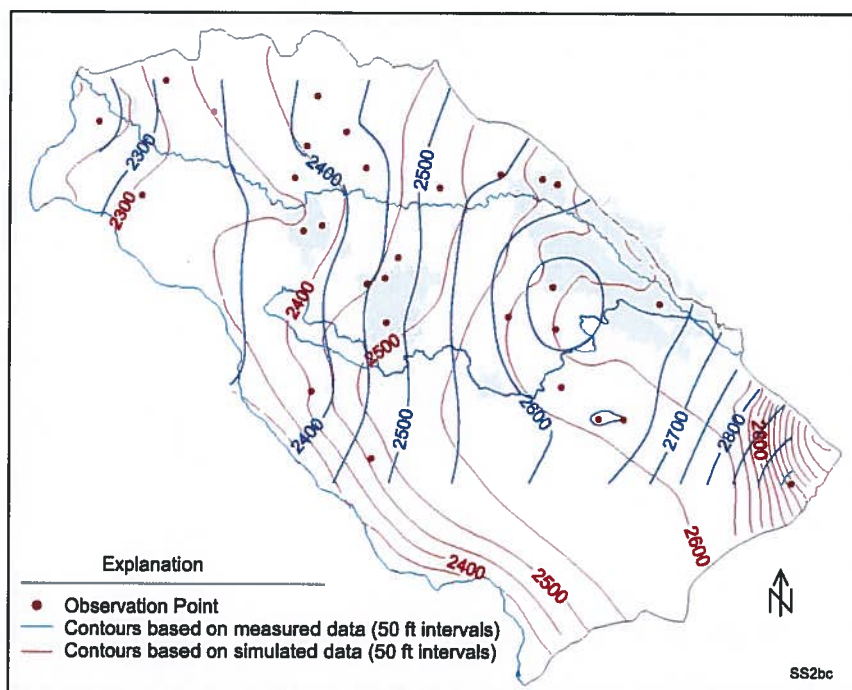


Figure 3-3: Simulated and observed potentiometric contours, layer 2 (base simulation).

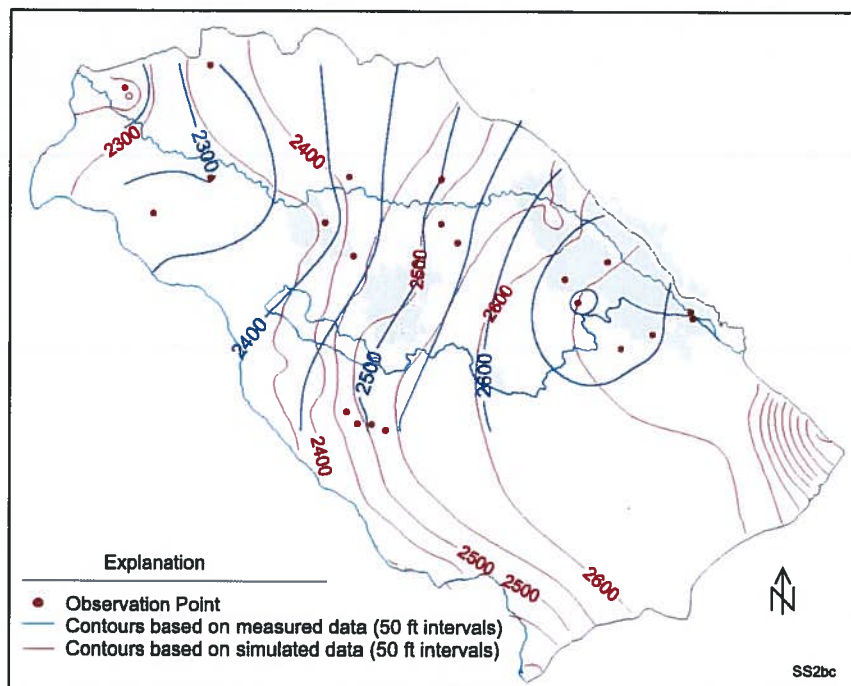


Figure 3-4: Simulated and observed potentiometric contours, layer 3 (base simulation).

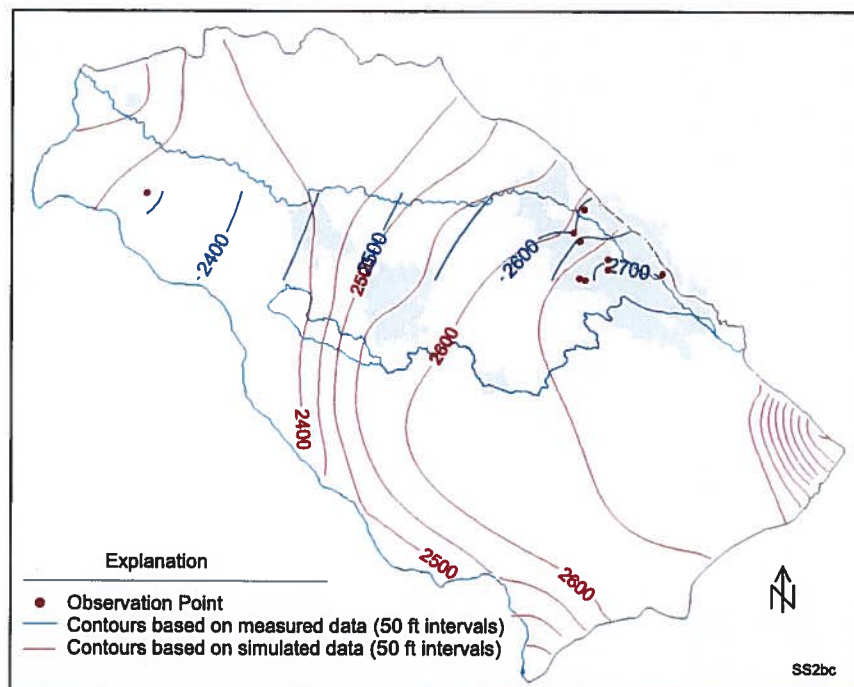


Figure 3-5: Simulated and observed potentiometric contours, layer 4 (base simulation).

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 absolute 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.

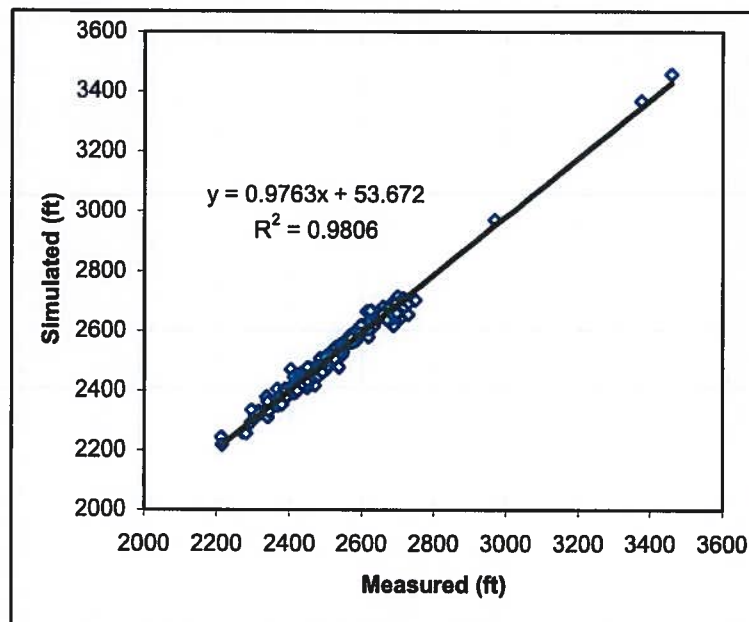


Figure 3-6: Simulated versus measured hydraulic head observations (minimum prediction; simulation $SS5e-min$).

Results – Minimum Head Level Prediction (<i>SS5e-max</i>) (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 absolute 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.

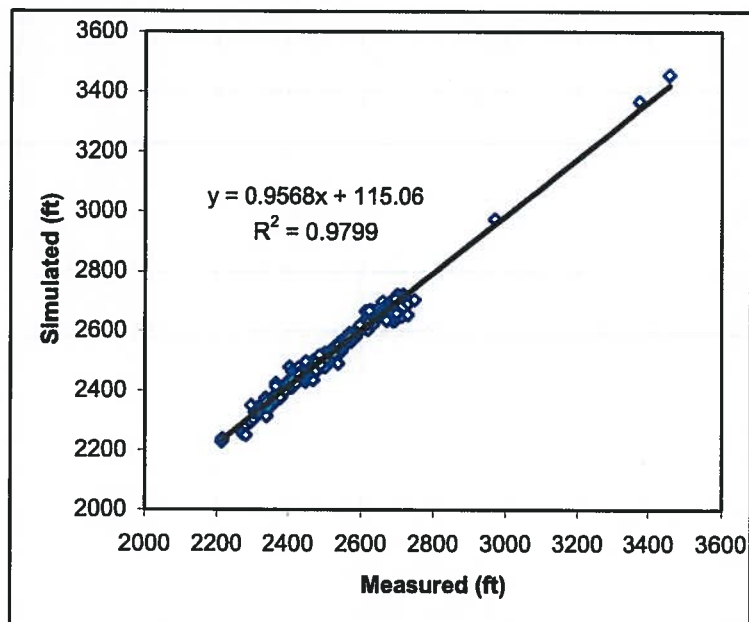


Figure 3-7: Simulated versus measured hydraulic head observations (minimum prediction; simulation *SS5e-max*).

Average Prediction Point Heads (ft)	Base Simulation (\$S2bc)	Scenario with Currently Unprocessed, Non-Supplemental Withdrawals	
		Minimum Heads (\$S5c-min)	Maximum Heads (\$S5c-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 (\$S2bc)	20% Increase in 1996 Rates (Minimum heads) (\$S5c-min)	Unprocessed Non-Supplemental Water Rights (Minimum Heads) (\$S5c-min)	Unprocessed Non-Supplemental Water Rights (Maximum Heads) (\$S5c-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 boundaries	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.

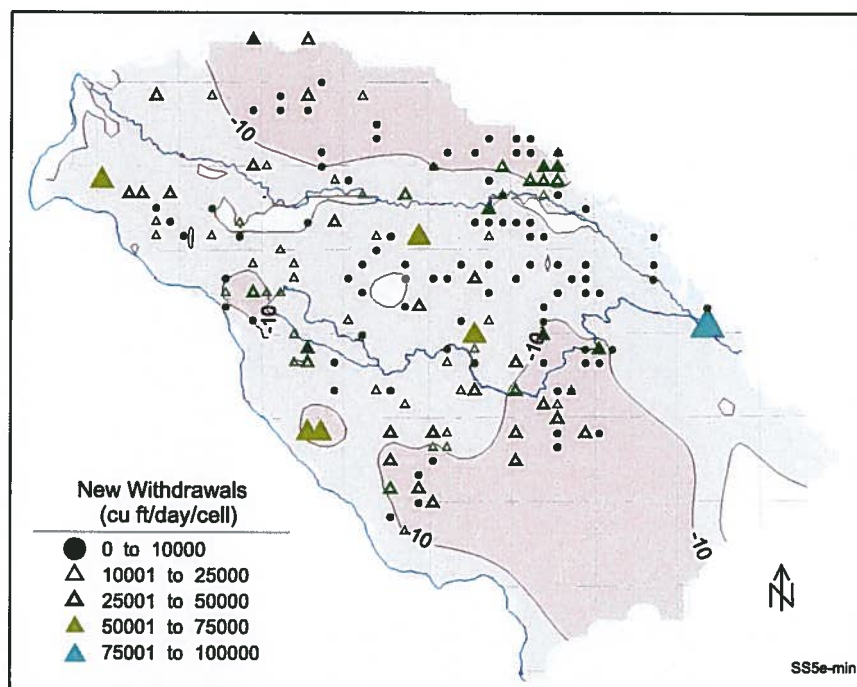


Figure 3-8: Head difference between base case and minimum predictive values, layer 1.

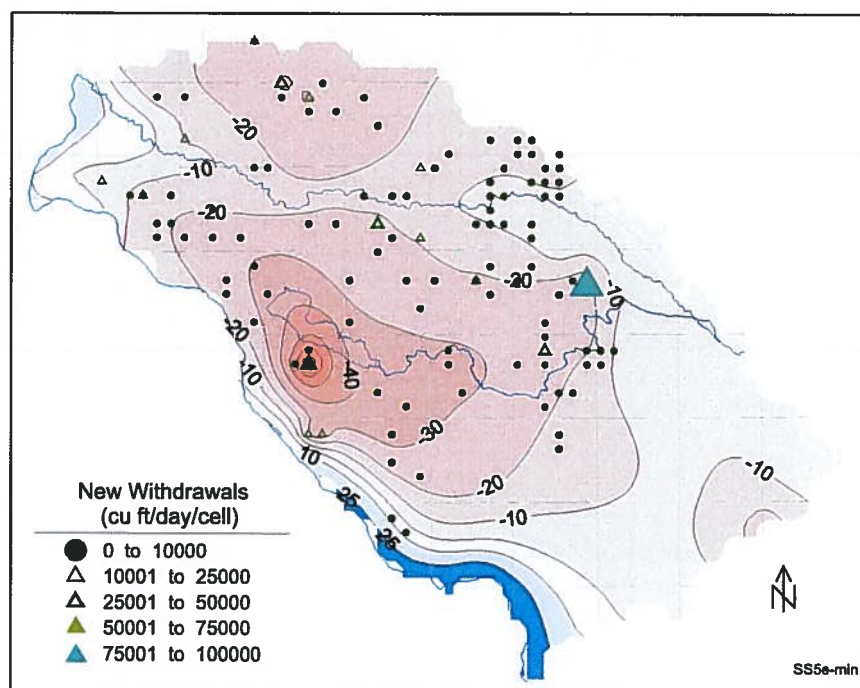


Figure 3-9: Head difference between base case and minimum predictive values, layer 2.

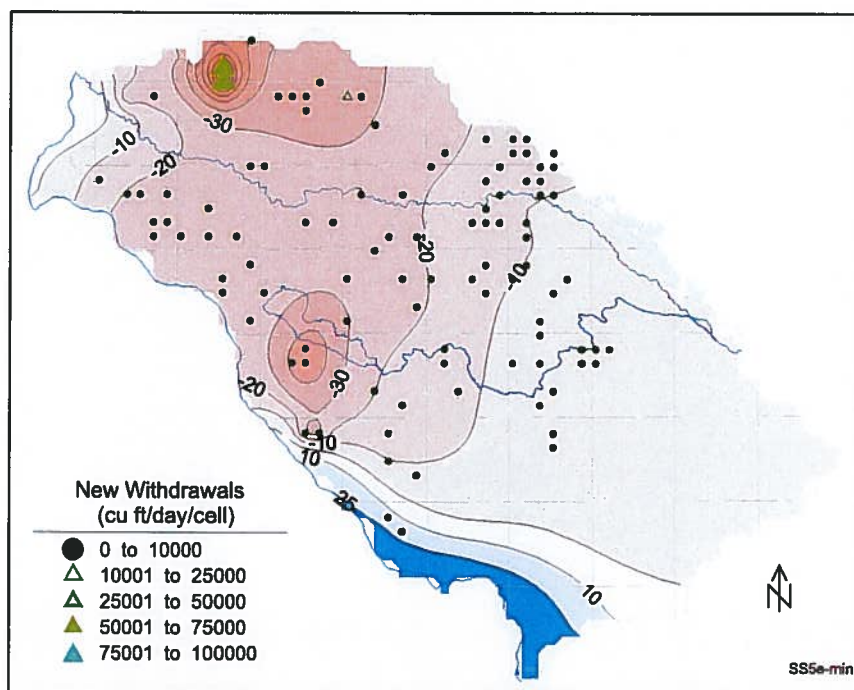


Figure 3-10: Head difference between base case and minimum predictive values, layer 3.

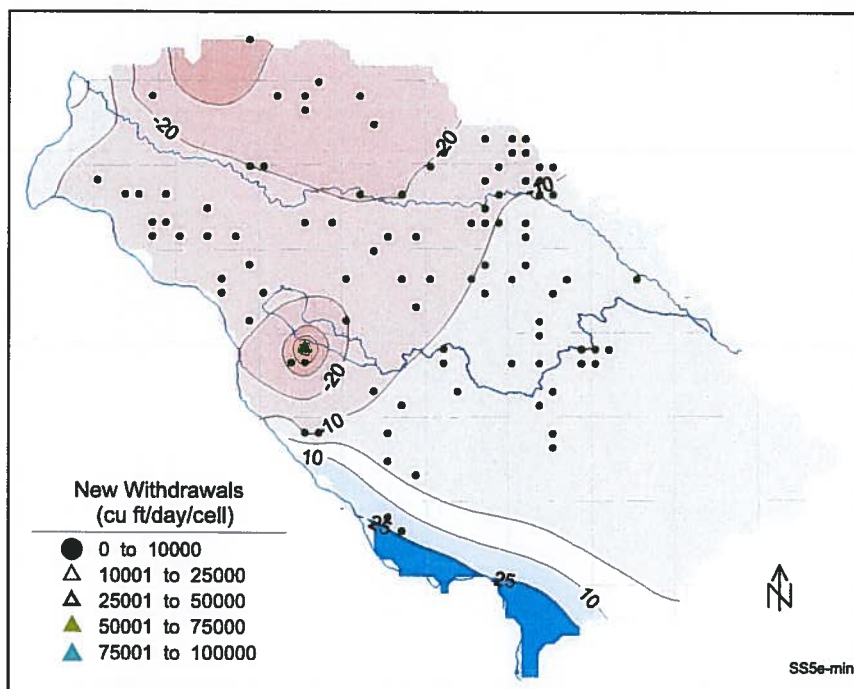


Figure 3-11: Head difference between base case and minimum predictive values, layer 4.

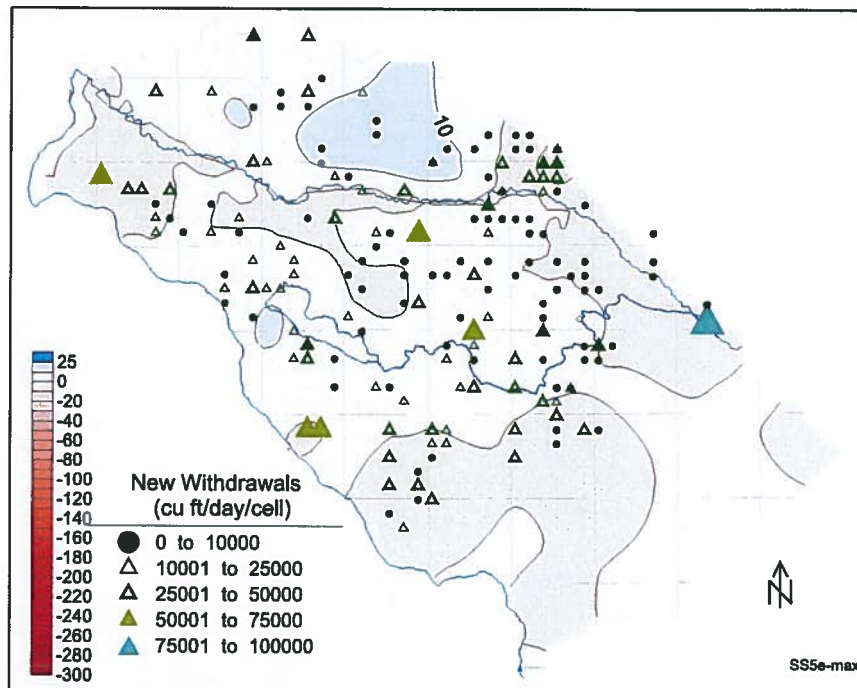


Figure 3-12: Head difference between base case and maximum predictive values, layer 1.

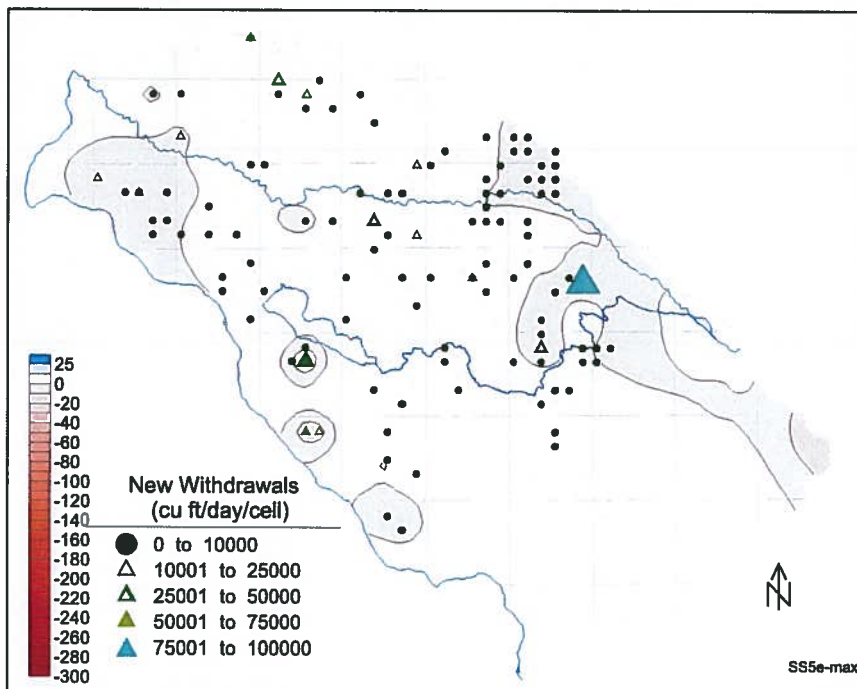


Figure 3-13: Head difference between base case and maximum predictive values, layer 2.

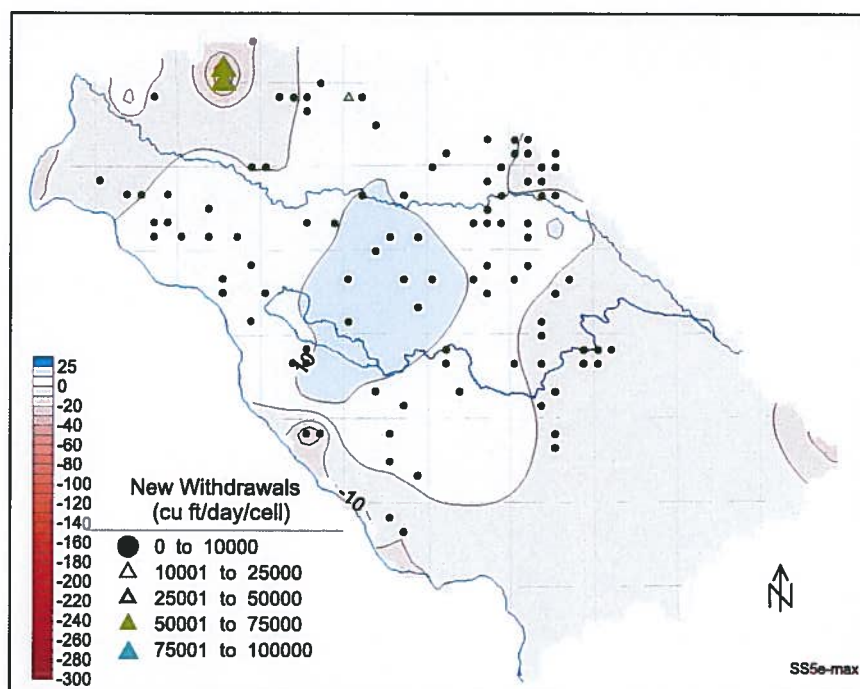


Figure 3-14: Head difference between base case and maximum predictive values, layer 3.

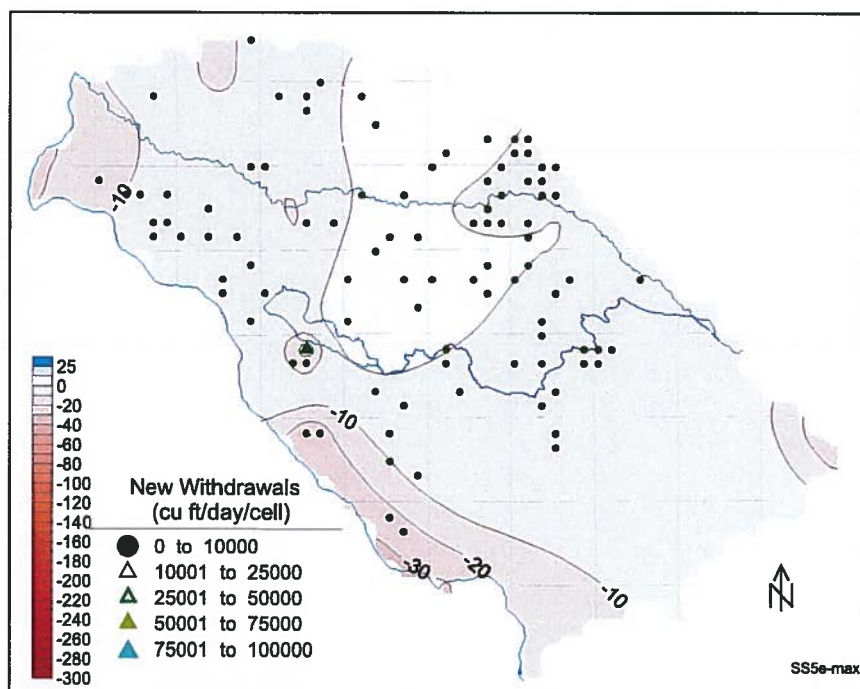


Figure 3-15: Head difference between base case and maximum predictive values, layer 4.

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).

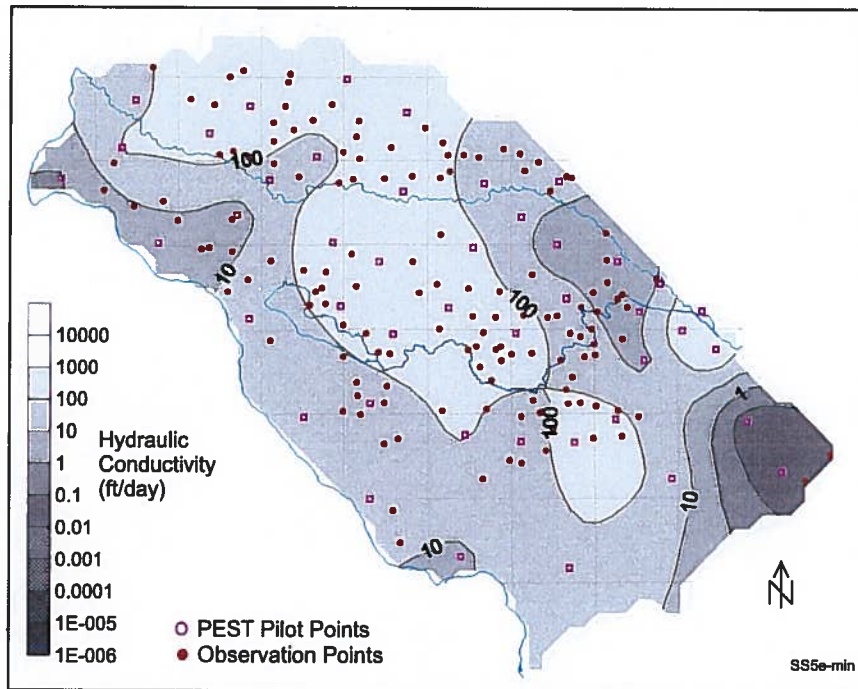


Figure 3-16: Horizontal hydraulic conductivity distribution for minimum predictive values, layer 1.

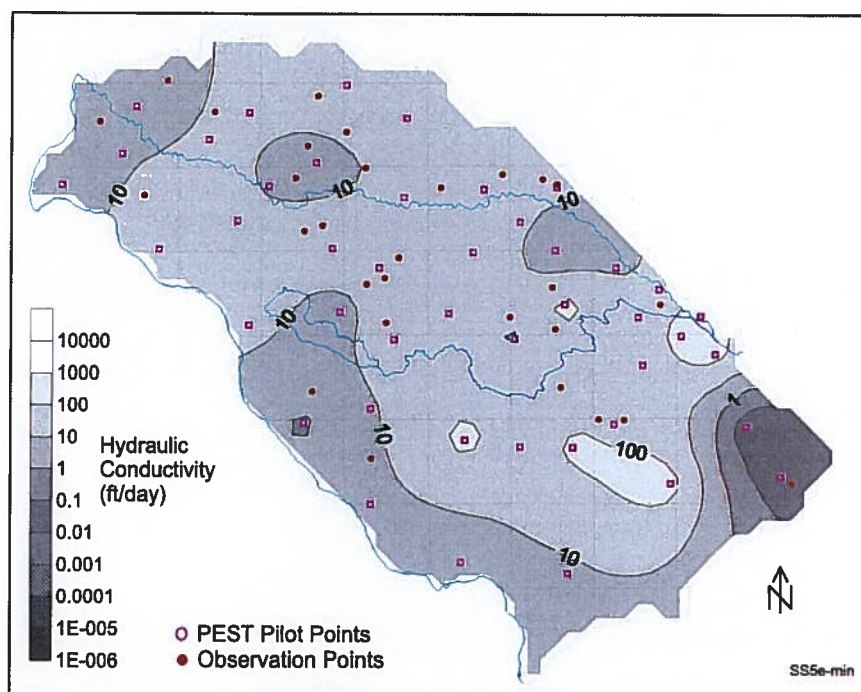


Figure 3-17: Horizontal hydraulic conductivity distribution for minimum predictive values, layer 2.

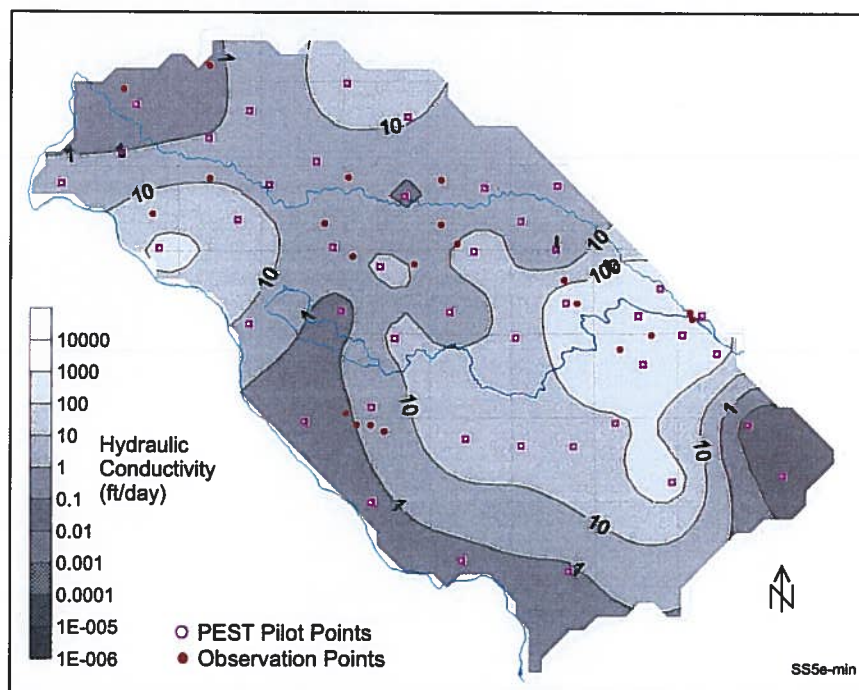


Figure 3-18: Horizontal hydraulic conductivity distribution for minimum predictive values, layers 3 and 4.

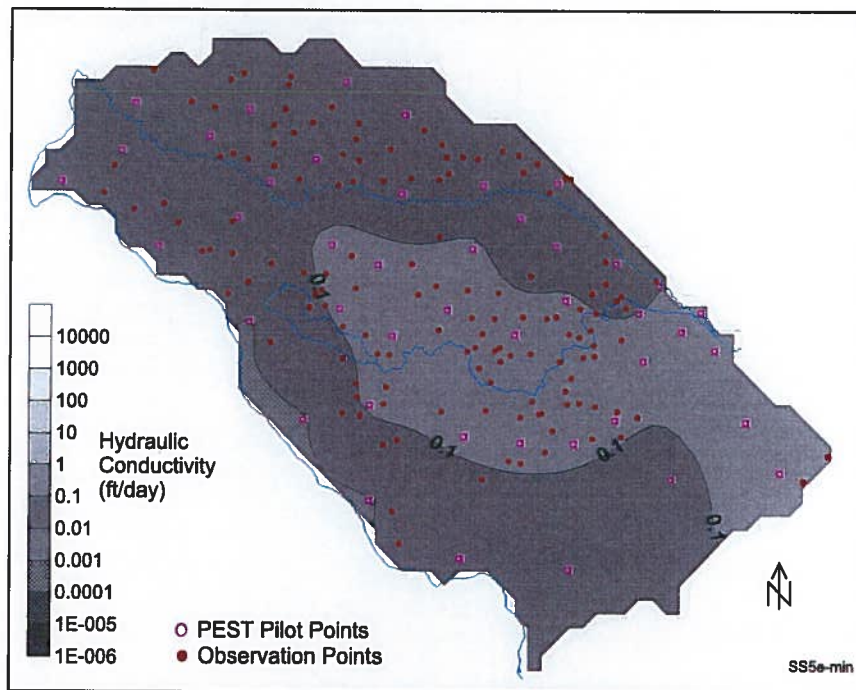


Figure 3-19: Vertical hydraulic conductivity distribution for minimum predictive values, layer 1.

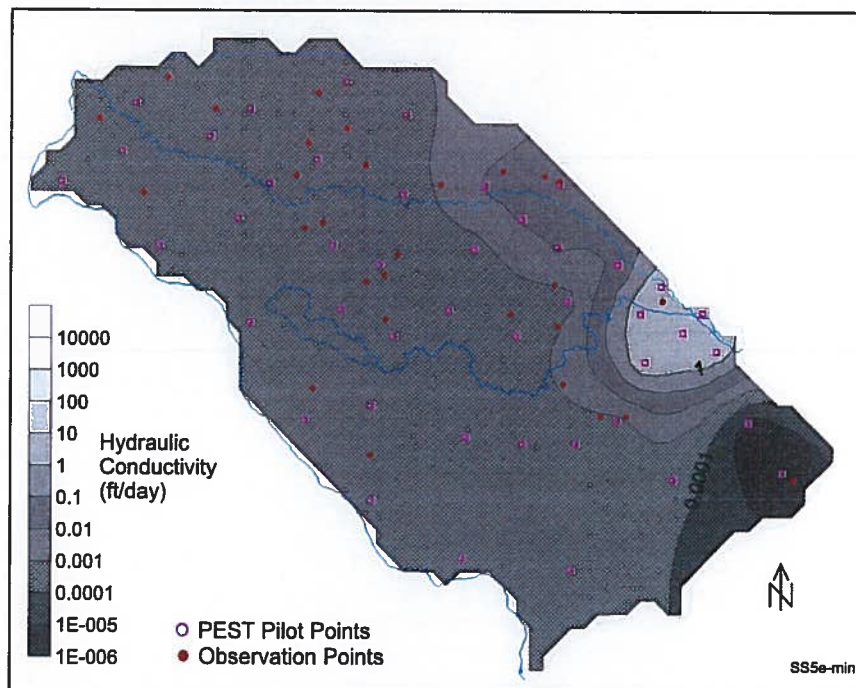


Figure 3-20: Vertical hydraulic conductivity distribution for minimum predictive values, layer 2.

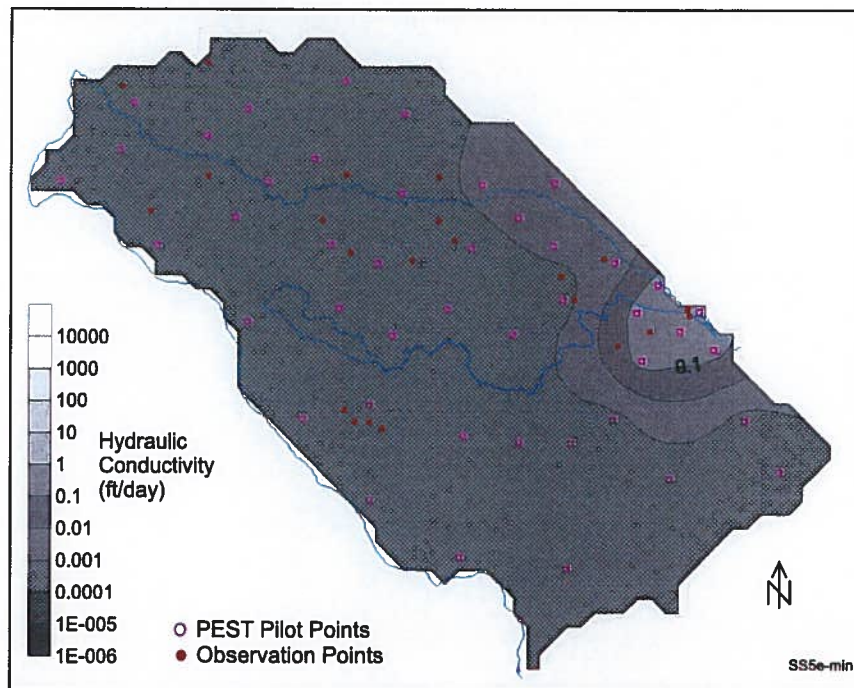


Figure 3-21: Vertical hydraulic conductivity distribution for minimum predictive values, layers 3 and 4.

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 foot² = 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 applications	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 Mercator) (feet)	Easting (Universal Transverse Mercator) (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(m)	UTMy(m)	Requested Diversion Rate (ft ³ /s)	Total Estimated Extraction (ac/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

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
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

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTAD(M)	UTLEY(M)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (af/yr)	Water Use List
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	1828906.7	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

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTM Nor (m)	UTM East (m)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (cfs)	Water Use List
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

ID	Sequence Number	Priority Date	ROW	COL	Target Depth	Assigned Layer	UTAD(M)	UTMY(M)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (af/yr)	Water Use List
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

ID	Sequence Number	Priority Date	ROW	GOL	Target Depth	Assigned Layer	UTMX(ft)	UTMY(ft)	Requested Diversion Rate (ft /s)	Total Estimated Extraction (af/yr)	Water Use List
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	UTM(X)(ft)	UTM(Y)(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	UTM(X)	UTM(Y)	Requested Diversion Rate (ft/s)	Total Estimated Extraction (ac/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(m)	UTMY(m)	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

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.

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Boise Project Board of Control

Account

ID 23119

Serial # BK-634 A

Owner

EMMERT, CHRIS A

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Combination ID 88

Submitter EMMERT, CHRIS

Serial No	Owner	Paid-Up	Pink Card	Allowance	Usage	Balance
20.00 BK-634 A	EMMERT, CHRIS A	✓	✓	75.00	72.42	2.58
17.71 BK-636	EMMERT, CHRIS A	✓	✓	289.54	374.90	-85.36
13.04 BK-639	EMMERT, CHRIS A	✓	✓	273.90	358.43	-84.53
96.83 BK-657	EMMERT, CHRIS	✓	✓	363.11	308.44	54.67
20.03 BK-705 A	EMMERT, CHRIS A	✓	✓	75.11	68.43	6.68
11.18 BK-707	EMMERT, CHRIS	✓	✓	266.93	368.95	-102.02
158.36 BK-729	PYWELL, MARLEN E	✓		593.85	473.89	119.96
516.65 <i>Acres</i>						
	Total			1937.44	2025.46	-88.02

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Total Usage 2025.46 ÷ Total Acres = 3.92 acre ft per acre

Exhibit 109

BPBOC00405

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EMMERT, CHRIS A

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Combination ID 64 Submitter EMMERT, CHRIS

Serial No	Owner	Paid-Up	Pink Card	Allowance	Usage	Balance
<u>20.06</u> <u>BK-634 A</u>	EMMERT, CHRIS A	✓		75.00	11.90	63.10
<u>77.21</u> <u>BK-636</u>	EMMERT, CHRIS A	✓	✓	289.54	406.61	-117.07
<u>73.04</u> <u>BK-639</u>	EMMERT, CHRIS A	✓		273.90	155.71	118.19
<u>96.83</u> <u>BK-657</u>	EMMERT, CHRIS	✓		363.11	212.23	150.88
<u>20.03</u> <u>BK-705 A</u>	EMMERT, CHRIS A	✓		75.11	26.78	48.33
<u>71.18</u> <u>BK-707</u>	EMMERT, CHRIS	✓	✓	266.93	323.31	-56.38
<u>358.29</u> <u>acres</u>						
	Total			1343.59	1136.54	207.05

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Total Usage 1136.54 ÷ Total Acres = 3.17 ac ft per acre

WaterPac 2014

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ID 23119

Serial # BK-634 A Owner

EMMERT, CHRIS A

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Combination ID 101 Submitter EMMERT, CHRIS

Serial No	Owner	Paid-Up	Pink Card	Allowance	Usage	Balance
20.00 BK-634 A	EMMERT, CHRIS A	✓	✓	75.00	86.09	-11.09
77.21 BK-636	EMMERT, CHRIS A	✓	✓	289.54	318.35	-28.81
13.04 BK-639	EMMERT, CHRIS A	✓	✓	273.90	229.49	44.41
96.83 BK-657	EMMERT, CHRIS	✓	✓	363.11	271.72	91.39
20.03 BK-705 A	EMMERT, CHRIS A	✓	✓	75.11	20.83	54.28
11.18 BK-707	EMMERT, CHRIS	✓	✓	266.93	336.21	-69.28
358.29 <i>9ans</i>						
	Total			1343.59	1262.69	80.90

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Total Usage 1262.69 ÷ Total Acres = 3.52 acre ft. per acre

Total Acres
358.29

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Account

ID 23119

Serial # BK-634 A

Owner

EMMERT, CHRIS A

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Account	Summary	Allowance	Allotment	Trans
Anderson	Polygons	History	Combos	Excess
				Carryover
				Orders

Total Acres 20.00

Paid-up Acres 20.00

Pink Card Acres 0.00

Last Calculated 10/31/2013

Allowance

	Posted	Running	Actual
Allowance Granted	75.00		75.00
Water Deliveries	70.42	0.00	70.42
Allowance Adjustments	0.00		0.00
Allowance Remaining (Excess)	4.58	0.00	4.58

Allotment

Water Protecting Anderson	0.00	0.00	0.00
Anderson Remaining	0.00	0.00	0.00
Water Available	0.00	0.00	0.00

Carryover

Carryover from Last Season	2.30
Additional Anderson Pending Payment	0.00
Anderson Remaining, this Account	0.00
Anderson Remaining, Transferred to Other Accounts	0.00
Theoretical Carryover to Next Season	0.00
Actual Anderson Available Next Season (net of Loss Factor)	0.00

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Total Usage 928.32 ÷ Total Acres = 2.59 acre ft Per Acre
Total Usage 928.32

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Account

ID 24275

Serial # Owner

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Total Acres Paid-up Acres Pink Card Acres Last Calculated

Allowance

	Posted	Running	Actual
Allowance Granted	289.54		289.54
Water Deliveries	237.03	0.00	237.03
Allowance Adjustments	0.00		0.00
Allowance Remaining (Excess)	52.51	0.00	52.51

Allotment

Water Protecting Anderson	0.00	0.00	0.00
Anderson Remaining	0.85	0.00	0.85
Water Available	0.85	0.00	0.85

Carryover

Carryover from Last Season	30.66
Additional Anderson Pending Payment	0.00
Anderson Remaining, this Account	0.85
Anderson Remaining, Transferred to Other Accounts	0.00
Theoretical Carryover to Next Season	0.85
Actual Anderson Available Next Season (net of Loss Factor)	0.68

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Account

ID 22581

Serial # BK-639

Owner

EMMERT, CHRIS A

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Account	Summary	Allowance	Allotment	Trans	Orders
Anderson	Polvgons	History	Combes	Excess	Carryover

Total
Acres

73.04

Paid-up
Acres

73.04

Pink Card
Acres

0.00

Last
Calculated

10/31/2013

Allowance

	Posted	Running	Actual
Allowance Granted	273.90		273.90
Water Deliveries	122.00	0.00	122.00
Allowance Adjustments	0.00		0.00
Allowance Remaining (Excess)	151.90	0.00	151.90

Allotment

Water Protecting Anderson	0.00	0.00	0.00
Anderson Remaining	0.60	0.00	0.60
Water Available	0.60	0.00	0.60

Carryover

Carryover from Last Season	61.41
Additional Anderson Pending Payment	0.00
Anderson Remaining, this Account	0.60
Anderson Remaining, Transferred to Other Accounts	0.00
Theoretical Carryover to Next Season	0.60
Actual Anderson Available Next Season (net of Loss Factor)	0.48

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Account

ID 26896

Serial # Owner

Account	Summary	Allowance	Allotment	Trans
Anderson	Polygons	History	Combos	Excess
			Carryover	Orders

Total Acres Paid-up Acres Pink Card Acres Last Calculated

Allowance

	Posted	Running	Actual
Allowance Granted	363.11		363.11
Water Deliveries	177.53	0.00	177.53
Allowance Adjustments	3.97		3.97
Allowance Remaining (Excess)	189.55	0.00	189.55

Allotment

Water Protecting Anderson	4.03	0.00	4.03
Anderson Remaining	1.77	0.00	1.77
Water Available	5.80	0.00	5.80

Carryover

Carryover from Last Season	62.00
Additional Anderson Pending Payment	0.00
Anderson Remaining, this Account	1.77
Anderson Remaining, Transferred to Other Accounts	0.00
Theoretical Carryover to Next Season	1.77
Actual Anderson Available Next Season (net of Loss Factor)	1.42

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Account

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Serial # Owner

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Total Acres
 Paid-up Acres
 Pink Card Acres
 Last Calculated

Allowance

	Posted	Running	Actual
Allowance Granted	75.11		75.11
Water Deliveries	62.48	0.00	62.48
Allowance Adjustments	1.98		1.98
Allowance Remaining (Excess)	14.61	0.00	14.61

Allotment

Water Protecting Anderson	0.00	0.00	0.00
Anderson Remaining	0.67	0.00	0.67
Water Available	0.67	0.00	0.67

Carryover

Carryover from Last Season	5.33
Additional Anderson Pending Payment	0.00
Anderson Remaining, this Account	0.67
Anderson Remaining, Transferred to Other Accounts	0.00
Theoretical Carryover to Next Season	0.67
Actual Anderson Available Next Season (net of Loss Factor)	0.54

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Account

ID 23390

Serial # Owner

Account	Summary	Allowance	Allotment	Trans
Anderson	Polygons	History	Combos	Excess
			Carryover	Orders

Total Acres Paid-up Acres Pink Card Acres Last Calculated

Allowance

	Posted	Running	Actual
Allowance Granted	266.93		266.93
Water Deliveries	258.86	0.00	258.86
Allowance Adjustments	2.98		2.98
Allowance Remaining (Excess)	11.05	0.00	11.05

Allotment

Water Protecting Anderson	0.00	0.00	0.00
Anderson Remaining	1.94	0.00	1.94
Water Available	1.94	0.00	1.94

Carryover

Carryover from Last Season	66.81
Additional Anderson Pending Payment	0.00
Anderson Remaining, this Account	1.94
Anderson Remaining, Transferred to Other Accounts	0.00
Theoretical Carryover to Next Season	1.94
Actual Anderson Available Next Season (net of Loss Factor)	1.55

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Account

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Combination ID Submitter

Serial No	Owner	Paid-Up	Pink Card	Allowance	Usage	Balance
20.00 BK-634 A	WATTS, OTHA	✓		75.00	57.12	17.88
77.21 BK-636	WATTS, OTHA	✓	✓	289.54	389.76	-100.22
73.04 BK-639	EMMERT, CHRIS A	✓	✓	273.90	280.70	-6.80
96.83 BK-657	EMMERT, CHRIS	✓	✓	363.11	365.95	-2.84
20.03 BK-705 A	EMMERT, CHRIS A	✓	✓	75.11	68.43	6.68
91.18 BK-707	EMMERT, CHRIS	✓	✓	266.93	274.72	-7.79
358.29 <i>acres</i>						
	Total			1343.59	1436.68	-93.09

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Total Usage 1436.68 ÷ Total Acres = 4.00 acre ft per acre

WaterPac 2011

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Account

ID 22581

Serial # BK-639 Owner

EMMERT, CHRIS A

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Combination ID 51 Submitter EMMERT, CHRIS

Serial No	Owner	Paid-Up	Pink Card	Allowance	Usage	Balance
26.00 BK-634 A	WATTS, OTHA	✓	✓	75.00	74.38	0.62
77.21 BK-636	WATTS, OTHA	✓	✓	289.54	294.56	-5.02
73.04 BK-639	EMMERT, CHRIS A	✓	✓	273.90	326.32	-52.42
96.83 BK-657	EMMERT, J L	✓	✓	363.11	261.83	101.28
71.18 BK-707	EMMERT, J L	✓	✓	266.93	292.57	-25.64
358.29 Acres						
	Total			1268.48	1249.66	18.82

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$$\text{Total Usage } 1249.66 \div \text{Total Acres} = 3.69 \text{ ac ft per acre}$$

WaterPac 2010

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Combination ID Submitter

Serial No	Owner	Paid-Up	Pink Card	Allowance	Usage	Balance
13.04 BK-639	EMMERT, CHRIS A	✓	✓	273.90	323.14	-49.24
33.05 BK-645	KAUFMAN, MICHAEL J	✓		123.94	0.00	123.94
96.83 BK-657	EMMERT, J L	✓	✓	363.11	308.45	54.66
71.18 BK-707	EMMERT, J L	✓	✓	266.93	228.13	38.80
274.10 ~~acres~~						
	Total			1027.88	859.72	168.16

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$$\text{Total Usage } 859.72 \div \text{Total Acres} = 3.13 \text{ acre ft per acre}$$

**Conjunctive Hydrologic Modeling Analysis of Proposed New
Groundwater Pumping in the Boise Basin South of Lake Lowell**

(Appl. 63-84079 and 63-84080)

Robert D Schmidt

2/13/2017

Executive Summary

Hydrologic modeling of proposed new groundwater pumping in eastern Canyon County, south of Lake Lowell (Appl. 63-34079 and 63-34080) is conducted to assess the impact of proposed groundwater withdrawals on nearby Boise Board of Control (BOC) managed facilities, including Lake Lowell, the New York Canal, the Deer Flat Highline Canal and the Mora Canal.

The impact of proposed pumping on BOC managed facilities is estimated using a hydrologic modeling methodology known as analytic elements (Strack, 1985). Analytic elements are solutions to the governing linear differential equation for steady-state, two-dimensional groundwater flow. Source-sink analytic elements are used to represent rivers, canals, drains, and pumping wells. Analytic elements are also used to represent aquifer inhomogeneities. Unlike numerical models which require spatial approximation using a grid mesh, analytic element models have unlimited spatial resolution, and are especially well suited for conjunctive surface and groundwater problems involving a dense network of interacting surface and groundwater water features.

The South Lake Lowell analytic element model simulates unconfined flow conditions in an aquifer that is comprised of the terrace gravels of the Snake River Group, and the upper and middle sand, silt, and gravel units of the Glenns Ferry Formation. The saturated thickness of this aquifer ranges from 300 to about 550 feet. The model was developed using a well-established analytic element software package known as GFLOW (Scientific Software, 2017).

All surface water hydrologic features, including canals, drains, Lake Lowell, and the Snake River in the South Lake Lowell model are represented by strings of source-sink analytic elements, for which an elevation (head) and a bed resistance to seepage loss are specified. Canal, drain, river, and reservoir water elevations are taken from USGS digital elevation maps. Bed resistances are derived through model calibration.

The representation of all surficial hydrologic features as head-specified boundary conditions instead of flow-specified boundary conditions is fundamentally important to the South Lake Lowell model's predictive capability, since model predictions of aquifer recharge or discharge rates are made only for surficial features that are head-specified. Aquifer recharge or discharge rates from flow-specified boundary conditions are fixed by the model user.

Not all surface water features in the South Lake Lowell model area are impacted by new groundwater pumping. If the elevation of the saturated surface of the aquifer is below the resistance bed of a canal,

drain or lake, then seepage is independent of aquifer head and the feature is said to be percolating. If the saturated surface is above the elevation of the resistance bed and in direct contact with the canal, then seepage is dependent on changes in aquifer head conditions. By lowering the aquifer head beneath a head dependent canal, groundwater pumping induces additional seepage. However lowering aquifer head beneath a percolating canal has no effect on seepage rate.

With GFLOW it is not necessary to know in advance which lakes, rivers, canals or drains are above the saturated surface of the aquifer and which are in contact with it. GFLOW incorporates an iterative procedure for making this determination when the model is run. In those cases where head-specified features are perched above the saturated surface GFLOW automatically determines the seepage rate, and converts the head-specified feature to a flow-specified (percolating) feature.

Two South Lake Lowell GFLOW models are developed to assess the impacts of the new Emmert well pumping on BOC surface water facilities, the base case model representing current conditions and the Emmert well model which introduces pumping from the two proposed wells (63-34079 and 63-34080) in the base case model. Three Emmert well pumping scenarios are modeled; 42 AF per year, 235 AF per year and 668 AF per year.

The impact of proposed Emmert well pumping in the South Lake Lowell area is conveyed in terms of four categories of potential surface water depletion; Increased Lake Lowell seepage, increased canal seepage, reduced groundwater discharge to drains, and reduced Snake River and Boise River base flows. Depletions are calculated by subtracting the flow of every head-specified element in the Emmert well model from the flow of every comparable head-specified element in the base case model. The modeled depletions in each of the four categories, for each of the three Emmert well pumping scenarios, are presented in tables giving both the magnitude of depletion and the depletion as a percentage of total Emmert well pumping.

In addition to Lake Lowell and the Snake River, base case model results indicate that portions of the New York Canal, the Deer Flat Highline Canal, and the Mora Canal are currently in direct contact with the underlying saturated surface. Clearly, representing canals as potentially head-dependent boundary conditions and allowing the hydrologic model to determine which are percolating and which are actually head dependent is critical for an accurate accounting of all surface water depletions that will ultimately result from proposed well pumping.

The table below summarizes the South Lake Lowell model depletion tables contained in this report. Part A of this table summarizes results for all surface water features in the model area. Part B summarizes results for BOC surface water features only. Percentage depletions are the same for all three Emmert well pumping scenarios, although the magnitude of depletion increases with increased pumping.

Part A: South Lake Lowell surface water depletions due to Emmert well pumping, all scenarios.	
Model boundary feature	South Lake Lowell surface water depletions, % of total Emmert well pumping
Lake Lowell	2.1 %
All drains	41.9%
All canals	26.4%
Snake River	20.6%
Boise River	8.9%
Total	100%
Part B: BOC surface water depletions due to Emmert well pumping, all scenarios.	
Model boundary feature	BOC depletions, % of total Emmert well pumping
BOC canals	19.0%
Lake Lowell	2.1%
Total	21.1%

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Conjunctive Hydrologic Modeling Analysis of Proposed New Groundwater Pumping In the Boise Basin South of Lake Lowell

Objective and Background

Hydrologic modeling of new groundwater pumping south of Lake Lowell in eastern Canyon County, is focused on assessing the impact of proposed groundwater withdrawals (Appl. 63-84079 and 63-84080) on nearby Boise Board of Control (BOC) managed facilities, including Lake Lowell, the New York Canal, the Deer Flat Highline Canal and Mora Canal.

The impact of new groundwater pumping on BOC facilities is estimated using a computer-based groundwater model of the Boise basin south of Lake Lowell that was developed by the Bureau of Reclamation in 2003. Portions of that USBR Report of Investigation (USBR, 2003) are reproduced here. Reclamation hydrogeologic investigations, IDWR and USGS observation well data, and a later-published water budget for irrigated lands in the Boise basin (USBR, 2008) were used to develop and calibrate what is referred to here as the South Lake Lowell area groundwater model (the model).

The South Lake Lowell Model Area of Interest

The South Lake Lowell groundwater area of interest is centered roughly on a dry lake bed located in Canyon County about five miles south of the east end of Lake Lowell (Stevens, 1962). The area encompasses about 155 square miles and includes all of Lake Lowell, Boise Project managed canals and drains located south and east of Lake Lowell, and a portion of the Snake River (figure 1).

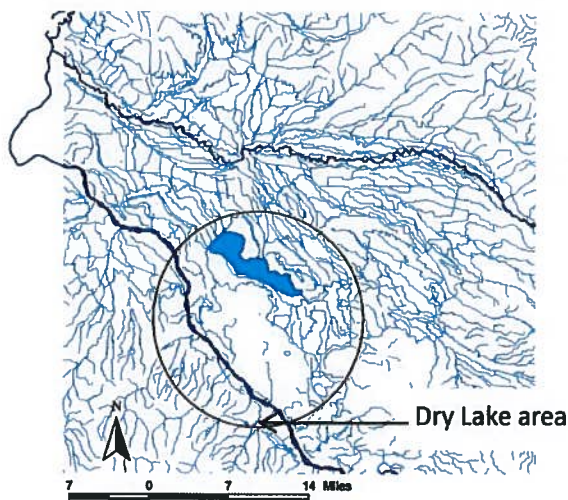


Figure 1. Approximate South Lake Lowell model area of interest.

Hydrogeology of the South Lake Lowell Area

Numerous studies of Boise Basin geology and hydrogeology have been conducted by the USGS, the University of Idaho, Boise State University and others. The principal reports are those of Stevens (1962), Wood and Anderson (1981), Anderson and Wood (1981) Whitehead (1986), Newton (1991), Squires, Wood, and Osiensky (1992), Othberg (1994), Kjelstrom (1995), Lindholm (1996), and Wood and Clemens (2001). The report by Stevens, and a draft report by Graves and Bendixsen (IDWR, 1995) are the only ones to focus exclusively on the area south of Lake Lowell however.

In summary, the Boise Basin is characterized geologically as a graben, with high angle, north-west south-east trending faults along its boundaries, and downwarping toward the center of the basin. The basin is filled with sediments derived from erosion of surrounding granitic mountains inter-fingered with basalt flows. Unconsolidated or poorly consolidated flood plain, glacial, and lake deposits extend to a depth of 2000 feet or more in the basin, and range in age from Pliocene to recent (figure 2).

Three geologic units in the Boise Basin have been identified as important cold water aquifers. They are (1) the fractured basalts, and (2) the sands and gravels of the Snake River Group, and (3) the sands, silts, and gravels in the upper and middle Idaho Group, which includes the Glens Ferry Formation (figure 2).

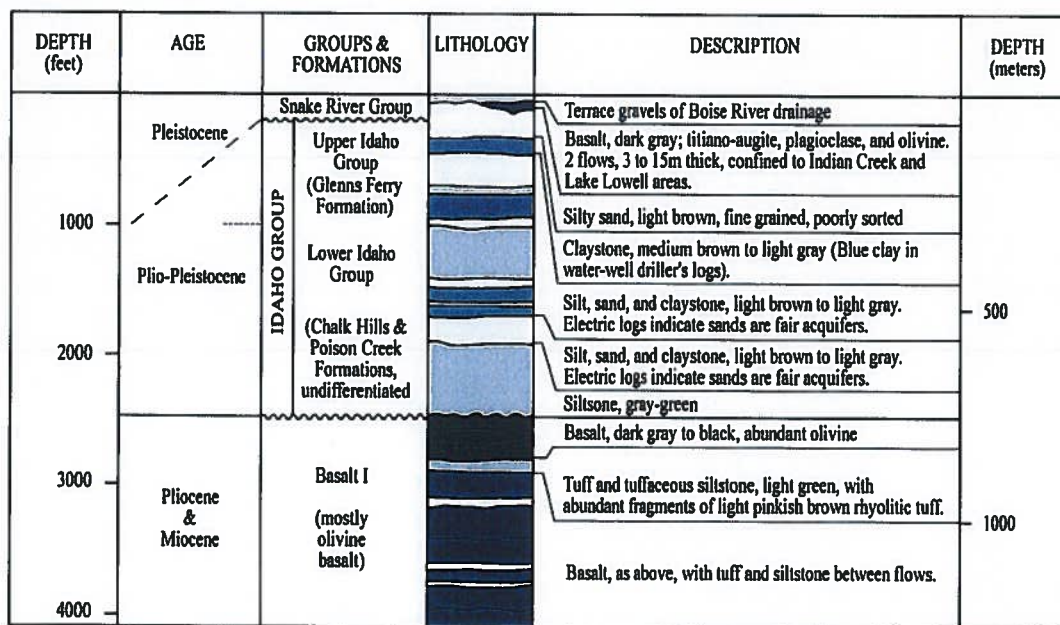


Figure 2. Generalized lithologic log of the Boise River Basin (adapted from Wood and Anderson, 1981).

The sands, silts, and gravels of the Glens Ferry Formation are frequently separated from lower units in the Idaho Group by clay layers having a "bluish" color (as reported in drilling logs). The blue clay layers,

which together can be up to 400 feet thick, are fine sediments that formed under chemically reducing conditions, at the bottom of prehistoric Lake Idaho.

The blue clay layers have been interpreted by some as a large regional confining layer overlying a much deeper geothermal aquifer (Wood and Anderson, 1981). Other hydrogeologists have interpreted these layers as a third intermediate aquifer, albeit with a much lower permeability than the upper sands, silts, and gravels (Newton, 1991).

Figure 3 is a generalized north-south cross-section showing groundwater elevation in the Boise Basin, through Lake Lowell. Lake Lowell marks the location of a groundwater divide in the basin. South of the divide the direction of groundwater flow is to the south or southwest toward the Snake River. North of the divide, groundwater flows north or northwest, toward the Boise River. (The vertical scale in this figure is greatly exaggerated.)

The groundwater divide south of Lake Lowell is not a fixed hydrologic feature, and the location of the divide fluctuates somewhat during the year in response to changes in aquifer recharge rates, groundwater pumping, and the level of Lake Lowell itself. A previous study has indicated that during winter months, when the lake level is high and canals are dry, the divide shifts slightly to the north. During summer months, when the lake level is low and canals are full, it shifts slightly to the south (USBR, 2000).

The principal sources of groundwater in the South Lake Lowell area are the terrace gravels of the Snake River Group, and the upper and middle sand, silt, and gravel units of the Glens Ferry Formation. Collectively, these two units have a saturated thickness of between 300 and 550 feet. Wells drilled in the area encounter thin stringers of blue clay at various depths, however multiple, thick layers (up to 45 feet) have been encountered only at depths below 2100 feet msl. elevation (Stevens, 1962). Depths to groundwater in the area range from 17 feet to more than 400 feet. The Snake River basalts are above the watertable throughout most of the area.

The course of the Snake River through the South Lake Lowell area is structurally controlled by faulting that is concentrated along the margins of the basin. A series of steeply dipping faults, all striking in a northwest-southeast direction, are exposed along the north rim of the Snake River Canyon (figure 4). These fault zones (together with tilting of stratigraphic units to the north-east) are believed to act as a partial barrier to groundwater flow, and are probably the reason there are almost no springs along the canyon wall on the north side of the river. A structural trough, also associated with faulting extends east

and south from Lake Lowell to include the Deer Flat area, north of the Mora Canal and is believed to be partly responsible for the groundwater divide that extends east of Lake Lowell.

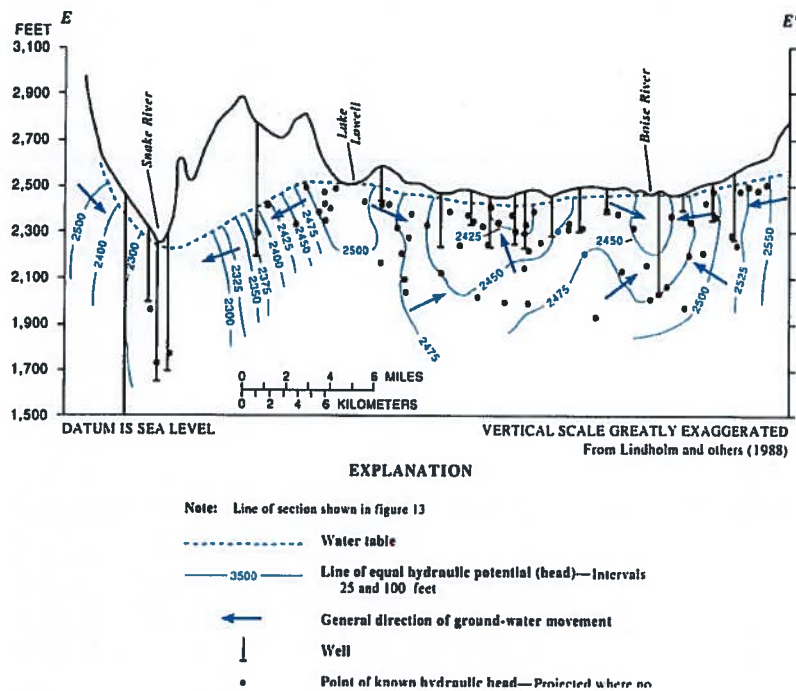


Figure 3. Generalized watertable cross section beneath the South Lake Lowell area (from Lindholm, 1988).



Figure 4. Geologic Faulting in the South Lake Lowell Area, (adapted from Wood and Anderson, 1981).

Groundwater elevations in the model area south of Lake Lowell have been monitored either by the USGS or IDWR since the early 1960's. Maps made by USGS in the early 1960's (Stevens, 1962) depict groundwater elevations ranging between 2220 feet and 2575 feet msl., and a groundwater gradient to the south or southwest toward the Snake River.

South Lake Lowell Area Water Budget

The South Lake Lowell area water budget is part of a distributed-parameter water budget developed by Reclamation for irrigated lands in the Boise River Basin (USBR & IDWR, 2008). Individual components of this water budget include canal diversions, farm deliveries, canal seepage, on-farm loss, groundwater pumping, return flow to drains, Snake River and Boise River base flows, and Lake Lowell gains and losses. The water budget provides a spatially distributed, average monthly value for each component, based on historical records of diversion and water use in the basin during the period 1967 to 1997.

Lake Lowell Gains and Losses

Water budget calculations for Lake Lowell (which take into account flows in and out of the lake, in addition to lake evaporation, and evapotranspiration by lake vegetation) indicate that from a multi-year perspective, Lake Lowell gains and losses roughly balance out. In any given year however, Lake Lowell may be either be gaining or losing. Net annual gains occur mainly in dry years when average lake level is lower. Net annual losses are more likely in wet years when the average lake level is higher. Over the past three decades, annual Lake Lowell gains have been as high as 42,000 acre-feet, and losses have been as high as 45,000 acre-feet. Month to month gains and losses from Lake Lowell depend on lake level (figure 5). During an average year, Lake Lowell gains up to 8,100 acre-feet during August, when the lake level is lowest, and loses up to 6,100 acre-feet during April, when the lake level is highest.



Figure 5. Average monthly lake level and average monthly gain or loss from Lake Lowell (USBR&IDWR, 2008).

Canal Seepage in the South Lake Lowell Area

Estimates of average monthly seepage from all canals in the South Lake Lowell area serving BOC divisions 3 and 4 are based on Board of Control records of diversion and farm delivery, and estimates of canal ET (Figure 6). Seepage occurs throughout the year, since some diversions are made to fill Lake Lowell during winter months. However the vast majority of canal seepage occurs during the irrigation season. Between May and September, canal seepage ranges between 30,200 and 68,200 acre-feet per month. Year-round, monthly seepage from area canals averages 22,200 acre-feet.

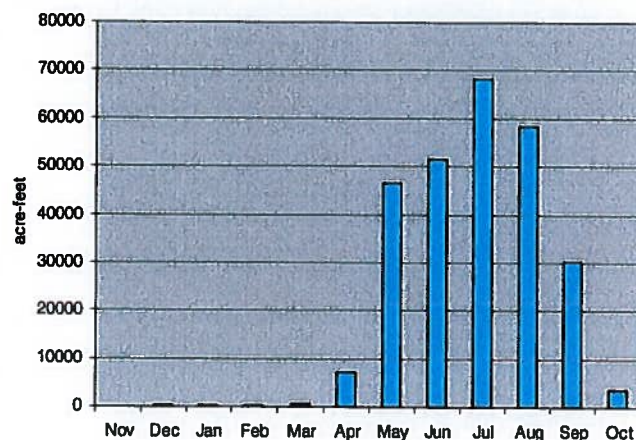


Figure 6. Average monthly seepage from South Lake Lowell canals (1967- 1997).

Mora Canal Seepage

Seepage from the Mora Canal is a major source of aquifer recharge in the South Lake Lowell area. BOC records of canal diversions (at the New York Canal and at Richards Point) and records of drain discharges indicate losses during the irrigation season range between 4,900 and 33,200 acre-feet per month (Figure 7).

On average during the period 1967 to 1997, about 118 thousand acre-feet per year, or about 37 percent of the total annual diversion to the Mora Canal, seeped from the canal somewhere along its 38 mile length.

Historical records of canal seepage and groundwater withdrawals indicate that increased Mora canal seepage is associated with increased groundwater pumping in the South Lake Lowell area. The bar chart in figure 8 shows estimated annual Mora Canal seepage loss from 1957 through 1997 (USBR, 2002). The line chart in this figure shows the maximum potential groundwater withdrawal that could occur each year in the South Lake Lowell area based on the annual volume limitation specified for all water rights

granted up to that point in time (IDWR, 2003). This is not necessarily the actual groundwater withdrawal that occurs each year, but it is a good indicator of the overall trend in groundwater withdrawal over the years.

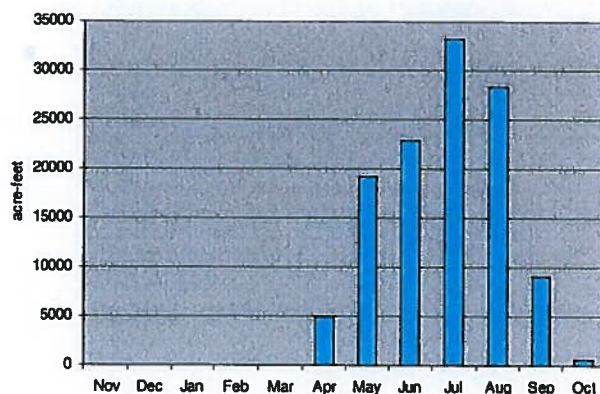


Figure 7. Average monthly seepage from the Mora Canal (1967-1997)

While there is considerable variability in year to year Mora Canal seepage rates, there are a couple obvious trends. First, canal losses are lowest during the driest years such as 1977 and 1992, when there is much less water to divert. In average water years or in wet years such as 1982, 1983, 1985 or 1997, canal losses are higher. Second, prior to 1970 canal losses generally range from 80 to 100 thousand acre-feet per year. However by the mid 1980's canal losses have increased to between 120 and 140 thousand acre-feet per year. During the same time period, maximum potential groundwater withdrawals for irrigation in the South Lake Lowell area increased from less than 40,000 acre-feet per year to almost 90,000 acre-feet per year. It is apparent in figure 8 that much of this increase in groundwater withdrawals occurred in a single year, 1977 (IDWR, 2003).

As of 2003, there were 277 wells in the South Lake Lowell area with water rights. Forty-seven of these wells were permitted in 1977, more than in any other year. Most of the wells were permitted in February and March of that year, and all are primary supply irrigation wells. Fourteen of the wells permitted in 1977 are located within a mile of the Mora Canal. Eleven more are within two miles of the canal. The remaining are three to five miles from the canal. During this one year, maximum potential groundwater withdrawals in the South Lake Lowell area increased by 18,000 acre-feet, or by 38 percent.

The impact of new groundwater pumping on Mora Canal seepage is apparent in the years following 1977. Canal losses increase significantly in 1979 and 1981, and remain generally at a higher level from then on.

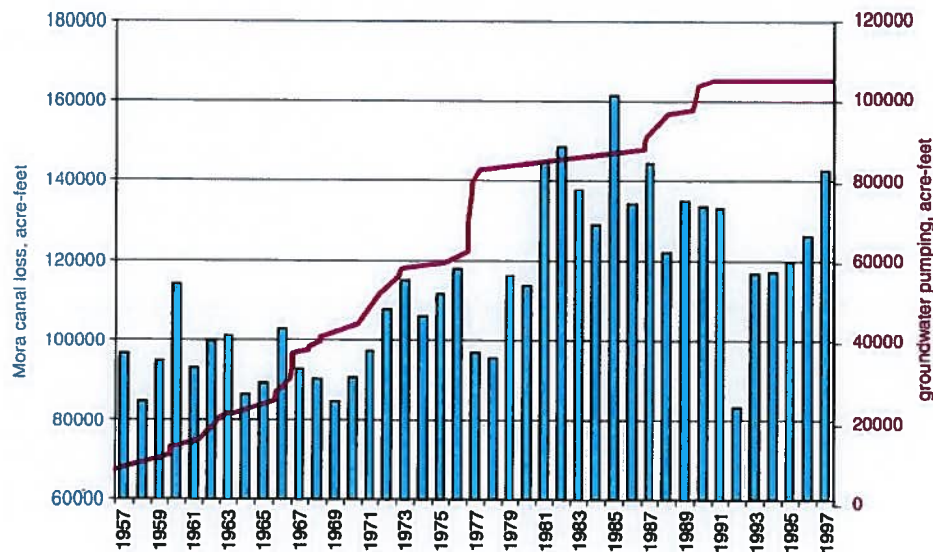


Figure 8. Annual Mora Canal seepage and maximum potential withdrawal for all groundwater rights in the South Lake Lowell area (1957-1997).

Increased seepage from the Mora Canal and its laterals has helped to sustain groundwater levels in the “Deer Flat” area just south of the Deer Flat Highline canal and north of the Mora Canal. Observation well data in the “Deer Flat” area indicates average annual groundwater levels range from 2525 to 2550 feet msl. (Table 1). Nevertheless, this is somewhat lower than what is indicated by watertable contour maps in USGS Water Supply Paper 1585 (Stevens P.R., 1962), even though these maps predate the construction of the Brooks lateral off the Mora Canal.

Table 1. Groundwater elevations in “Deer Flat” observation wells (IDWR, 2017).

Well ID	Land Surface datum feet msl.	Depth to water, feet (approx. time series average)	Groundwater elevation, feet msl. (approx. time series average)
2N3W02DCC1	2549	20	2529
2N3W12DAA1	2535	19	2514
2N2W17CBC1	2555	31	2526
2N2W28DDD1	2610	60	2550
2N3W13DAA1	2599	70	2529
2N2W30BBA-4	2590	60	2530
2N2W20CBB1	2563	35	2528
2N2W07CBC1	2550	20	2530

The South Lake Lowell Area AEM Groundwater Model

The impact of proposed pumping in the South Lake Lowell area on BOC managed facilities is estimated using a hydrologic modeling methodology known as analytic elements. The analytic element method (AEM) has its origins at the University of Delft (De Josselin De Jong, 1969), (Verruijt, 1982). But it was

primarily developed at the University of Minnesota, beginning in the 1980's (Strack, 1989). Unlike numerical models which require spatial approximation using a grid mesh, analytic element models have unlimited spatial resolution, and are especially well suited for conjunctive surface and groundwater problems involving a dense network of surface water features such as canals, drains, rivers and lakes. As such, AEM models have become a standard with government agencies, universities, and many consulting firms. In Idaho, an AEM model was used by IDEQ to delineate wellhead protection zones for 549 municipal wells in the Treasure Valley (IDEQ, 2001).

The methodology of analytic element modeling (AEM) is based on the superposition of analytic functions (elements) representing a wide variety of surface and subsurface hydrologic features that influence groundwater flow in both confined and unconfined aquifers. Each analytic element in an AEM model is a solution to the governing linear differential equation for steady-state, two-dimensional groundwater flow (the Laplace or Poisson equation). Strings of line source-sink elements are used to represent rivers, canals and drains. Point source-sink elements are used to represent wells. Doublet elements are used to represent inhomogeneities in aquifer permeability. Areal-recharge elements are used to represent aquifer infiltration such as on-farm loss. A boundary condition (either a fixed elevation head or a fixed flow rate) is required for each analytic element. Analytic elements with a fixed head are referred to as head-specified and analytic elements with a fixed flow are referred to as flow-specified.

Individual analytic element solutions to the governing linear differential equation are additive, and can be superimposed on one another in order to generate a comprehensive solution for a groundwater flow problem that involves many different surficial water features. Since the analytic element solutions are derived analytically (rather than numerically using a grid) it is possible to represent individual canal and drain features at their exact locations, with exact widths and depths, on a basin-wide scale.

The AEM software used to model the South Lake Lowell area is GFLOW (Scientific Software Group, 2017), which is a proprietary software package developed at Indiana University. GFLOW was chosen over other public domain AEM software because it incorporates a canal and river routing algorithm which runs in conjunction with the groundwater model.

South Lake Lowell Model Boundaries

The South Lake Lowell AEM model simulates unconfined flow conditions in an aquifer that is comprised of the terrace gravels of the Snake River Group, and the upper and middle sand, silt, and gravel units of the Glenns Ferry Formation. The saturated thickness of this aquifer ranges from 300 to about 550 feet.

The base of the aquifer is assumed to be the blue clay layers which underlie the upper and middle sand, silt, and gravel units of the Glenns Ferry Formation. In the South Lake Lowell area this layer is generally encountered between 2000 and 2100 feet msl. elevation (Stevens, 1962). The base elevation of the modeled aquifer is therefore set at 2000 feet msl. A small upward leakage of groundwater from the deeper confined aquifer (.001 ft/day) (Newton, 1991) is imposed uniformly over the model area.

A combination of flow-specified and head-specified analytic elements are used to represent hydrologic features. Flow-specified analytic elements are used to represent wells and on-farm loss. Specified flows for these elements, i.e. pumping rates and on-farm infiltration rates are fixed, and are obtained from the Boise Basin water budget and IDWR well data base. Pumping rates from primary supply wells are the maximum annual allowable by water right.

Near-field surficial hydrologic features including canals, drains, Lake Lowell, and a portion of the Snake River are all represented by strings of head-specified analytic elements, for which a msl. elevation head and a bed resistance are specified. Canal, drain, river, and reservoir elevations are taken from USGS digital elevation maps.

Canal bed resistance refers to properties of a constructed canal liner or a natural feature which resists canal seepage loss. In most cases in the South Lake Lowell area it takes the form of a natural feature such as a localized hardpan layer or a clay lens below the bottom of a canal and at or near the watertable surface. With the onset of irrigation, canal seepage causes head to build up beneath the canal above the resistance layer. Canal seepage becomes head-dependent when head buildup causes the saturated surface to come in contact with the canal. Groundwater pumping lowers the watertable in the vicinity of the canal so that head buildup above the resistance bed is reduced. Drillers' logs indicate shallow low permeability hard pans and clay lenses are common within alluvial interbedded silts, sands and gravels of the Glenns Ferry Formation. (See for example 2N2W23CBB1, 2N3W13DAA1, 2W28DDD1, 2N2W30BBA-4 and 2N2W07CBC1 in table 2).

Modeled bed resistances are defined as the thickness of the low permeability bed divided by its vertical hydraulic conductivity. Modeled canal bed resistances for near-field hydrologic boundaries range from 0.5 to 300.0 ft/(ft/min) and are derived through model calibration. More distant hydrologic boundaries (e.g. Boise River) are represented by far-field head-specified analytic elements for which only an elevation is specified.

Regardless of which type of boundary condition is imposed, the model will calculate the unspecified condition. Thus, for head-specified canal, drain and river elements, the model will calculate the seepage rate or base flow, and for flow-specified wells the model will calculate the head at the well bore.

The distribution of analytic elements that make up the South Lake Lowell model is shown in figure 9. The model contains 1,546 head-specified line source-sink elements representing canals and drains, Lake Lowell, and a portion of the Snake River. The latter is represented by two parallel strings of line source-sink elements representing the north bank and the south bank of the river. In addition the model contains 976 flow-specified wells, and 38 flow-specified infiltration areas representing the spatial distribution of on-farm loss. Three permeability zones are used to represent fault zones and other aquifer inhomogeneities.

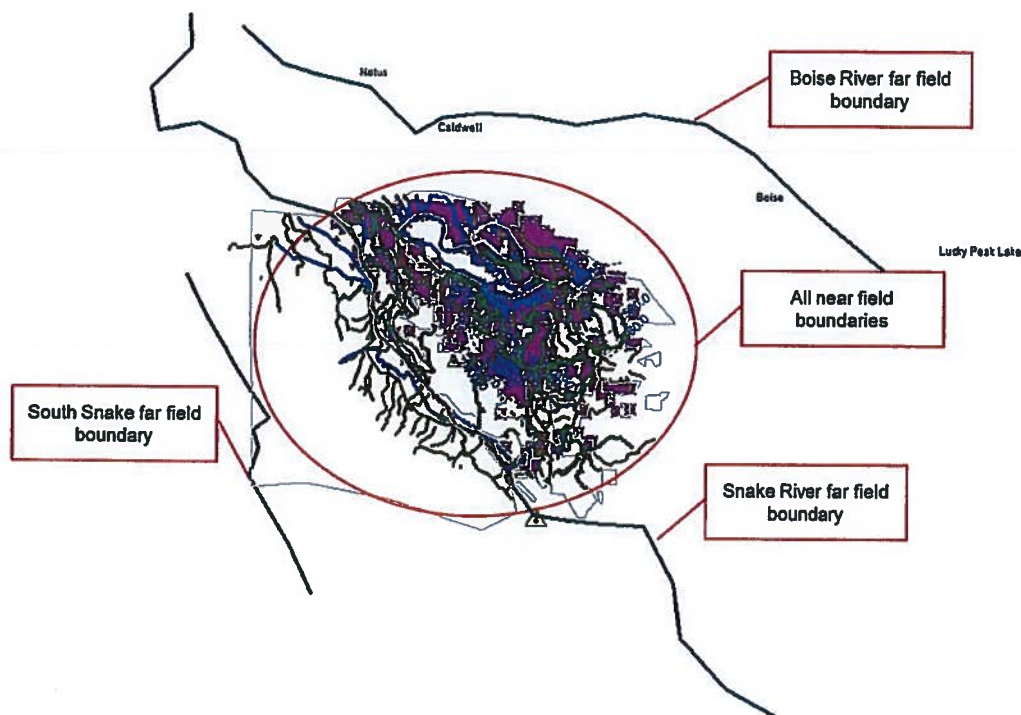


Figure 9. South Lake Lowell analytic element model near-field and far-field boundaries.

South Lake Lowell Base Case Model Calibration

Calibration targets for the South Lake Lowell base case model include groundwater elevations in observation wells, seepage from canals, groundwater returns to drains, Lake Lowell gains and losses, and Snake River base flow, prior to 2003. Calibration parameters include aquifer permeabilities and bed resistances. Calibration parameters are adjusted in order to achieve the best possible match between targeted and modeled conditions of aquifer head, Lake Lowell gains and losses, canal seepage, drain return and Snake River base flow, on an average annual basis.

The head conditions imposed on Lake Lowell, drains, and the Snake River, are therefore annual averages. However the head conditions imposed on canals are representative of conditions that exist during the irrigation season, i.e. the model assumes that canal seepage occurs at a uniform rate, year around. As a result, canal bed resistances are presumed to represent about twice their actual value. Whether canal loss or drain return occurs uniformly throughout the year, or all within a six month period during the year is not important from a steady-state modeling perspective, so long as the annual total is the same in both cases.

All of the 43 observation wells used in model calibration have an open interval in the upper aquifer, (i.e. above 2000 feet msl. elevation). Annual average groundwater elevations range from 2212 feet msl. to 2637 feet msl. The average difference between observed and simulated well head in the calibrated model is 13 feet, and the root mean square difference is 21 feet. The model deviation from observed head is about 5 percent of the total range in head (figure 10).

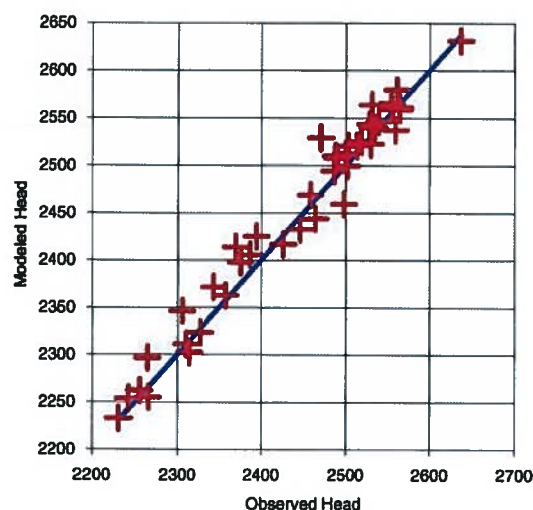


Figure 10. Base case model calibration with respect to observation well levels (in feet msl.).

Model calibration with respect to calculated flows for head-specified analytic elements includes targeted and modeled seepage from Lake Lowell, targeted and modeled groundwater return to drains, targeted and modeled seepage rates from the Mora Canal and from all other canals in the model area, and targeted and modeled base flow to the Snake River.

On average, annual Lake Lowell gains and losses are comparatively small, netting about 3,752 acre-feet annually. Lake Lowell net gain in the calibrated model is 3,816 acre-feet, which is within 2 percent of the Lake Lowell target. The water budget estimate of average monthly seepage from the Mora Canal is 118,128 acre-feet, and the calibrated model estimate of seepage is 115,272 acre-feet, which is within 2 percent of the Mora Canal target. The water budget estimate of average annual reach gain to the Snake River is 128,400 acre-feet, and the model estimate is 137,400 acre-feet, a difference of 7 percent. The water budget estimate of average annual groundwater return flow to drains in the South Lake Lowell model area is 133,488 acre-feet, and the model estimate is 129,372 acre-feet, a difference of 3 percent (all of which occurs north of the New York Canal). The water budget estimate of average annual canal seepage in the model area (north of the Snake River) is 266,604 acre-feet, and the model estimate, is 291,156 acre-feet, a difference of 9 percent.

Calibrated aquifer permeabilities range from 0.1 to 75 feet/day, which is comparable to the Treasure Valley groundwater model (Petrich, 2002) and to the earlier USGS model (Newton, 1991). One area of higher permeability is associated with a geologic structure just south of Lake Lowell. Another low permeability area follows the exposure of several faults along the north rim of the Snake River Canyon (figure 4).

Base Case Model Results: Groundwater Elevations

Groundwater elevation contours generated by the calibrated base case model range from about 2600 feet msl. beneath a portion of the Mora Canal south of Lake Lowell, to about 2300 feet msl. beneath the Snake River (figure 11). The groundwater gradient in the South Lake Lowell area is generally to the south or southwest, toward the Snake River. An area of elevated groundwater exists north and east of the Mora Canal and south of the Deer Flat Highline Canal in an area referred to on topographic maps as "Deer Flat". At its highest, groundwater elevation in the "Deer Flat" area is about 2555 feet msl. North of the Deer Flat Highline Canal, groundwater elevation gradually declines from 2545 feet msl. beneath the canal to 2530 feet msl. at the boundary of Lake Lowell. South and west of the Mora Canal groundwater elevations also decline from between 2550 and 2500 feet msl. along the canal to about

2300 feet beneath the Snake River. A steep groundwater gradient also exists along the north rim of the Snake River Canyon due to low permeability fault zones and tilted beds which limit the flow of groundwater toward the Snake River.

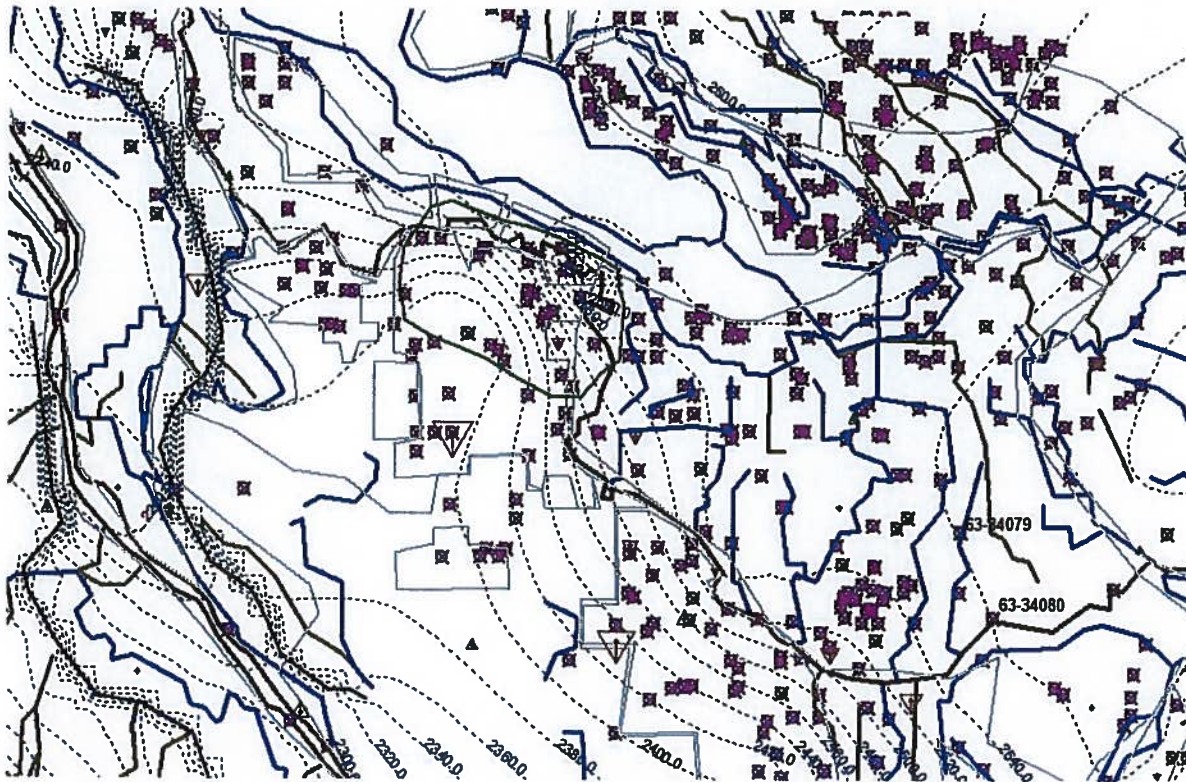


Figure 11. Base case model head contours in the South Lake Lowell area and locations of proposed Emmert wells 63-34079 and 63-37080.

Base Case Model Results: Groundwater and Surface Water Interactions

Hydrologic interactions between surface water features and groundwater in the South Lake Lowell model area depend in part on the degree of physical contact that exists between the surface water feature and the saturated surface of the underlying aquifer. In GFLOW modeling, if the saturated surface beneath a canal is less than the specified-head in the canal minus the resistance bed thickness then canal seepage is head-independent and the canal is said to be percolating. If the aquifer head is greater than the specified head in the canal minus the resistance layer thickness, then the canal seepage is head-dependent. By lowering the aquifer head, groundwater pumping induces additional seepage beneath a head-dependent canal. However lowering aquifer head beneath a percolating canal has no effect on seepage.

A large portion of Lake Lowell is known to be in direct contact with the saturated surface of the underlying aquifer, and the watertable in much of the "Deer Flat" area north and south of the Deer Flat Highline canal is also close to the surface (Table 1), so that some canals and drains may also be in direct contact with the underlying saturated surface. In modeling with GFLOW, it is not necessary to know in advance which lakes, rivers, canals or drains are above the saturated surface of the aquifer and which are in contact with it. GFLOW incorporates an iterative procedure for making this determination when the model is run. In those cases where head-specified canals are perched, GFLOW automatically determines the seepage rate based on bed resistance, and converts the head-specified canal to a flow-specified (percolating) canal. Discharge to drains occurs only if the drain is in direct contact with the underlying saturated surface. In those cases where a head-specified drain is perched, specified flow is zero.

Locations where GFLOW base case modeling indicates direct canal contact with the saturated surface of the aquifer are indicated in figure 12 by heavy colored lines. Three BOC canals have segments in direct contact with the underlying saturated surface; a portion of the Deer Flat Highline Canal just south of Lake Lowell where aquifer head beneath the canal during the irrigation season ranges from 2547 to 2554 feet msl., a portion of the Mora Canal further to the west where aquifer head beneath the canal ranges from 2645 to 2642 feet msl., and a portion of the New York Canal in the last few miles before it discharges into Lake Lowell where aquifer head ranges from 2542 to 2529 feet msl.

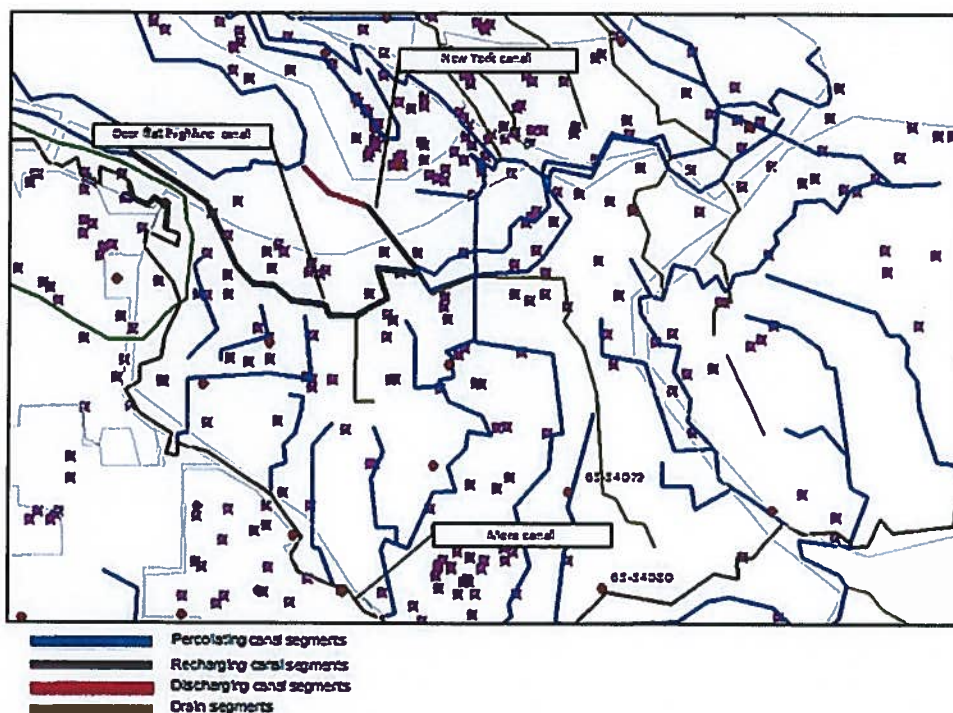


Figure 12. Locations of BOC canal in contact with the aquifer saturated surface.

The Emmert Well Pumping Model

The Emmert well model is simply the base case model incorporating the two proposed Emmert wells, applications 63-34079 in T2N-R2W-35, and 63-34080 in T1N-R2W-1 (locations shown in figure 11). The wells are assumed to fully penetrate the upper aquifer, i.e. well depth extends to 2000 feet msl. elevation. Three Emmert well pumping scenarios are developed to simulate three possible total pumping rates; 42 AF per year, 235 AF per year and 668 AF per year.

At the outset of well pumping, groundwater that is withdrawn from the aquifer comes mainly from aquifer storage. In an unconfined aquifer this is termed specific yield. However as well pumping continues and a cone of depression expands about the new wells, the proportion of well withdrawal that comes from specific yield diminishes, and the proportion of well withdrawal that comes from surface water sources increases.

Over time, the impact of the proposed well pumping is expected to be a depletion of surface water, either through reduced discharge to drains, increased seepage from canals, reduced gains or increased losses from Lake Lowell, or reduced base flow to the Snake River. The total (steady-state) surface water

depletion that results from proposed Emmert well pumping is expected to be equivalent in magnitude to total well withdrawal.

Comparative Analysis of Base Case Model and Emmert Model Results

Estimating surface water depletions in the South Lake Lowell model area involves a comparative analysis of calibrated base case model results with Emmert well model results. The impacts of proposed Emmert well pumping are summarized in terms of four categories of potential surface water depletion;

- increased Lake Lowell seepage (or reduced gains)
- increased canal seepage (or reduced gains)
- reduced groundwater discharge to drains
- reduced Snake River and Boise River base flow.

Depletions are calculated by subtracting the flow of every head-specified element in the Emmert well model from the flow of every comparable head-specified element in the base case model.

Model -Wide Surface Water Depletions

The depletions that occur in each of the four categories, for each of the three Emmert well pumping scenarios are presented in tables 2, 3 and 4. Table 2 gives model results for the 42 AF per year pumping scenario, table 3 gives results for the 235 AF per year pumping scenario, and table 4 gives results for the 668 AF per year pumping scenario.

The three tables are all formatted the same. Column 1 is the model boundary feature in question, where a distinction is made between near field and far field boundary features (see figure 10). Columns 2 and 3 are the recharge and discharge flow rates associated with that boundary feature in the base case model. Columns 4 and 5 are the recharge and discharge flow rates associated with that boundary feature given the additional pumping rates of each scenario. Columns 6 and 7 are the changes in recharge and discharge rates for each feature, and column 8 is the total depletion from each feature due to increased recharge and/or reduced discharge. Column 9 is total depletion as a percentage of new pumping. As noted in the last row of each table the depletions sum to the Emmert well pumping rate of each scenario.

Total depletions increase proportionally to pumping rate in tables 3 and 4, so that while the magnitude of pumping impacts increases, percentage wise the distribution of depletions is unchanged from Table 2.

Constant proportionality of depletions with respect to pumping rate is not a given, it occurs in this case because even the highest pumping rate being simulated (668 AF per year) is not high enough to cause head conditions beneath canals that are in direct contact with the underlying saturated surface to become percolating features, or in the case of drains to become perched.

1. Model boundary feature	2. Recharge base case, AF	3. Discharge base case, AF	4. Recharge 42 AF pumping	5. Discharge 42 AF pumping	6. Increased recharge, AF	7. Reduced discharge, AF	8. Total change in recharge and discharge, AF	9. Percent change with 42 AF pumping
Lake Lowell (near field)	(6,058.90)	9,250.39	(6,059.21)	9,249.83	0.31	0.56	0.87	2.1%
canals (near field)	(307,396.42)	100,164.87	(307,404.75)	100,162.07	8.32	2.80	11.12	26.5%
drains (near field)	-	122,198.95	-	122,185	-	15.37	15.37	36.6%
Snake River (near field)	-	138,333.81	-	138,331	-	3.14	3.14	7.5%
Snake River (far field)	-	773,232.94	-	773,227	-	5.50	5.50	13.1%
Boise River (far field)	-	32,612.16	-	32,608	-	3.73	3.73	8.9%
South of Snake River (drains)	(782,017.85)		(782,015.58)		2.27		2.27	5.4%
total	(1,095,473.2)	1,175,794.1	(1,095,479.5)	1,175,763.0	10.9	31.1	42.0	100.0%

1. Model boundary feature	2. Recharge base case, AF	3. Discharge base case, AF	4. Recharge 235 AF pumping	5. Discharge 235 AF pumping	6. Increased recharge, AF	7. Reduced discharge, AF	8. Total change in recharge and discharge, AF	9. Percent change with 235 AF pumping
Lake Lowell (near field)	(6,058.90)	9,250.39	(6,060.63)	9,247.24	1.73	3.15	4.89	2.1%
canals (near field)	(307,396.42)	100,164.87	(307,442.92)	100,149.23	46.50	15.64	62.14	26.4%
drains (near field)	-	122,198.95	-	122,114	-	85.93	85.93	36.6%
Snake River (near field)	-	138,333.81	-	138,316	-	17.70	17.70	7.5%
Snake River (far field)	-	773,232.94	-	773,202	-	30.88	30.88	13.1%
Boise River (far field)	-	32,612.16	-	32,591	-	20.90	20.90	8.9%
South of Snake River (drains)	(782,017.85)		(782,030.42)		12.57		12.57	5.3%
total	(1,095,473.2)	1,175,794.1	(1,095,534.0)	1,175,619.9	60.8	174.2	235.0	100.0%

1. Model boundary feature	2. Recharge base case, AF	3. Discharge base case, AF	4. Recharge 668 AF pumping	5. Discharge 668 AF pumping	6. Increased recharge, AF	7. Reduced discharge, AF	8. Total change in recharge and discharge, AF	9. Percent change with 668 AF pumping
Lake Lowell (near field)	(6,058.90)	9,250.39	(6,063.83)	9,241.42	4.93	8.97	13.90	2.1%
canals (near field)	(307,396.4)	100,164.87	(307,529.67)	100,121.36	133.24	43.51	176.75	26.5%
drains (near field)	-	122,198.95	-	121,955	-	244.47	244.47	36.6%
Snake River (near field)	-	138,333.81	-	138,284	-	50.29	50.29	7.5%
Snake River (far field)	-	773,232.94	-	773,145	-	87.81	87.81	13.1%
Boise River (far field)	-	32,612.16	-	32,553	-	59.33	59.33	8.9%
South of Snake River (drains)	(782,017.85)		(782,053.25)		35.40		35.40	5.3%
total	(1,095,473.2)	1,175,794.1	(1,095,646.8)	1,175,299.7	173.6	494.4	668.0	100.0%

Model Results: Individual Drain Depletions

Tables 5, 6 and 7 give a breakdown of individual drain depletions for each of the three pumping scenarios. Model results indicate that four drains, the Elijah, Wilson, Golden Gulch and Herron account for nearly all drain depletion. All four are located north of the New York Canal. Model results also indicate that on an average annual basis, there is no direct contact between drains and the underlying saturated surface south of the New York Canal. As noted in the last row of each table, individual drain depletions due to Emmert well pumping sum to the total drain depletion of each scenario.

Table 5. Modeled drain depletions for head-specified drain boundaries with 42 AF of new well pumping.				
1. Model boundary feature	2. Recharge base case, AF	3. Discharge 42 AF pumping	4. Reduced discharge, AF	5. Percent change with 42 AF pumping
Elijah Drain	23758.9	23753.3	5.6	13.4%
Wilson Drain	51574.1	51571.2	3.0	7.1%
Golden Gulch Drain	531.6	529.3	2.3	5.4%
Herron Drain	4538.6	4537.8	0.8	1.9%
all other drains north of Snake River	41796.6	41793.0	3.7	8.8%
total	122199.9	122184.6	15.4	36.6%

Table 6. Modeled drain depletions for head-specified drain boundaries with 235 AF of new well pumping.				
1. Model boundary feature	2. Recharge base case, AF	3. Discharge 235 AF pumping	4. Reduced discharge, AF	5. Percent change with 235 AF pumping
Elijah Drain	23758.9	23727.47494	31.5	13.4%
Wilson Drain	51574.1	51557.53028	16.6	7.1%
Golden Gulch Drain	531.6	518.885437	12.7	5.4%
Herron Drain	4538.6	4534.12888	4.5	1.9%
all other drains north of Snake River	41796.6	41776.01807	20.6	8.8%
total	122199.9	122114.0	85.9	36.6%

Table 7. Modeled drain depletions for head-specified drain boundaries with 668 AF of new well pumping.				
1. Model boundary feature	2. Recharge base case, AF	3. Discharge 668 AF pumping	4. Reduced discharge, AF	5. Percent change with 668 AF pumping
Elijah Drain	23758.9	23669.42604	89.5	13.4%
Wilson Drain	51574.1	51526.92463	47.2	7.1%
Golden Gulch Drain	531.6	495.353495	36.3	5.4%
Herron Drain	4538.6	4525.831474	12.8	1.9%
all other drains north of Snake River	41796.6	41737.94554	58.7	8.8%
total	122199.9	121955.5	244.5	36.6%

Model Results: Individual BOC Canal Depletions

Canal depletions occur in canal segments where the canal is in direct contact with the underlying saturated surface of the aquifer, so that lowering aquifer head due to pumping causes either an increase in canal seepage (or a decrease in canal gain). Model results indicate that the impact of Emmert well pumping on BOC canal seepage is limited to segments of three canals; the New York Canal, the Deer Flat Highline Canal and the Mora Canal, where base case model results indicate the canals are in direct contact with the underlying saturated surface (see figure 13). Tables 8, 9 and 10, show, for each of the three pumping scenarios, the magnitude of each BOC canal depletion and the percentage of new pumping that it represents. Table formatting is the same as that of the previous summary tables. As noted in the last row of each table, individual canal depletions due to Emmert well pumping sum to the total canal depletion of each scenario.

1. Model boundary feature	2. Recharge base case, AF	3. Discharge base case, AF	4. Recharge 42 AF pumping	5. Discharge 42 AF pumping	6. Increased recharge, AF	7. Reduced discharge, AF	8. Total change in recharge and discharge, AF	9. Percent change with 42 AF pumping
Deer Flat High Line Canal	(44,268.54)	-	(44,273.31)	-	4.77	-	4.77	11.3%
New York Canal	(192.24)	41.71	(192.00)	41.66	0.24	0.05	0.29	0.7%
Mora Canal	(35,747.72)	-	(35,750.63)	-	2.91	-	2.91	6.9%
All other canals ¹	(202,158.80)	97,857.04	(202,156.64)	97,856.05	2.16	0.99	3.16	7.5%
total	(307,396.42)	100,164.87	(307,388.10)	100,162.07	8.32	2.80	11.12	26.5%

¹ depletions are from non-BOC canals

1. Model boundary feature	2. Recharge base case, AF	3. Discharge base case, AF	4. Recharge 235 AF pumping	5. Discharge 235 AF pumping	6. Increased recharge, AF	7. Reduced discharge, AF	8. Total change in recharge and discharge, AF	9. Percent change with 235 AF pumping
Deer Flat High Line Canal	(44,268.54)	-	(44,295.17)	-	26.63	-	26.63	11.3%
New York Canal	(192.24)	41.71	(193.60)	41.44	1.35	0.28	1.63	0.7%
Mora Canal	(35,747.72)	-	(35,763.96)	-	16.24	-	16.24	6.9%
All other canals ¹	(202,158.80)	97,857.04	(202,170.92)	97,851.52	12.11	5.52	17.64	7.5%
total	(307,396.42)	100,164.87	(307,442.92)	100,149.23	46.50	15.64	62.14	26.4%

¹ depletions are from non-BOC canals

Table 1. Modeled canal depletions of head-specified BOC and non-BOC canal boundaries with 668 AF of new well pumping.								
1. Model boundary feature	2. Recharge base case, AF	3. Discharge base case, AF	4. Recharge 668 AF pumping	5. Discharge 668 AF pumping	6. Increased recharge, AF	7. Reduced discharge, AF	8. Total change in recharge and discharge, AF	9. Percent change with 668 AF pumping
Deer Flat High Line Canal	(44,268.54)		(44,344.29)		75.75	-	75.75	11.3%
New York Canal	(192.24)	41.71	(196.21)	41.04127088	3.97	0.67	4.64	0.7%
Mora Canal	(35,747.72)	-	(35,793.91)	-	46.19	-	46.19	6.9%
All other canals ¹	(202,158.80)	97,857.04	(202,193.69)	97,841.77	34.89	15.27	50.17	7.5%
total	(307,396.42)	100,164.87	(307,529.67)	100,121.36	133.24	43.51	176.75	26.5%

¹ depletions are from non-BOC canals

Summary and Conclusions

The South Lake Lowell AEM model has been demonstrated to be a conceptually valid and well calibrated model of unconfined flow conditions in the upper (cold water) aquifer in this area of the Boise Basin. Because it uses analytical methods instead of grid based numerical methods, the model is able to calculate the relatively small amounts of individual canal, drain, and reservoir depletion that result from pumping of individual wells.

GFLOW is a steady state model, meaning that model results are representative of an aquifer system in which inflows and outflows are presumed to be in equilibrium, and a mass water balance can be calculated that does not include change in aquifer storage. GFLOW modeled depletions should therefore be interpreted as representing aquifer conditions which develop over the course of several years of new pumping, and after aquifer storage in the vicinity of the pumping wells has been depleted.

While it is generally not possible to directly measure the surface water depletions that result from a single new well, it is possible to measure the depletions that result from the cumulative effects of many new wells that begin pumping at about the same time. The 30 to 40 percent increase in depletions from the Mora Canal that followed a 38 percent increase in groundwater pumping south of Lake Lowell in the South Lake Lowell area in 1977, is evidence for this. In this regard, the 2 to 4 year time lag between the onset of pumping and the Mora Canal seepage response can be seen as a rough indicator of the time lag that would exist between onset of proposed Emmert well pumping and increased BOC canal seepage.

Drains account for the largest percentage of depletions due to Emmert well pumping, combined Boise and Snake River depletions are second largest, and canal depletions are third. Percentagewise Lake Lowell depletions are the smallest. And, since depletions increase in proportion to pumping rate, the percentage distribution is the same for all three Emmert well pumping scenarios (42, 235 or 668 AF per year). Depletion of BOC surface facilities accounts for 21.1% of proposed Emmert well pumping, of which 2.1% is Lake Lowell depletion and 19% is BOC canal depletion.

South Lake Lowell model results show directly, what historical records of Mora Canal loss and groundwater pumping show indirectly, i.e. that portions of the Deer Flat Highline Canal, the Mora Canal and Lake Lowell are in direct contact with the underlying saturated surface of the aquifer, and therefore canal seepage is dependent on aquifer head. Ultimately, new groundwater pumping will result in increased seepage from these canals and from Lake Lowell.

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Appendix A GFLOW Iterative Solver Log, Base Case Model

Appendix B GFLOW Computational Results, Base Case Model

Average Water Use Per Acre Project Wide 1996-2016:

1996 - 2.88

1997 - 3.02

1998 - 2.69

1999 - 3.06

2000 - 2.99

2001 - 1.85

2002 - 2.68

2003 - 2.58

2004 - 2.49

2005 - 1.70

2006 - 2.51

2007 - 2.21

2008 - 2.69

2009 - 2.73

2010 - 2.52

2011 - 2.80

2012 - 3.37

2013 - 1.85

2014 - 2.51

2015 - 2.27

2016 - 2.88

Analysis of Hydrologic Impacts of New Groundwater Pumping

in the Dry Lake Area of Canyon County, Idaho

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**US Bureau of Reclamation,
Pacific Northwest Region**

April 15, 2003

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Analysis of Hydrologic Impacts of New Groundwater Pumping in the Dry Lake Area of Canyon County, Idaho

Objective

A hydrologic analysis of new groundwater pumping in the Dry Lake area of southern Canyon County, was performed in order to assess the impact of a proposed groundwater withdrawal in T1N-R3W-S3 (Appl. 63-31423) (the Chase well), on nearby Reclamation facilities, including (but not limited to) the Mora Canal, the New York Canal, the Deer Flat Lowline Canal, and the Deer Flat Highline Canal, the East Valley Mound Wasteway, the Elijah drain, the Wilson drain, and Lake Lowell. The cumulative impact of pumping from nine other proposed wells in the Dry Lake area, all having earlier water right application dates than the Chase well, was also analyzed.

The impact of new groundwater pumping on Reclamation facilities was estimated using a computer-based groundwater model of the Dry Lake area. Previous hydrogeologic investigations of the area, together with observation well data, and a recently developed distributed-parameter water budget for irrigated lands in the Boise Basin, provided information necessary to develop and calibrate the Dry Lake area model.

The Dry Lake Area of Interest

The Dry Lake area is centered roughly on an actual dry lake bed, located in Canyon County about five miles south of Lake Lowell. As defined by Stevens (1962), the Dry Lake area encompasses about 53 square miles of mostly agricultural land, bounded on the north by the Mora Canal and on the south by the Snake River. The Dry Lake area of interest for this hydrologic analysis is somewhat larger than this. It encompasses about

155 square miles and includes all of Lake Lowell, some Boise Project lands located east of Lake Lowell, a portion of the Snake River, and some non-project lands immediately south of the Snake River (figure 1).

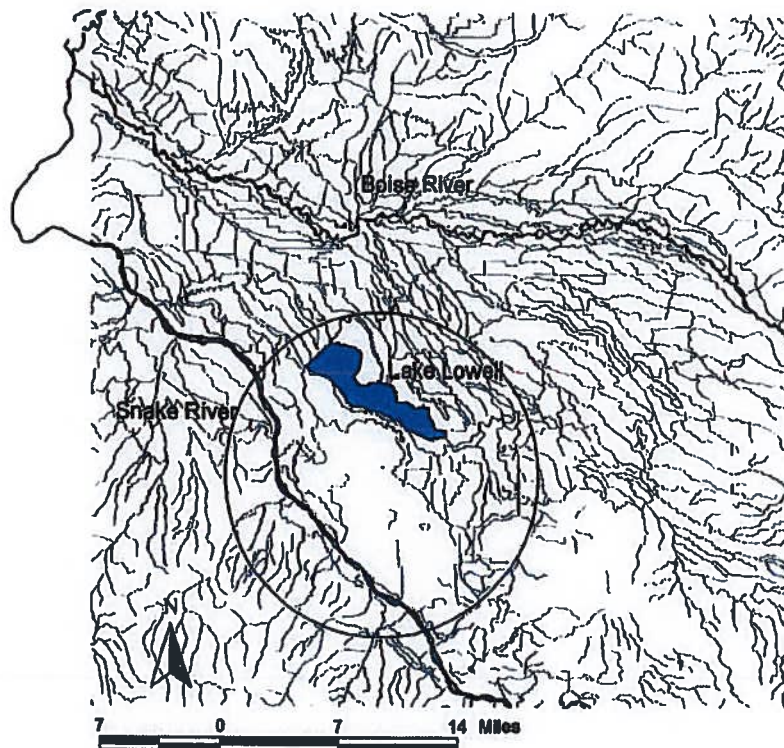


Figure 1. Dry Lake area of interest.

Hydrogeology of the Dry Lake Area

Numerous studies of Boise Basin geology and hydrogeology (which include the Dry Lake area) have been conducted by the USGS, the University of Idaho, Boise State University and others. The principal reports are those of Stevens (1962), Wood and Anderson (1981), Anderson and Wood (1981) Whitehead (1986), Newton (1991), Squires, Wood, and Osiensky (1992), Othberg (1994), Kjelstrom (1995), Lindholm

(1996), and Wood and Clemens (2001). The report by Stevens, and a draft report by Graves and Bendixsen (IDWR, 1995) are the only ones to focus exclusively on the Dry Lake area however.

In summary, the Boise Basin is characterized geologically as a graben, with high angle, north-west south-east trending faults along its boundaries, and downwarping toward the center of the basin. The basin is filled with sediments derived from erosion of surrounding granitic mountains interfingered with basalt flows. Unconsolidated or poorly consolidated flood plain, glacial, and lake deposits extend to a depth of 2000 feet or more in the basin, and range in age from Pliocene to recent (figure 2).

Three geologic units in the Boise Basin have been identified as important cold water aquifers. They are, (1) the fractured basalts, and (2) the sands and gravels of the Snake River Group, and (3) the sands, silts, and gravels in the upper and middle Idaho Group, which includes the Glens Ferry Formation (figure 2).

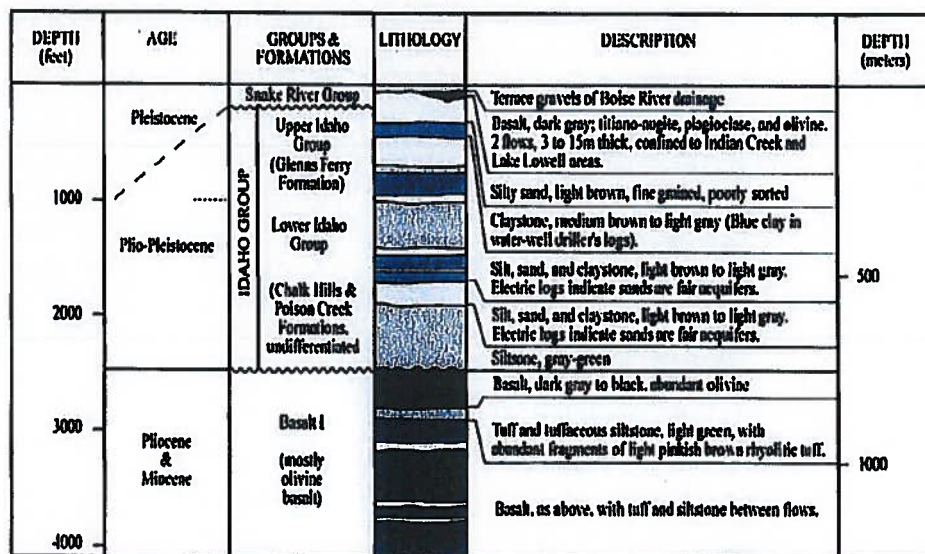


Figure 2. Generalized lithologic log of the Boise River Basin (adapted from Wood and Anderson, 1981).

The sands, silts, and gravels of the Glens Ferry Formation are frequently separated from lower units in the Idaho Group by clay layers having a "bluish" color (as reported in drilling logs). The blue clay layers, which together can be up to 400 feet thick, are fine sediments that formed under chemically reducing conditions, at the bottom of prehistoric Lake Idaho. The Dry Lake area is very near to what was once the center of this ancient lake.

The blue clay layers have been interpreted by some as a large regional confining layer overlying a much deeper geothermal aquifer (Wood and Anderson, 1981). Other hydrogeologists have interpreted these layers as a third intermediate aquifer, albeit with a much lower permeability than the upper sands, silts, and gravels (Newton, 1991).

Figure 3 is a generalized north-south cross-section showing groundwater elevations in the Boise Basin, near the Dry Lake area. Lake Lowell marks the location of a groundwater divide in the basin. South of the divide, in the Dry Lake area, the direction of groundwater flow is to the south or southwest toward the Snake River. North of the divide, groundwater flows north or northwest, toward the Boise River. (The vertical scale in this figure is greatly exaggerated.)

The groundwater divide south of Lake Lowell is not a fixed hydrologic feature, and the location of the divide fluctuates somewhat during the year in response to changes in aquifer recharge rates, groundwater pumping, and the level of Lake Lowell itself. A previous study has indicated that during winter months, when the lake level is high and canals are dry, the divide shifts slightly to the north. During summer months, when the lake level is low and canals are full, it shifts slightly to the south (USBR, 2000).

The principal sources of groundwater in the Dry Lake area are the terrace gravels of the Snake River Group, and the upper and middle sand, silt, and gravel units of the Glens Ferry Formation. Collectively, these two units have a saturated thickness of between 300 and 550 feet. Wells drilled in the Dry Lake area encounter thin stringers of blue clay at various depths, however multiple, thick layers (up to 45 feet) have been encountered only

at depths below 2100 feet msl. elevation (Stevens, 1962). Depths to groundwater in the Dry Lake area range from just over 100 feet to more than 400 feet. The Snake River basalts are above the water table throughout most of the Dry Lake area.

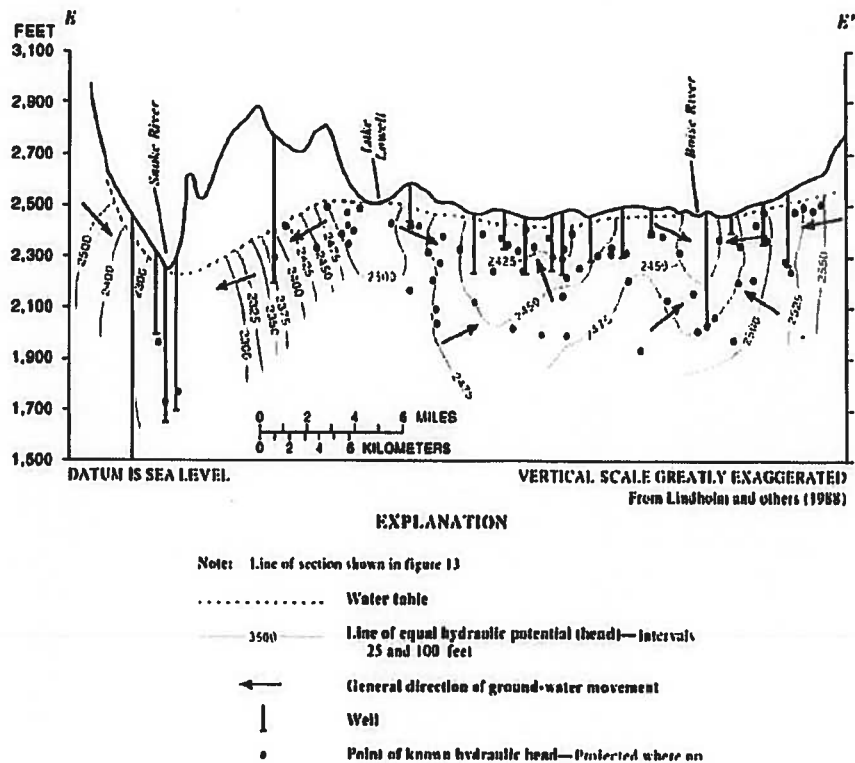


Figure 3. Generalized water table cross section beneath the Dry Lake area (from Lindholm, 1988).

The course of the Snake River through the Dry Lake area is structurally controlled by faulting that is concentrated along the margins of the basin. A series of steeply dipping faults, all striking in a northwest-southeast direction, are exposed along the north rim of the Snake River Canyon (figure 4). These fault zones (together with tilting of stratigraphic units to the north-east) are believed to act as a partial barrier to groundwater

flow in the Dry Lake area, and are probably the reason there are almost no springs along the canyon wall on the north side of the river. A structural trough, also associated with faulting, is believed to be partly responsible for the groundwater divide just south of Lake Lowell.

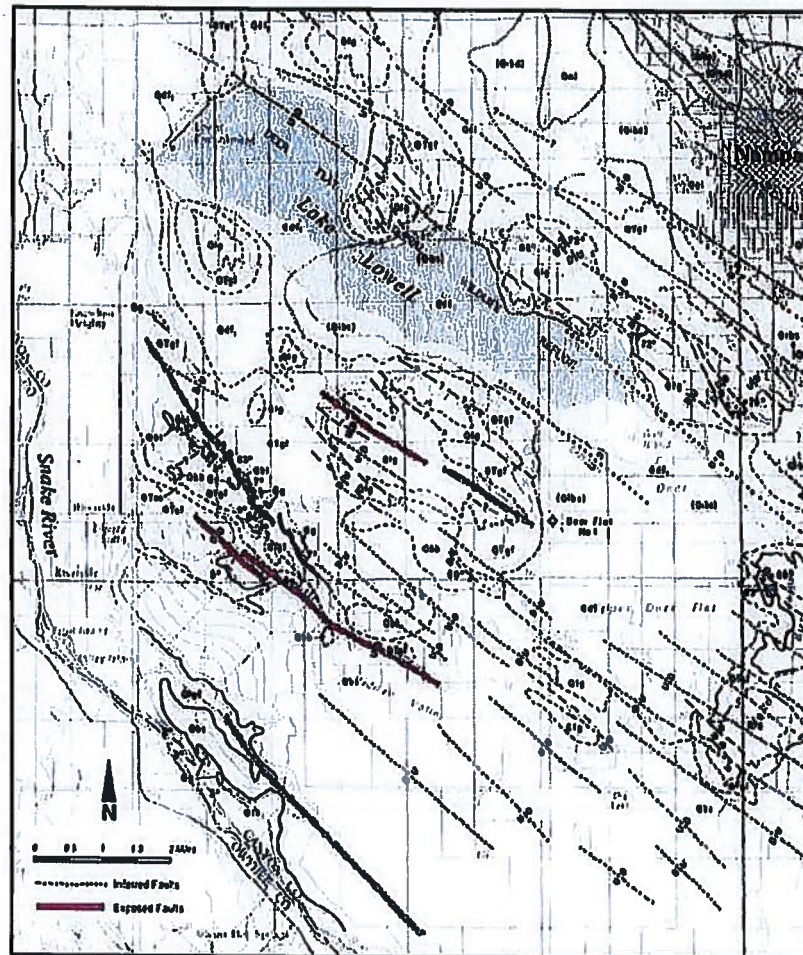


Figure 4. Geologic Faulting in the Dry Lake Area, (adapted from Wood and Anderson, 1981)

Dry Lake Area Water Budget

The Dry Lake Area water budget is part of a distributed-parameter water budget being developed by Reclamation for irrigated lands in the Boise River Basin (USBR, 2002). Individual components of this water budget include canal diversions, farm deliveries, canal seepage, precipitation, evapotranspiration, on-farm loss, groundwater pumping, return flow to drains, Snake River and Boise River gains and losses, Lake Lowell gains and losses, and net aquifer recharge. The distributed-parameter water budget provides a spatially distributed, average monthly value for each of these components, based on historical records of diversion and water use in the basin during the period 1967 to 1997.

Net Aquifer Recharge

Recharge of the Boise Basin aquifer occurs mainly as a result of canal loss and on-farm loss of irrigation water (precipitation has a minor effect). On average, canal seepage recharges the aquifer with about 588 thousand acre-feet of water each year, which is about 50 percent of the total annual aquifer recharge. On-farm loss accounts for about 677 thousand acre-feet of aquifer recharge. About 578 thousand acre-feet of groundwater is discharged to drains each year. Total groundwater pumping for irrigation averages about 125 thousand acre-feet per year (USBR, 2002), of which about 25 thousand acre-feet is used for supplemental water supply.

Net aquifer recharge is a composite water budget parameter developed for irrigated lands, that combines these three budget components in the following way;

net aquifer recharge = canal loss + on farm loss – groundwater pumping.

The spatial distribution of net aquifer recharge in the Boise Basin, is shown in figure 5. During an average year, most of the irrigated lands in the basin experience net aquifer recharge, at rates that range from 1 to as much as 14 acre-feet per acre. The exceptions to

this occur on lands that are irrigated exclusively with groundwater. Net aquifer discharge (negative recharge) on these lands can be as much as 3 acre-feet per acre per year.

The largest contiguous area in the basin to be irrigated exclusively with groundwater is located in the Dry Lake area, just south of the Mora Canal. Pumping for irrigation of these lands is estimated to be about 60 thousand acre-feet per year. The net deficit in aquifer recharge (aquifer discharge) on these lands averages about 1.8 acre-feet per acre per year. Lands in the Dry Lake area that are closer to the Snake River are irrigated with water pumped directly from the river. Net aquifer recharge on these lands averages about 2.2 acre-feet per acre per year.

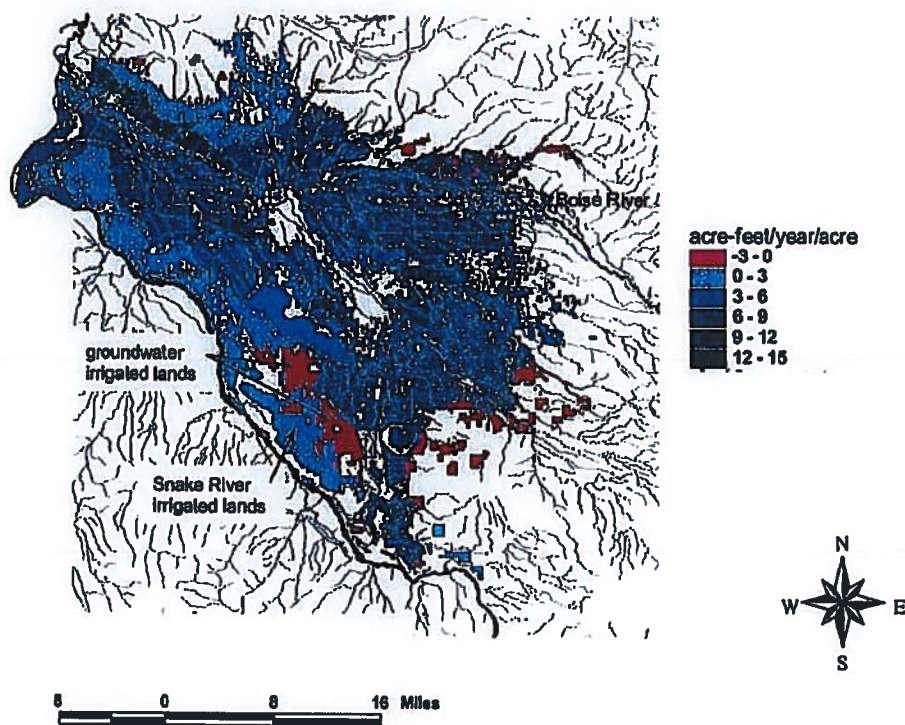


Figure 5. Spatial distribution of net aquifer recharge on irrigated lands in the Boise Basin.

Lake Lowell Gains and Losses

Water budget calculations for Lake Lowell (which take into account flows in and out of the lake, in addition to lake evaporation, and evapotranspiration by lake vegetation) indicate that Lake Lowell presently gains about 3,752 acre-feet per year, on average, from the aquifer. In any given year however, Lake Lowell may either gain or lose water. Net annual gains occur mainly in dry years when average lake level is lower. Net annual losses are more likely in wet years when the average lake level is higher. Over the past three decades, annual Lake Lowell gains have been as high as 42,000 acre-feet, and losses have been as high as 45,000 acre-feet.

Month to month gains and losses from Lake Lowell also depend on lake level (figure 6). During an average year, Lake Lowell gains up to 8,100 acre-feet during August, when the lake level is lowest, and loses up to 6,100 acre-feet during April, when the lake level is highest.

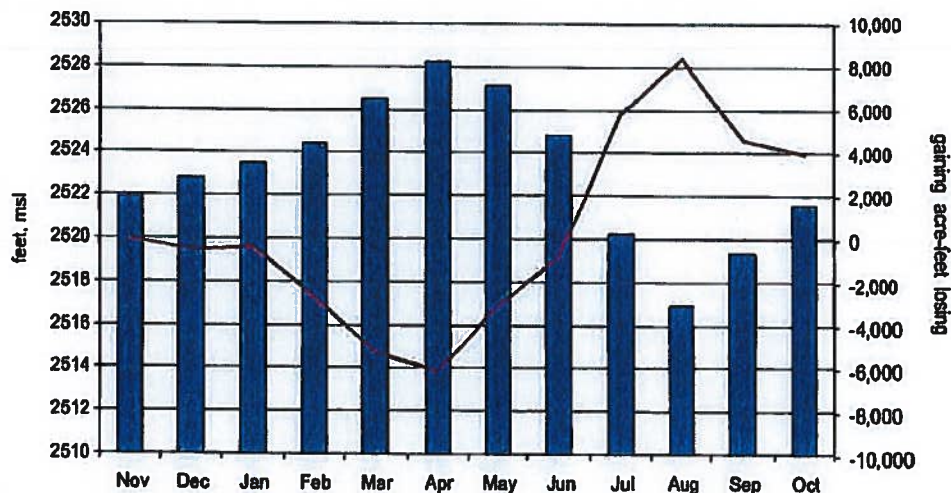


Figure 6. Average monthly lake level and average monthly gain or loss from Lake Lowell.

Canal Seepage in the Dry Lake Area

Board of Control (BOC) records of diversion and farm delivery, and estimates of canal ET, were used to calculate an aggregate measure of seepage from Boise Project canals. Figure 7 is water budget data which shows the average monthly seepage rate from all canals in the Dry Lake area of interest serving BOC divisions 3 and 4.

Canal seepage occurs throughout the year, since some diversions are made to the New York Canal to fill Lake Lowell during winter months. However the vast majority of canal loss occurs during the irrigation season. Between May and September, canal seepage ranges between 30,200 and 68,200 acre-feet per month. The year-round average monthly seepage from canals in the Dry Lake area is 22,200 acre-feet.

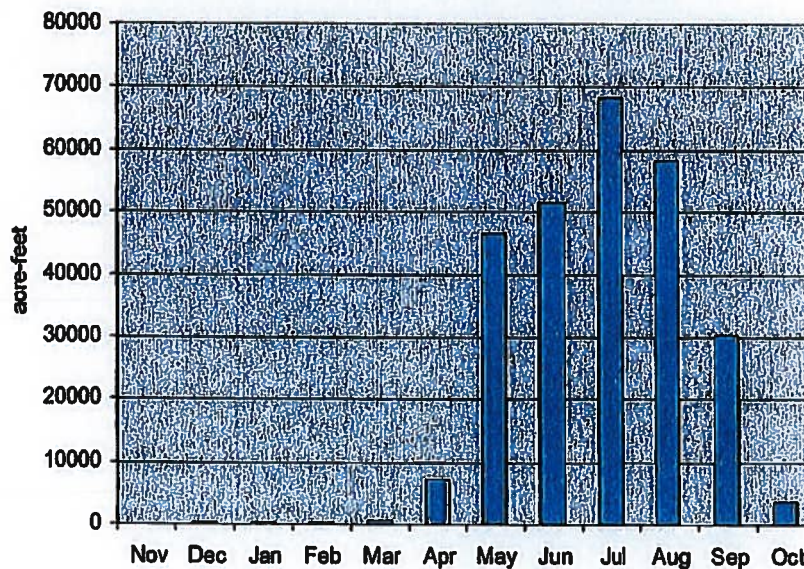


Figure 7. Average monthly loss from all canals in the Dry Lake area, north side, (1967-1997).

Seepage from the Mora Canal by itself is a major source of aquifer recharge in the Dry Lake area. The Mora Canal seepage rate above Richards Point, (which is just south of Lake Lowell) was calculated using BOC records of canal diversions (at the New York

Canal and at Richards Point) and records of drain discharges. Below Richards Point, where diversion and drain records are unavailable, canal seepage is estimated by assuming that seepage occurs in the same proportion to water use as it does above Richards Point.

Figure 8 shows the average monthly seepage rates from the canal. Water budget data indicates that about 37 percent of the total diversion to the Mora Canal seeps from the canal somewhere along its 38 mile length. On average, about 118 thousand acre-feet per year. Losses during the irrigation season range between 4,900 and 33,200 acre-feet per month, the annual average is 9,844 acre-feet per month

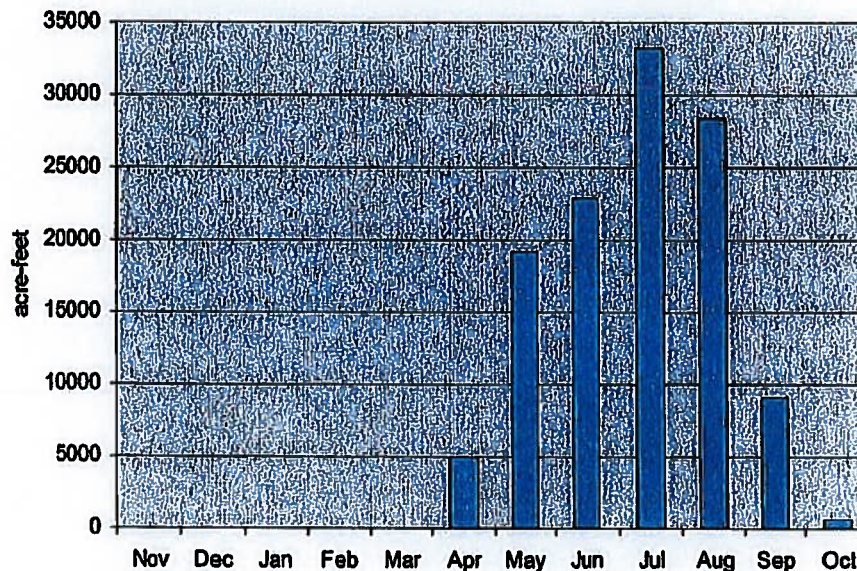


Figure 8. Average monthly loss from the Mora Canal (1967-1997).

Drain Discharge in the Dry Lake Area

The water budget calculation of return flow to drains is based on measured drain returns in natural drainage sub-areas within the Boise Basin. Measured return flows are available for fourteen drainage sub-areas, including the Lake Lowell sub-area and the Garland drain sub-area, which are part of the Dry Lake area of interest.

Returns to most drains decrease over the winter, and then increase in the spring at the start of the irrigation season. During winter months almost all drain returns are groundwater. The increase in returns that occurs at the start of the irrigation season is almost all surface water. In succeeding summer months, both the groundwater and surface water components of drain return increase. In water budget calculations, groundwater returns are assumed to increase during summer months at the same rate that they decrease during winter months. This assumption enables a separate calculation of the groundwater component and a surface water component of total drain returns.

Figure 9 is water budget data which shows the estimated average monthly distribution of groundwater returns to drains in the Dry Lake area (on the north side of the Snake River). During an average year, groundwater discharge to drains ranges from 9,800 to 12,300 acre-feet per month. The average is 11,124 acre-feet per month. In the Dry Lake area of interest, groundwater returns account for about 74 percent of total annual drain return. Most groundwater returns to drains occur east and northeast of Lake Lowell, however some groundwater returns occur along the Snake River Canyon, just south of the Mora Canal extension

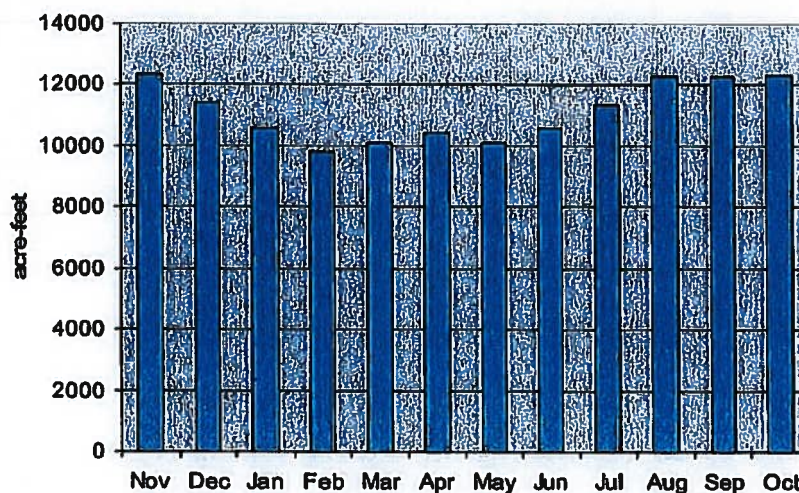


Figure 9. Average monthly groundwater return to all drains in the Dry Lake area, north side.

Snake River Gains

Base flow to the Snake River is calculated using Hydromet gage data for the years 1977 to 1996. Total reach gain between Murphy and Nyssa during these years averaged 586 thousand acre-feet per year.

Snake River gains are not uniformly distributed throughout the year (figure 10). Gains are highest early in the irrigation season, presumably due to high surface runoff to drains. However, they diminish during the irrigation season, reaching a low point in August, most likely due to extensive pumping from the river at this time of year. Gains pickup again in September and October after most pumping has ended, and then decline again during winter months as groundwater elevations decline. Despite what this figure shows, it is unlikely that the river is actually losing water to the aquifer during December, January, and February. Most likely the small negative numbers during winter months represent error in flow measurement. It is likely however, that reach gains between Murphy and Nyssa are nearly zero during these three months.

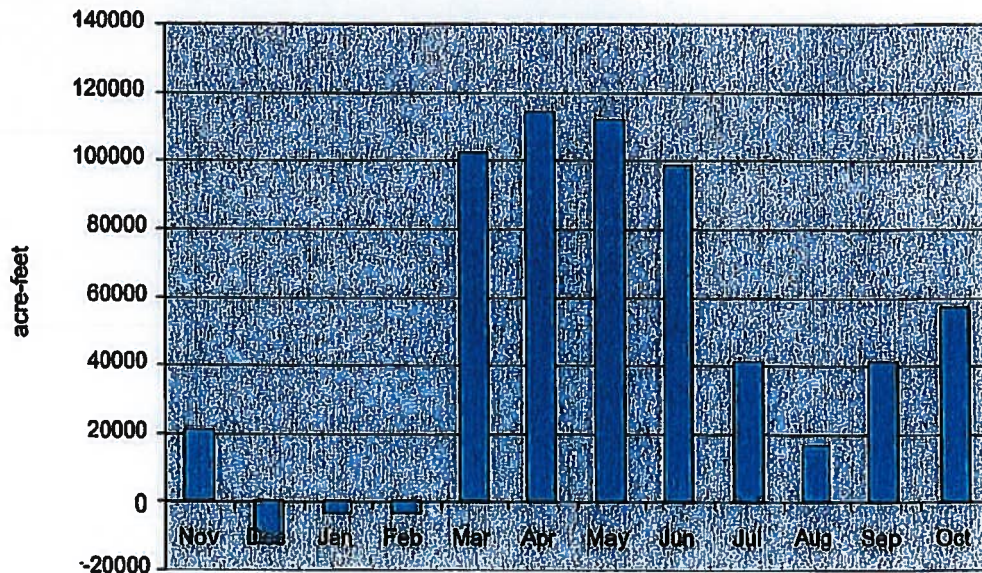


Figure 10. Average monthly Snake River reach gains between Murphy and Nyssa (USBR, 2002).

About 250 thousand acre-feet of the 586 thousand acre-feet total reach gain between Murphy and Nyssa is assumed to come from the south and west side of the river (IDWR, 1998). This leaves 335,500 acre-feet per year from the north and east side. Returns to the Snake River drain sub-area (both groundwater and surface water) total 207 thousand acre-feet per year, which leaves 128,500 acre-feet per year of gain from base flow to the main stem of the Snake River, or on average about 10,700 acre-feet per month.

Groundwater Elevations in the Dry Lake Area

Groundwater elevations in the Dry Lake area have been monitored either by IDWR or the USGS since the early 1960's. Figure 11 shows groundwater elevation contours in the Dry Lake area based on observation well measurements made during the spring of 1995. Groundwater elevations range between 2240 feet and 2520 feet msl. The groundwater gradient over most of the Dry Lake area is to the southwest, toward the Snake River.

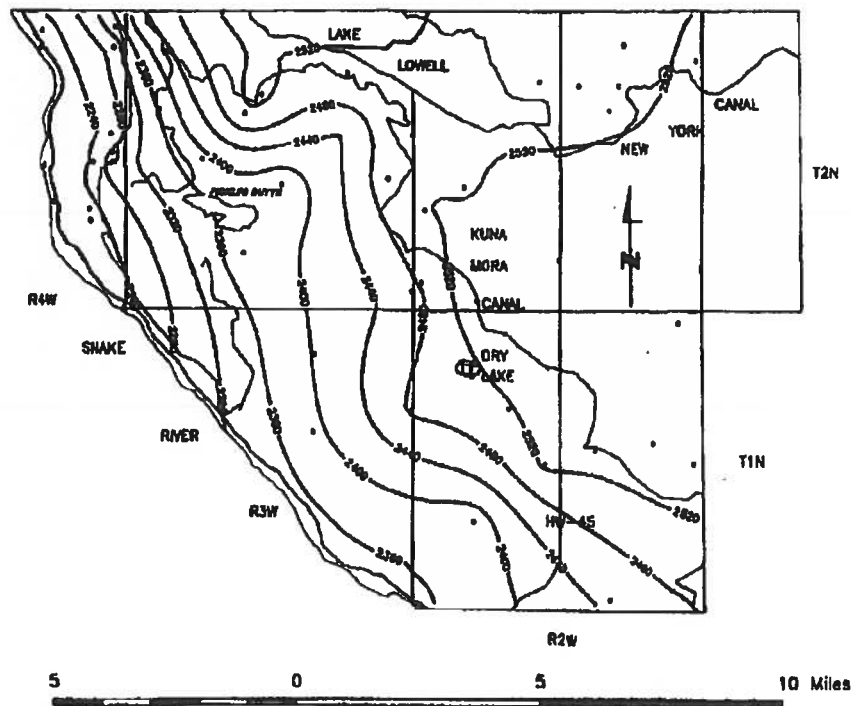


Figure 11. Groundwater elevations in the Dry Lake area 1995 (from IDWR, 1995).

Observation well records also reveal that some significant changes in groundwater elevations have occurred in the Dry Lake area during the last three or four decades (figure 12). Groundwater level declines of as much as 80 feet have been recorded in the area immediately south of the Mora Canal. Further to the south and east, (near the dry lake bed) declines of as much as 17 feet have been recorded. However groundwater levels have risen as much as 70 feet in the area along the Snake River, south and west of these declining areas.

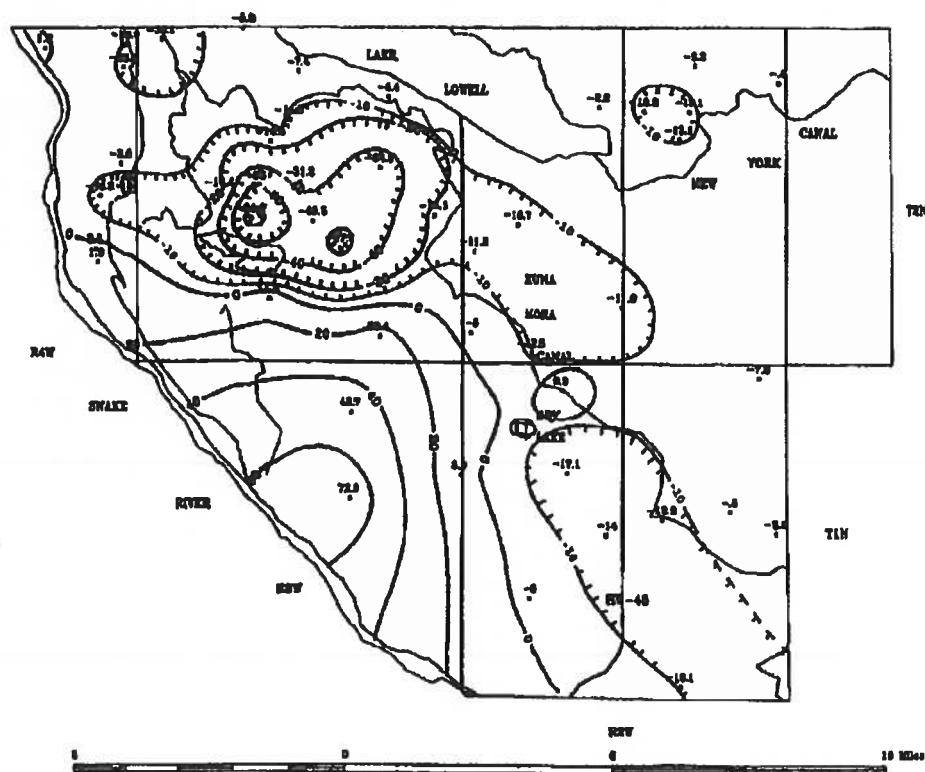


Figure 12. Change in groundwater elevation in the Dry Lake area since the late 1960's (adapted from IDWR, 1995).

The areas of groundwater decline in figure 12 generally coincide with areas showing a deficit in net aquifer recharge in figure 5, strongly suggesting that the decline is due to a

groundwater pumping rate which exceeds the rate of aquifer recharge from canal seepage and on-farm loss on these lands. The area of rising groundwater level in figure 12 coincides with the Snake River irrigated lands, and the absence of groundwater pumping.

The Dry Lake Area Groundwater Model

The impact of proposed pumping in the Dry Lake area on Reclamation facilities is estimated using a computer-based groundwater model. The Dry Lake area model is part of a larger groundwater model being developed by Reclamation, for use in conjunctive management of surface water and groundwater in the Boise Project.

The Analytic Element Modeling Method

The modeling methodology used to develop the Dry Lake area model is known as analytic elements. The analytic element method (AEM) has its origins at the University of Delft (De Josselin De Jong, 1969), (Verruijt, 1982). But it was primarily developed at the University of Minnesota in the 1980's (Strack, 1989). Analytic element models have become a standard with many consulting firms, universities, and government agencies because they are able to solve steady-state groundwater flow problems far more efficiently than numerical models such as Modflow (McDonald and Harbaugh, 1988).

Analytic element models have been used to address a wide variety of groundwater flow problems including well head protection (USEPA, 1987), and characterization of the Yucca Mountain Nuclear Waste Repository (Bakker, 2002). In Idaho, an AEM model was used recently by IDEQ to delineate wellhead protection zones for 549 municipal wells in the Treasure Valley (IDEQ, 2001).

The analytic element modeling method is based on the superposition of analytic functions (elements) representing a wide variety of surface and subsurface hydrologic features that influence groundwater flow. Each analytic element in an AEM model is a solution to the governing linear differential equation for steady-state, two-dimensional groundwater flow

(the LaPlace or Poisson equation). Strings of line source-sink elements are used to represent rivers, canals and drains. Point source-sink elements are used to represent wells. Doublet elements are used to represent inhomogeneities in aquifer permeability. Areal-recharge elements are used to represent aquifer infiltration from precipitation, and on-farm loss. A boundary condition (either a fixed head or a fixed flow rate) is required for each analytic element. Analytic elements with a fixed head are referred to as head-specified, and analytic elements with a fixed flow are referred to as flow-specified.

In a confined aquifer, individual analytic element solutions to the governing linear differential equation can be superimposed on one another, in order to generate a comprehensive solution for a groundwater flow problem that involves many different analytic element boundaries. Superposition may also be used to model flow in an unconfined aquifer, if local variations in the water table elevation are small compared to total saturated thickness of the aquifer.

Since the analytic element solutions are derived analytically (rather than numerically using a grid) it is possible to maintain a high degree of model accuracy on both a large (basin-wide) scale and on a small (individual well and canal) scale.

AEM Software

At least three AEM models are widely used by consultants, universities, and government agencies. WHAEM (USEPA, 1987) is a public domain AEM model developed for the EPA, and used nationwide for delineation of well head protection zones. SLAEM and Gflow are proprietary software packages that include analytic element features not found in the public domain software.

The Gflow model (Gflow, 2000) was selected for the Dry Lake Area application. Gflow was developed at Indiana University by the same modeling team that developed the WHAEM model for the EPA. It was selected for the Dry Lake application for two reasons. It incorporates a canal and river routing algorithm that runs in conjunction with

the groundwater model. The routing algorithm prevents the groundwater model from predicting a seepage rate from a canal that exceeds the available flow. The model also incorporates a utility for converting a steady-state AEM model to an equivalent USGS Modflow model. If necessary, Modflow can then be used to determine the transient effects of new pumping on canals, drains, and rivers.

Dry Lake Area AEM Model Boundaries

The Dry Lake area AEM model simulates unconfined flow conditions in an aquifer that is comprised of the terrace gravels of the Snake River Group, and the upper and middle sand, silt, and gravel units of the Glenns Ferry Formation. The saturated thickness of this aquifer ranges from 300 to about 550 feet.

The base of the aquifer is assumed to be the blue clay layers which underlie the upper and middle sand, silt, and gravel units of the Glenns Ferry Formation. In the Dry Lake area this layer is generally encountered between 2000 and 2100 feet msl. elevation (Stevens, 1962). The base elevation of the modeled aquifer is therefore set at 2000 feet msl. A small upward leakage of groundwater from the deeper confined aquifer (.001 ft/day) (Newton, 1991) is imposed uniformly over the Dry Lake model area.

A combination of flow-specified and head-specified analytic elements are used to represent the hydrologic features of the Dry Lake area. Flow-specified analytic elements are used to represent wells and on-farm loss. Specified flows for these elements, i.e. pumping rates and on-farm infiltration rates, are obtained directly from the Boise Basin water budget.

Canals, drains, Lake Lowell, and the Snake River are all represented in the model by head-specified elements, for which an elevation and a bed conductance must be specified. Elevations of all canals, drains, rivers, and reservoirs are taken from USGS digital elevation maps. Bed conductances are derived via model calibration.

Regardless of which type of boundary condition is imposed, the model will provide the solution for the unspecified condition. Thus, for head-specified canal elements, the model will calculate the seepage rate, and for flow-specified wells, the model will calculate the head at the well bore.

Head specified source-sink elements used to represent canals, the Snake River, and Lake Lowell, may either gain water from the aquifer (aquifer discharge) or lose water to the aquifer (aquifer recharge), depending on head conditions. However head-specified drain elements may only gain water from the aquifer. No aquifer recharge (or discharge) occurs if the aquifer head drops below the elevation of a drain.

The distribution of analytic elements that make up the Dry Lake area model is shown in figure 13. The model contains 1,546 head-specified line source-sink elements representing canals and drains, Lake Lowell, and a portion of the Snake River. The latter is represented by two parallel strings of line source-sink elements representing the north bank and the south bank of the river. In addition the model contains 976 flow-specified wells, and 38 flow-specified infiltration areas representing the spatial distribution of on-farm loss. Three permeability zones are used to represent inhomogeneities in the aquifer.

Some canals and drains in the Dry Lake area are in direct contact with the underlying water table and some are perched above the water table. Increased depletions due to new pumping can occur only in those canals and drains that are in direct contact with the watertable surface. It is not necessary to know in advance, which canals and drains are above the water table and which are in contact with it. Gflow incorporates an iterative procedure for making this determination when the model is run. In those instances where canals are perched above the water table, Gflow automatically determines the seepage rate based on bed conductance, and converts the head-specified canal element to a flow-specified element.

Aquifer permeabilities in the model range from .1 to 75 feet/day, which is comparable to the current Treasure Valley groundwater model (Petrich, 2002) and the earlier USGS

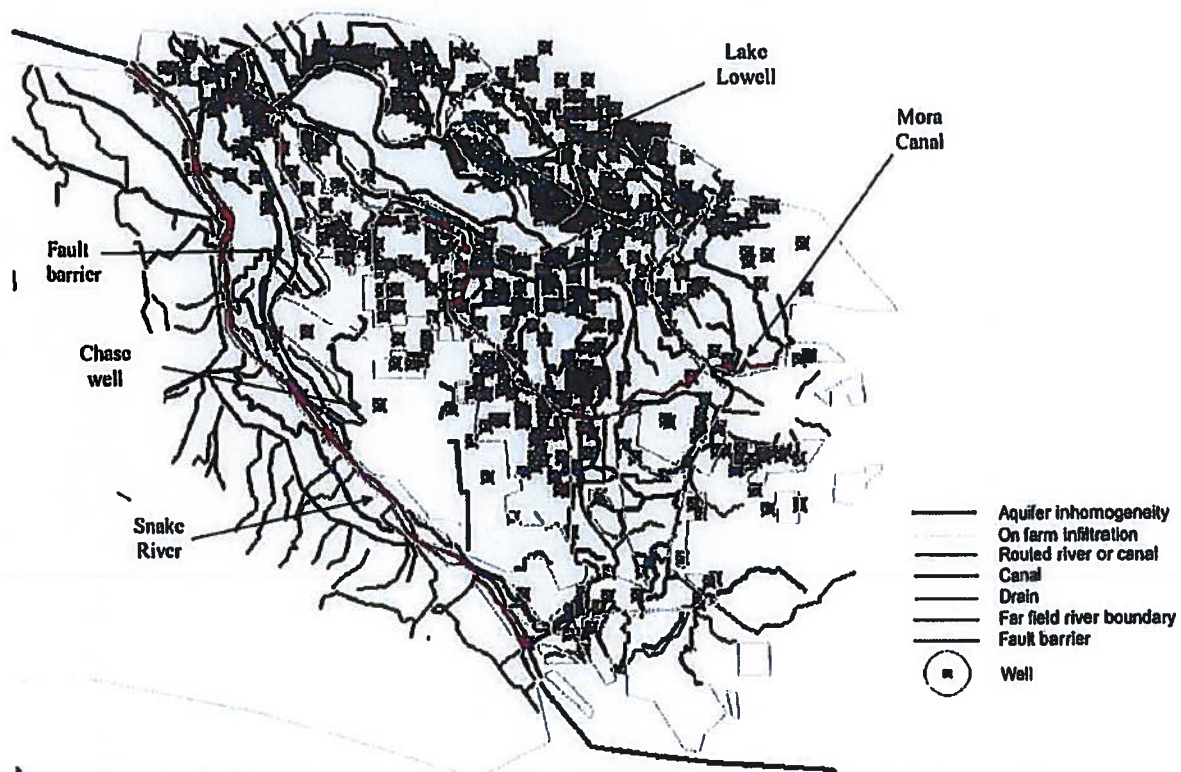


Figure 13. Analytic elements in the Dry Lake Area groundwater model.

model (Newton, 1991). Most of the Dry Lake area is modeled with a permeability of 75 feet per day. One area of higher permeability is associated with a structural trough just south of Lake Lowell. Another low permeability area follows the exposure of several faults along the north rim of the Snake River Canyon (figure 4).

Dry Lake Area Model Calibration

Calibration targets for the Dry Lake Area model include water level elevations in observation wells, seepage from canals, groundwater returns to drains, Lake Lowell gains, and Snake River base flow. Calibration parameters, include aquifer permeabilities, and river bed, canal bed, and lake bed conductances. Model calibration is achieved by adjusting these parameters until a reasonable match is achieved between targeted and simulated aquifer flux conditions and aquifer heads.

The Dry Lake area model is calibrated with respect to average annual conditions of drain return, Snake River base flow, Lake Lowell gains, and canal loss. The head conditions imposed on drains, the Snake River, and Lake Lowell are therefore average annual heads. However, the head condition imposed on canals is representative of conditions that exist only during the irrigation season, i.e the model assumes that canal losses occur at a uniform rate, year around. As a result, canal conductance, which is one of the main calibrating parameters of the model, is not truly representative of canal bed conditions, but rather of bed conditions as if canals were filled with water year around. (Most calibrated canal conductances are therefore about half of there true value). Whether canal loss occurs uniformly throughout the year, or all within a six month period during the year is not important from a steady-state modeling perspective, so long as the total annual canal loss is the same in both cases.

Figure 14 shows the results of model calibration with respect to measured and simulated head at the locations of 43 observation wells. All of these observation wells have an open interval in the upper aquifer, (i.e. above 2000 feet msl elevation). Static water level elevations, range from 2212 feet msl to 2637 feet msl., are annual averages. The average difference between observed and simulated well head in the calibrated model is 13 feet, and the root mean square

difference is 21 feet. The model deviation from observed head is about 5 percent of the total range in head.

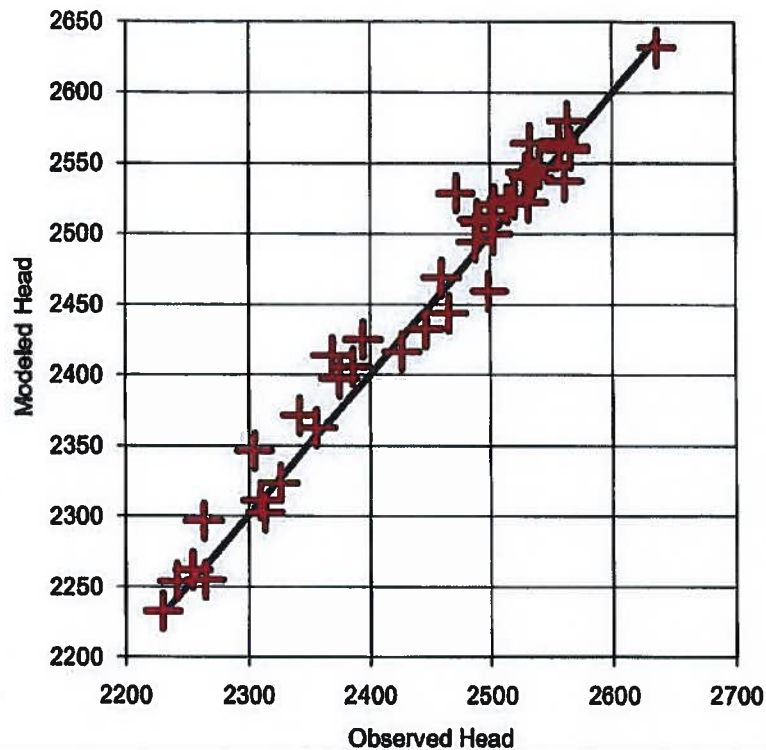


Figure 14. Model calibration with respect to observation well levels (in feet msl).

The distribution of groundwater elevations that results from running the calibrated Dry Lake area model is shown in figure 15. Modeled groundwater elevations range from about 2640 feet msl. directly beneath a portion of the Mora Canal, to about 2230 feet msl along the Snake River. As in figure 11, the groundwater gradient north of the Snake River is generally to the southwest, toward the Snake River. A groundwater divide is located just south of Lake Lowell. North of the divide the groundwater gradient is to the north or northwest. In the area south of the Snake River, the groundwater gradient is to the northeast, toward the river.

The steep hydraulic gradient that appears in figure 15 along a portion of the north rim of the Snake River Canyon, is due to the presence of a semi-permeable barrier element representing

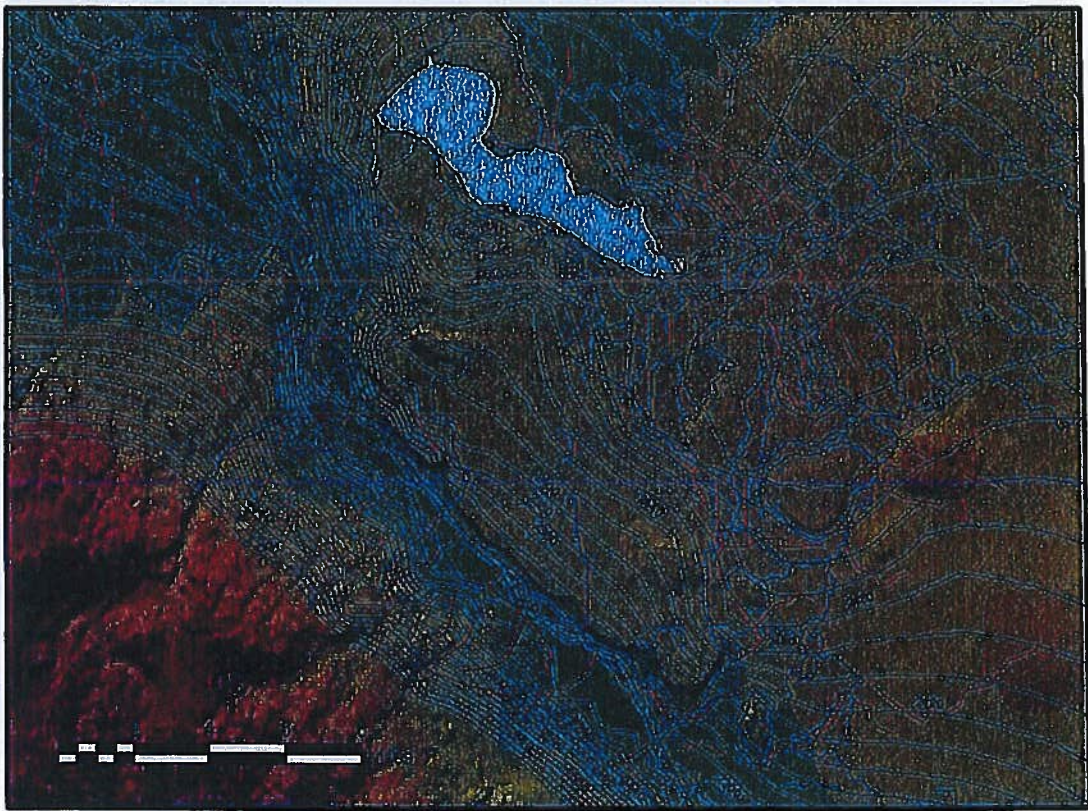


Figure 15. Modeled groundwater elevations in the Dry Lake area of interest

the low permeability fault zones and tilted beds which limit the flow of groundwater toward the Snake River in this area. The presence of a low permeability feature at this location is essential for good model calibration.

The presence of this low permeability feature also explains why the groundwater elevation has risen as much as 70 feet since the 1960's beneath lands in the Dry Lake area that are irrigated with Snake River water (figure 12). The low permeability feature prevents much of the groundwater that has recharged the aquifer in this area over the years, through on-farm loss, from flowing back to the river. Instead, year by year, head builds up in the aquifer.

Table 1 shows the results of model calibration in which the flow conditions computed by the model for head-specified analytic elements, are compared to flow targets derived from water budget data. The table compares targeted and simulated seepage rates from the Mora Canal, targeted and simulated base flow to the Snake River, and targeted and simulated seepage from Lake Lowell. The table also compares targeted and simulated groundwater return to drains, and targeted and simulated canal loss for the entire Dry Lake area of interest.

Water budget data indicates that Lake Lowell gains (on average) about 3,752 acre-feet of water from the aquifer annually, or about 312 acre-feet per month. Model calibration resulted in simulated Lake Lowell gain of 318 acre-feet per month, which is within 2 percent of the Lake Lowell target. Average monthly seepage from the Mora Canal is estimated to be 9,844 acre-feet. Model calibration resulted in a simulated Mora Canal seepage rate of 9,606 acre-feet, which is within 2 percent of the Mora Canal target.

The water budget estimate of average monthly reach gain to the Snake River (from the aquifer on the north side of the river only) is 10,700 acre-feet. The simulated Snake River reach gain was 11,450 acre-feet, which is within 7 percent of this target value.

Table 1. Model calibration with respect to aquifer recharge and discharge conditions.

(acre/feet per month)	water budget	simulated	Percent difference
Lake Lowell gain	312	318	2
SNAKE RIVER gain (north side)	10,700	11,450	7
MORA Canal loss	9,844	9,606	2
Total groundwater return to drains (north side)	11,124	10,781	3
Total canal loss (north side)	22,217	24,263	9

The water budget estimate of average monthly groundwater discharge to drains in the Dry Lake area is 11,124 acre-feet. The model estimate of drain discharge (north of the Snake River only) is 10,781 acre-feet, a difference of 3 percent. The water budget estimate of average monthly canal loss in the entire Dry Lake area, is 22,217 acre-feet, and the model estimate (north of the Snake River only), is 24,263 acre-feet, a difference of 9 percent.

Estimating Surface Water Depletions Due to Proposed Pumping

The long-term impact of new groundwater pumping in the Dry Lake area is expected to be a depletion of surface water, either through increased seepage from canals, reduced drainage to drains, reduced gains to Lake Lowell, or reduced base flow to the Snake River. The total depletion that results from new pumping is expected to be equivalent in magnitude to the new groundwater withdrawal, however the distribution of the depletions among these features is expected to vary, depending on the location(s) of the new well(s).

Figure 16 shows the location of the Chase well in T1N-R3W-S3, and the location of nine other proposed wells in the Dry Lake area (Appl. 63-11885, 63-11754, 63-11865, 63-11773, 63-12007, 63-12214, 63-11976, 63-12269, and 63-12520), that are pending under the current moratorium on processing of new applications for water appropriation in basin 63 (IDWR, 1996).

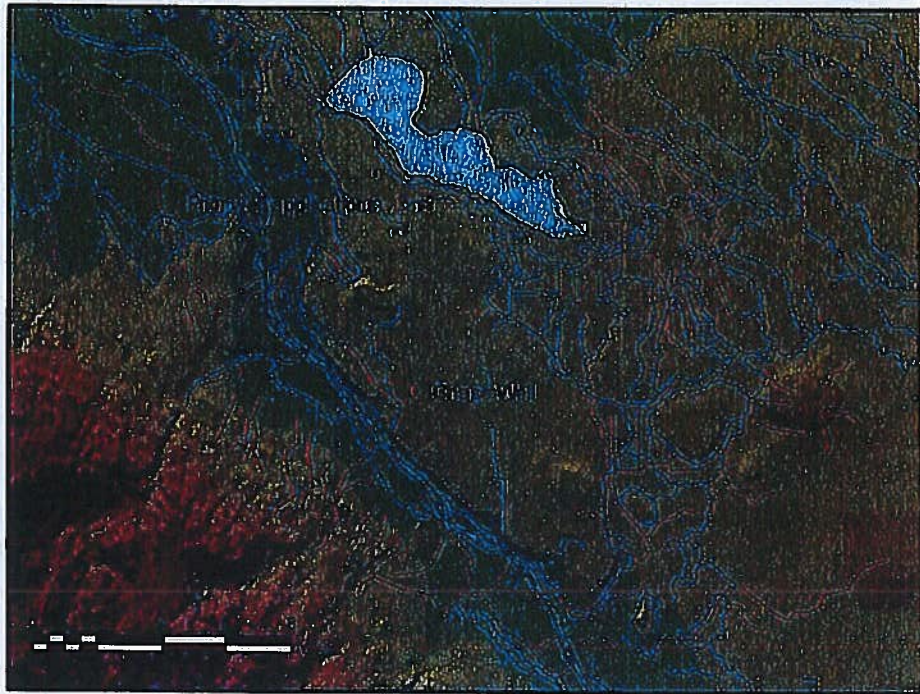


Figure 16. Locations of all wells in the Dry Lake Area with pending applications.

Estimating the surface water depletions to Reclamation facilities due to pumping from any or all of these wells involves a comparative analysis of results from the Dry Lake area model. In the following discussion, the calibrated Dry Lake area model is referred to as the base-case model. The base-case model with the addition of the proposed Chase well is referred to as the Chase dairy model, and the Chase dairy model with the addition of the other nine wells is referred to as the cumulative effects model. All of the proposed wells are assumed to fully penetrate the upper aquifer, i.e. well depth extends to 2000 feet msl. elevation. Simulated pumping rates for the proposed wells are the maximum annual withdrawal rates specified in each application.

Recall that the AEM model calculates the flow associated with every head-specified analytic element, i.e. the seepage rate from canals, the drainage rate to drains, the gains to Lake Lowell, and the base flow to the Snake River. Surface water depletions due to pumping from the Chase well are calculated by subtracting the flow of every head-

specified element in the Chase dairy model from the flow of every comparable head-specified element in the base-case model. Similarly, the surface water depletions due to pumping from all ten proposed wells is obtained by subtracting flows calculated in the cumulative effects model from those calculated in the base-case model.

The results of these calculations are summarized in subsequent tables, in terms of five categories of surface water depletion.

- Depletions to canal flows north of the Snake River due to increased seepage,
- Depletion of Lake Lowell storage due reduced gains (or increased losses) from the lake,
- Depletion of drain flows north of the Snake River due to reduced groundwater discharge to drains,
- Depletion of Snake River flows due to reduced base flow,
- Collective depletion from all canals and drains located south of the Snake River.

The Chase Dairy Model

The proposed well in the Chase dairy model (figure 16) is assumed to pump at a constant rate of .55 cfs (33.2 acre-feet/month). The year-around depletions that result from pumping the Chase well are presented in table 2, in acre-feet per month, and as a percentage of pumping withdrawal.

As table 2 shows, only about 10.6 acre-feet per month, or about 32 percent of the total depletions due to pumping from the Chase well, are from the Snake River itself. This is not an unexpected result given that river-aquifer interaction is limited by the (calibrated) conductance of silts and sediments in the river bed, and by low permeability fault zone features along the Snake River Canyon.

Table 2. Modeled distribution of depletions due to proposed Chase pumping.

Distribution of depletions	Depletion, acre-feet per month	Depletion as a percentage of pumping withdrawal (.55 cfs)
Reduced Snake River reach gain	10.6	32 %
Increased canal seepage north of the Snake River	4.4	13 %
Reduced drain discharge north of the Snake River	10.9	33 %
Reduced gain to (or increased loss from) Lake Lowell	4.3	13 %
Increased canal seepage and reduced drain discharge south of the Snake River	3.0	9 %
Total depletion	33.2	100 %

The depletion to Reclamation canals, drains, and reservoirs located north of the Snake River totals 19.6 acre-feet per month, or about 59 percent of the Chase well withdrawal. Most of the impact comes from reduced drain discharge.

As mentioned previously, only the canals drains and reservoirs that are in direct contact with the water table surface are affected by new pumping. The Mora Canal is in contact with the water table near Richards Point, south of Lake Lowell, and as a result, it is the canal most affected by proposed Chase well pumping (about 30 percent of total canal depletion). However, portions of the Deer Flat Highline Canal, the Nicholzen Ditch, and the New York Canal are also affected by pumping.

Drain depletion accounts for more than half of the impact to Reclamation facilities. An unnamed drain that goes from the Stewart Lateral to the Deer Flat Low Line Canal, along with the Blijah, Herron, and Wilson drains are those most affected by pumping

Table 2 also shows that a small percentage, (about 9 percent) of the depletions due to new pumping are to canals and drains located on the south side of the Snake River.

Aquifer/river interaction is limited by river bed conductance. This allows the hydrologic stresses to be transmitted within the aquifer, from one side of the river to the other.

Based on a streamline mass balance calculation (Strack, 1984), the groundwater capture

depth of the Snake River was estimated to extend about 125 feet beneath the river bed (i.e. to about 2100 feet msl. elevation) in the Dry Lake area.

Cumulative Effects Model

Since the Chase application is being considered out of priority, the cumulative effects analysis is intended to show the depletions to Reclamation facilities that could be expected if the other proposed wells in the Dry Lake area, with applications dates earlier than that of the Chase well, were also permitted. Table 3 provides some details of these applications, including the maximum annual withdrawal, which ranges from 22 to 886 acre-feet per year.

Comparison of figures 16, 5, and 12, reveals that seven of the nine wells are located in the area where the water budget indicates a net deficit in aquifer recharge, and where observation well data shows that groundwater elevations have been in decline.

Table 3. Nine prior groundwater applications in the Dry Lake Area.

Application number	Application date	Location	Usage	Not to Exceed (acre-feet/year)
63-11885	6/24/92	T3N-R4W-S36 NWNE	irrigation	22
63-11754	4/6/92	T2N-R3W-S5 SENE	irrigation	333
63-11865	6/15/92	T2N-R3W-S9 SESE	irrigation	720
63-11773	4/16/92	T2N-R3W-S10 SENW	irrigation	436
63-12007	4/14/93	T2N-R3W-S10 SWNE	irrigation/stockwater	720
63-12214	5/9/95	T2N-R3W-S10 SWNE	irrigation	121
63-11976	1/19/93	T2N-R3W-S16 NWNE	irrigation	360
63-12269	8/28/95	T2N-R3W-S16 NESE	irrigation	886
63-12520	4/23/99	T2N-R3W-S24 SWNE	irrigation	45

The depletions that occur as a result of pumping from all ten wells are presented in table 4. Only about 7 percent of the total surface water depletions due to new pumping are

from the Snake River. About 89 percent of the surface water depletions are from Reclamation canals, drains and reservoirs. Canal depletions account for about 38 percent of the total depletion, and Lake Lowell depletion accounts for another 34 percent.

Table 4. Modeled distribution of depletions due to cumulative effects of all ten pending groundwater applications in Dry Lake Area.

Distribution of depletions	Depletion, acre-feet per month	Depletion as a percentage of pumping withdrawal (5.08 cfs)
Reduced Snake River reach gain	24.3	7 %
Increased canal seepage north of the Snake River	125.3	38 %
Reduced drain discharge north of the Snake River	58.5	17 %
Reduced gain to (or increased loss from) Lake Lowell	114.4	34 %
Increased canal seepage and reduced drain discharge south of the Snake River	14.1	4%
Total depletion	336.7	100 %

Because of its proximity to most of the new wells, the Mora Canal is the canal most affected by the proposed pumping. About 87 percent of the canal depletions that occur on the north side of the Snake River would come from the Mora Canal. Drain impacts are more widely distributed, although the Elijah, Herron, Wilson, and Golden Gulch drains would be affected by pumping.

Steady-State versus Time-Dependent Impacts of New Pumping

At the outset of new pumping, groundwater that is withdrawn from the aquifer comes mainly from aquifer storage. In an unconfined aquifer this is termed specific yield. However as pumping continues and a cone of depression expands about the new well, the proportion of well withdrawal that comes from specific yield diminishes, and the proportion of well withdrawal that comes from surface water sources increases.

The Dry Lake area model is a steady-state model. It can be used to predict the surface water depletions that will result from new pumping over the long term, however the

model provides no information about how much time will elapse before these depletions occur. In order to estimate the time-dependent impacts of new pumping on canal, drain, and river depletions, the Dry Lake area model would have to be converted to a transient model (using Modflow or some other numerical modeling software). The model conversion would require much additional hydrologic data, and substantial additional effort which is not justified at this time.

However some useful insights into the time-dependent relationship that exists between groundwater pumping and canal depletions in the Dry Lake area can be obtained by comparing historical records of losses from the Mora Canal with those of groundwater withdrawals in the Dry Lake area.

Figure 17 displays some of this historical data. The bar chart in this figure shows the estimated annual Mora Canal loss from 1957 through 1997 (USBR,2002). The canal losses are based on water budget data described previously. The line chart in this figure shows the maximum potential groundwater withdrawal that could occur each year in the Dry Lake area based on the annual volume limitation specified for all water rights granted up to that point in time (IDWR,2003). This is not necessarily the actual groundwater withdrawal that occurs each year, but it is a good indicator of the overall trend in groundwater withdrawal over the years.

While there is a considerable amount of "noise" in the canal loss data in figure 17, there are a couple obvious trends. First, canal losses are lowest during the driest years such as 1977 and 1992, when there is much less water to divert. In average water years or in wet years such as 1982, 1983, 1985 or 1997, canal losses are higher. Second, prior to 1970 canal losses generally range from 80 to 100 thousand acre-feet per year. However by the mid 1980's canal losses have increased to between 120 and 140 thousand acre-feet per year. During the same time period, maximum potential groundwater withdrawals for irrigation in the Dry Lake area of interest have increased from less than 40,000 acre-feet per year to almost 90,000 acre-feet per year. It is apparent in figure 17 that much of this increase in groundwater withdrawals occurred in a single year, 1977 (IDWR, 2003).

Currently there are 277 wells in the Dry Lake area with water rights. Forty-seven of these wells were permitted in 1977, more than in any other year before or since. Most of the wells were permitted in February and March of that year, and all are primary supply irrigation wells. Fourteen of the wells permitted in 1977 are located within a mile of the Mora Canal. Eleven more are within two miles of the canal. The remainder are three to five miles from the canal. During this one year, maximum potential groundwater withdrawal in the Dry Lake area increased by 18,000 acre-feet, or by 38 percent.

The impact of new groundwater pumping on Mora Canal seepage is apparent in the years following 1977. Canal losses increase significantly in 1979 and 1981, and remain generally at a higher level from then on. It appears in this case that at least four years are required for the full canal depletion effects to occur following the onset of new pumping in 1977. Note that figure 18 includes only those wells permitted in 1977 that are also located within the Dry Lake area. A number of other new wells located near the Mora Canal but outside the Dry Lake area are not included in this chart.

The time-dependent relationship between groundwater pumping and surface water depletion is also evident in the well hydrograph of figure 18. This figure shows the groundwater level decline that has occurred since 1965, in an observation well located in T2NR3W section 22 about two miles from the Mora Canal, just south of Lake Lowell.

Groundwater development in section 22 began in 1949. However substantial new groundwater developments occurred in 1966, 1972, and 1973. Figure 18 shows that up until 1985, the water level in this observation well declined steadily, as new groundwater withdrawals in and around section 22 depleted aquifer storage. By about 1985, increased surface water depletions began to offset groundwater withdrawals, and the aquifer moved toward a new equilibrium. The surface water feature most likely responsible for offsetting the groundwater withdrawals in section 22 is the nearby Mora Canal.

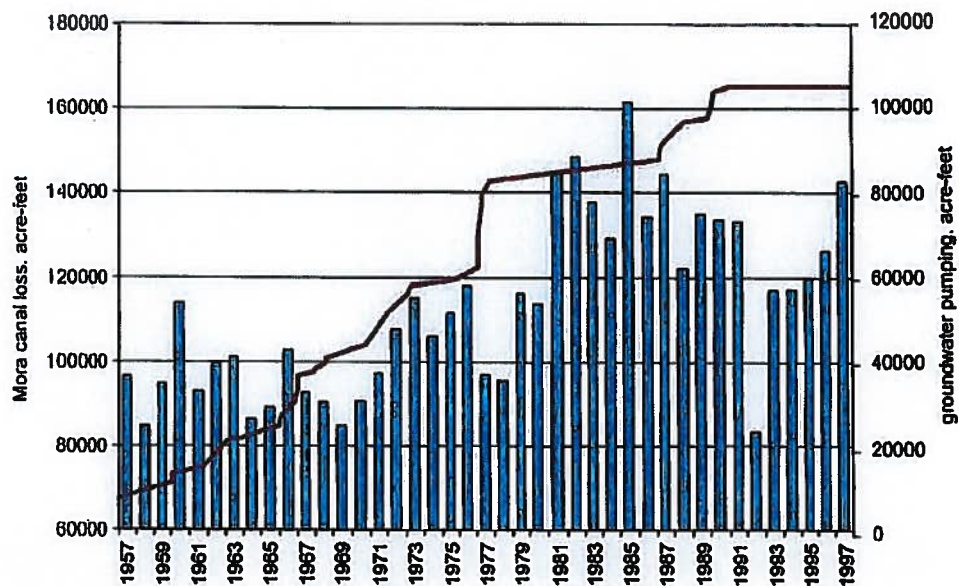


Figure 17. Annual Mora Canal seepage and maximum potential withdrawal for all groundwater rights in the Dry Lake area (1957-1997)

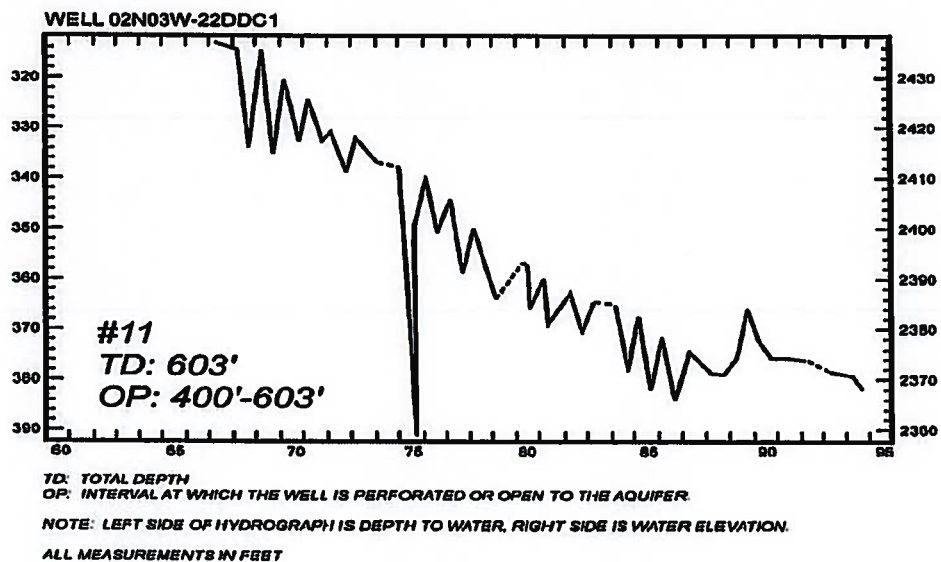


Figure 18. Change in groundwater elevation in observation well T2N3W, section 22 (from IDWR, 1995)

Summary and Conclusions

The Dry Lake Area AEM model has been demonstrated to be a conceptually valid and well calibrated model of unconfined flow conditions in the upper (cold water) aquifer beneath the Dry Lake area. Because it uses analytical methods instead of grid based numerical methods, the model is able to calculate the relatively small amounts of canal, drain, and reservoir depletion that result from pumping of individual wells.

The standard imposed under the current IDWR moratorium in Basin 63 for transfer of a water permit is one of no hydrologic impact (IDWR, 1996). The Dry Lake Area AEM model clearly demonstrates that the impact of proposed pumping from the Chase well is not zero. Over the long term, pumping from this well would result in a depletion to Reclamation canals, drains, and reservoirs equivalent to 59 percent of the proposed annual well withdrawal, or about 18.7 acre-feet per month. The Snake River depletions that result from proposed pumping would account for only 32 percent of the annual withdrawal, or 10.6 acre-feet per month.

It may appear that the Chase well, because of its relatively close proximity to the Snake River, would deplete the river far more than it would the canals and drains that are further away. In fact, because of the presence of a low permeability feature along the Snake River Canyon (the result of faulting and bed tilting), there is a relatively poor hydraulic connection between the aquifer and the river in much of the Dry Lake area. The clearest evidence for this is the documented buildup of aquifer head, beneath lands that are irrigated with water pumped from the Snake River. This head buildup, which borders the river, has occurred because the on-farm losses that have been steadily recharging the aquifer for the past three or four decades cannot be readily discharged back to the Snake River.

As the Dry Lake area model has demonstrated, the presence of a low permeability feature along the Snake River Canyon means that a substantial portion of the depletions induced

by pumping from the Chase well are not from the Snake River, but from canals, drains, and reservoirs located further to the north.

The cumulative effects model shows that even greater depletions to Reclamation facilities could be expected if nine other proposed wells in the Dry Lake area, with application dates earlier than that of the Chase well, were also permitted. Seven of the nine proposed wells are located in an area where the Boise Basin water budget has indicated that aquifer discharge from pumping currently exceeds aquifer recharge from canal loss and on-farm loss, and where observation well data shows groundwater elevations have declined by as much as 80 feet in the last three or four decades.

Because of their close proximity to the Mora Canal and Lake Lowell, pumping from these wells would result in depletions to Reclamation canals, drains, and reservoirs equivalent to about 89 percent of total annual well withdrawal, or about 298 acre-feet per month. Pumping would increase Mora Canal seepage by about 93 acre-feet per month. Annual gains to Lake Lowell would be reduced (or losses increased) by about 1,370 acre-feet.

While it is generally not possible to directly measure the surface water depletions that result from a single new well, it is possible to measure the depletions that result from the cumulative effects of many new wells that begin pumping at about the same time. The 30 to 40 percent increase in depletions from the Mora Canal that followed a 38 percent increase in groundwater pumping in the Dry Lake area in 1977, is evidence that portions of the Mora Canal in the vicinity of Richards Point are in direct contact with the watertable surface and are therefore impacted by groundwater level declines due to pumping.

The Mora Canal is generally on the northern boundary of the existing area of groundwater level decline in the Dry Lake area. Increased seepage from the Mora Canal is most likely responsible for sustaining groundwater levels at this location and preventing further northward expansion of the area of decline. Along the southern and

western boundaries of the existing area of decline, groundwater levels are most likely being sustained by on-farm losses from the Snake River irrigated lands. Increased groundwater pumping in this area (the area of the proposed Chase well) would no doubt cause further expansion of the existing area of water table decline in a southward direction.

The Dry Lake area model results show directly, what historical records of canal loss and groundwater pumping show indirectly, i.e that the Mora Canal and Lake Lowell are important head-dependent recharge boundaries for the shallow aquifer in the Dry Lake area, and that a portion of the Mora Canal (and a portion of the Deer Flat Highline canal among others) are in direct contact with the watertable surface. New groundwater pumping in the Dry Lake area will ultimately result in increased depletions from these and other canals, and from Lake Lowell.

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