IN THE MATTER OF APPLICATION FOR PERMIT NOS. 65-13912 AND 65-13913
IN THE NAME OF CAROL LYNN MACGREGOR

PANCHERIS' HEARING EXHIBITS

| NO. | DATE | DESCRIPTION | OFFERED | ADMITTED |
|---|---|---|---|---|
| 100. | January 27, 2005 | IDWR Staff Memorandum authored by John Westra, together with the materials attached thereto and/or cited therein | | |
| 101. | January 1971 | Merle W. Wells, Heat From the Earth's Surface: Early Development of Western Geothermal Resources, reprinted from Journal of the West, Vol. X, Number 1 | ✓ | ✓ |
| 102. | October 30, 1972 | Arthur A. Hart, "Idaho Yesterdays: Indians Used Warm Springs," The Idaho Statesman, at 12 | ✓ | ✓ |
| 103. | | N.S. Nokkentved, "Report: Water Pumping Reduces Bruneau Springs," The Times-News | ✓ | ✓ |
| 104. | 1993 | Charles Berenbock, Effects of Well Discharges on Hydraulic Heads in and Spring Discharges from the Geothermal Aquifer System in the Bruneau Area, Owyhee County, Southwestern Idaho, USGS Water-Resources Investigations Report 93-4001, Boise, Idaho | ✓ | ✓ |
| 105. | April 22-24, 1985 | Will L. Burnham and Spencer H. Wood, Field Guide: Boise Geothermal System, Idaho, 38th Annual Meeting, Rocky Mountain Section, The Geological Society of America | ✓ | ✓ |
| 106. | June 1998 | Kenneth W. Neely, Production, Temperature and Water Level Data for the Four Heating Systems in the Boise Front Low Temperature Geothermal Resource Area, 1977-1997, Idaho Department of Water Resources Planning and Policy Division, Technical Services Bureau, Ground Water Monitoring Section, Open File Report | ✓ | ✓ |
| 107. | December 1995 | Kenneth W. Neely, Production History for the State of Idaho Capitol Mall Geothermal System 1983-1994, Idaho Department of Water Resources | ✓ | ✓ |
| 108. | August 10, 2003 | Christian R. Petrich, Investigation of Hydrogeologic Conditions and Ground Water Flow in the Boise Front Geothermal Aquifer (Executive Summary), Idaho Water Resources Research Institute, Research Report IWRRI 2003-07, Draft | ✓ | |

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|---|---|---|---|---|
| 109. | October 2003 | Christian R. Petrich, Investigation of Hydrogeologic Conditions and Ground Water Flow in the Boise Front Geothermal Aquifer (Executive Summary), Idaho Water Resources Research Institute, Research Report IWRRI 2003-07 | ✓ | ✓ |
| 110. | | Well log notes from Clements well | ✓ | ✓ |
| 111. | July 14-15, 1983 | Notes from Larry Hellnake Well No. GEO-1, Well No. 2, and Spring, Roystone Hot Springs | ✓ | ✓ |
| 112. | April 1, 1980 | Lithologic log and temperature gradient, Well No. GEO-1, Roystone Hot Springs | ✓ | ✓ |
| 113. | October 22, 1980 | Ground Temperature Contours, Roystone Hot Springs | ✓ | ✓ |
| 114. | September 26, 2003 | Ken Neely, Semi-Annual Review of the Monitoring Data for the Boise Front Geothermal System, January-June 2003, Idaho Department of Water Resources | ✓ | ✓ |
| 115. | December 2004 | Geothermal Resources of Utah – An Overview, Geo-Heat Center Quarterly Bulletin, Vol. 25, No. 4, at 2 | ✓ | ✓ |
| 116. | December 2004 | Crystal Hot Springs – Salt Lake County, Geo-Heat Center Quarterly Bulletin, Vol. 25, No. 4, at 26 | ✓ | ✓ |
| 117. | July 1, 1999 | Correspondence from Terry M. Scanlan to Jo Beeman, Subject: MacGregor – Belvidere and Raspberry Ranches | | |
| 118. | November 10, 2001 | Correspondence from Terry M. Scanlan to Carol MacGregor, Subject: Belvidere Spring Monitoring – September 26, 2001 and November 2, 2001 | | |
| 119. | June 3, 2002 | Correspondence from Terry M. Scanlan to Carol MacGregor, Subject: Belvidere Spring Monitoring – June 1, 2002, and attachments thereto | | |
| 120. | October 12, 2002 | Correspondence from Terry M. Scanlan to Carol MacGregor, Subject: Belvidere Spring Monitoring – October 9, 2002, and attachments thereto | | |

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|---|---|---|---|---|
| 121. | September 2, 2003 | Correspondence from Terry M. Scanlan to Rob Whitney, Idaho Department of Water Resources, Subject: MacGregor Test Well Proposal, and attachments thereto | | |
| 122. | May 20, 2003 | Correspondence from Sherl Chapman, ERO Resources Corp., to Scott Campbell | | |
| 123. | October 1, 2003 | Correspondence from Sherl Chapman, ERO Resources Corp., to Scott Campbell | | |
| 124. | October 14, 2003 | Correspondence from Sherl Chapman, ERO Resources Corp., to John Westra, Idaho Department of Water Resources | | |
| 125. | | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 126. | | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 127. | | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 128. | | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 129. | | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 130. | | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 131. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 132. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 133. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 134. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 135. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 136. | March 2005 | Photograph taken by Duane and Laura Pancheri | | |
| 137. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |

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| 138. | March 2005 | Photograph taken by Duane and Laura Pancheri | ✓ | ✓ |
| 139. | March 2005 | Photograph taken by Duane and Laura Pancheri | | |
| 140. | March 2005 | Photograph taken by Duane and Laura Pancheri | | |
| 141. | March 2005 | Photograph taken by Duane and Laura Pancheri | | |
| 142. | March 2005 | Photograph taken by Duane and Laura Pancheri | | |
| 143. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 144. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 145. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 146. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 147. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 148. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 149. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 150. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 151. | February 9, 2005 | Photograph taken by Darwin and Joan Pancheri | ✓ | ✓ |
| 152. | | Photograph taken by Sherl Chapman | | |
| 153. | | Photograph ~~taken by Sherl Chapman~~ | ✓ | ✓ |
| 154. | | Photograph ~~taken by Sherl Chapm~~an | ✓ | ✓ |
| 155. | | Photograph ~~taken by Sherl Chapman~~ | ✓ | ✓ |
| 156. | | Photograph taken by Sherl Chapman | | |
| 157. | | Photograph ~~taken by Sherl Chapman~~ | ✓ | ✓ |
| 158. | | Photograph taken by Sherl Chapman | | |

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| 159. | | Photograph taken by Sherl Chapman | | |
| 160. | | Photograph ~~taken by Sherl Chapman.~~ | ✓ | ✓ |
| 161. | | Photograph taken by Sherl Chapman | | |
| 162. | | Photograph ~~taken by Sherl Chapman.~~ | ✓ | ✓ |
| 163. | | Photograph taken by Sherl Chapman | | |
| 164. | | Photograph taken by Sherl Chapman | | |

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# HEAT FROM THE EARTH'S SURFACE:

## *Early Development of Western Geothermal Resources*

*By* Merle W. Wells

*Archivist* Idaho State Historical Society, Boise, and
*Editor* Idaho Yesterdays

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# HEAT FROM THE EARTH'S SURFACE:

## *Early Development of Western Geothermal Resources*

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*Editor*, Idaho Yesterdays

COMMERCIAL DISTRIBUTION of geothermal resources commenced around the turn of the century on a modest scale in two different kinds of enterprise and in two widely separated areas. These interesting contributions to economic geology represented a major divergence from traditional exploitation of hot springs for resort and recreational purpose in the form of natatorium and tourist attractions. In one case, artesian hot water came into commercial use in the Western United States for heating of houses and buildings in 1892. In the other, geothermal power development got underway in Italy in 1904. Whether in the form of space heating and distribution of domestic hot water (that otherwise would have to be heated from some other power source) or of power for general commercial purposes (such as generation of electricity), these two uses of geothermal power pointed the way toward more widespread applications by the middle of the twentieth century. Unlike fossil fuels, geothermal power (whether used for heating or for other purposes), if developed wisely, won't be exhausted too easily. Anyway, it would take quite an ambitious enterprise to cool off the middle of the earth. Although pollution problems sometimes are associated with utlization of geothermal power, other nineteenth century heat sources (mostly coal and wood in Western frontier communities) could not begin to compare with pure artesian hot water for cleanliness and convenience.

But in spite of important and undeniable advantages, geothermal power has been developed quite slowly for commercial purposes. Except for space heating, most commercial utilization of geothermal energy takes the form of steam generating plants for electric power. In recent years, New Zealand (1950) and a number of other countries (Iceland, Mexico, the United States, Salvador, Japan, and Russia) have

commenced to exploit or at least to explore their steam fields.[1] But hot water heating, except for Iceland, has proceeded more slowly. In the widespread current interest in geothermal power, in fact, hot water heating is still almost overlooked outside that one island.

A large zone of major hot springs extends from the Yellowstone Park country westward to Mount Lassen and the Pacific Coast. Boise grew into a frontier city near the center of this geothermically favored zone. Hot springs occur over much of southern Idaho, and emigrants headed west on the Oregon Trail used to enjoy cooking meals in hot springs about halfway between Snake River crossing (near modern Glenns Ferry) and Boise. Commercial development of a number of hot springs in the Boise and Wood River mining regions began right after the 1862 gold rush: most of the mining camps in the area (Idaho City, Rocky Bar, Atlanta, Hailey, and Ketchum primarily) had hot springs somewhere nearby, and their possibilities for resorts were realized early in the mining era. Commercial use of hot springs near Idaho City still continues more than a century after that resort provided the scene for some of the exciting episodes in Idaho's early territorial history, and the development of a major Western ski resort (as well as summer resort) at Sun Valley since 1936 makes good use of some of the large Wood River hot springs that had proved to be a great attraction for early developers. Andrew Mellon, Jay Gould, and the Harrimans of the Union Pacific were connected in one way or another with promotion of these Wood River hot springs, and before the end of the nineteenth century, Boise and Wood River hot springs were attracting a lot of attention.

Artesian water possibilities were recognized around Boise when drillers went to work only eight years after settlement began. Exploring for a water company, they did not know precisely what to expect. According to a press report,

> The Artesian well boring was commenced. The apparatus works all right. They are bound to strike something. It is a mooted question whether they will strike cold water, oil, or hot water. There is thought to be some danger of the latter catastrophe. The boiling spring, a few miles up the valley, is on the same side, and the well at the penitentiary yields warm water. There is one consolation for us, in case they do tap a boiling spring, we can commence raising crops in the winter.[2]

Hot water did not materialize from that early effort: an equipment failure left the drillers unable to discover anything at all.[3] But the possibility for hot water remained.

Not too many years after most of the modern conveniences of the time (telegraph and telephone service, railway transportation, electric

1. Edwin B. McNitt, Exploration and Development of Geothermal Power in California (San Francisco 1963) p. 8.
2. *Idaho Statesman*, July 15, 1871, p. 3, c. 2.
3. *Ibid.*, July 27, 1871, p. 3, c. 2.

power and lights, for example) had been introduced, community leaders in Boise concluded that the time had come to install an adequate city water system. Before Idaho became a state in the summer of 1890, no one could recommend Boise's water supply, either for domestic use or for fire protection. A limited amount of water was available from existing wells serving individual owners. Others got water out of various small springs or out of the river. Irrigation ditches ran through town, but altogether the domestic water supply remained far from adequate. Some kind of community system clearly was needed. Then in the spring of 1890, Boise suddenly had an opportunity to get a complete city water system. In fact, for those who thought that only one city water system might not be enough, rival groups of investors organized two competitive companies that June. Right at the beginning, the evils of monopoly (which were receiving a lot of attention that year, when Congress was busy adopting the Sherman anti trust act) had become apparent. When the original company demanded three dollars per month per faucet, this rate was considered exorbitant.[4] So an opposition group decided to offer competition at a lower price.

Acting from a need to obtain better water for their Overland Hotel — a well known Boise landmark since 1864 — the owners had decided to expand their supply system. For years they had offered a limited water service to their neighbors as well as for their hotel from Hull's Gulch, a mile or more away on the north side of town. With permission obtained from the city council, October 3, 1889, to place a new pipeline in Boise streets, they decided to drill for more water than their springs provided. After some months of work, mostly in the spring of 1890, they developed three artesian wells by the middle of May. Producing 800,000 gallons of cold water a day from a depth of only twenty feet, they had enough water to consider providing a system for the entire city.[5] When they announced that their existing high charge would apply to their whole new projected system, another water syndicate entered the field. One of Boise's pioneer merchants, who owned a lot of land in Hull's Gulch near the Eastman (Overland Hotel) artesian wells, decided to drill for artesian water on his property, too. Confident of success, he joined a number of other prominent Boise pioneers in incorporating the Artesian Water and Land Improvement Company, June 2, 1890.[6] Then on June 23, just before the Artesian company struck artesian water in Hull's Gulch near the original Eastman well, the Eastman Overland Hotel interests (who already had arranged to set up Boise's original domestic water system) incorporated the Boise Water Works.[7] Although the Artesian company was incorporated earlier, it

4. *Ibid*, July 11, 1891, p. 2, c. 4.
5. *Ibid*, May 15, 1890, p. 2, c. 1, p. 3, c. 1, *Salt Lake Tribune*, May 27, 1890, p. 1, c. 5. Successful drilling of the original Eastman artesian well in Hull's Gulch was completed by the middle of May, 1890.
6. Records of Incorporation, Idaho Territory, Book C, p. 108, Idaho State Archives.
7. *Ibid*, p. 140, *Idaho Statesman*, June 28, 1890, p. 3, c. 2.

supplied opposition to the existing Eastman group, and believed in competition as a means of holding down prices in the water business. In contrast, the Eastman Overland Hotel concern preferred a single water system for the entire community, with monopoly an inherent feature of the system.

In the race to install pipes from cold artesian wells that both companies developed in Hull's Gulch on the north edge of town, the opposition concern took advantage of its head start. But by August 12, when the Artesian company began to install pipe, the Overland Hotel's Boise Water Work had pipe on hand.[8] That summer and fall Boise was growing rapidly, in spite of the inconvenience of having the streets torn up by two rival water companies. (The companies got into right-of-way trouble and litigation, as might be imagined. They also had problems of damages when breaks in one company's pipe led to erosion of the other's uncompleted excavations for water lines.)[9] From a population of 2,500 when the United States census was taken June 1, Boise grew to 4,020 by September 19 when the Board of Trade (not content with an optimistic but unverified estimate) prepared a signed registry of the inhabitants.[10]

Major irrigation canal construction underway next to town that summer accounted for much of the expansion. In addition, a substantial city building boom, unmatched up to that time, was transforming the appearance of the capital city of the new state of Idaho. Aside from an outburst of optimism that came with state admission, Boise served as a stage coach manufacturing center (an industry without a long range future, but good for more than another decade) as well as a popular camping spot for emigrant wagons that still came by in large numbers on the Oregon Trail.[11] Automobiles which would put the emigrant wagons and stage coaches off the roads had not yet materialized, and with preparations under way in the summer of 1890 to install an electric street car system, Boise expected to have all the conveniences of any progressive city within a year or two.[12] James J. Hill was reported as prepared to build a railroad from San Francisco through Boise to Butte as a major expansion of the Great Northern, so that Idaho's capital would not have to depend entirely upon the Union Pacific.[13] The two water companies looked with confidence toward rapid expansion to serve a growing community that would thrive with major irrigation projects which would make farming more important as a regional economic base.

8 *Idaho Statesman*, August 12, 1890, p. 4, c. 1.
9 *Ibid*., August 28, 1890, p. 4, c. 1, September 3, 1890, p. 4, c. 1, September 4, 1890, p. 1, c. 3, September 14, 1890, p. 4 c. 1.
10 *Ibid*., September 20, 1890, p. 4 c. 1, October 4, 1890, p. 4, c. 2.
11 *Ibid*., July 22, 1890, p. 4, c. 1, August 13, 1890, p. 4, c. 1.
12 *Ibid*., August 13, 1890, p. 4 c. 1, August 14, 1890, p. 2, c. 1, August 16, 1890, p. 4, c. 2-3. Articles of incorporation were drafted for the Boise Rapid Transit Company, August 12, and notice for bids for rails and ties for an electric street railway was given at the same time.
13 *Ibid*., July 29, 1890, p. 2, c. 2.

Nearby lode mining camps, for which Boise originally had been established as a service community a generation before, were approaching their maximum development. Part of the mining era fortune that some of Idaho's pioneer settlers had accumulated was available for investment, and the Boise water works and electric street car projects provided good outlets for local capital in 1890.

As soon as service became available in the two competing water systems, a bitter fight for supremacy gave prospective customers some exceptionally good offers. The opposition company, anxious to hold back potential customers from the Overland Hotel group, advertised early in October that no one should sign a service contract without considering the Artesian offer. Not to be outdone, the Boise Water Works announced that they would provide free water until 1892 to those who would contract for their service.[14] The Overland group obviously preferred to operate as a monopoly. Fearing that they would be cut out altogether, the opposition syndicate continued to advocate the merit of maintaining two independent community water systems, asserting that two competing companies would be required to preserve a low-rate structure. Duplicate pipe systems in the same streets would offer customers a free choice; in no other way would Boise be assured the low cost water supply that the community deserved.

Competing for contracts to supply city fire hydrants as well as to gain private customers, the two water companies took their fight to the city council on November 6, 1890. After successful testing of a fire hydrant on their new system the Artesian Water and Land Improvement Company offered to place twenty-five fire plugs (owned and supplied by the city) on their lines, and to provide service for all of them for $600 a year. This rate ran $22.50 annually for each fire hydrant. At the same meeting, the older and larger Boise Water Works asked permission to bid on the fire hydrants before a contract should be let to their competitors.[15] No one doubted the inadequacy of the existing system, but the city council held up proceedings for a few days, when the matter might be resolved in a special meeting. Some of Boise's most prominent and successful pioneers, represented by "a stunning array of legal lights," turned out for the shown-down on November 8. At this point the Artesian crew suggested that each company assume half of the fire hydrant contract at whatever rate the city might specify. With representation on the council (no one seemed to worry too much about conflict of interest right then), the Artesian company had little fear that the charge would be set too low. All along, the newer Artesian company, in order to stay in business at all, had to argue that the community interest demanded preservation of two competing water systems, and that their fire protection proposal would help insure their survival so

14 *Ibid*, October 8, 1890, p. 4, c. 2; October 11, 1890, p. 4, c. 3.
15 *Ibid*, November 7, 1890, p. 1, c. 2.

that competition could be assured. But the delegation "upholding the dignity of the Waterworks" declined to concur. They wanted time to prepare a counter offer which would restore their monopoly. A "dense silence" ensued.[16]

After a taxpayers' petition requested further tests of the two companies' capabilities, negotiations for a division of the fire hydrants continued. An inspection of both companies' facilities November 13, convinced the city council that each was adequate.[17] Adopting the position of the competitive Artesian company, the council proposed an equal division of the fire hydrants. But the original monopoly Boise Water Works dissented again. Objecting to the refusal of the council to accept bids for service by only one company, the Water Works formally offered, November 21, to supply the fire hydrants at eight dollars each. Compared with the $22.50 Artesian company offer, this bid appeared to be low enough to support quite adequately the monopoly company's original request for the entire city patronage.[18] Eventually, the council decided, December 4, 1890, to allot thirty hydrants to the larger Boise Water Works at their bid price of eight dollars each, and to contract with the smaller Artesian company for twenty hydrants at twenty-five dollars each. (This figure exceeded the latter's original bid of $22.50 only slightly.) The eight dollar suggestion appeared to be a low initial bid to capture business, and the council's excuse for offering a rate more than three time as high had to be justified on the grounds of preserving competition.[19] Considering that the larger Boise Water Works was offering free water to everyone else, something had to be done if the Artesian company were to overcome the disadvantage of having to charge at least a nominal rate for service. No one expected the unrealistic low bid of the Water Works to be renewed after the initial year. And no one expected the initial free water service to continue indefinitely for other customers. If the council played a mean trick on the Boise Water Works by accepting their astonishingly low bid while paying the Artesian company more than three times as much, an explanation could be found in the council's interest in protecting the city from a still higher monopoly rate in a subsequent year. Since the Water Works refrained from entering the Artesian company's proposal to divide the market at a higher rate, the council hardly had any other choice if both companies were to be preserved to maintain competition. The way things turned out, the Boise Water Works never got around to supplying any eight dollar hydrants and sustained no loss in the matter.[20]

16 *Ibid*. November 9, 1890, p. 4, c. 4.
17 *Ibid*. November 14, 1890, p. 4, c. 2.
18 *Ibid*. November 21, 1890, p. 4, c. 2. November 23, 1890, p. 6, c. 3.
19 *Ibid*. December 5, 1890, p. 4, c. 2.
20 Minutes of the Boise City Council, January 8, June 4, July 6, 1891, in the office of the city clerk; this and much of the information concerning early activity of these companies has been supplied by Thomas G. McFadden of the Idaho State Historical Society, a Rhodes Scholar whose current research interest is Boise's water system in the nineteenth century.

"Hatred and strife" were rampant — "in the fierce factional fight" for mastery over Boise's water system;[21] in their search for a way to gain control, some of the major Water Works investors decided to go into the hot water business as well. They chose to investigate a potential artesian well site where hot water seepage made a swamp at the edge of a hill northwest of the state penitentiary. Drilling commenced shortly before Christmas, in time for an announcement on December 24, 1890, that warm water (92°) had been struck at a depth of eighty feet.[22] That was only the beginning. After penetrating a hard rock formation, December 27, a much stronger flow was encountered at 112 feet. Here the water temperature had risen to 112° with enough sulphur that the whole supply was identified as coming "right from Hades."

> This hot water overflowed the top of [the] well casing to such an extent that it became necessary to tap the pipe several feet below in order to draw off this overflow so as not to interfere with the drill. The company will continue to sink the well in the hope that at a greater depth a higher temperature may be obtained. The outcome of this experiment is of course problematical, depending entirely on this desired result. The water is clear, but strongly impregnated with sulphur. A large number of curious people visited the well yesterday afternoon. The company will sink two more wells very shortly.[23]

Before the year's end, the driller's five inch pipe delivered a still warmer, larger flow from 168 feet: during the first week of January, both the supply and the temperature increased daily as drilling progressed.[24] Then at 308 feet on January 13, the Boise Water Work's stockholders were jubilent to find a "greatly augmented" flow with the "temperature very materially raised" that gave them 150 gallons a minute of 154° water. "The water now is hotter than that in any of the famous hot springs in Arkansas, and visions of bath houses and all the paraphernalia of a springs resort are already forcing themselves in the minds of the fortunate possessors of the well."[25] Encouraged by these promising results, the drillers went on until January 22, when their equipment failed. Pressure got so great that their light drill could be used no longer. Sending out for a heavier drill, they struck their real bonanza, January 24. At a depth of nearly 400 feet "a tremendous flow of water was encountered, and further operations were necessarily discontinued."[26]

During February, the company sank another well through harder rock about fifty feet from the first one. Here the results were almost as spectacular. Going through the same stages as the first, the new well had higher temperatures as the drillers worked their way down. When

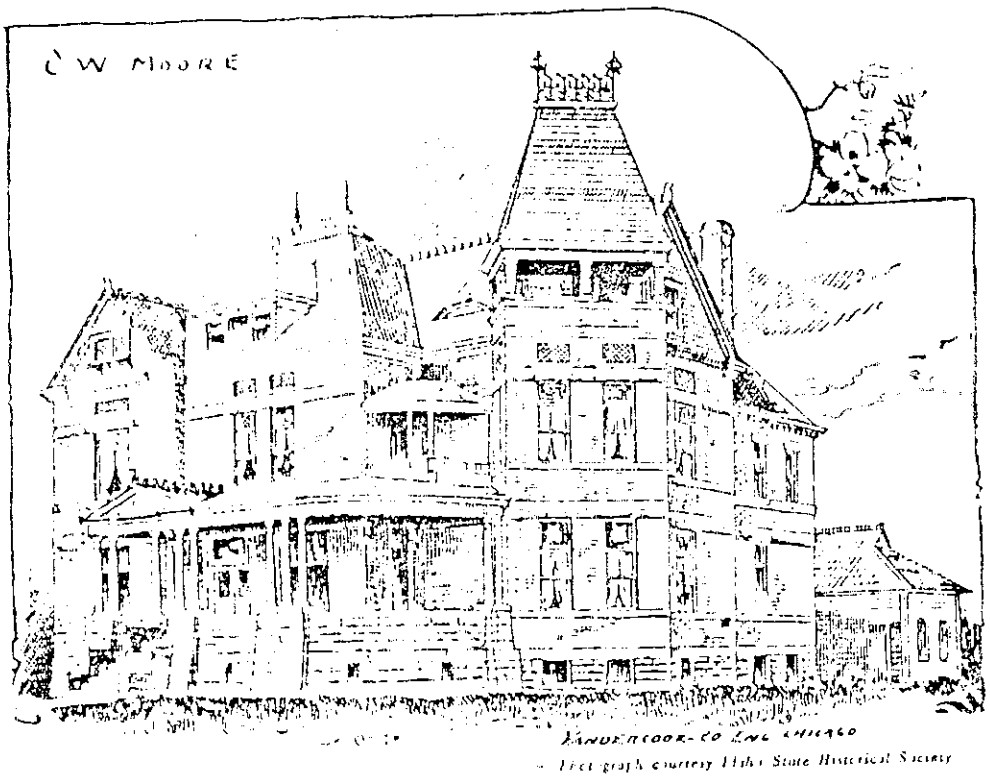
21 *Idaho Statesman*, March 29, 1891, p. 8, c. 1.
22 *Ibid*., December 24, 1890, p. 8, c. 2.
23 *Ibid*., December 28, 1890, p. 8, c. 1.
24 Ibid., December 31, 1890, p. 8, c. 1; January 1, 1891, p. 8, c. 2; January 8, 1891, p. 8, c. 1.
25 *Ibid*., January 14, 1891, p. 8, c. 2.
26 *Ibid*., January 30, 1891, p. 8, c. 2.

the main source was reached at 404 feet, March 12, large chunks of rock were forced up, and the total volume (at 170°) exceeded 800,000 gallons daily.[27] While the second well was being drilled, a Union Pacific chemist who tested the water pronounced it excellent for boiler purposes.[28] Then one of the company stockholders, United States Senator George L. Shoup, got the United States Department of Agriculture to undertake careful chemical tests of the water. When it turned out to be more than pure enough for household use, the company knew that in addition to a resort (for which they had more than enough hot water already), they had a truly colossal hot water heater for domestic consumption.[29]

Satisfied with these reports, the owners immediately purchased a site for a natatorium on Warm Springs Road and began to consider going into the hot water business. Although they would be competing with Kelly's Hot Springs — a resort on the other side of Table Rock, a few miles farther away — which had opened in a big way in the summer of 1890, their natatorium had more definite promise than their domestic hot water system.[30] Some pessimists doubted that their hot artesian water would stay hot, or that the supply would last indefinitely. But the company went right ahead, and the promise of being able to provide both hot and cold water for domestic use gave the Boise Water Works the upper hand in their battle for the city market. Within weeks the Artesian company gave up the fight, conceding monopoly to be superior to competition after all. The Boise Water Works absorbed their rival in a consolidation completed March 28. Yet the name under which the new corporation emerged, the Artesian Hot and Cold Water Company, suggested the opposition company. Stock was exchanged on a basis favoring the company that had the hot water, two shares to one.[31] As a consequence of the artesian hot water discovery the corporate purposes were expanded: in addition to the original "municipal, fire, sanitary and mechanical purposes," and "domestic and ornamental uses," the consolidated venture assumed authority to "furnish steam for heating, motive power and mechanical purposes." In addition the new enterprise proposed to "maintain sanitariums, hotels, baths, bath houses, and all other necessary or convenient buildings at or near said Boise City."[32]

Concerned over the effect of the merger on the rate structure, the customers of the two companies wondered whether they would have to go back to the original high water cost proposed before competition had

27 *Ibid*., February 5, 1891, p. 8, c. 1; February 11, 1891, p. 8, c. 1; February 24, 1891, p. 8, c. 1; March 11, 1891, p. 8, c. 1; March 13, 1891, p. 8, c. 1; March 14, 1891, p. 8, c. 1.
28 *Ibid*., February 28, 1891, p. 8, c. 2.
29 J. M. Buck to George L. Shoup, February 25, in the *Idaho Statesman*, March 7, 1891, p. 8, c. 2.
30 *Idaho Statesman*, August 9, 1890, p. 4, c. 1; March 24, 1891, p. 8, c. 1.
31 *Ibid*., March 29, 1891, p. 8, c. 1; April 1, 1891, p. 2, c. 1-2; April 2, 1891, p. 2, c. 1.
32 Record of Incorporations, State of Idaho, Book A, p. 300, Idaho State Archives.



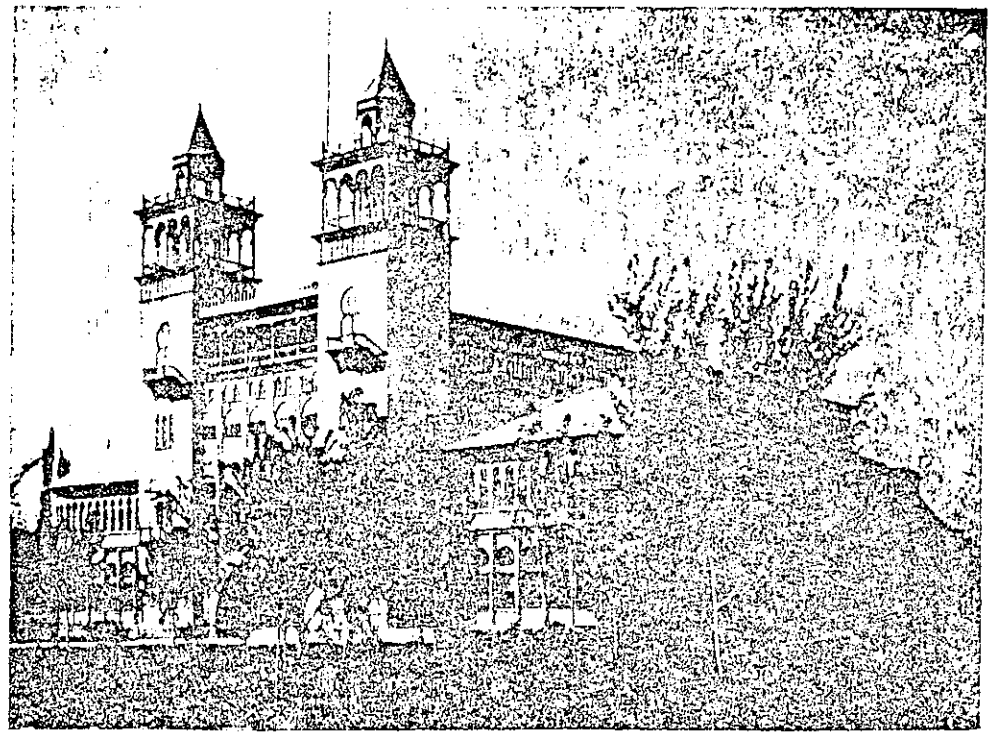

*Photograph courtesy Idaho State Historical Society*

FIRST GEOTHERMAL HOME

*The new home of C. W. Moore, one of the early advocates of using geothermal heating in Boise, and office buildings, was the first residence in Boise, Idaho, to employ the method.*

altered the situation. The merger had been anticipated for months. After all, neither company could be expected to supply water indefinitely at a loss. Because the competitive Artesian company had offered nominal rates until 1892 (the same period that the Boise Water Works charged nothing at all) and reasonable rates in the future, hope was expressed that the Artesian element in the combine might try to keep the price reasonable after the merger. However, the original monopoly company which absorbed its competition had been smart enough not to promise anything like low charges in the future. Moreover, their offer of free water until 1892 was

> a good one for the public but a bad one for the company. Nobody demanded it, nobody thought that it was meant in good faith, but all felt that it was a bluff at the rival company and would last only until a consolidation was effected; hence, as they were giving something for nothing that company [which had discovered hot artesian water] may not be blamed if its promise is not kept.
>
> But the Artesian Water and Land Improvement company offered in the language of its card to "furnish water at reasonable rates until that



*Photograph courtesy Idaho State Historical Society*

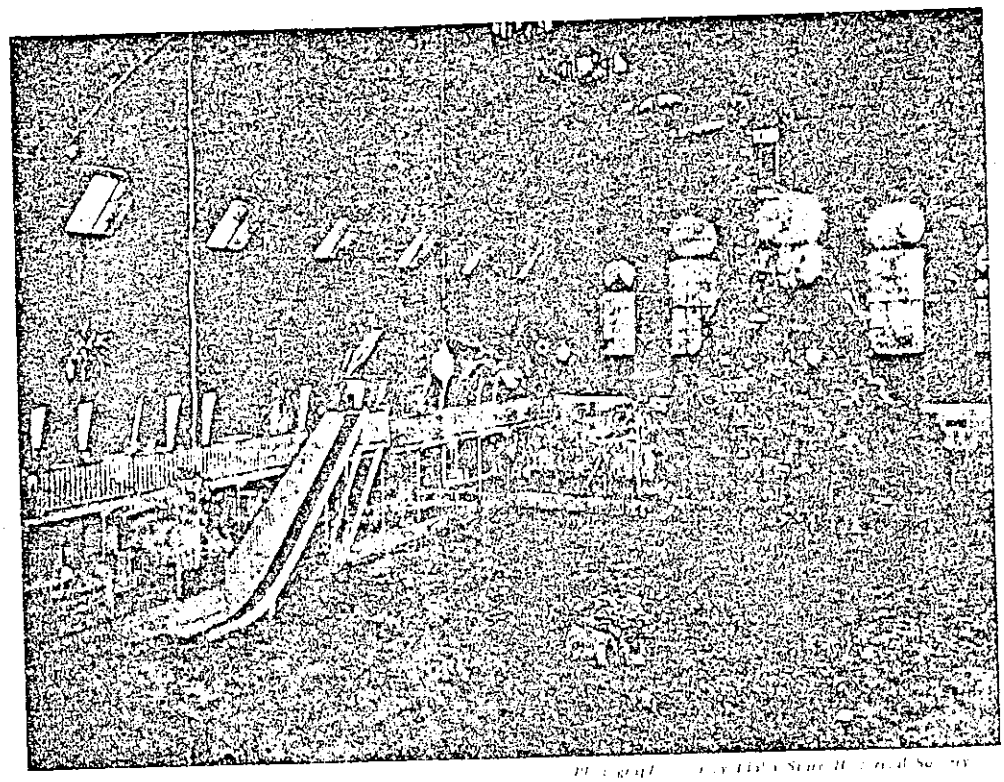
EXTERIOR VIEW OF THE FAMOUS NATATORIUM

time, and continue to do the same thereafter." By virtue of that offer it made a contract to furnish water at "reasonable rates." The rates were established and people accepted them and placed the pipes in their houses. Those contracts were understood to hold good until January 1, 1892. Will the Hot and Cold water people [the new consolidated company] about one half of whom were stock holders in the Artesian company, see to it that the old rates are maintained.

The amount invested by the two water companies was a large sum. Nobody will deny that a reasonable profit should be derived from the investment. Money placed in works of this character does not belong to the public but to the individual. The investment helped the city and added permanently to the assessed valuation, thereby in a measure, decreasing the rate of taxation. That, we believe, is the argument which the company will use when they fix the new rates.

But the rate payer has some rights also. The rate should be a reasonable one. It should be such that the [illegible] may receive fair returns [illegible] and at the same time the rate payer may meet with it no severity. Pure mountain water is a luxury and many can live without it. If the rates are placed too high the company will find a decrease of patronage. But if a reasonable rate is maintained, and the promises made to the public are kept, there will be no trouble about it and no grumbling from the people.[33]

33. *Idaho Statesman* March 31 1891 p 2 c 1

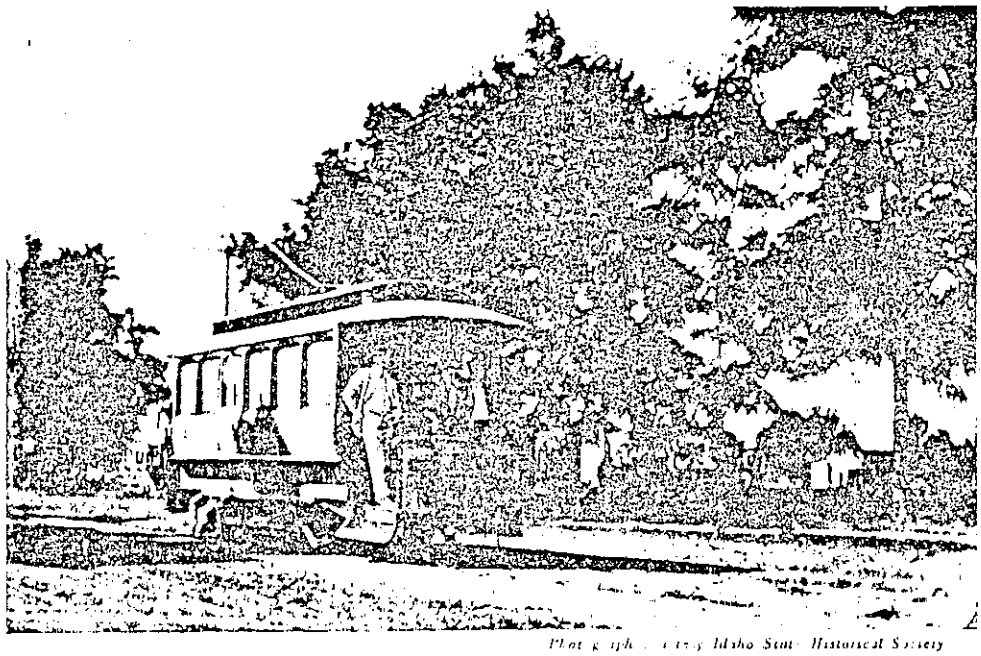


Interior View of the Natatorium

Although the consolidated company held off for a while, a modest increase to a third of the earlier three dollar monopoly rate was imposed before the municipal election in July.

During the campaign for mayor and city council, a combine of the new water company and the new electric street car company intervened in an unexpected way. In addition to the regular Republican and Democratic tickets, these utilities offered a third party with a Citizens' ticket. With many of Idaho's most prominent political leaders joined (as utility investors) in supporting this independent slate, the regular party organization candidates felt threatened. In desperation, the Republicans (who normally might have been expected to triumph) appealed to the Democrats to stay with their own party ticket rather than to desert to the water works and street car party. The utility interests went to the trouble of starting a daily newspaper of their own — the *Boise Citizen* — as a campaign organ "with seven editors, and gratuitous circulation of several hundred copies."[34] They had to reply to charges from the *Idaho Daily Statesman* (the city's long established

34 *Ibid*, July 10, 1891, p. 2, c. 1.



*Photograph courtesy Idaho State Historical Society*

WARM SPRINGS AVENUE STREET CAR

*This line served the residents of fashionable Warm Springs Avenue and the citizens of Boise who spent their recreation hours at the Natatorium. Note the unpaved street*

Republican organ) "against rapicity of these water fiends and money cormorants."[35]

As a campaign issue, the Republicans focussed upon the evils of having the city council composed of owners and agents of the water company with which the city would have to contract for water. Similar opposition was voiced against the electric street car candidates. (They actually were mostly the same people.) Problems of conflict of interest were pointed out clearly and specifically. On top of that, the utilities faced other disparaging accusations: "It is notorious that the saloons on Main street are amply supplied with funds" from the utilities to swing the election, "and that these saloons are now reaping a harvest."[36] Perhaps the water and street car combine succeeded in corraling the Main Street vote. At least enough of the electorate was unimpressed by the possible danger of making the city council the agent of the water and street car companies. After all, these concerns were established by some of the leading citizens of Boise in order to bring progress and prosperity to the community. When the votes were counted, the water company's Citizens' ticked emerged on top. W. E. Borah, who had settled

35. *Ibid.* July 11, 1891, p. 2, c. 2.
36. *Ibid.* July 10, 1891, p. 2, c. 1.

in Boise in the fall of 1890, led the Republican ticket as candidate for city attorney and was nearly elected. But the rest of a strong party ticket faltered against the assault of the water forces.[37]

Fears that domestic and municipal rates would soar after the water company took over the city council (along with the rest of Boise's city government) failed to materialize. Since the eight-dollar a year fire hydrant bargain never had materialized either, all the city business had gone to the opposition company which the council had upheld in an unsuccessful arrangement to divide the fire contract. So the new city council stabilized the city's monthly bill at $114.58 — a figure close to what the earlier council had figured was fair when the two companies had been competing.[38]

Meanwhile the consolidated water company went right ahead with plans to enter the hot water business. Engaging the services of John C. Paulsen, a talented Helena architect who also was designing mansions for some of the wealthy water company investors, the company hastened to build Boise's widely admired natatorium.[39] This became a show place of the Northwest. While construction was underway, interest was mounting in the prospect of hot-water heating. (Until the water could be used at the "Nat" and for domestic heating, the company had to resort to such undistinguished outlets as street sprinkling.[40] A better disposal of the immense hot water supply certainly was needed.) A large number of houses were being built along Warm Springs Avenue, where hot water service was expected.[41] The company really needed a reliable test of hot water heating, though. Conscious that theirs was a pioneer effort in an entirely untried enterprise, these natural hot water experimenters decided to see how their system worked in some of the owner's homes. They started with the company president C. W. Moore, who had joined B. M. DuRell in founding the First National Bank of Idaho in 1867, set up the initial test. He had a sub-

37 *Ibid.*, July 11, 1891, p. 8, c. 1. In the election returns, Borah was reported as losing to C. C. Stevenson, 472 to 369, but a few years later he was told that he actually had had more votes; the canvassers simply had decided they had better make sure that the utility ticket candidate became city attorney. Claudius O. Johnson, Borah of Idaho (New York, 1936), 40.

38 Council Minutes, September 24, 1891-November 3, 1892, February 2-July 6, 1893.

39 C. W. Moore went to Helena in April, 1891, to examine the natatorium there and to engage Paulsen's services. Work on the Boise "Nat" proceeded rapidly, with the pool section built before the rest of the design was even finished. Paulsen came to Boise September 22-24, after the building contract was let. *Idaho Statesman*, April 4, 1891, p. 8, c. 3; May 26, 1891, p. 8, c. 1; June 30, 1891, p. 8, c. 3; July 2, 1891, p. 8, c. 3; September 7, 1891, p. 8, c. 1; September 15, 1891, p. 8, c. 3; September 23, 1891, p. 8, c. 1; September 25, 1891, p. 8, c. 3; October 14, 1891, p. 5, c. 1-2; October 23, 1891, p. 8, c. 3. A biographical notice of Paulsen, from the *Helena Daily Independent*, April 1, 1897, appears in Fred Whiteside, "The Graft that Failed," *Montana Magazine* (Autumn, 1959), p. 10. Arthur A. Hart, director of the Idaho State Historical Museum, is engaged in research on Paulsen and Boise architecture and supplied most of this information.

40 *Idaho Statesman*, August 28, 1891, p. 8, c. 3; *Idaho Democrat* (Boise), quoted in the *Caldwell Tribune*, January 3, 1893, p. 6, c. 3.

41 *Idaho Statesman*, October 5, 1891, p. 8, c. 3; May 24, 1892, p. 5, c. 4-6.

stantial new "elegant mansion" completed at the beginning of 1892. During February and March he found that his novel heating system of natural hot water performed beautifully.[42] Next door, H. B. Eastman of the Overland Hotel followed up with similar success when his new house was done. Eastman's company already had suggested that the new city hall, as well as the fire station, resort to natural hot water heating: now that feasibility was being demonstrated, at "least one-third of the Main street property owners" had "evinced their willingness to become the patrons of the company" for heat as well as for water by the end of March.[43] Special costs for installation of the hot water lines were expected to bring the community heating investment to $20,000. But fuel savings, figured for the community at $50,000 a year, would more than justify the expense. Fire insurance savings offered an additional incentive. With little heat loss expected in several miles of pipe, and with a head "sufficient to force the water into pipes upon the top floor of an ordinary four or five-story building," success for the enterprise was assured.

A full explanation of the merits of natural hot water heating appeared in the *Idaho Daily Statesman*, April 2:

> It is probable that Boise people do not fully realize the value of the hot water that flows in such abundance from the artesian wells. It is understood in a general way to be a nice idea to have houses heated by such an agency, but very few whose attention has not been called to the subject appreciate what the influence of this method of heating will be upon the future of the city.
>
> There are several things that can make a great city, but of not the least importance is that it should be a desirable place of residence. Business advantages build up a community, but it is often found that people, while making their money in one city, will live in another, because of superior attractions of the place that they select for their residence. When business advantages are equal, the city that offers the greatest inducements as a city of homes, forges ahead of its rivals; where business and residence advantages are combined, as in the case of Boise, the city must make great progress.
>
> The hot water supply gives the city a leverage that no other place in the country enjoys; when we stop to consider what the possibilities of the system of heating are, that fact immediately appears. So far as we know, coal will always be expensive; so also will wood. At best, both wood and coal are expensive, and create dirt and smoke. Those who have always had them about the house may have become accustomed to their litter, but there is no one who would not appreciate a heating system that would be free from all the objectionable features of the stove and fireplace.
>
> In time, this hot water will come into general use. All houses will be heated by it, and the heating will be done without care or annoyance on the part of the occupants, while the savings in expense will be enormous.

42. *Ibid*, October 14, 1891, p. 8, c. 1, February 3, 1892, p. 8, c. 1, March 20, 1892, p. 8, c. 2.
43. *Ibid*, March 30, 1892, p. 5, c. 1, November 22, 1892, p. 4, c. 1.

> The poorest family with cultured tastes will be able to maintain a conservatory filled with flowers the year round
>
> Housework will be made easy, because of the wonderful cleansing power of the water.
>
> Every family will be able to maintain a bath, without the expense and danger incurred in putting in water-backs and boilers, and it will be a life giving mineral bath into the bargain.
>
> The new well which is proposed will probably bring boiling water, and this used for flushing the sewers, will make the health conditions of the city perfect.
>
> Under glass in his back yard, every resident can produce a constant supply of delicate garden products, gathering lettuce and radishes for his table in the coldest weather
>
> Such are a few of the advantages that the hot water brings to Boise
>
> It requires no stretch of the imagination to foresee that they will make this place the favorite residence city of the intermountain country. It is a great point to be able to say to the people whose business is in these mountains "We can afford you the finest residence conditions that exist in the country"
>
> People quickly appreciate such conditions; and we have but to get along a little further and take on more metropolitan airs, to line these streets for miles with the homes of men whose business reaches from Bear Lake County in the southeast to Kootenai County in the northwest

While the citizens of Boise were anticipating the wonders of natural hot water heating, they had a chance to try out the large indoor swimming pool that artesian hot water also made possible. Completed in time to commence business on May 25, 1892, the "Nat" (as the Natatorium was known) immediately became a great attraction. A grand dedication ball, June 2, demonstrated that the new building was good for more than swimming and bathing. A special ballroom floor could be installed over the pool, converting the plunge area into quite a different kind of establishment.[44] Many important social affairs were held there, including a number of inaugural balls. Aside from the pool or ballroom area, this large structure (100 by 150 feet in ground area) contained "fifty bath and dressing rooms"[45] A special system of wooden pipe brought hot water one-half mile or more to the "Nat," and for heating purposes was extended down Warm Springs Avenue into the business district. The wooden pipe, chosen to provide insulation, was no innovation: the Helena Natatorium (which the architect had designed previously) used that arrangement.[46] But from there on, the Boise natural hot water heating pioneers went on their own.

With no experience or precedent to guide them, the developers of Boise's hot water system had to go to considerable expense to solve their supply and distribution problems. By 1894, their two hot water wells leaked so badly that they required packing. This reduced their size so

44 *Ibid*, May 26, 1892, p. 8, c. 1; June 3, 1892, p. 8, c. 1.
45 *Ibid*, May 8, 1891, p. 15, c. 1-2.
46 *Ibid*., May 27, 1891, p. 8, c. 2.

much that a third well (450 feet deep) had to be installed to restore the original 800,000 gallon daily flow.[47] (Yet with 550 gallons a minute, their hot water supply was almost as large as all of their cold artesian water obtained from Hull's Gulch.)[48] Wooden piping had to be abandoned in 1896 "as dangerous and useless," and some of the other experiments proved futile as well as expensive.[49]

Capturing enough hot water heating business to absorb their supply, the company at least refrained from going to the effort of developing boiler technology and natural hot water power. Their chief innovation turned out to be commercial utilization and distribution of hot water along lines quite different from the traditional resort and natatorium development that required little or no imagination to work out. Boise's needs gave them a good outlet for household and commercial heating, but did not encourage power generation that the company had considered along with the other possibilities. Conversion of Cyrus Jacobs' flour mill water power system into a hydroelectric plant to operate city street car service came just at the same time that artesian hot water became available.[50] Cold water out of the river provided more than enough electrical generating capacity to meet current needs, and cold river water had no application for heating houses or anything else. A little over a decade after Boise's Artesian Hot and Cold Water Company began to provide commercial distribution of geothermal resources, an Italian enterprise undertook geothermal power generation in 1904.[51] Both of these novel contributions to economic geology — commercial geothermal heating and commercial geothermal power — are closely related, and both commenced at close to the same time, if in widely separated places.

Efforts to increase the hot water flow led to a lot of trouble before they proved successful. With three wells of 394, 404, and 450 feet in depth, the company spent a lot of money on additional new wells, but the flow did not change.[52] Then air pumps increased the hot water supply by twenty-five percent. But the original pumps proved unreliable, and within four years the air had rusted out the metal pipes of the entire system. At that point, the company drilled a new sixteen-inch well, enlarged one of the others to sixteen inches, "and installed two ten-inch Byron Jackson Five Stage Perpendicular Centrifugal Pumps, both electrically driven and placed one hundred and fifty feet down each

47 Boise Artesian Hot and Cold Water Company, *Tariff Rules and Regulations Governing the Use of Hot and Cold Water* (Boise, 1918) pp. 14-16.

48 Israel C. Russell, Preliminary Report on Artesian Basins in Southwestern Idaho and Southeastern Oregon (Washington, 1903), 29-30.

49 Tariff Rules 16.

50 *Idaho Statesman*, October 31, 1891, p. 8, c. 2, November 21, 1891, p. 8, c. 2. The *Statesman* reported that "Cy. Jacobs says it takes less water to run the street railroad than it did his grist mill which has been converted into the powerhouse."

51 McNitt, 8.

52 Waldemar Lindgren, Geological Atlas of the United States, *Boise Folio* (Washington, 1898), 9.

well"[53] These new pumps succeeded perfectly, bringing the total flow to 1,200,000 gallons a day. Natural flow, however, remained at the original 800,000 gallons that had been constant from the beginning. In spite of some early doubt, water temperature never changed, so the company's hot water resource proved quite stable over the years.

Aside from technological problems, the company also had difficulty in getting customers to conserve hot water. Cold water meters enabled the company to abandon a complex rate system based upon house size or, for commercial customers, the kind of business. Hot water meters proved ineffective, although the flat rate of two dollars a month was modest indeed for homes of eight rooms, or less. Larger houses ran as high as three dollars a month, certainly a competitive rate when coal cost seven or eight dollars a ton. Yet the way the company explained matters, all kinds of unfortunate practices had to be curbed:

> The waste and unauthorized use of the natural hot water is enormous and has become a menace to the efficiency of the service. In very cold weather this waste amounts to a large percentage of the whole and practically all of it is unnecessary.
>
> Some of the most prominent ways in which the water is wasted are:
>
> Opening the faucet and letting the water run continuously, with the hope of getting more heat.
>
> Attaching a towel or other fabric to a faucet and allowing it to hang into a wash bowl, sink, bathtub or other set fixture, turning the water on, and allowing the cloth to smother the steam and noise.
>
> Using hose for the same purpose.
>
> Having openings not authorized.
>
> Having a toilet attached, and similar other ways.
>
> All of the above practices waste much water, and most of them weaken the service that is expected to be benefited.
>
> Letting the water run a very short time will get as hot as it ever will be. In a house that is heated with natural hot water it will not take over two minutes to obtain hot water at the faucets.[54]

With nine miles of hot water pipe, about half in large (four to twelve inch) main lines and the other half in smaller feeders, the Boise hot water heating system emerged as a stable, unvarying enterprise.[55] The heating system, in fact, turned out to be far more durable than the traditional natatorium development. Construction materials (but not design) of the "Nat" proved unequal to the strain of supporting a large building in damp surroundings. After forty years the framework and trusses got into "an extremely rotten and decaying condition."[56] Moisture from the pool was blamed for the decay. This unsatisfactory situation came rather abruptly to public notice, July 30, 1934, when part of the roof blew in during a sudden twenty-minute afternoon thunder-

53 Tariff Rules 16.
54 *Ibid.*, 22.
55 *Ibid.*, 16-17.
56 *Idaho Statesman*, August 2, 1934, p. 6, c. 1.

storm. A twenty six mile an hour wind (about as strong as Boise ever gets) and a deluge of rain brought havoc over the community, mainly to trees. The city building inspector, who thought he was lucky to get out of the building alive, found the "Nat" "in an extreme state of decay and deterioration, rendering it unsafe and extremely hazardous. . ." when he examined the situation, August 1. He concluded that "the only thing that is holding the roof together is the shape of the arch which puts pressure on broken beams and prevents them from caving in."[57] The building could not be saved under such conditions, but the city took over the pool (which never had been especially profitable by itself) and preserved it as a regular outdoor cold water plunge.[58] Still in operation, the pool serves as a reminder of a bygone time when the "Nat" was one of the real attractions of the Northwest.

Hot water heating quietly continues to serve a section of the city that the warm water system did so much to develop after 1890. Warm Springs Avenue, which the hot water heat line made into the community's most important residential street (in place of Grove Street, where only one of the old mansions has survived) still has most of its outstanding houses, including C. W. Moore's home that pioneered the natural hot water system. Artesian hot water heating continues to be practical, and more than economically competitive. Rates are determined by the size of the hot water discharge outlet, and run around two hundred dollars a winter for an average house on the system. This price includes hot water for domestic use (making a hot water heater unnecessary) as well as for heat.[59] Except for the coldest weather, natural hot water heat is adequate, although an auxiliary system is necessary for large stores and buildings when conditions get severe. Such conditions do not occur too often: although a prolonged stretch of sub-zero weather would put a strain on an artesian hot water heating system, Boise has gone eight years now since the temperature got down to zero, and even when a severe cold wave strikes, the number of hours in a year that the temperature runs below zero is very small. In a more extreme climate, such a heating system might not be so practical.

Expansion of the artesian heating system cannot be managed on any major scale because of the 1,200,000 daily gallon limit. In the past decade, in fact, a gradual decline in patronage has set in. As late as 1958, 241 customers used artesian hot water to heat their houses or businesses; by 1970 about 200 houses and ten or a dozen business establishments remained. New developments in the city, with some of the old houses giving way to commercial development, with other natural hot water houses displaced by the state capitol complex (heated and

57. *Ibid.*, and see also *Idaho Statesman*, July 31, 1934, p. 1, c. 1, p. 2, c. 1-2, August 2, 1970, p. D1, c. 1-3.
58. *Idaho Statesman*, August 3, 1934, p. 1, c. 1-2, August 4, 1934, p. 5, c. 1-3.
59. Information concerning current service and rates comes from the staff of the company, December 18, 1970.

cooled by an unnatural hot and cold water system), and with urban renewal projects taking out some of the established business customers, disrupt the artesian heating system. No new establishments have adopted natural hot water heat for at least several years. In spite of inflation, though, rates have not risen; those fortunate enough to be in the system have a pretty good and convenient heating bargain that promises to last a long time.

Boise no longer can boast of being unique in utilizing natural hot water for space heating. Most notable of such geothermal enterprises has been widespread use in Iceland. Large volumes of natural hot water, along with important steam fields, give geothermal heating a great boost there. Lack of any other fuel in abundance also enhances natural hot water as a domestic and commercial heat source. Reykjavík, the capital, with a population close to that of Boise, commenced natural hot water heating in 1928 and expanded the system greatly in 1942. (In connection with the expansion project, engineers came from Iceland to examine the Boise system.) One half of all of Iceland's heating now comes from hot springs water, and ninety percent of Reykjavík depends upon geothermal heat. Some water comes ten miles to help heat Iceland's capital, and drilling projects continue to expand the system. That way less oil has to be imported for heating.[60] Geothermal heating has come a long way since some Boise pioneers commenced to experiment with a natural hot water system. And with rapidly mounting concern for environmental pollution, geothermal heating is likely to expand substantially in order to give more people the advantage that its Boise promoters saw so clearly back in 1892.

Recent underground nuclear tests in Nevada have developed a system by which massive geothermal plants might be installed in a favored location where magma (hot underground rock) might occur near the earth's surface. A nuclear device exploded at a depth of 2,000 to 3,000 feet would blast a large cavity but leave it full of loose rock into which water could be piped down from the surface. Steam (to supply a generating plant in a closed system) would rise through a separate vent. Installation costs (of one million dollars or so) would be competitive, and Western state nuclear commissions would be interested. A practical site should be in a dry area, away from springs and other underground water to avoid widespread contamination. So far, no satisfactory site is known: the vast lava beds of the Snake River Plains, for example, have far too much underground water to qualify.[61] Subject to discovery of a suitable location, geothermal energy in the future will not be restricted to natural steam and hot water sites of the kind presently used.

60. Wright Britton, "Sailing Iceland's Rugged Coasts," *National Geographic* (August, 1969), 136:240.

61. S. M. Barton, a Boise mining engineer and a member of the Idaho State Nuclear Energy Commission, mentioned this kind of possibility to the Idaho Commission, on January 19, 1971, after returning from an inspection of the 900-foot cavity in the Nevada test site.

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*Idaho Yesterdays*

# Indians Used Warm Springs

By ARTHUR A. HART
Director, Idaho
Historical Museum

Hot springs are a common tural feature in just about l parts of Idaho, and in ost parts of the state have en developed for recrea- nal or therapeutic use. turally, these locations re well known to the orig- al inhabitants of the region o, and were popular win- ring spots for Idaho's In- ans.

Five miles up the river om Boise, in a draw on the st side of Table Rock, once owed the best-known warm prings in this part of Idaho. s early as 1869, an account The Statesman mentions at a detachment of sol- ers from Fort Boise was unding up all of the In- ans in town and trans- orting them to "their old rounds above the warm prings, where they will be ept by themselves here- fter."

Fear of a smallpox epi- emic accounted for this ove, for the article notes nat "as a measure of afety, they have all been acinated."

By 1871, the springs had een developed into a resort or the people of Boise and icinity, and the proprietors, tubbs & Call, were running egular passenger carriages rom Boise.

The road, which was not he main route to Idaho City t that time, since there was toll road up Rocky Canyon, became known as Warm prings Road, and has con- inued to the present day as Warm Springs Avenue. Stubbs & Call proclaimed that "the arrangements are completed for a luxurious bath, steam, shower, or plunge, as may be desired. Look for the wagon."

In 1872, a Dr. Stevens ad- vertised that he had "built a substantial and comfortable set of bath rooms at the hot springs, and otherwise im- proved this delightful re- sort."

Stevens said that "after emerging from the sul- phurous fumes of the bath room a person can slosh around without danger of getting his shirt bosom bucked." Mr. and Mrs. M. F. Payne were now listed as proprie- tors.

By 1876, the amount of free space in The Statesman devoted to the resort suggests that Judge Milton Kelly, editor and owner of the paper, had ac- quired the property. Kelly owned an extensive ranch in that area.

Social life at the springs was also picking up, accord- ing to these accounts, for even in mid-winter of 1876, a dance was held there, "Tat- ro's coach and Agnew's bus," hauling people to the affair.

Milton Kelly's Hot Springs Ranch included the springs themselves, but the judge leased their actual operation to others. Through the years the names of James D. Dunn, Thomas Clark, Joseph Perrault (a son-in-law), and F. A. McCarthy appear in ads for the resort.

In 1889, Kelly sold The Ida- ho Statesman and retired to Hot Springs Ranch in failing health. He had a paralytic stroke, but was recovered sufficiently by September, 1891, that he could greet old friends at the Springs. By this time the new streetcar lines ran out Warm Springs Avenue as far as the site of the Natatorium, then under construction.

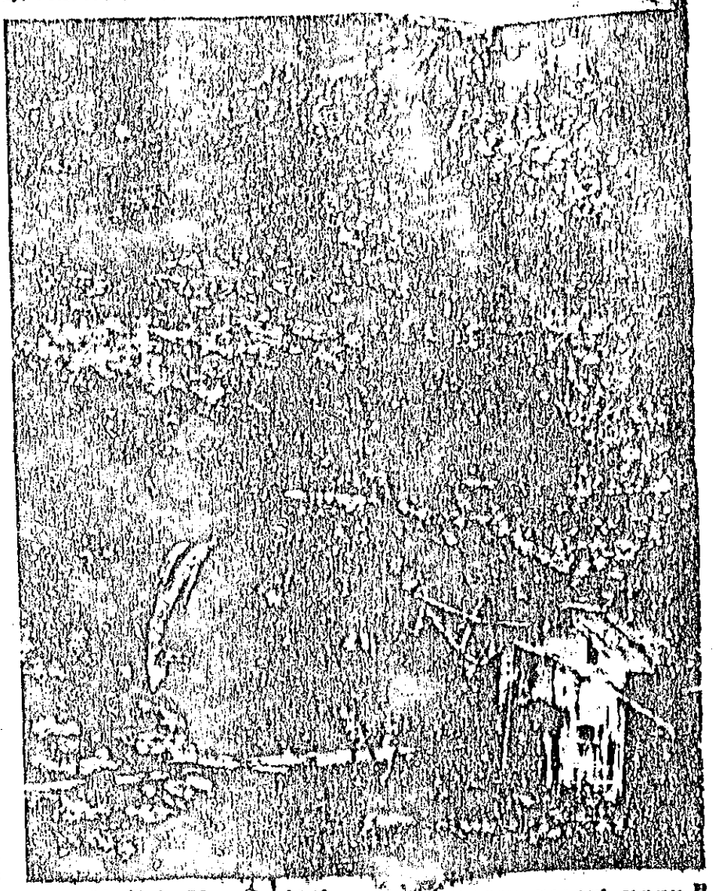
Travelers to the Springs took a "buss" from there — horse-drawn, of course. The fare was twenty-five cents, compared to the fifty cents it had cost fifteen years ear- lier.

Continued declining health forced Milton Kelly to return to Boise for the winter of 1891-92. On February 8, he deeded his Hot Springs Ranch and other property to his daughter, Mrs. Joseph Perrault, with whom he was staying. When Kelly died, on April 9, 1892, the property passed into the hands and management of the Per- raults, who continued to make improvements in it.

The drilling of wells west of Table Rock in 1891 led to the establishment of the fa- mous Natatorium and Boise's natural hot water system — first of its kind in the United States.

Whether this was the cause of it or not, Kelly's Hot Springs declined there- after, although Joseph Per- rault conducted drilling op- erations there as late as 1904.

* * *



*Kelly's Hot Sp[illegible] famous resort near B*



*Milton Kelly, owner of The Statesman, acquired hot springs resort*

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# Report: Water pumping reduces Bruneau springs

By N.S. Nokkentved
Times-News writer

TWIN FALLS – A long-awaited U.S. Geological Survey report released Thursday shows what has long been suspected: Groundwater pumping has reduced spring flows in the Bruneau-Grandview area.

"We know for a fact" that pumping has affected spring flows at the Indian Bathtub hot spring, said Jerry Hughes Director of the USGS Boise office, which produced the report.

The dropping groundwater has dried up or reduced flows from hot springs that support the Bruneau hot springsnail, listed as endangered by the U.S. Fish and Wildlife Service earlier this year.

The report was delayed when an error in computing the rate of natural recharge in the aquifer was discovered in March. The error cast doubts on the snail listing, which relied in part on the report.

But recharge is not the issue, Hughes said. The report focused on the relationship between groundwater pumping and spring flows, he said.

And pumping has reduced the hydraulic pressure in the aquifer – and hence the level – he said. Hydraulic pressure is what forces water in a leaky bucket to squirt farther out the holes when there's more water in the bucket.

The increases in pumping in the 1960s and 1970s are reflected in corresponding decreases in spring flows, Hughes said.

The Idaho Department of Water Resources is confident that the report is solid and will serve as a foundation for determining options and alternatives to slow or halt the declining groundwater level, spokesman Dick Larsen said.

The department long has acknowledged that pumping has lowered the groundwater level. In 1982 the department established the Bruneau-Grandview Groundwater Management Area to protect water rights from the dropping water level.

Listing the Bruneau snail may affect federal crop subsidies, price supports, deficiency payments and federal loan guarantees. But it also has made people pay attention to what is happening to the aquifer, Hughes said.

Over the long term – snail or no snail – the aquifer will continue to decline if the present trend continues, he said. The dropping water level will drive up the cost of pumping irrigation water and may drive some irrigators out of business.

Water Resources wants to get involved in Fish and Wildlife's snail recovery plan to see what can be done to reduce groundwater use to slow the decline, Larsen said. Such a plan may help protect existing water rights as well as protect the tiny snail – less than one-fourth inch long.

Some of the options would include the Fish and Wildlife buying water rights, or the area could form a water district to control locally the administration of water.

# Groups ask water court to reconsider decision

By N.S. Nokkentved
Times-News writer

TWIN FALLS – Four Idaho environmental groups have asked again to intervene in the Snake River Basin Adjudication.

The Idaho Conservation League, Idaho Rivers United, Idaho Wildlife Federation and the Northwest Resource Information Center want to make sure the court considers the "public trust doctrine" in the massive legal case.

Fifth District Judge Daniel Hurlbutt, who presides over the adjudication, ruled against the groups earlier this year. Tuesday the groups asked him to reconsider his decision.

"If you don't do it now, when are you going to do it?" said attorney Laird Lucas of the Boise office of the Land and Water Fund of the Rockies, which is representing the groups.

The adjudication will affect about 150,000 water rights in the Snake River Basin. When completed, the court will issue a ruling that decrees valid water rights.

An adjudication of 87 percent of the state's water ought to consider the public trust, Lucas said. The groups aren't saying that any water rights are violating the public trust, but it should be considered, Lucas said.

The public trust doctrine is an ancient concept found is Roman law and English common law, he said. It is based on the idea that nobody can own certain fundamental resources. Water is one.

Unlike real property, water is not fixed. It supports fish, navigation and supplies a variety of uses. It is something in which everybody has an interest, Lucas said.

To serve those varied public interests, the state retains ownership of water and the river or lake beds. And it controls the use of water within its boundaries.

Water rights convey only the right to use water. They are not ownership rights, he said.

In other states, courts have ruled that the public trust can limit existing water rights.

Boise attorney Bill Ringert said the doctrine doesn't apply to water rights under Idaho water law.

Please see WATER/B2

## Water

Continued from B1

"I cannot rationalize the public trust doctrine with water rights in Idaho," Ringert said.

But Lucas insists it applies. It has been widely recognized and embraced by the Idaho Supreme Court, he said.

Ringert, who opposes the groups' motion, said they are asking the court to limit all other water rights "because someone who doesn't have a water right wants to use the water."

Hurlbutt questioned Lucas about the effect of periodically reviewing water rights in the context of public trust. That could make water rights so insecure that farmers would be unable to get annual operating loans, he said.

Lucas acknowledged that agriculture and hydroelectric power are very important to the state and to the Magic Valley.

"We're not trying to upset that apple cart," he said. But other public interests ought to be considered, he said.

"What happens to fish or to people who recreate when all the water is removed?" he asked.

The groups also have challenged five individual water rights for the same purpose, to insure the court considers the public trust in the adjudication.

Blay FUNERAL HOME 2551 Kimberly Road 736-0777

PENGAD-Bayonne, N. J.

# Effects of Well Discharges on Hydraulic Heads in and Spring Discharges from the Geothermal Aquifer System in the Bruneau Area, Owyhee County, Southwestern Idaho

By Charles Berenbrock

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U.S. Geological Survey
Water-Resources Investigations Report 93-4001

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## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| acre | 0.004047 | square kilometer |
| acre-foot (acre-ft) | 1,233 | cubic meter |
| acre-foot per year (acre-ft/yr) | 1,233 | cubic meter per year |
| calorie per second (cal/s) | 4.184 | watt |
| cubic foot per day ($ft^3/d$) | 0.02832 | cubic meter per day |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| cubic mile ($mi^3$) | 4.168 | cubic kilometer |
| foot (ft) | 0.3048 | meter |
| foot per day[1] (ft/d) | 0.3048 | meter per day |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer |
| foot per year (ft/yr) | 0.3048 | meter per year |
| foot squared per day[2] ($ft^2/d$) | 0.09290 | meter squared per day |
| gallon per minute (gal/min) | 0.003785 | cubic meter per minute |
| gallon per minute per foot [(gal/min)/ft] | 0.2070 | liter per second per meter |
| inch (in.) | 25.4 | millimeter |
| inch per year (in/yr) | 25.4 | millimeter per year |
| kilowatthour (kWh) | 3,600,000 | joule |
| mile (mi) | 1.609 | kilometer |
| picocurie per liter (pCi/L) | 0.037 | becquerel per liter |
| square mile ($mi^2$) | 2.590 | square kilometer |

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = 5/9\ (°F-32)$$

**Sea level:** In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

[1]The standard unit for hydraulic conductivity is cubic foot per day per square foot. This mathematical expression reduces to foot per day, which is used in this report.

[2]The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness. This mathematical expression reduces to foot squared per day, which is used in this report.

# Effects of Well Discharges on Hydraulic Heads in and Spring Discharges from the Geothermal Aquifer System in the Bruneau Area, Owyhee County, Southwestern Idaho

*By* Charles Berenbrock


## Abstract

Demand for ground water in the 600-square-mile Bruneau study area has increased since 1954 because of agricultural development. Declining flow at Indian Bathtub Spring is adversely affecting a unique species of snail that inhabits the spring.

The Bruneau study area is underlain by sedimentary and volcanic rocks that form a regional geothermal aquifer. Sedimentary rocks range in thickness from zero in the southern part of the study area to more than 3,000 feet in the northeastern corner. Volcanic rocks underlie the entire study area and extend southward to the Jarbidge Mountains. In the central part of the study area, the volcanic rocks are probably 2,000 to 3,000 feet thick. For purposes of study, the regional geothermal aquifer system was divided into sedimentary- and volcanic-rock aquifers.

Ground water flows northward through the volcanic-rock aquifer to the sedimentary-rock aquifer, from areas of recharge along the Jarbidge and Owyhee Mountains into the study area, where it is discharged as spring flow or leaves the study area as underflow. Prior to extensive ground-water development, about 10,100 acre-feet was discharged by springs.

Ground-water discharge from wells began in the late 1890's. From the 1890's through 1951, annual discharge was less than 10,000 acre-feet. From 1952 to 1978, annual discharge increased to about 40,600 acre-feet. During 1978–91, well discharge declined from the maximum of 49,900 acre-feet in 1981 to 34,700 acre-feet in 1991. Through 1991, nearly 1,400,000 acre-feet of ground water discharged from wells; about 546,000 acre-feet discharged from 1978 through 1991. Most pumped water is from the volcanic-rock aquifer.

Ground-water development since the mid-1890's locally has modified the direction of water movement in both the sedimentary- and volcanic-rock aquifers. In 1989, ground water moved toward four cones of depression created by pumping—two in the northern part of the study area are in the sedimentary-rock aquifer, two in the southern part are in the volcanic-rock aquifer. Pumping has caused hydraulic heads in the volcanic-rock aquifer to decline more than 30 feet in much of the area and at least 70 feet in one well. About 1 mile from Indian Bathtub Spring, the water level in one well declined about 10 feet during 1979–92, or about 0.7 feet per year.

Within the past 25 years, discharge from monitored springs along Hot Creek and the Bruneau River has declined, most notably from Indian Bathtub Spring. Discharge from Indian Bathtub Spring in 1964 was about 2,400 gallons per minute, and by the summer of 1989, discharge was zero. Discharge began to decline in the mid-1960's when the rate of increase in pumpage accelerated. In contrast, discharge from Pence Hot Spring has ranged from about 700 gallons per minute to about 1,100 gallons per minute.

Changes in discharge from monitored springs corresponded with changes in hydraulic head, which fluctuates seasonally, and are

substantially less in late summer than in the spring. A hydraulic head/spring discharge relation was developed for two sites at Indian Bathtub Spring and a nearby test hole. The relation for Indian Bathtub Spring indicated that a spring discharge of 2,400 gallons per minute would relate to a hydraulic head of about 2,708 feet at the spring, which is about 34 feet higher than the head at zero spring discharge.

## INTRODUCTION

Bruneau, Little, and Sugar Valleys, within the 600-mi² Bruneau study area (fig. 1) in north-central Owyhee County, have undergone extensive agricultural development since the turn of the century. Additional water is needed for irrigation (due to phasing out of "set aside" irrigated lands) in those valleys. A geohydrologic study of the same general area by Littleton and Crosthwaite (1957) indicated that available surface water was inadequate for all irrigable lands. They also noted that the regional geothermal aquifer is perhaps the most promising source for additional water. In 1980, about 25,000 acres in the study area were irrigated with surface water and about 20,000 acres were irrigated with ground water (Lindholm and Goodell, 1986). Young and others (1979, p. 15) estimated that in 1978, about 39,000 acre-ft of ground water was discharged from wells in the study area. Pumping of ground water for irrigation has lowered hydraulic heads throughout the area. Consequently, discharge from monitored geothermal springs along the Bruneau River and Hot Creek is declining, with intermittent flow from Indian Bathtub Spring. Young and others (1990) showed that Indian Bathtub Spring did not flow from July through October 1989 and from July through September 1990.

The Bruneau Hot Springs snail is present in springs along Hot Creek and the Bruneau River in Owyhee County. Within the past 25 years, flows from monitored springs have declined; this decline may have restricted the snail's habitat. Several public agencies, the general public, and Idaho's congressional delegation have become concerned about the continued existence of the snail. The U.S. Fish and Wildlife Service (USFWS) is concerned that declines in spring flow might cause the snail's extinction.

### Purpose and Scope

In 1987, the USFWS entered into a cooperative agreement with the U.S. Geological Survey (USGS) to develop and implement a three-phase ground-water study of the Bruneau area. This study focused on the hydrology of the regional geothermal system and the hot springs. During the first phase of the study, completed in 1989 (Young and Parliman, 1989), the hydrologic data base was updated and evaluated and a ground-water and spring-monitoring program was implemented in the Indian Bathtub study area, which occupies about 145 mi² of the larger Bruneau study area. The second phase, completed in 1990 (Young and others, 1990), resulted in the drilling of eight test holes at four sites near the Indian Bathtub Spring (fig. 1). These test holes were designed to provide a better understanding of the relation between hydraulic heads and spring discharge. The purpose of the third phase of the study, described in this report, is to determine the cause or causes of declining flow at Indian Bathtub Spring.

The third phase, completed in 1992, included (1) evaluating all available information about the regional geothermal aquifer system; (2) describing the geohydrology of the Bruneau study area, including ground-water recharge, discharge, movement, and hydraulic head; (3) describing vertical variations in hydraulic head; and (4) determining the effects of discharge from wells on hydraulic heads and spring flows in the study area.

### Description of the Study Area

The Bruneau study area is near the southern margin of the western Snake River Plain, about 65 mi southeast of Boise (fig. 1). The study area includes the Indian Bathtub area and extends north from about 42°45' latitude to the Snake River, east from the drainage divide between Shoofly Creek and Little Jacks Creek to the drainage divide between the Bruneau River and Sailor Creek—an area of about 600 mi². The study area includes

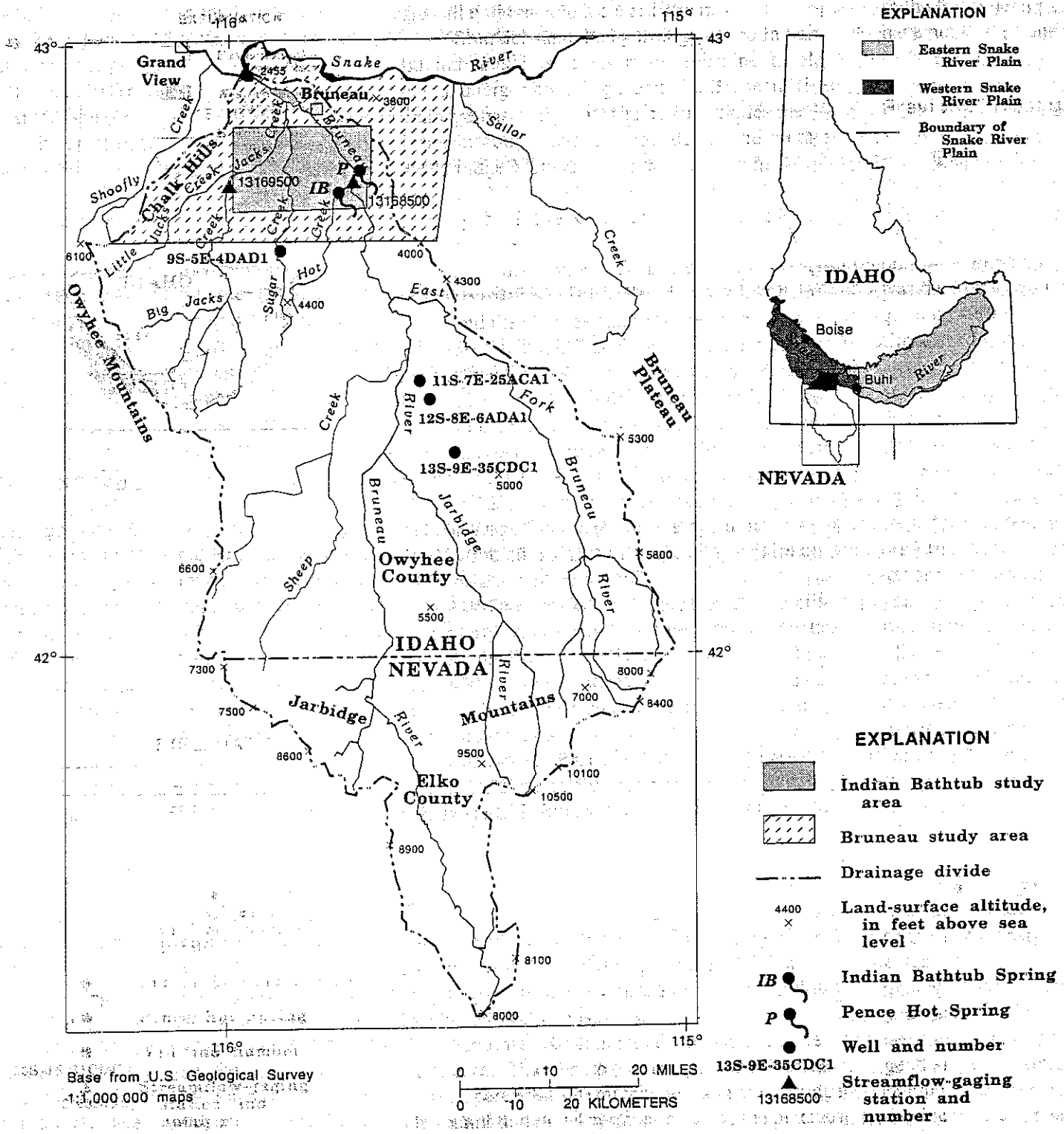



Figure 1. Location of study area.

Bruneau, Little (includes valleys of Little and Big Jacks Creeks), and Sugar Valleys, which are separated by plateaus several hundred feet higher than the valley floors and included streams.

To understand the hydrology of the Indian Bathtub area, it is necessary to determine its relation to a larger hydrologic unit, the Bruneau River drainage basin (fig. 1). The basin includes the Bruneau study area and is bounded on the south by the Jarbidge Mountains, on the west by the Owyhee Mountains and the Chalk Hills, on the north by the Snake River, and on the east by the Bruneau plateau.

The study area has an arid climate. Average annual precipitation on valley floors is less than 10 in. and the average annual air temperature is about 50°F (10°C). Rainfall is infrequent during the summer; most precipitation (which includes snowfall) is from October through March. Summers are characterized by hot days (average daily maximum temperature is 90°F, or 32°C) and warm nights (average daily minimum temperature is 54°F, or 12°C); winters are characterized by cool days (average daily maximum temperature is 43°F, or 6°C) and cold nights (average daily minimum temperature is 24°F, or -4°C).

The Bruneau River drainage area has a predominantly rural population dependent on irrigated agriculture. The city of Bruneau, with a 1990 population of about 300 people, covers several square miles in the northern part of the area and is the largest community.

Most of the Bruneau River drainage area is Federal land leased for grazing under the jurisdiction of the U.S. Bureau of Land Management (BLM). Bruneau, Little, and Sugar Valleys have been irrigated extensively since the turn of the century, whereas intervening plateaus are undeveloped desert. The main crops are hay and alfalfa, associated with the raising of cattle; corn and beans are also grown in Little and Sugar Valleys. Water for irrigation is obtained from streams and from flowing and pumped wells.

Perennial and ephemeral streams drain the study area. The principal drainage is the Bruneau River, a perennial stream that heads in the Jarbidge Mountains and flows northward across the plateaus in deeply incised canyons to the Snake River. Many streams in the study area are ephemeral and flow only in response to rainstorms or spring runoff; included are Big Jacks, Browns, Deer Heaven, Hot, Little Jacks, and Sugar Creeks. Springs discharge directly to some creeks, like Hot Creek, but in the last several years, some monitored springs have not flowed during the summer months.

## Previous Investigations

Early studies of ground-water resources in the Bruneau River drainage area were done by Russell (1903), Stearns (1922), Piper (1924), and Stearns and others (1937). Their reports focus primarily on the artesian conditions. Piper (1924) was the first to estimate the annual withdrawal of ground water from wells. In 1954, Littleton and Crosthwaite (1957) reexamined ground-water resources in the study area and estimated the annual withdrawal from wells. They suggested that further development of the regional geothermal system was possible. Ralston and Chapman (1969) studied ground-water conditions and availability in northern Owyhee County.

More recent ground-water investigations in the Bruneau River drainage area were directed toward geothermal resource assessment. Historical data from geothermal wells and springs in Idaho were summarized by Ross (1971). Young and Mitchell (1973) inventoried and sampled 124 geothermal wells and springs in Idaho for chemical analyses (6 in the Bruneau area) and suggested future geothermal studies in 23 areas of the State, including the Bruneau-Grand View area. Areas for study were selected on the basis of estimated aquifer temperatures greater than 140°C. On the basis of the above recommendations, Young and Whitehead (1975) inventoried and sampled 94 wells and springs in the Bruneau-Grand View area to assess the geothermal system and its probable sources of recharge. They also described the areal extent of the geothermal system on the basis of geological and geophysical evidence. Rightmire and others (1976) used isotopic and geochemical analyses of water from springs and wells in the geothermal system to determine possible sources of recharge. They also indicated that water-level declines since 1954 continued during the 1970's because ground-water withdrawals exceeded recharge. Renner and others (1975) estimated stored heat in the geothermal system on the basis of

a reservoir temperature of 145°C and a reservoir volume of 1,300 mi³. Brook and others (1979) estimated the stored heat on the basis of a reservoir temperature of 107°C and a reservoir volume of 439 mi³. Young and others (1979) estimated that the discharge from springs and flowing and pumped wells in 1978 was about 50,500 acre-ft. Young and Lewis (1982) developed a conceptual model of the geothermal system and speculated that the recharge area lies somewhere to the south, probably in the Jarbidge and Owyhee Mountains. Using a heat balance equation, they estimated that 29,000 acre-ft of ground water per year is recharged and 18,000 acre-ft of ground water per year is discharged by underflow from the geothermal system from the Idaho-Oregon State line to Buhl (Young and Lewis, 1982, p. 16).

Gemperle (1988) described the regional geothermal aquifer system and the overlying cold-water aquifer. He also identified data needs and proposed ways to optimally manage ground-water resources in the Bruneau-Grand View area. Young and Parliman (1989) collected information on well and spring locations, well construction, and hydraulic head. Water samples from 33 geothermal wells and 5 springs were collected for chemical and isotopic analysis. Young and others (1990) presented geologic and hydrologic data collected during January 1989 through September 1990 from eight test holes drilled near Indian Bathtub Spring and from selected geothermal wells and springs in and around the Indian Bathtub area. At three of the sites, piezometers were installed at different depths to determine changes in hydraulic head with changes in depth. At two sites, piezometers were installed at the same altitude as a nearby spring to enable monitoring of the zone within the regional geothermal aquifer system that controls the spring discharge. Water samples were collected from each test hole to aid in understanding the vertical variations in water quality. Their report includes completion, lithologic, and gamma logs for the test holes; hydrographs of hydraulic head and spring discharge; and chemical and isotopic analyses of water from six of the test holes.

A Regional Aquifer-System Analysis (RASA) of the 15,600-mi² Snake River Plain began in October 1979. The main purposes of the study were to refine knowledge of regional ground-water-flow systems, determine effects of conjunctive use of ground and surface water, and describe ground-water chemistry (Lindholm, 1981). Interpretive RASA reports that include the Bruneau study area are: (1) a regional water-table map and description of the ground-water-flow system (Lindholm and others, 1983 and 1988); (2) a description of the geohydrologic framework (Whitehead, 1986 and 1992); (3) water budgets and streamflow in the Snake River and ground-water budgets for the Snake River Plain (Kjelstrom, 1986 and 1992); (4) water use (Bigelow and others, 1987; Goodell, 1988); (5) a map showing irrigated land and other land uses (Lindholm and Goodell, 1986); and (6) results of ground-water-flow modeling of the western Snake River Plain (Newton, 1991). About 300 model cells out of 3,000 active model cells were used to represent the Bruneau study area.

## Acknowledgments

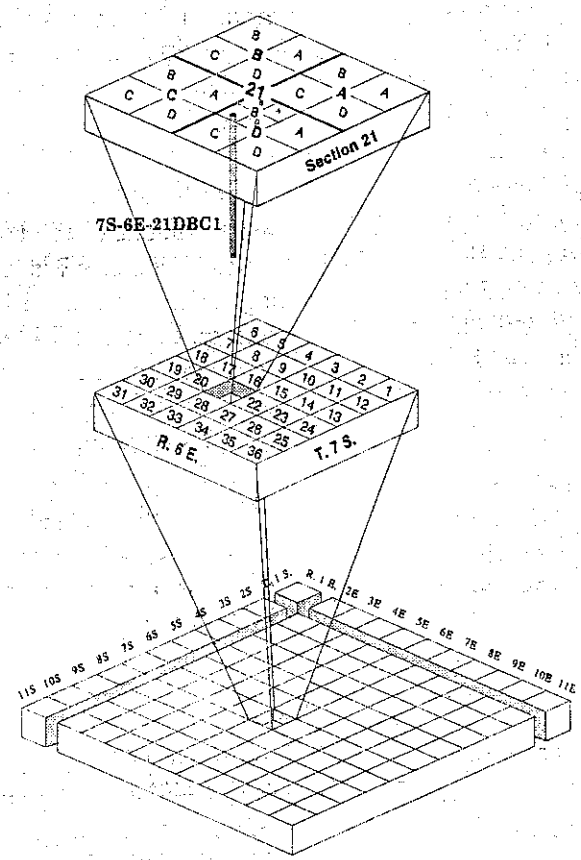
Appreciation is extended to residents in the study area who supplied data and permitted the use and testing of their wells during this investigation. The Idaho Power Company furnished electrical power data for estimation of irrigation pumpage. Particular appreciation is extended to H.W. Young, U.S. Geological Survey, for calculating pumpage using electrical power data and for measuring water levels in and discharge from irrigation wells in the study area. Special thanks are extended to Margaret D. Jenks, Bill Bonnichsen, and Martha M. Godchaux, Idaho Geological Survey, for providing preliminary information concerning geology and faults.

## Well- and Spring-Numbering System

The well- and spring-numbering system used by the U.S. Geological Survey in Idaho (example on next page) indicates the location of wells within the official rectangular subdivision of public lands, with reference to the Boise base line and Meridian. The first two segments of the number designate the township (north or south) and range (east or west). The third segment gives the section num-

ber; four letters, which indicate the ¼ section (160-acre tract), ¼-¼ section (40-acre tract), ¼-¼-¼ section (10-acre tract) and, when needed, ¼-¼-¼-¼ section (2½-acre tract); and serial number of the well within the tract.

Quarter sections are designated by the letters A, B, C, and D in counterclockwise order from the northeast quarter of each section. Forty-acre, 10-acre, and 2½-acre tracts within each quarter section are lettered in the same manner. Well 7S-6E-21DBC1, for example, is in the SW¼NW¼SE¼ sec. 21, T. 7 S., R. 6 E., and is the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example, 8S-6E-3BDD1S.




## GEOHYDROLOGY

The development of a conceptual model of the geothermal system in the Bruneau study area involved (1) describing the geology and boundaries of the aquifer system, (2) determining aquifer properties, (3) estimating recharge to and discharge from the aquifer system, and (4) determining the effects of ground-water development on the aquifer system. In addition to reports listed under "Previous Investigations," geology of the study area and surrounding areas is discussed in reports by Malde and Powers (1962), Malde and others (1963), Harper (1963), and Young and Whitehead (1975). Geologic structure is discussed in most of these reports. However, recent geologic mapping in the area indicated that the degree of faulting, especially near Indian Bathtub (M.D. Jenks and others, Idaho Geological Survey, written commun., 1992) is greater than previous investigators thought. Only a brief summary of the geohydrology of the regional geothermal system is included here. The reader is referred to referenced reports for a more complete description of the geohydrology.

### Geology

Rocks in southwestern Idaho and north-central Nevada range in age from Precambrian to Holocene and represent a varied and complex geologic history. Cores of the Owyhee and Jarbidge Mountains, west and south of the study area, are composed of sedimentary and metamorphic rocks of Precambrian and Paleozoic age, intruded by granitic rocks of Mesozoic and Tertiary age. The mountains are as much as 10,500 ft above sea level (fig. 1). Tertiary volcanic rocks ranging in composition from rhyolite to basalt underlie most of the plateaus. Plateaus are from 4,000 to 6,000 ft above sea level and, at high altitudes, are dissected by deeply incised streams. Tertiary and Quaternary rocks and unconsolidated rocks of fluvial and lacustrine origin are present in most of the lower areas and locally are overlain by Quaternary basalt.

For this report, surficial geology was generalized and divided into nine units (Whitehead, 1986, sheet 1). Each unit was delineated on the basis of geohydrologic characteristics. The areal distribution of these units is shown in figure 2.

Pre-Cretaceous (undifferentiated) and granitic rocks crop out only in the Jarbidge Mountains in the Bruneau River drainage area (fig. 2A) and have not been reached by drilling in the Bruneau

study area. Young and Whitehead (1975, p. 12) indicated that granitic rocks probably form the core of the Owyhee and Jarbidge Mountains and are similar in age and composition to the Idaho batholith. Their thickness is unknown.

Basalt of various ages is present in the Bruneau River drainage area. The older basalt unit, which consists chiefly of Banbury Basalt of Miocene age, is exposed throughout the study area. Although older basalt also is widespread in the subsurface, it was not possible to correlate rock units from the surface to the subsurface (fig. 3). Thickness of the older basalt unit is variable and is unknown in much of the study area. Young and Whitehead (1975) indicated that, in the Bruneau-Grand View area, the unit ranges in thickness from less than 100 ft to nearly 1,200 ft. Ralston and Chapman (1969, p. 17–18) indicated that the Banbury Basalt consists of two types: a relatively fresh, nonaltered basalt and a highly altered basalt. The nonaltered basalt is present mainly in the eastern part of the study area and has well developed columnar and platy horizontal jointing. The altered basalt is present mainly in the western part of the study area, where a high degree of weathering has caused secondary mineralization in fractures and cavities (Ralston and Chapman, 1969, p. 18).

Silicic volcanic rocks of Miocene and Pliocene age, including Idavada Volcanics and other rhyolitic rocks, are exposed on plateaus south of the Snake River (fig. 2) and underlie the entire study area. The predominantly latitic composition of the Idavada Volcanics differentiates them from the other volcanic rocks in this unit. They are mainly thick layers of highly fractured, faulted, and jointed devitrified welded tuff (Young and Whitehead, 1975, p. 11). Idavada Volcanics are probably 2,000 to 3,000 ft thick (Young and Lewis, 1982, p. J4); total thickness of the silicic volcanic rocks is largely unknown but may be as much as 7,000 ft (McIntyre, 1979, p. 7–10).

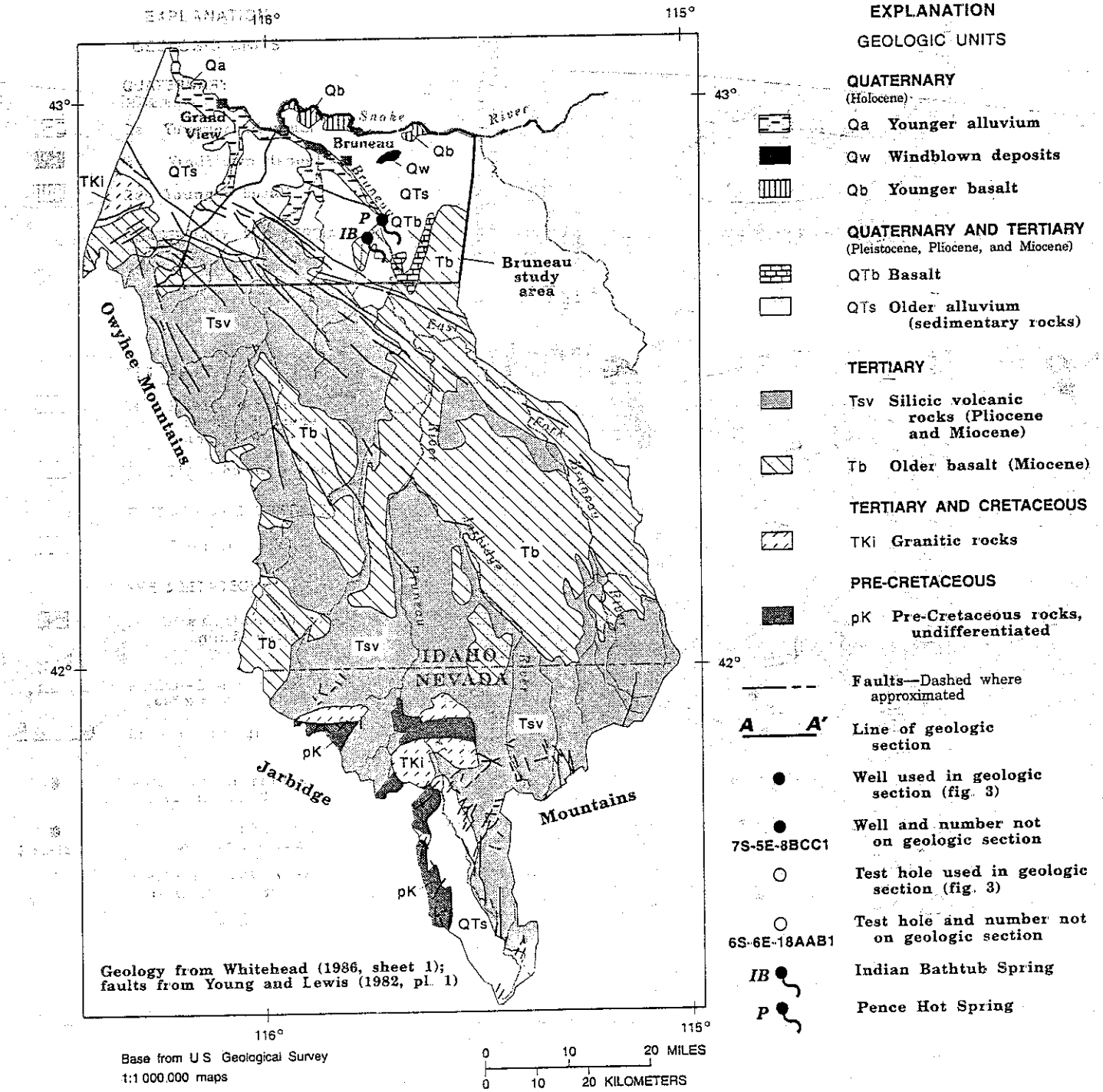
Basalt of Pleistocene to Miocene age (Idaho Group) crops out in one small area adjacent to the Bruneau River near Indian Bathtub (Whitehead, 1986, sheet 1). Quaternary basalt is exposed only along the Snake River north of Bruneau Valley (fig. 2).

Hereafter, the Tertiary and Quaternary basalt and silicic volcanic rocks are referred to as the volcanic rocks.

Alluvium is of Holocene to Miocene age. Older alluvium (hereafter referred to as sedimentary rocks) of Pleistocene to Miocene age consists of fluvial and lacustrine rocks and includes the Idaho Group. These sedimentary rocks are composed chiefly of unconsolidated, poorly to well-sorted gravel, sand, silt, and clay. The percentage of silt and clay increases toward the Snake River. The sedimentary rocks are predominant in the northern part of the Bruneau River drainage area (fig. 2A). They range in thickness from 0 ft, where they abut against basalt or silicic volcanic rocks in the southern part of the Bruneau area to more than 3,000 ft in the northeastern part (fig. 4A). The distribution of the sedimentary rocks was estimated from drillers' logs (Whitehead, 1986, sheet 2). Thicknesses shown probably are maximum because interbedded basalt and silicic volcanic rocks are included. The altitude of the base of the sedimentary rocks varies, as shown in figure 4B.

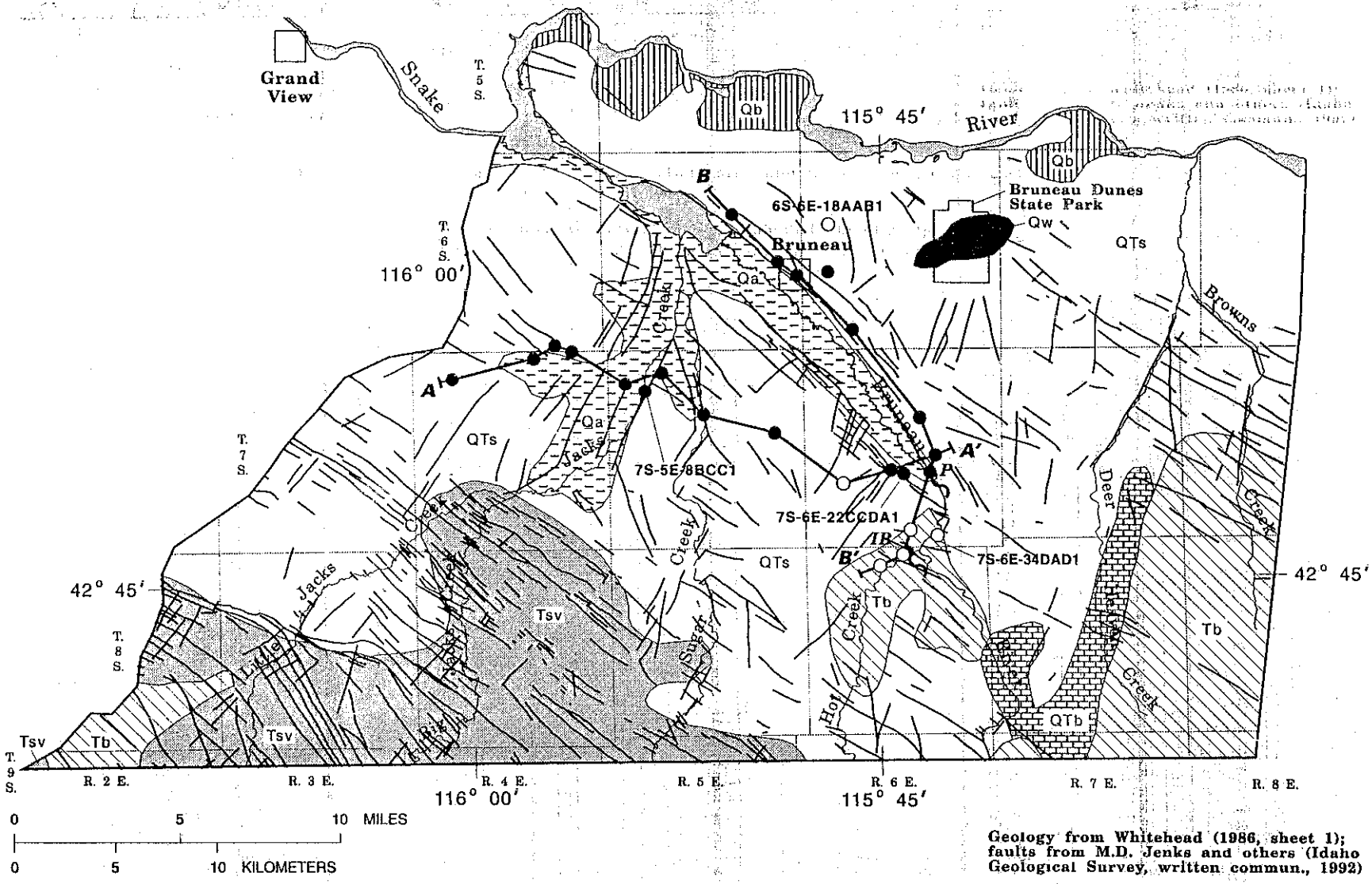
The younger alluvium of Holocene age covers the floors of tributary valleys and the flood plains of main streams, as in Bruneau and Little Valleys (fig. 2B). These sedimentary rocks range in thickness from 0 to about 50 ft (Littleton and Crosthwaite, 1957, p. 167). Windblown rocks of Holocene age consist of a veneer of sand (usually 100 ft or less in thickness). Active sand dunes at Bruneau Dunes State Park in northeastern Owyhee County are included in these rocks.

The study area is an intensively faulted structural depression (Hill, 1963). Geologic and geophysical data indicate that northwest-trending faults are predominant (fig. 2). Young and Whitehead (1975, p. 13 and fig. 4) indicated that several hundred feet of vertical displacement along major faults may be typical. Faulting appears related to tectonic events that formed the present western Snake River Plain (Malde and Powers, 1962) in early Pliocene and Pleistocene time (Young and Lewis, 1982, p. J4). Recently, an older northeast-trending set of faults has been mapped (M.D. Jenks and others, Idaho Geological Survey, written commun., 1992).




A. Generalized geology of the Bruneau River drainage basin and adjacent areas

**Figure 2.** Generalized geology of the Bruneau River drainage basin and adjacent areas (A) and the Bruneau study area (B)




B. Generalized geology of the Bruneau study area and location of geologic sections

**Figure 2.** Generalized geology of the Bruneau River drainage basin and adjacent areas (A) and the Bruneau study area (B)—Continued.

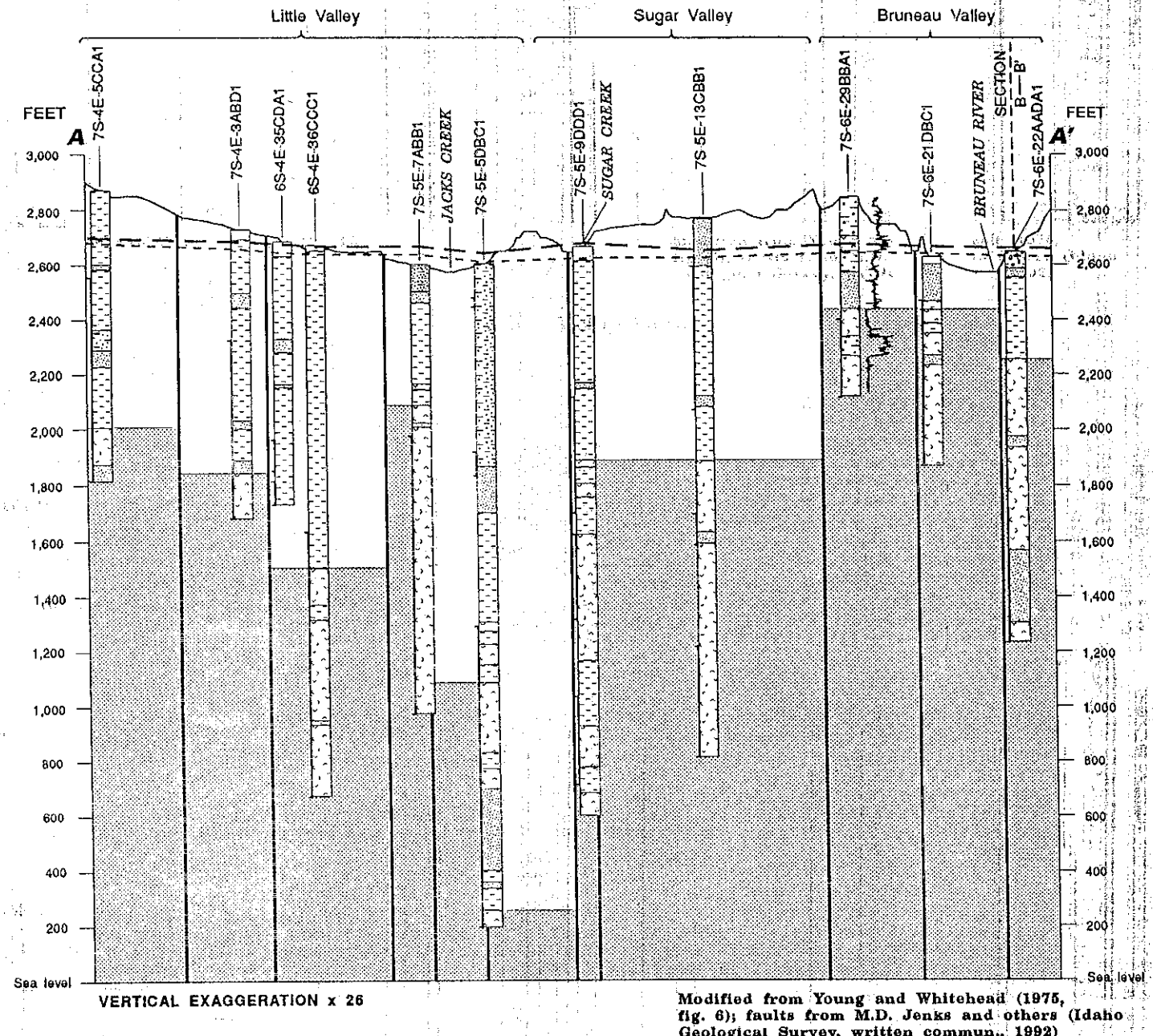
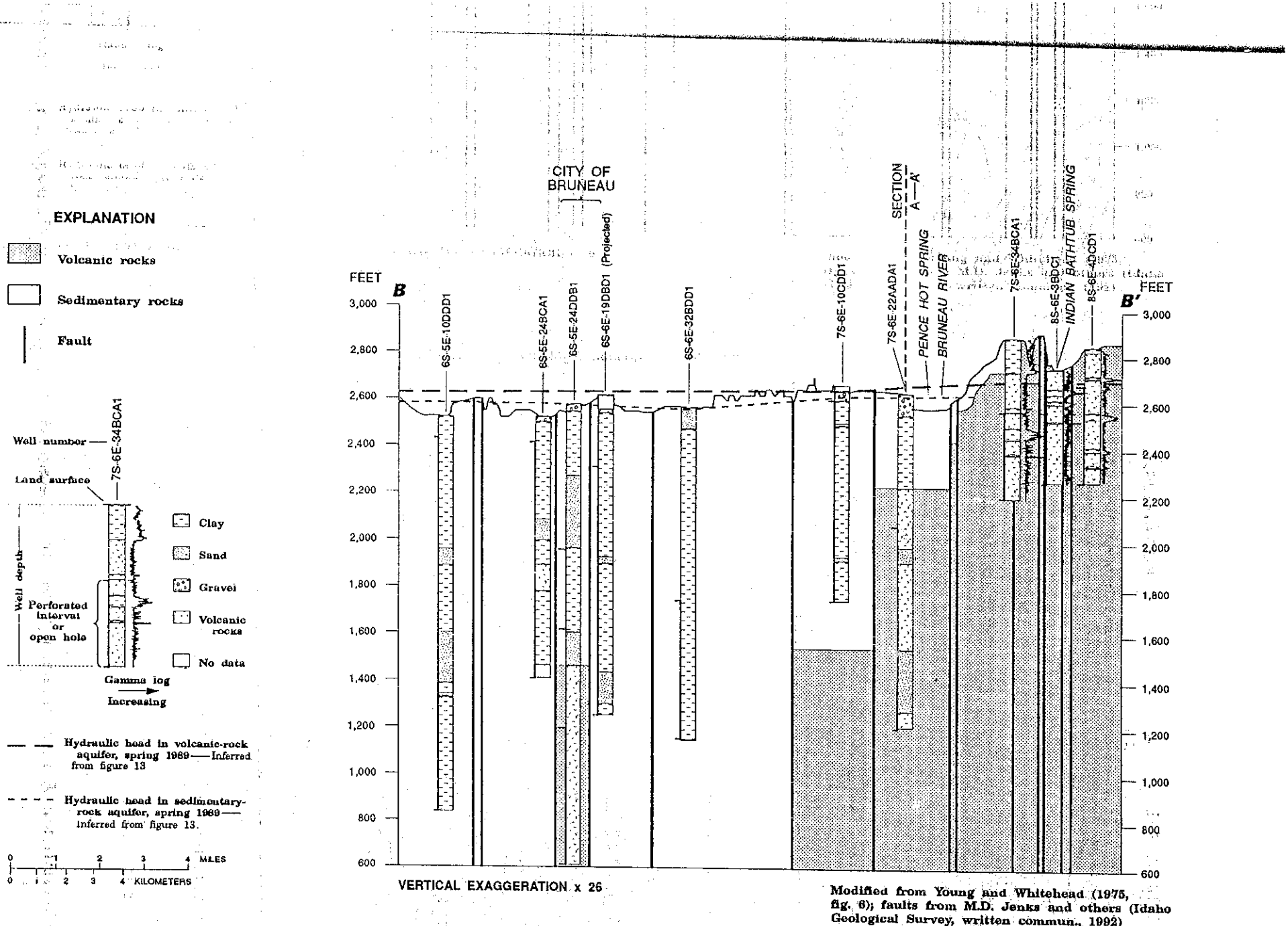
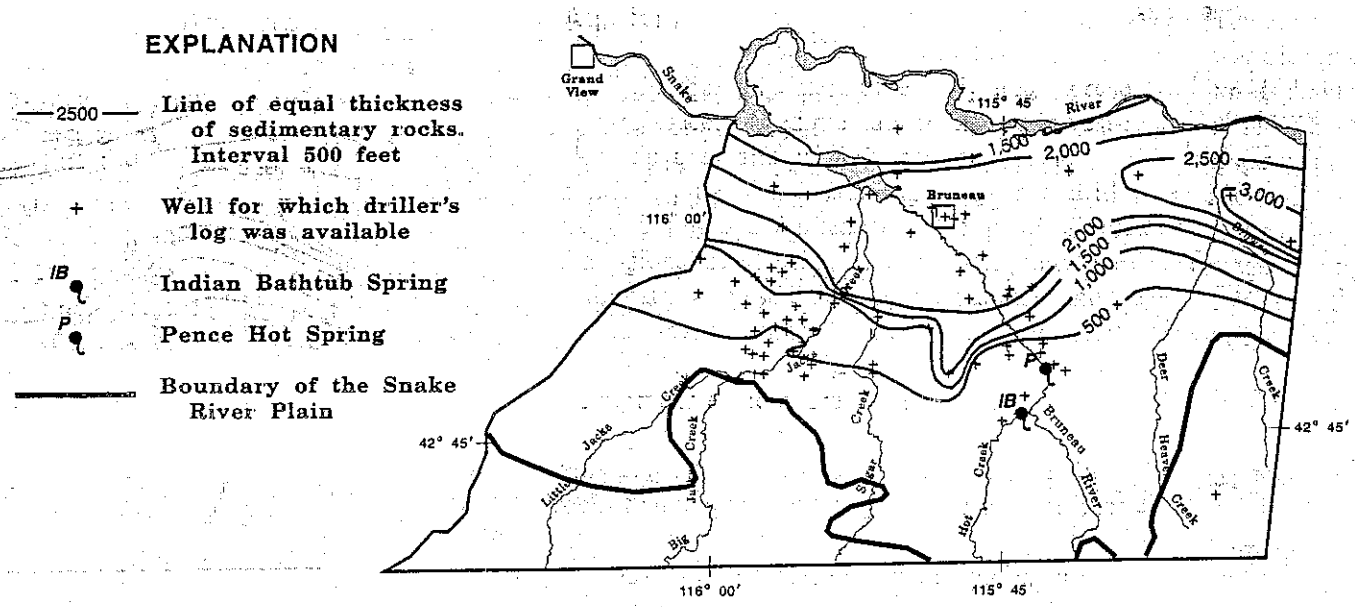



**Figure 3.** Geologic sections.



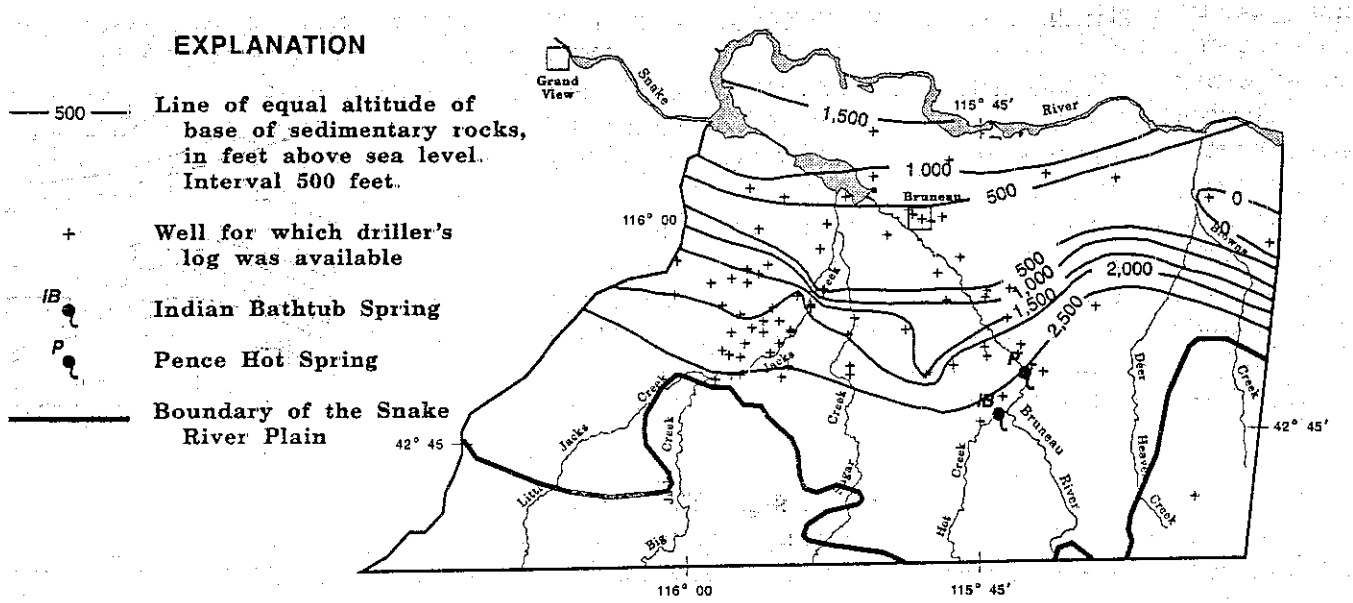

Modified from Young and Whitehead (1975, fig. 6); faults from M.D. Jenks and others (Idaho Geological Survey, written commun., 1992)

**Figure 3.** Geologic sections—Continued.




Modified from Whitehead (1986, sheet 2)

**A. Thickness of sedimentary rocks**




**B. Altitude of base of sedimentary rocks**

0 10 20 MILES
0 10 20 KILOMETERS

**Figure 4.** Thickness of sedimentary rocks (A) and altitude of base of sedimentary rocks (B).

## Aquifers

Geothermal water in the study area is present in pore spaces of sedimentary rocks and in vesicles, fractures, and rubble zones of volcanic rocks. On the basis of lithologic logs from drill holes, Young and Whitehead (1975, p. 13) divided the regional geothermal aquifer system into two main parts—the sedimentary-rock aquifer and the volcanic-rock aquifer. An aquifer can consist of rocks of different types and of different ages that are permeable and hydraulically connected. For this report, the term "aquifer" refers to hydraulically connected volcanic rocks and sedimentary rocks that together compose the regional geothermal aquifer system.

Cold-water and geothermal aquifers are present in the Bruneau study area. The cold-water aquifer is thin (less than 100 ft) and of small areal extent (alluvium along stream channels, fig. 2). Cold water is unconfined and recharge is from infiltration of precipitation, streamflow, and applied irrigation water. Small quantities of recharge may be from upward-moving geothermal water.

Underlying the cold-water aquifer is a geothermal aquifer. Data are unavailable to adequately define hydrologic relations between the two. Therefore, it is not known whether the cold-water aquifer is perched above or grades into the geothermal aquifer. In 1991, the U.S. Geological Survey (R. Thompson, oral commun., 1992) cored a 1,000-ft test hole about 1 mi north of the city of Bruneau (fig. 2B). Except for the upper few feet, the entire interval tested was predominantly clay. No cold or hot water entered the hole. During test drilling near Indian Bathtub Spring for this study (table 1 and Young and others, 1990), only geothermal water was encountered.

Cold water differs from geothermal water not only in temperature but also in chemical and isotopic composition. Young and Lewis (1982, p. J10–J18) reported that cold-water temperatures ranged from 4° to 15°C, whereas geothermal water temperatures ranged from 27° to more than 80°C. Cold water is generally a calcium bicarbonate type with a dissolved-solids concentration of less than 120 mg/L, whereas geothermal water is generally a sodium carbonate or bicarbonate type with a dissolved-solids concentration of less than 400 mg/L. Young and Lewis (1982, p. J9–J11) also reported that tritium and delta deuterium in cold-water springs and wells (alluvial aquifer) ranged from 59 to 119 TU (tritium units) and -116 to -128 permil, respectively, whereas tritium in geothermal springs and wells (sedimentary- and volcanic-rock aquifers) was less than 1.9 TU and delta deuterium ranged from -130 to -140 permil. (One TU equals a $^3H/H$ ratio of about $10^{-18}$, or about $3.2 \times 10^{-18}$ picocuries per liter.) They indicated that, on the basis of tritium analyses, the cold water is less than 20 years old, whereas geothermal water is meteoric in origin and, on the basis of delta deuterium analyses, was recharged during an earlier pluvial period (late Pleistocene). Carbon isotope analyses of geothermal water indicate an apparent age of 18,000 to 25,000 years (Young and Lewis, 1982, p. J16–J17).

The sedimentary-rock aquifer consists of unconsolidated alluvial and lacustrine deposits that partly fill the structural depression in the study area. Some volcanic rocks are interbedded within the sedimentary rocks. Sedimentary rocks underlie about 500 $mi^2$ of the study area, or less than one-seventh of the Bruneau River drainage area (fig. 2A). The base of the sedimentary-rock aquifer corresponds to the base of the sedimentary rocks (fig. 3B), and saturated thickness is approximately the thickness of the sedimentary rocks (fig. 3A) minus 100 ft (the approximate thickness of the cold-water aquifer). The sedimentary-rock aquifer is bounded on the south by silicic volcanic rocks and older basalt and on the north by younger basalt (fig. 2A). It is part of a more extensive aquifer in the western Snake River Plain (Newton, 1991, p. 4–7). The eastern and western boundaries for this study are not based on differences in lithology but follow approximate ground-water-flow lines. The eastern boundary is assumed to be coincident with the topographic divide between Bruneau River and Sailor Creek. The topographic divide approximates a flow line based on the March 1982 potentiometric surface (Moffatt and Jones, 1984, pl. 2). The western boundary is assumed to be coincident with the topographic divide between Shoofly Creek and Little Jacks Creek. The topographic divide approximates a flow line based on the 1979 potentiometric surface (Young and Lewis, 1982, pl. 2). There was no

significant movement of ground water across these boundaries after about 90 years of pumping.

The sedimentary rocks consist primarily of fine sand, silt, and clay of low permeability (fig. 4). Fine-grained sedimentary rocks confine or partly confine water in coarser grained sedimentary rocks, which are recharged by water from the volcanic-rock aquifer (Young and Whitehead, 1975, p. 44). Yield from wells completed in the sedimentary rocks ranges from a few gallons per minute from silt and clay to several hundred gallons per minute from sand and gravel, depending on the percentage of fine-grained rocks (Young and Whitehead, 1975, p. 9; Whitehead, 1986, sheet 1).

In the southern part of the study area, the volcanic-rock aquifer consists of basalt and silicic volcanic rocks with some interbedded sedimentary rocks. The volcanic rocks extend southward to the Jarbidge Mountains. The base of the volcanic-rock aquifer is poorly defined and has not been reached by drilling; therefore, saturated thickness is largely unknown. Saturated thickness in the southern part of the study area is approximately the thickness of the volcanic rocks (2,000 to 3,000 ft) minus depth to the top of the volcanic-rock aquifer. Where overlain by the sedimentary-rock aquifer, thickness of the volcanic-rock aquifer is estimated to be about 2,500 ft, probably the average thickness of the volcanic rocks. For the purpose of this study, the eastern and western boundaries of the volcanic-rock aquifer flow system are assumed to be the same as those of the sedimentary-rock aquifer.

In the northern part of the study area, water in the volcanic rocks is confined by fine-grained sedimentary rocks; in the southern part, water is confined by overlying dense volcanic rocks and fine-grained interbeds. In each of the test holes at four sites near Indian Bathtub Spring (Young and others, 1990), water in the hole rose to higher altitudes than first-encountered water during drilling (table 1). This indicates that water in the volcanic rocks is confined. Three wells (11S-7E-25ACA1, 12S-8E-6ADA1, and 13S-9E-35CDC1) about 23 to 35 mi south of Indian Bathtub Spring had higher hydraulic head than first-encountered water during drilling (table 1). Recharge to the volcanic-rock aquifer is chiefly from precipitation in the mountains south and southwest of the study area where rocks are exposed at the surface (Young and Whitehead, 1975, p. 44).

Piper (1924, p. 36–38) indicated that many of the springs in the Bruneau study area are controlled by faults. However, he attributed the control of springs at Indian Bathtub to the exposure of water-bearing rocks at land surface, as in the canyon walls along Hot Creek. Littleton and Crosthwaite

**Table 1** Selected wells in the regional geothermal aquifer system used to represent confining conditions in the Bruneau River drainage basin

[Altitude of land surface in feet above sea level. Depth of well, perforated interval or open hole, depth to first-encountered water, and depth to water, in feet below land surface]

| Well No. | Altitude of land surface | Depth of well | Perforated interval or open hole | Date of well construction | Depth to first-encountered water | Depth to water | Date measured | Confining unit |
|---|---|---|---|---|---|---|---|---|
| **About 23 miles south of Indian Bathtub Spring** | | | | | | | | |
| [1]11S-7E-25ACA1 | 4,345 | 1,400 | 20–1,400 | 7- -63 | 1,004 | 842 | 7- 1-63 | Basalt |
| **About 25 miles south of Indian Bathtub Spring** | | | | | | | | |
| [1]12S-8E-6ADA1 | 4,450 | 1,400 | 40–1,400 | 9- 1-63 | 1,030 | 881 | 9- 1-63 | Silicic volcanic rocks |
| **About 35 miles south of Indian Bathtub Spring** | | | | | | | | |
| [1]13S-9E-35CDC1 | 5,250 | 953 | 853–873, 938–953 | 7-16-56 | 840 | 623 | 7-16-56 | Rhyolite |
| **Test holes** | | | | | | | | |
| [2]7S-6E-29BBA1 | 2,832.5 | 760 | 415–760 | 5-14-90 | 233 | 157 | 5-23-90 | Tuffaceous siltstone |
| [2]7S-6E-34BCA1 | 2,889.5 | 681 | 322–681 | 4-25-90 | 300 | 211 | 4-27-90 | Basalt, silt, and sand |
| [2]8S-6E-3BDC1 | 2,754.6 | 480 | 194–480 | 3-31-90 | 90 | 76.1 | 4-11-90 | Basalt and tuffaceous silt and sand |
| [2]8S-6E-4DCD1 | 2,837.7 | 600 | 170–600 | 4-14-90 | 170 | 158 | 4-17-90 | Basalt |

[1] Data from drilling records on file in the Boise, Idaho, office of the U.S. Geological Survey.
[2] Data from Young and others (1990).

(1957, p. 173) indicated that many of the springs are along faults that allow water to flow upward and reach land surface because of sufficiently high hydraulic head. They described Indian Bathtub Spring as at the contact between basalt and weathered tuff. Recent geologic mapping in the study area by M.D. Jenks and others (Idaho Geological Survey, written commun., 1992) indicated that basalts near Indian Bathtub are more faulted and fractured than previous investigators thought. M.D. Jenks and others also indicated that basalt in the vicinity of Indian Bathtub Spring consists of many flows with interbedded sediments. They noted no evidence of faulting in the basalts or sediments at Indian Bathtub Spring, which indicates that the spring is not fault related. Additional geologic data are needed to determine geologic controls on springs, especially Indian Bathtub Spring.

Most previous investigators indicated that nearly all springs in the study area originate from the volcanic-rock aquifer. Young and Whitehead (1975) and Rightmire and others (1976) suggested that, on the basis of the similarity of water temperature, electrical conductivity, concentrations of major ions, and values of stable hydrogen and oxygen isotopes, water from the springs has moved upward from the volcanic rocks. Water from the eight test holes at four sites near Indian Bathtub Spring (Young and others, 1990) has essentially the same physical and chemical characteristics as does water from the springs, further evidence that spring water is from the volcanic rocks.

## Hydraulic Characteristics

Aquifer properties, including transmissivity, hydraulic conductivity, and storage coefficient, affect the rate at which water moves through an aquifer, the amount of water in storage, and the rate and areal extent of water-level declines caused by ground-water development. Aquifer properties in the study area vary considerably because of the heterogeneity of the rocks composing the aquifers. Aquifer properties were estimated from aquifer, slug, and specific-capacity tests.

### Transmissivity and Hydraulic Conductivity

Transmissivity ($T$) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1972, p. 6); hydraulic conductivity is the capacity of a rock or unconsolidated material to transmit water in a unit of time through a unit area under a unit hydraulic gradient through a unit length of flow (Lohman, 1972, p. 6). Transmissivity of an aquifer is equal to hydraulic conductivity times aquifer thickness. Transmissivity and hydraulic conductivity were estimated from (1) four aquifer tests conducted by private consultants, (2) five slug tests conducted during this study, and (3) numerous specific-capacity tests conducted by drillers and entered into the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) data base prior to the beginning of this study. Methods used to analyze each of these tests are discussed in the following sections.

#### Aquifer Tests

Two wells completed in volcanic rocks more than 23 mi south of Indian Bathtub Spring were tested by Richard Young (U.S. Geological Survey, written commun., 1963) to determine transmissivity of the volcanic rocks. Previously, no aquifer tests had been conducted in the study area. Well 11S-7E-25ACA1 (fig. 1), pumped at 27 gal/min for 20 min, caused a water-level decline of 24 ft; calculated transmissivity was about 25 ft²/d. Well 12S-8E-6ADA1 (fig. 1), pumped at 25 gal/min for 24 hours, caused a water-level decline of 11 ft; calculated transmissivity was about 110 ft²/d. These low transmissivity values probably are representative of the massive, unfractured silicic volcanic rocks as compared to the highly fractured, more transmissive volcanic rocks in the Bruneau study area.

Large-capacity irrigation wells in the study area were tested by L. Mink (Morrison-Knudsen Company, Inc., written commun., 1984) to determine aquifer properties. In the first aquifer test, transmissivities of 60,000 ft²/d and 57,000 ft²/d were calculated on the basis of pressure drawdown and recovery, respectively, in observation well 7S-5E-8BCC1 (fig. 2B), located about 4,000 ft from pumped well 7S-5E-7ABB1 (fig. 3). These

values probably are high because observation well 7S-5E-8BCC1 is open to 670 ft of volcanic rocks and 410 ft of sedimentary rocks, whereas the pumped well 7S-5E-7ABB1, with an open interval of 993 ft, is open entirely to volcanic rocks (fig. 3). In the second aquifer test, well 7S-6E-22CCDA1 (fig. 2B) flowed for 20 hours at a rate of about 2,500 gal/min; transmissivity, calculated from the pressure recovery phase of the test, was about 29,000 ft²/d from an open interval of 472 ft. This value is probably a composite of the two rock types because one-third of the well is open to sedimentary rocks and two-thirds to volcanic rocks. L. Mink (Morrison-Knudsen Company, Inc., written commun., 1984) indicated that neither of the two observation wells, the closest being 1 mi from the production well, had any water-level changes. The highly fractured nature of the volcanic rocks in the study area allows water to be readily transmitted to wells and accounts for the high transmissivity.

### Slug Tests

The most commonly used method for analyzing water-level response to a slug or bailer test, where a known volume of water is instantaneously injected into or removed from a well completed in a confined aquifer, is that of Cooper and others (1967, p. 263–269). This method is for nonoscillatory responses. However, three of the five slug tests conducted during this study generated oscillatory responses. Those tests were analyzed using methods developed by van der Kamp (1976) and Kipp (1985). Van der Kamp's method is an approximate solution in the form of a decaying sinusoidal curve to the equations governing the well/aquifer system. Kipp's method uses a numerical inversion of the Laplace-transform solution that takes into account inertial effects and well-bore storage. Kipp's method is better suited to slug tests conducted during this study than is van der Kamp's method; therefore, it was used for analysis. Analysis indicated that the oscillatory behavior was caused by inertial effects.

Assumptions made for both methods were that (1) the aquifer is homogeneous and isotropic, (2) the aquifer has uniform thickness with impermeable upper and lower confining boundaries, (3) the change in volume of water removed or added is instantaneous, (4) the initial potentiometric surface is horizontal, (5) there are no delayed yield effects, and (6) the water is of constant density in the well bore and constant compressibility in the aquifer. Aquifers are seldom as ideal as outlined; however, these assumptions are most nearly met by confined aquifers where wells are at considerable distances from aquifer boundaries. A full explanation of the theoretical development, solution technique, numerical solution and resulting type curves, and examples of slug test analysis are included in reports by Cooper and others (1967, p. 263–269) for nonoscillatory behavior and by Kipp (1985, p. 1,397–1,408) for oscillatory behavior.

Test holes 8S-6E-3BDC2 and 8S-6E-3BDC3 (fig. 2B), open mainly to sedimentary rocks, were slug tested and analyzed using type curves developed by Cooper and others (1967). The water level against time data were read from pressure transducers; the dimensionless water-level displacement ($H/H_0$) was plotted against the logarithm of time as shown in figure 5. For test hole 8S-6E-3BDC2, a good match to the type curve with a dimensionless storage parameter ($\alpha$) of $10^{-4}$ was obtained; the match point was $t = 33s$ at $Tt/r_c^2 = 1$. Field data greater than 50 seconds were used because data collected early in the test probably were affected by the hydraulic properties and large volume of the surrounding gravel pack. The gravel pack consists of permeable pea gravel that extends 2 in. beyond the casing and more than 20 ft above the potentiometric surface. Therefore, transmissivity estimates from data collected later in the test probably best represent the aquifer. A storage coefficient of 0.00001 was used for this analysis and was derived by multiplying aquifer thickness by a specific storage coefficient of $1 \times 10^{-6}$ ft$^{-1}$ (Lohman, 1972, p. 53). The test hole's open interval was used as the aquifer thickness. The calculated transmissivity of 160 ft²/d is probably representative of the fine-grained rocks tested (fig. 4; Young and others, 1990, fig. 2, p. 8–9). A hydraulic conductivity of 16 ft/d was calculated by dividing the transmissivity by the well's perforated interval of 10 ft. Bouwer (1978, p. 38) indicated that a hydraulic conductivity of 16 ft/d is within the fine-sand category. Test hole 8S-6E-3BDC3 responded more rapidly to slugging and the test was completed within about 50 seconds. A good match to the type curve with an $\alpha$ of $10^{-4}$ was obtained (fig. 5); the

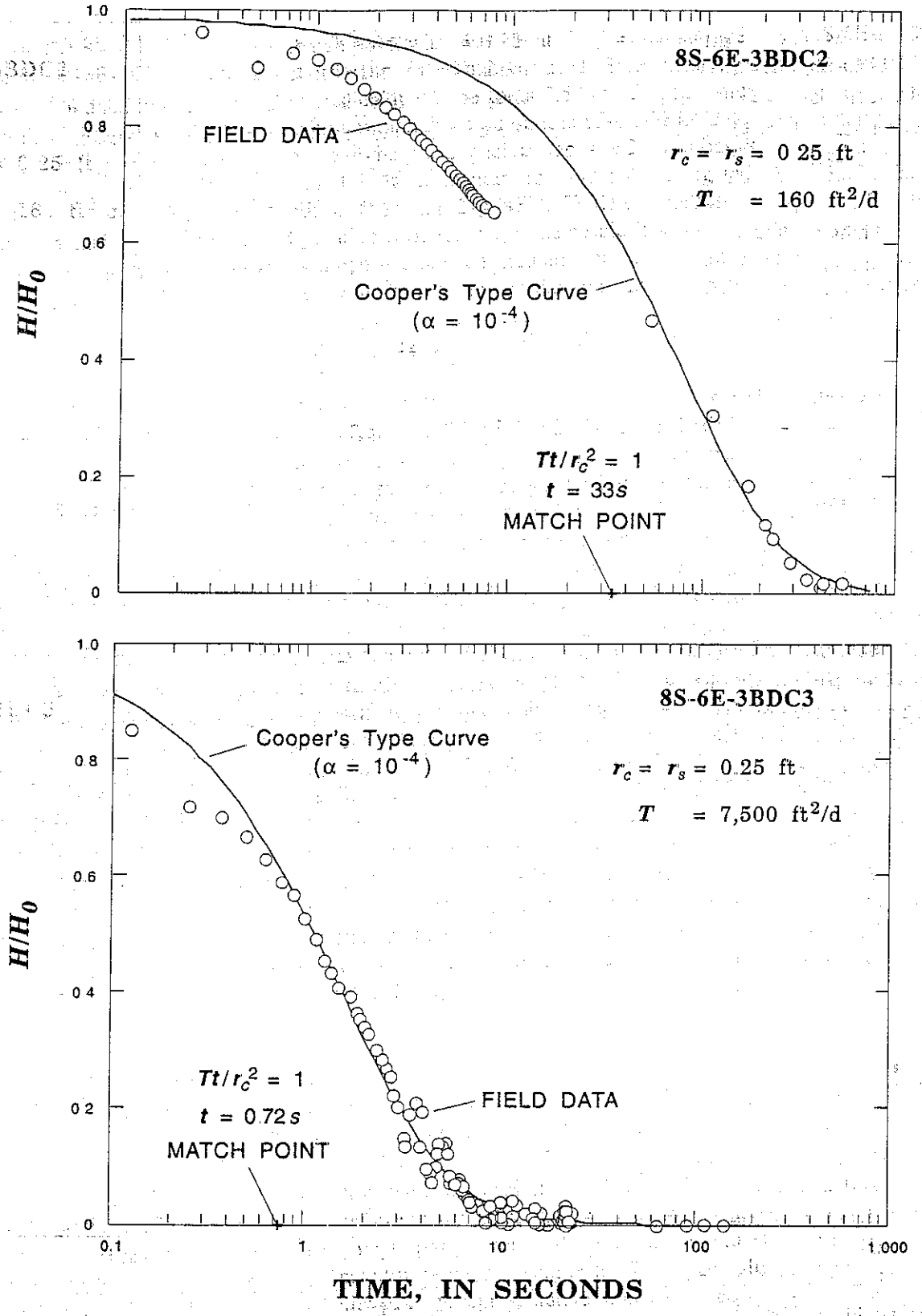



**Figure 5.** Application of method of Cooper and others (1967) to analysis of slug tests in test holes 8S-6E-3BDC2 and 8S-6E-3BDC3.

match point was $t = 0.72s$ at $Tt/r_c^2 = 1$. A storage coefficient of 0.00002 was used. Transmissivity was calculated to be about 7,500 ft²/d. This value is higher than that for test hole 8S-6E-3BDC2 because the gravel pack is opposite 20 ft of basalt and 20 ft of sedimentary rocks (fig. 4; Young and others, 1990, fig. 2, p. 8–9). To determine the hydraulic conductivity of the basalt, it was assumed that the fine-grained rocks above and below the basalt were similar and had a hydraulic conductivity of 16 ft/d, as determined from the previous slug test. Therefore, the resulting value of hydraulic conductivity for the basalt was about 360 ft/d.

Test holes 7S-6E-29BBA1, 8S-6E-3BDC1, and 8S-6E-4DCD1 (fig. 2B), open mainly to basalt, were slug tested and analyzed using type curves developed by Kipp (1985). The water level as a function of time data were read from pressure transducers; the dimensionless water-level displacement ($w'$) was plotted against the logarithm of time as shown in figure 6. Kipp's $w'$ can be equated with the $H/H_0$ of Cooper and others (1967) by multiplying the numerator by -1 to account for the oscillatory behavior about $w' = 0$ ($w' = -H/H_0$). A storage coefficient of 0.0003 was used for analysis of test holes 7S-6E-29BBA1 and 8S-6E-3BDC1 and 0.0004 was used for test hole 8S-6E-4DCD1. These values were derived by multiplying aquifer thickness by a specific storage coefficient of $1 \times 10^{-6}$ ft$^{-1}$ (Lohman, 1972, p. 53). The test hole's open interval was used as the aquifer thickness. Storage coefficients of 0.0003 and 0.0004 are reasonable for confined aquifers. Data for test hole 7S-6E-29BBA1 reasonably matched the type curve with a damping factor ($\zeta$) of 0.20 (fig. 6); the match point was $t = 3.75s$ at $\hat{t} = 1$. Calculated transmissivity was 9,000 ft²/d, which is low due to the large amounts of fine-grained rocks in the vicinity of this hole (fig. 4; Young and others, 1990, fig. 2, p. 5).

A type curve with a $\zeta$ of 0.04 was matched to the slug test data for test hole 8S-6E-3BDC1 (fig. 6); the match point was $t = 2s$ at $\hat{t} = 1$. Calculated transmissivity was 100,000 ft²/d, the highest estimated from the five slug tests. This high value is believed to be representative of basalt in the area. The hole tested is open to 285 ft of basalt and 6 ft of fine sand from 219 to 225 ft (Young and others, 1990, fig. 2, p. 9). If the hydraulic conductivity of 16 ft/d for sedimentary rocks in test hole 8S-6E-3BDC2 is used for the 6-ft fine-sand layer in 8S-6E-3BDC1 (fig. 2B), the resulting hydraulic conductivity of the basalt would be 355 ft/d, which is about the same as the 360 ft/d obtained for well 8S-6E-3BDC3 (fig. 2B).

For test hole 8S-6E-4DCD1 (fig. 2B), a good match to the type curve with a $\zeta$ of 0.10 was obtained (fig. 6); the match point was $t = 1.15s$ at $\hat{t} = 1$. Calculated transmissivity was 60,000 ft²/d, which is probably representative of basalt with lesser amounts of interbedded clay and fine-grained sand (fig. 4; Young and others, 1990, fig. 2, p. 10).

### Specific-Capacity Tests

Specific-capacity data from the U.S. Geological Survey's WATSTORE (Baker, 1977) data base also were used to estimate transmissivities and hydraulic conductivities of sedimentary and volcanic rocks in the study area. Specific capacities are expressed as well yield, in gallons per minute per foot of drawdown [(gal/min)/ft]. Properly designed wells completed in aquifers with high transmissivities have higher specific capacities than do wells completed in aquifers with low transmissivities. Well drillers, the U.S. Geological Survey, and private consultants have made many specific-capacity tests on wells in the study area (table 2). Data indicate a wide range in specific-capacity values. Two wells completed exclusively in the cold-water aquifer had specific-capacity values of about 1 (gal/min)/ft. Wells in the sedimentary-rock aquifer had values ranging from less than 1 to 100 (gal/min)/ft; wells in the volcanic-rock aquifer had values ranging from 10 to about 200 (gal/min)/ft, except for well 7S-4E-23CBB1, which had a value of 700 (gal/min)/ft. Wells 9S-5E-4DAD1, 11S-7E-25ACA1, 12S-8E-6ADA1, and 13S-9E-35CDC1 are outside the study area (fig. 1) so were excluded from further analysis; however, these four wells are included in table 2 to show the hydraulic characteristics of the volcanic rocks upgradient from Indian Bathtub.

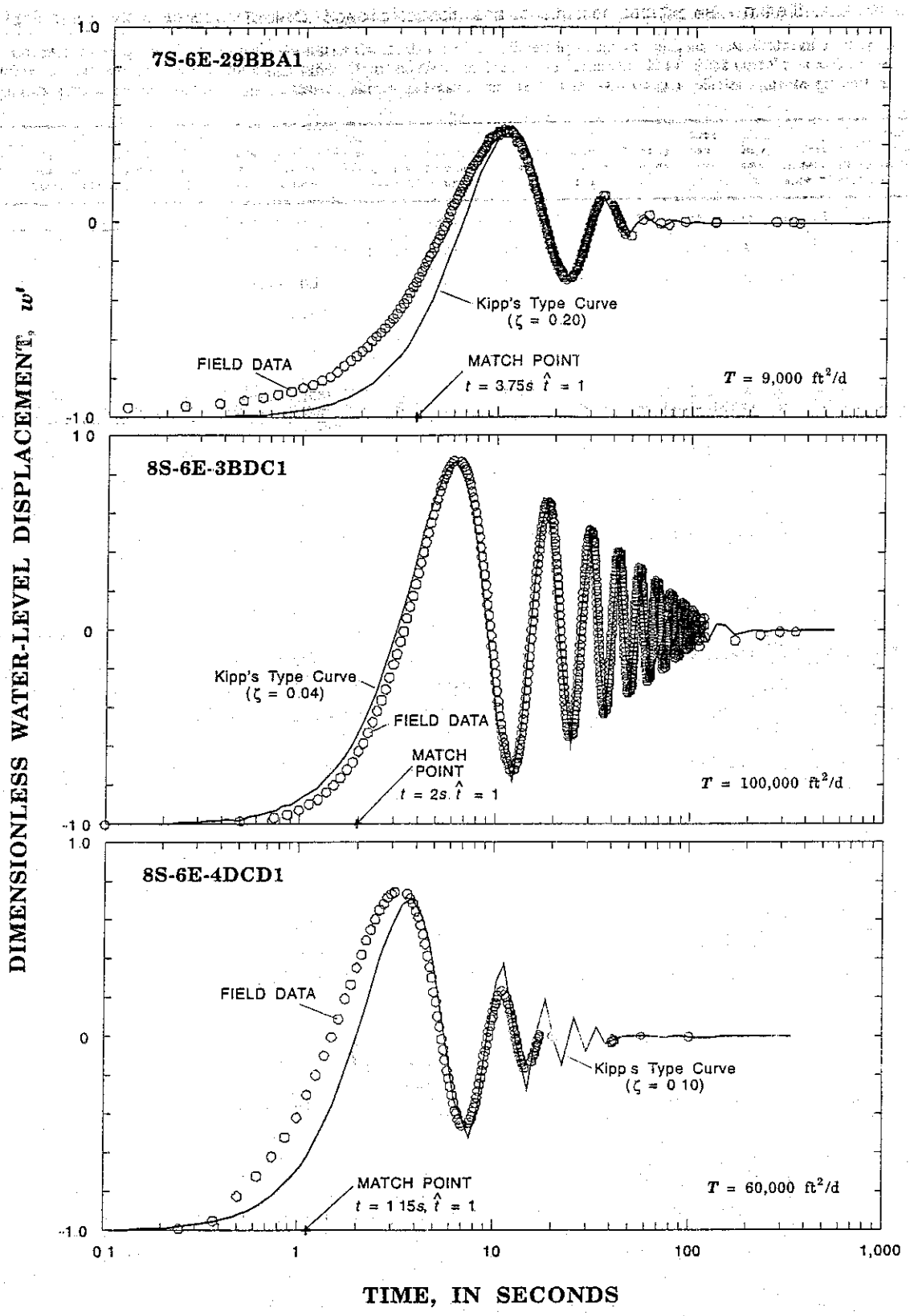



**Figure 6.** Application of method of Kipp (1985) to analysis of slug tests in test holes 7S-6E-29BBA1, 8S-6E-3BDC1, and 8S-6E-4DCD1.

## Table 2. Specific-capacity and construction data for wells in the Bruneau study area

[Aquifer tested: Cw, cold-water; Sr, sedimentary rock; Vr, volcanic rock. Source of data: D, driller's log; US, U.S. Geological Survey; M, E.L. Mink, Morrison-Knudsen, Inc., written commun., 1984. Rock type: Vr, volcanic rocks; C, clay; S, sand; G, gravel. Abbreviations and symbols: gal/min, gallons per minute; ft, feet; —, no data available; <, less than; negative value indicates water level above land surface]

| Well No. | Aquifer tested | Discharge (gal/min) | Date measured | Source of data | Pumping period (hours) | Static water level (ft) | Draw-down (ft) | Specific capacity [(gal/min)/ft] | Altitude of land surface (ft) | Depth of well (ft) | Perforated interval (ft) | Open hole (ft) | Rock type (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6S-4E-35ACC1 | Sr | 1,800 | 1-30-73 | D | 21.5 | 56 | 225 | 8 | 2,705 | 865 | 724–764, 804–845 | 855–865 | 50%, unknown; 43%, C; 7%, S |
| 6S-4E-35ADD1 | Cw, Sr | 1,300 | 8-20-72 | D | 11 | 65 | 195 | 7 | 2,660 | 329 | — | 72–329 | 96%, C; 3%, S; 1%, C and S |
| 6S-4E-35CDA1 | Sr | 1,800 | 6-15-72 | D | 4 | 45 | 130 | 14 | 2,690 | 955 | 730–810, 870–890 | 892–955 | 97%, C; 3%, S |
| 6S-5E-24DDD1 | Sr | 130 | 2-22-75 | D | 6 | 40 | 130 | 1 | 2,545 | 370 | 283–293, 310–330, 335–345 | — | 100% S |
| 6S-5E-25AAA1 | Cw | 25 | 5-18-80 | D | 1 | 30 | 40 | <1 | 2,527 | 55 | — | 45–55 | 100% S |
| 6S-5E-26BBB1 | Sr | 16 | 6-20-76 | D | 1 | 55 | 95 | <1 | 2,512 | 205 | 185–205 | 90–180 | 100% C |
| 6S-5E-26BCD1 | Sr | 20 | 12-13-71 | D | 1 | 78 | 160 | <1 | 2,560 | 465 | — | 50–465 | 100%, C |
| 6S-5E-35CBD1 | Sr | 2,000 | 5-23-73 | D | 9 | 62 | 20 | 100 | 2,620 | 476 | 230–350 | 350–476 | 93%, C; 7% S and C |
| 6S-6E-11CCC1 | Cw | 60 | 4-20-68 | D | 24 | 46.7 | 65 | 1 | 2,510 | 160 | 67–77 | — | 80%, G and S; 20%, C, G and S |
| 6S-6E-12CCB1 | Sr | 130 | 12-24-68 | D | 10 | 240 | 205 | 1 | 2,510 | 990 | 920–980 | 980–990 | 100% S |
| 7S-4E-2ABB1 | Sr | 600 | 5-26-69 | D | 12 | 75 | 212 | 3 | 2,700 | 342 | — | 197–342 | 55% S; 45% C |
| 7S-4E-3BBC1 | Sr | 2,380 | 3-30-66 | D | 28 | 100 | 260 | 9 | 2,770 | 1,050 | 100–538 | 538–600, 780–1,050 | 50%, C; 15%, Vr; 15%, C and S; 14%, S and C; 6%, S and G |
| 7S-4E-5CCA1 | Sr | 1,800 | 1-25-72 | D | 10 | 191 | 300 | 6 | 2,865 | 1,040 | — | 292–1,040 | 58%, C; 24%, S; 10%, C and G; 8%, Vr |
| 7S-4E-10D8C1 | Sr | 2,700 | 3-9-65 | D | 8.5 | 51 | 92 | 29 | 2,750 | 907 | — | 200–907 | 52%, Vr; 37%, C; 7% S and G; 3%, C and G; 1%, S and G |
| 7S-4E-11CBC1 | Sr | 3,150 | 2-12-67 | D | 15 | 73 | 165 | 19 | 2,760 | 1,500 | — | 720–1,500 | 96%, Vr; 3%, C; 1% C and G |
| 7S-4E-14ABC1 | Sr | 5,400 | 5-15-63 | D | 2 | 27 | 100 | 54 | 2,725 | 1,146 | — | 223–1,146 | 62%, Vr; 17%, Vr and C; 13%, C; 4%, G; 2%, Vr and S; 2% C and G |
| 7S-4E-14CDC1 | Sr, Vr | 2,970 | 10-17-63 | D | 3 | 57 | 138 | 22 | 2,755 | 950 | — | 200–950 | 50%, Vr; 25%, C; 9%, G and C; 8% C and G; 4%, S; 4%, G |
| 7S-4E-15ACD1 | Sr, Vr | 2,830 | 2-18-68 | D | 5.5 | 103 | 65 | 44 | 2,790 | 1,065 | — | 246–1,065 | 71%, Vr; 27%, C; 2%, Vr and C |
| 7S-4E-22BBD1 | Vr | 400 | 7-11-66 | D | 10 | 114 | 16 | 25 | 2,825 | 1,000 | — | 330–1,000 | 94%, Vr; 6% Vr and C |
| 7S-4E-23CBB1 | Vr | 4,000 | 6-58 | D | 5 | 75 | 5.5 | 700 | 2,765 | 810 | — | 326–810 | 100% Vr |
| 7S-4E-26BCB1 | Sr, Vr | 1,500 | 2-23-64 | D | 3 | 55 | 150 | 10 | 2,750 | 867 | 130–180 | 180–867 | 91%, Vr; 6% C; 3%, C and Vr |
| 7S-5E-10ADC1 | Sr | 1,200 | 4-18-83 | D | 6 | 62 | 48 | 25 | 2,670 | 564 | — | 168–564 | 100%, C |
| 7S-5E-10DDB1 | Sr | 350 | 7-27-73 | D | 3 | 65 | 180 | 2 | 2,705 | 190 | 100–160 | 180–190 | 70%, S and C; 27%, S; 3% G and S |
| 7S-5E-13CBB1 | Sr, Vr | 3,000 | 4-10-69 | D | 4.5 | 81 | 290 | 10 | 2,771 | 1,954 | 180–710, 1,070–1,180, 1,560–1,680 | 1,680–1,950 | 47%, C; 42% Vr; 8% S; 3%, Vr, S, and G |
| 7S-5E-16ACD1 | Sr | 4,000 | 4-10-68 | D | 5 | 13 | 160 | 25 | 2,700 | 1,510 | 520–708, 1,136–1,432 | 1,470–1,510 | 35%, S; 35% Vr; 30% C |
| 7S-5E-28BDA1 | Sr, Vr | 1,400 | 9-30-51 | D | 4 | 105 | 20 | 70 | 2,800 | 1,003 | 116–234 | 234–640, 700–1,003 | 47%, Vr; 22%, C; 19%, S; 11%, Vr, S, and C; 1% G |

Table 2. Specific-capacity and construction data for wells in the Bruneau study area—Continued

| Well No. | Aquifer tested | Discharge (gal/min) | Date measured | Source of data | Pumping period (hours) | Static water level (ft) | Drawdown (ft) | Specific capacity [(gal/min)/ft] | Altitude of land surface (ft) | Depth of well (ft) | Perforated interval (ft) | Open hole (ft) | Rock type (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7S-6E-16ABB2 | Sr | 15 | 8-17-73 | D | 1.5 | 6 | 23 | 1 | 2,553 | 190 | — | 158–190 | 100%, S |
| 7S-6E-22CCDA1 | Sr, Vr | 2,450 | 4- -84 | M | — | — | — | 111 | 2,605 | 630 | — | 158–630 | 78%, Vr; 22%, C and G |
| | | 385 | 3-12-91 | US | 3 | 55.40 | 7.41 | 52 | | | | | |
| 7S-6E-34BCA1 | Vr | 43.5 | 2-13-91 | US | 4 | 217.24 | 5 | 87 | 2,889.5 | 681 | — | 322–681 | 84%, Vr; 15%, C and S; 1% S |
| 7S-6E-34DADI | Vr | 1,650 | 4- -84 | M | — | — | — | 204 | 2,725 | 300 | — | 46–300 | 100% Vr |
| | | 111 | 3-11-91 | US | 1 | -5.4 | 3.5 | 32 | | | | | |
| 9S-5E- 4DADI | Vr | 240 | 12-31-59 | D | 48.8 | 811 | 2 | 120 | 3,633.5 | 2,500 | 1,880–2,480 | — | 100% Vr |
| 11S-7E-25ACA1 | Vr | 27 | 7- 1-63 | D | <1 | 846 | 24 | 1 | 4,345 | 1,400 | — | 20–1,400 | 100% Vr |
| 12S-8E- 6ADA1 | Vr | 25 | 9- 1-63 | D | 24 | 890 | 11 | 2 | 4,450 | 1,400 | — | 40–1,400 | 100% Vr |
| | | 15 | 12-19-89 | US | 1 | 893.82 | 1.76 | 8 | | | | | |
| 13S-9E-35CDC1 | Vr | 22 | 3-14-69 | D | 24 | 637 | 24 | 1 | 5,250 | 953 | 853–873, 938–953 | — | 100% Vr |

Driscoll (1986, p. 1021) stated that for confined aquifers, specific capacity in units of gallons per minute per foot multiplied by 267 approximated transmissivity in units of feet squared per day. This relation between specific capacity and transmissivity was assumed to be representative of sedimentary and volcanic rocks in the study area. For example, L. Mink (Morrison-Knudsen Company, Inc., written commun., 1984) reported that the specific capacity for well 7S-6E-22CCDA1 (table 2) was 111 (gal/min)/ft. If 111 is multiplied by 267, estimated transmissivity is about 30,000 ft²/d, which is essentially the same as the calculated aquifer-test value of 29,000 ft²/d. This example supports Driscoll's assumption. The hydraulic conductivity of the sedimentary and volcanic rocks was estimated by dividing transmissivity estimated from specific-capacity data by saturated thickness of the aquifer (table 3). The estimated transmissivity and hydraulic conductivity values determined by this method ranged from less than 300 ft²/d and 0.1 ft/d in the sedimentary-rock aquifer to 190,000 ft²/d and 95 ft/d in the volcanic-rock aquifer. Values thus determined seem too low if the entire aquifer is not supplying water to the well. To correct for less than total aquifer thickness being contributory, a common practice is to assume that values of transmissivity calculated from specific-capacity tests apply only to the perforated interval of the well (Heath, 1983, p. 61). To apply this value to the entire aquifer thickness, calculated transmissivity is divided by the length of the perforated inteival to determine hydraulic conductivity. Values thus determined then are multiplied by the entire saturated thickness of the aquifer to obtain total aquifer transmissivity (table 3, fig. 4). Thickness of the sedimentary rocks is shown in figure 4; those values minus 100 ft, the thickness of the cold-water perched aquifer (see section, "Aquifers"), generally equals thickness of the sedimentary-rock aquifer. Thickness of the volcanic rocks is about 2,000 to 3,000 ft (Young and Lewis, 1982, p. J4), and the assumed average is 2,500 ft. Where the sedimentary-rock aquifer overlies the volcanic-rock aquifer, in the northern part of the drainage area, volcanic-rock aquifer thickness was assumed to be about 2,500 ft, the total estimated thickness of the volcanic rocks. In the southern part of the study area, thickness of the volcanic-rock aquifer was assumed to be 2,500 ft (an average value) minus depth to the top of the confined aquifer, which is depth to first-encountered water. Using this method of estimation at well 12S-8E-6ADA1, for example, the saturated thickness of the volcanic-rock aquifer is about 1,470 ft [2,500 ft - 1,030 ft (table 1) = 1,470 ft (table 3)]. Transmissivity and hydraulic conductivity determined by this method ranged from 1,700 ft²/d and 0.7 ft/d for the sedimentary-rock aquifer to 980,000 ft²/d and 390 ft/d for the volcanic-rock aquifer. These values are too large if that part of the aquifer supplying water to the well is thicker than the length of the perforated interval and (or) open hole. Hydraulic properties determined by these methods and presented in table 3 probably represent the range of values for transmissivity and hydraulic conductivity in the study area.

**Table 3.** Estimated transmissivity and hydraulic conductivity from specific-capacity tests for wells in the Bruneau study area

[Aquifer tested: Cw, cold-water; Sr, sedimentary-rock; Vr, volcanic-rock. Abbreviations and symbols: (gal/min)/ft, gallons per minute per foot; $ft^2/d$, foot squared per day; ft/d, feet per day; ft, foot; —, no data available; <, less than. Values in columns B, F, and G are rounded]

| Well No. | Aquifer tested | Specific capacity [(gal/min)/ft] (table 2) (A) | Trans-missivity ($ft^2/d$) (B=A x 267) | Thickness of aquifer (ft) (C) | Hydraulic conductivity based on total saturated thickness (ft/d) (D=B/C) | Length of perforated interval and (or) open hole (ft) (E) | Hydraulic conductivity based on length of perforated interval (ft/d) (F=B/E) | Trans-missivity ($ft^2/d$) (G=C x F) |
|---|---|---|---|---|---|---|---|---|
| 6S-4E-35ACC1 | Sr | 8 | 2,140 | 1,355 | 1.6 | 91 | 24 | 33,000 |
| 6S-4E-35ADD1 | Cw, Sr | 7 | 1,900 | — | — | 257 | — | — |
| 6S-4E-35CDA1 | Sr | 14 | 3,700 | 1,140 | 3.3 | 163 | 23 | 26,000 |
| 6S-5E-24DDD1 | Sr | 1 | 300 | 2,195 | .1 | 40 | 8.0 | 18,000 |
| 6S-5E-25AAA1 | Cw | <1 | <300 | 32 | <9 | 10 | <30 | <1,000 |
| 6S-5E-26BBB1 | Sr | <1 | <300 | 2,162 | <.1 | 110 | <3 | <6,000 |
| 6S-5E-26BCD1 | Sr | <1 | <300 | 2,260 | <.1 | 415 | <.7 | <2,000 |
| 6S-5E-35CBD1 | Sr | 100 | 27,000 | 2,320 | 12 | 246 | 110 | 260,000 |
| 6S-6E-11CCC1 | Cw | 1 | 300 | 30 | 10 | 10 | 30 | 900 |
| 6S-6E-12CCB1 | Sr | 1 | 300 | 1,860 | .2 | 70 | 4.3 | 8,000 |
| 7S-4E- 2ABB1 | Sr | 3 | 800 | 1,100 | .7 | 145 | 5.5 | 6,000 |
| 7S-4E- 3BBC1 | Sr | 9 | 2,400 | 1,020 | 2.4 | 770 | 3.1 | 3,200 |
| 7S-4E- 5CCA1 | Sr | 6 | 1,600 | 815 | 2.0 | 748 | 2.1 | 1,700 |
| 7S-4E-10DBC1 | Sr | 29 | 7,800 | 650 | 12 | 707 | 11 | 7,200 |
| 7S-4E-11CBC1 | Sr | 19 | 5,100 | 891 | 5.7 | 780 | 6.5 | 5,800 |
| 7S-4E-14ABC1 | Sr | 54 | 14,000 | 410 | 34 | 923 | 15 | 6,200 |
| 7S-4E-14CDC1 | Sr, Vr | 22 | 5,900 | — | — | 750 | — | — |
| 7S-4E-15ACD1 | Sr, Vr | 44 | 12,000 | — | — | 819 | — | — |
| 7S-4E-22BBD1 | Vr | 25 | 6,700 | 2,500 | 2.7 | 670 | 10 | 25,000 |
| 7S-4E-23CBB1 | Vr | 700 | 190,000 | 2,500 | 76 | 484 | 390 | 980,000 |
| 7S-4E-26BCB1 | Sr, Vr | 10 | 2,700 | — | — | 737 | — | — |
| 7S-5E-10ADC1 | Sr | 25 | 6,700 | 1,678 | 4.0 | 396 | 17 | 29,000 |
| 7S-5E-10DDB1 | Sr | 2 | 500 | 1,540 | .3 | 70 | 7.1 | 11,000 |
| 7S-5E-13CBB1 | Sr, Vr | 10 | 2,700 | — | — | 1,030 | — | — |
| 7S-5E-16ACD1 | Sr | 25 | 6,700 | 800 | 8.4 | 524 | 13 | 10,000 |
| 7S-5E-28BDA1 | Sr, Vr | 70 | 19,000 | — | — | 827 | — | — |
| 7S-6E-16ABB2 | Sr | 1 | 300 | 1,153 | .3 | 32 | 9.4 | 11,000 |
| 7S-6E-22CCDA1 | Sr, Vr | 111 | 30,000 | — | — | 472 | — | — |
| | | 52 | 14,000 | — | — | 472 | — | — |
| 7S-6E-34BCA1 | Vr | 87 | 23,000 | 2,178 | 11 | 359 | 64 | 140,000 |
| 7S-6E-34DAD1 | Vr | 204 | 54,000 | 2,454 | 22 | 254 | 210 | 520,000 |
| | | 32 | 8,500 | 2,454 | 3.5 | 254 | 34 | 83,000 |
| 9S-5E- 4DAD1 | Vr | 120 | 32,000 | 1,500 | 21 | 600 | 53 | 80,000 |
| 11S-7E-25ACA1 | Vr | 1 | 300 | 1,496 | .2 | 396 | .8 | 1,200 |
| 12S-8E- 6ADA1 | Vr | 2 | 500 | 1,470 | .3 | 370 | 1.4 | 2,100 |
| | | 8 | 2,100 | 1,470 | 1.4 | 370 | 5.7 | 8,400 |
| 13S-9E-35CDC1 | Vr | 1 | 300 | 1,660 | .2 | 35 | 8.6 | 14,000 |

### Storage Coefficient

The storage coefficient of an aquifer is the volume of water released from or taken into storage per unit of surface area per unit change in head (Lohman, 1972, p. 8). For confined aquifers, the water released from storage when the hydraulic head declines comes from expansion of water and from compaction of the aquifer (Heath, 1983, p. 28). The sedimentary-rock aquifer, composed mainly of fine- to coarse-grained rocks with some volcanic rocks, is considered to be confined because it is overlain by fine-grained rocks. The volcanic-rock aquifer also is confined because it is overlain by sedimentary rocks, and where sedimentary rocks are absent, water in the volcanic rocks is confined by the dense volcanic rocks and fine-grained interbeds as discussed in the section, "Aquifers." Storage coefficient was determined at only one site where observation wells were available (L. Mink, Morrison-Knudsen Company, Inc., written commun., 1984). Mink calculated storage coefficients of 0.0002 and 0.0003 for the drawdown and recovery phases of the aquifer test at 7S-5E-8BCC1. These values are lower than expected for the geothermal aquifer if aquifer thickness is assumed to be the same or greater than the well's open interval of 1,080 ft.

The minimum storage coefficient of confined aquifers also can be estimated by multiplying aquifer thickness by a specific storage coefficient of $1 \times 10^{-6}$ ft$^{-1}$ (Lohman, 1972, p. 53). The sedimentary rocks are as much as 2,000 ft thick. Thickness of the sedimentary-rock aquifer at locations listed in table 3 ranges from about 400 to about 2,300 ft; therefore, storage coefficient is estimated to range from about 0.0004 to 0.002. Thickness of the volcanic-rock aquifer at locations listed in table 3 ranges from about 1,500 to 2,500 ft; therefore, storage coefficient for the volcanic rocks is estimated to range from about 0.0015 to 0.0025.

## THE GEOTHERMAL AQUIFER SYSTEM

Before the effects of ground-water development on hydraulic heads and spring discharges could be determined, an understanding of the hydrology of the geothermal system in the study area was necessary. This involved (1) determining natural recharge to and discharge from the geothermal system, (2) determining discharge due to ground-water development, (3) defining potentiometric surfaces in the sedimentary- and volcanic-rock aquifers, (4) identifying directions of ground-water movement, horizontally and vertically, and (5) developing a conceptual model of the geothermal system. A conceptual model can improve understanding of the geothermal system and the effects of ground-water development (ground-water discharge by wells) on water resources.

### Natural Recharge and Discharge

Prior to extensive ground-water development in the Bruneau study area (fig. 1), long-term natural recharge to the geothermal system was balanced by natural discharge, a steady-state condition. During steady state, there is no change in ground-water storage.

Natural recharge to the geothermal system in the Bruneau study area originates almost entirely from precipitation on mountains to the south. Littleton and Crosthwaite (1957, p. 172) indicated that the highly fractured and faulted volcanic rocks along the Owyhee Mountain front (similarly, along the Jarbidge Mountain front) are highly permeable and permit water to infiltrate and move easily. For example, based on sparse data, they indicated that the entire "normal flow" of Little and Big Jacks Creeks and other creeks infiltrates to the ground-water system. At a small experimental watershed in the Owyhee Mountains about 30 mi southwest of the study area, Stephenson and Zuzel (1981) studied rainfall-infiltration relations and indicated that recharge to the ground-water system probably is derived entirely from precipitation on the mountains. They determined that rainfall in excess of 0.8 to 1.2 in. over a 24-hour period contributes significant quantities of water to the ground-water system. Because runoff infiltrates near the mountain front where streams first cross faulted and fractured volcanic rocks, the natural recharge is termed "mountain front recharge."

As rain falls on the volcanic rocks or overlying shallow soils, it can (1) be held as soil moisture, (2) infiltrate past the root zone to recharge the aquifer, (3) run off to stream channels and infiltrate

to ground water through fractured, faulted, or otherwise permeable streambeds, or (4) be taken up by vegetation and transpired back to the atmosphere. Precipitation at Bruneau averages about 9 in/yr; most is lost to evaporation, which, in the study area, averages about 45 in/yr from free water surfaces or from shallow lakes (Farnsworth and others, 1982). Precipitation that infiltrates the soil eventually is consumed by native and cultivated plants that can transpire several feet of water per year if water is available to the root zone. In the valleys, the cold-water aquifer receives a small amount of recharge from precipitation in addition to recharge from canals, applied irrigation water, and streams. Gemperle (1988, p. 41–43) indicated that the Bruneau River probably contributes water to the cold-water aquifer where it first crosses sedimentary rocks in the valley. Little, if any, precipitation on the Bruneau study area infiltrates to the geothermal system.

Recharge to the geothermal system in the Bruneau study area was estimated by two methods, basin yield and hydraulic gradient (Darcy's equation). Using the basin yield method, Kjelstrom (1986) estimated average annual net water yield from the Bruneau River drainage basin upstream from streamflow-gaging stations for the period 1934–80. Net water yield is the total amount of water available from precipitation in a drainage area. Kjelstrom (1986) estimated net water yield by using regression analysis. Drainage area, mean annual precipitation, and percentage of forest cover were independent variables in the regression equation. Kjelstrom (1986) estimated underflow from the drainage basin upstream from gaging stations as net water yield minus irrigation water use and streamflow. The underflow estimate of Kjelstrom is recharge to the Bruneau study area.

Net water yield and other water budget terms were calculated for two contributing areas using streamflow data at gaging stations Bruneau River near Hot Spring (13168500) and Big Jacks Creek near Bruneau (13169500, fig. 1). These stations account for more than 90 percent of the drainage area contributing underflow to the Bruneau study area. Kjelstrom (1986) estimated that during 1934–80, net water yield from the Bruneau River and Big Jacks Creek drainage areas averaged 367,000 and 10,000 acre-ft/yr, respectively. Mean annual discharge at gaging stations Bruneau River near Hot Spring (water years 1910–14, 1944–80) and Big Jacks Creek near Bruneau (water years 1940–49, 1966–80) was 286,000 and 3,000 acre-ft/yr, respectively. Kjelstrom then adjusted the values of mean annual discharge to the period 1934–80. The revised estimate of discharge at Bruneau River near Hot Spring was 297,000 acre-ft/yr; the estimate at Big Jacks Creek did not change. An estimated 20,000 acre-ft of water per year was used for irrigation upstream from the Bruneau River near Hot Spring gaging station; water used for irrigation upstream from the Big Jacks Creek gaging station was negligible. Thus, natural recharge (underflow) was calculated to be 50,000 acre-ft/yr at Bruneau River near Hot Spring and 7,000 acre-ft/yr at Big Jacks Creek, and total natural recharge to the study area was calculated to be about 57,000 acre-ft/yr. This is a minimum value because underflow from 10 percent of the contributing area, drained by Little Jacks and Logan Creeks, has not been estimated.

Another method for estimating recharge to the Bruneau study area is to apply Darcy's equation (Bouwer, 1978, p. 48, eq. 3.13). This method uses estimates of hydraulic gradients, aquifer extent, and aquifer properties to estimate underflow (recharge to the Bruneau study area). Underflow was estimated at the southern boundary of the Bruneau study area (fig. 1) because estimates of hydraulic gradient (Young and Lewis, 1982, pl. 2) and hydraulic conductivity (table 3) were available.

The 1979 potentiometric surface map for the regional geothermal system in southwestern Idaho (Young and Lewis, 1982, pl. 2) indicates that ground-water movement is northwestward toward the Snake River. Darcy's equation, $Q=TIW$, was used to calculate underflow, where $Q$ is ground-water discharge (length$^3$/time); $T$ is transmissivity (length$^2$/time); $I$ is hydraulic gradient (length/length); and $W$ is the width of the aquifer normal to the direction of flow (length). Wells 7S-6E-34BCA1, 7S-6E-34DAD1, and 9S-5E-4DAD1 (figs. 1 and 2B), representative of the volcanic-rock aquifer, were used for this analysis. The wells are located between the 2,600- and 2,800-ft potentiometric surface contours delineated by Young

and Lewis (1982, pl. 2). Underflow was first estimated using conservative estimates of hydraulic conductivity, aquifer thickness, and width of the flow system. Transmissivity in this case was estimated by averaging the hydraulic conductivities for the wells listed above (table 3, column D) and multiplying that value by 1,500, the approximate thickness, in feet, of the volcanic-rock aquifer at well 9S-5E-4DAD1 (table 3, column C). An average hydraulic conductivity from the two tests at well 7S-6E-34DAD1 was used. The average hydraulic conductivity for the three wells completed in the volcanic-rock aquifer is about 15 ft/d; therefore, transmissivity ($T$) would be about 22,000 ft²/d. If the hydraulic gradient ($I$) is about 24 ft/mi (Young and Lewis, 1982, pl. 2) and the width ($W$) is 35 mi, ground-water discharge ($Q$) is calculated to be about 18,000,000 ft³/d, or about 150,000 acre-ft/yr. This estimate of underflow is nearly triple that estimated by the basin yield method.

However, uncertainties in hydraulic conductivity, aquifer thickness, aquifer width, and hydraulic gradient make estimates by the Darcy method questionable. Hydraulic conductivity for the three wells used to estimate underflow ranged from 3.5 to 22 ft/d (table 3, column D), a factor of about 6. Using these high and low values of hydraulic conductivity to estimate transmissivity, underflow at the southern boundary is calculated to be about 230,000 and 37,000 acre-ft/yr, respectively. If transmissivity is estimated by averaging the results from the slug tests for test holes 8S-6E-3BDC1 and 8S-6E-4DCD1 (fig. 6), underflow is calculated to be about 560,000 acre-ft/yr. This is more than the 377,000 acre-ft/yr that is available from precipitation in the Bruneau River drainage area as presented in the basin yield method. Aquifer tests are

**Table 4.** Spring discharges in the Bruneau study area prior to extensive ground-water development

[gal/min, gallons per minute; acre-ft/yr, acre-feet per year. Values are rounded]

| Spring location | Discharge (gal/min) | References | General area |
|---|---|---|---|
| 6S-5E-32A | 10 | (1,2) | Little Valley |
| 7S-4E-24D | 135 | (1,2) | Little Valley |
| 7S-4E-13 | 180 | (3) | Little Valley |
| 7S-5E-5 | 45 | (3) | Little Valley |
| 7S-6E-21D | 1,200 | (1) | Bruneau Valley |
| 7S-6E-22C | 35 | (1,2) | Bruneau Valley |
| 7S-6E-22DADB1S | 1,000 | (1,2) | Pence Hot Spring |
| 7S-6E-34 | 1,200 | (1,2,4) | Bruneau Valley, east of the Bruneau River including springs 7S-6E-34DCB1S and 7S-6E-35BBB1S |
| 8S-6E-3BDD1S | 2,200 | (2,5) | Bruneau Valley, Indian Bathtub Spring |
| 8S-6E-3 | 250 | (3) | Bruneau Valley, near Indian Bathtub Spring |
| **TOTAL=** | 6,255 gal/min | | |
| **TOTAL=** | 10,100 acre-ft/yr | | |

[1] Stearns and others (1937, p. 148).
[2] Piper (1924, p. 36–37).
[3] Gemperle (1988, p. 32–33).
[4] Rightmire and others (1976).
[5] Littleton and Crosthwaite (1957, p. 173).

needed to more accurately determine hydraulic conductivities and transmissivities in this area. Also, no wells in the study area have penetrated the entire thickness of the volcanic-rock aquifer. Without a more accurate estimate of saturated thickness, hydraulic conductivity cannot be reliably converted into estimates of transmissivity. Aquifer width at the southern boundary was estimated to be about 35 mi. Additional drilling is needed to help define aquifer extent more precisely. Although more information is available on hydraulic gradients than on hydraulic properties for the study area, hydraulic gradient data are still sparse near the southern boundary. The level of uncertainty for any of these properties is unknown. If one of the properties is in error by a factor of two, underflow also will be in error by a factor of two because these properties are proportional to underflow ($Q$). A smaller value of underflow would represent a more conservative estimate for water resource management purposes

Natural discharge from the study area consists of spring flow and underflow to the Snake River and out of the Bruneau study area. Gemperle (1988, p. 31–34) estimated discharge from springs in the Bruneau-Grand View area prior to extensive ground-water development (1922). These estimates are probably representative of steady-state conditions because spring discharges did not change significantly from 1922 to 1954 (Littleton and Crosthwaite, 1957, p. 173) and were revised on the basis of more recent information and regrouping of springs in the Bruneau study area. Total estimated discharge from springs prior to extensive ground-water development was about 10,100 acre-ft/yr (table 4)—9,500 acre-ft from Bruneau Valley and 600 acre-ft from Little Valley. Spring discharges given in table 4 were measured. Gemperle (1988, p. 32–33) also reported that two springs south of the study area near the Owyhee Mountains had a combined discharge of 1,260 gal/min, or about 2,000 acre-ft/yr, if discharge is assumed to remain constant throughout the year. Young and Lewis (1982, table 1, p. J5) reported that several springs in the Jarbidge Mountains had a combined discharge of about 2,000 gal/min, or 3,200 acre-ft in 1978. Estimates of underflow to the Snake River and out of the Bruneau study area were not possible because of inadequate data.

## Ground-Water Development

The Bruneau River provided water to early travelers and soon thereafter was used for irrigation. Bruneau, Little, and Sugar Valleys have supported irrigated agriculture for many years. The number of acres irrigated initially was dependent on the quantity of surface water available (Piper, 1924, p. 27). Shortly after the turn of the century, water from the Bruneau River was used to irrigate about 4,200 acres in the lower Bruneau River Valley and about 6,000 acres in the Grand View area (Piper, 1924, p. 33). Piper (1924, p. 35) also indicated that surface-water supply was inadequate during the summer when streamflows are lowest and recommended the use of ground water as a supplemental supply. In parts of Bruneau, Little, and Sugar Valleys, ground water is currently the sole source of supply.

In 1896, the first test holes were drilled in the lower Bruneau River Valley (near 6S-5E-9AD and 6S-5E-14DC, fig. 7) in an attempt to obtain artesian water from wells. That attempt was unsuccessful because drilling stopped at first-encountered water, which had a temperature of about 15°C (Piper, 1924, p. 40, table 10, wells 1 and 2). The test holes indicated the presence of a cold-water aquifer. That same year, five 2-in.-diameter wells were successfully completed in Little Valley near a geothermal spring in the southeastern corner of sec. 24, T. 7 S., R. 4 E. (fig. 7), and development of the regional geothermal aquifer system had begun. Locations of irrigation wells and year drilled in each of the three valleys are shown in figure 7. Water was used for irrigation, municipal, domestic, and stock supplies. From 1896 to 1912, well drilling proceeded slowly and about 15 flowing wells were completed. The number of irrigation wells drilled increased to more than 100 in 1922 (fig. 8). By 1922, Piper (1924, p. 40–45) reported a total of 40, 63, and 4 wells in Bruneau, Little, and Sugar Valleys, respectively. Eighty of these wells flowed. Most of the flowing wells were less than 1,000 ft deep and were completed in what Piper (1924, table 10, p. 40–45) called the valley aquifer (sedimentary-rock aquifer). The present quantity of water used for municipal, domestic, and stock supplies is small in comparison with the quantity used for irrigation. The Bruneau Water Company, which supplies the

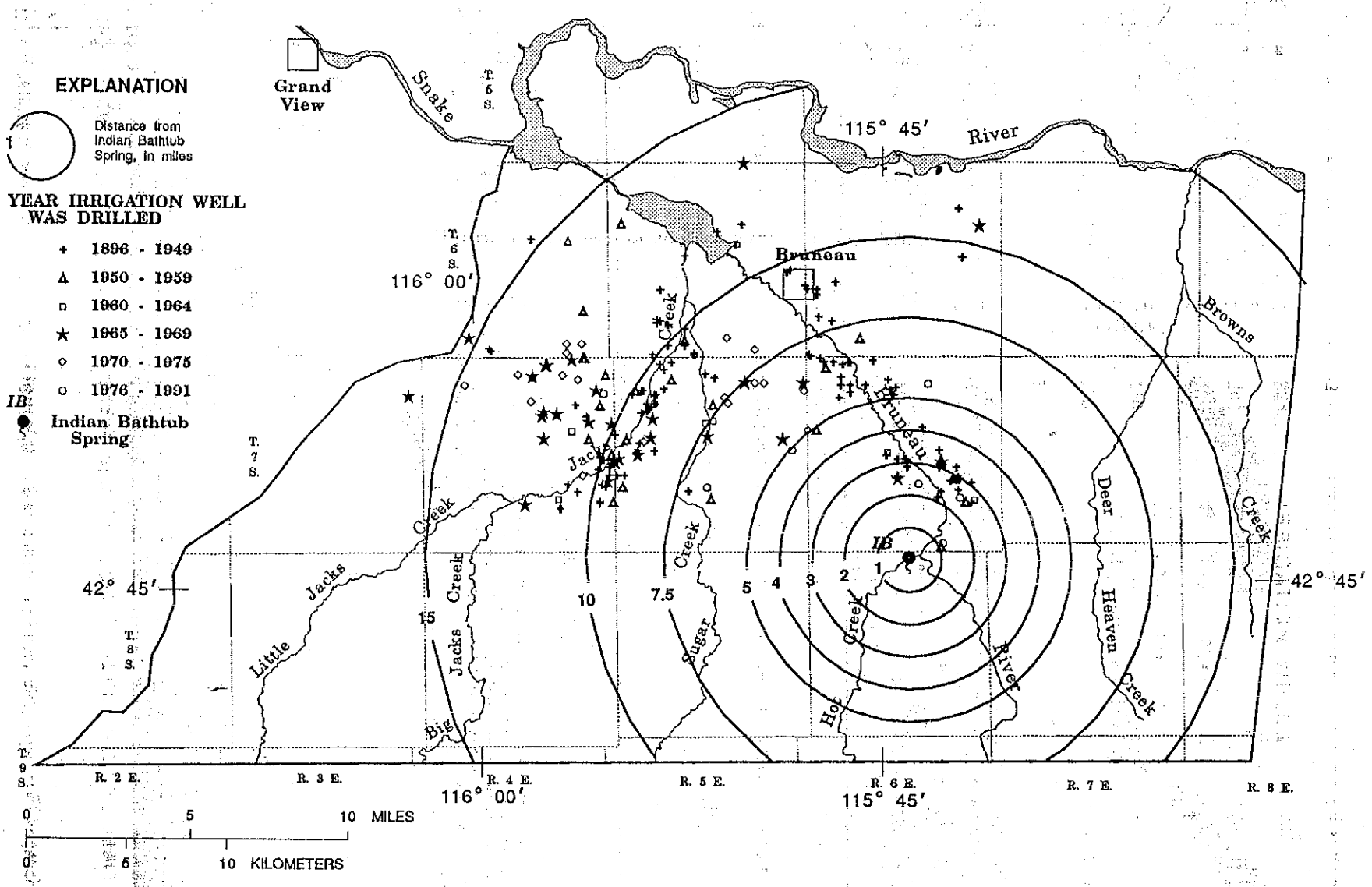



**Figure 7.** Location of irrigation wells and year drilled.

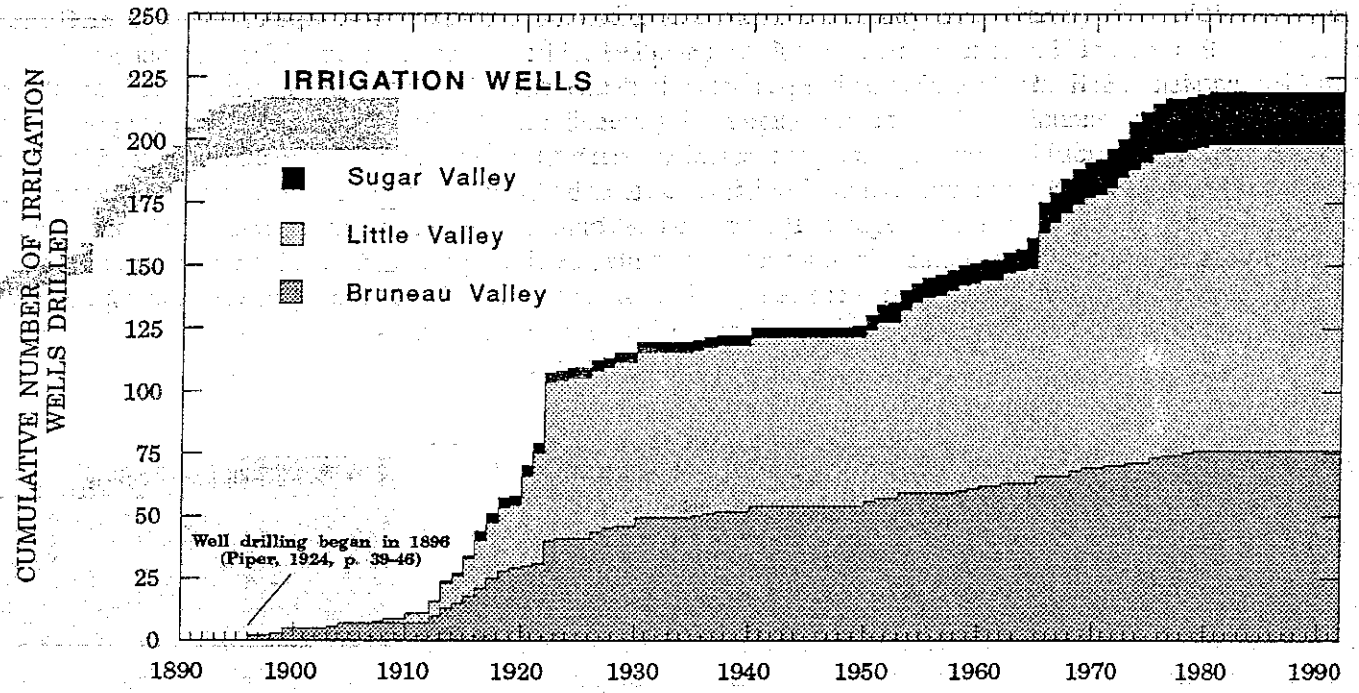



**Figure 8.** Cumulative number of irrigation wells drilled in the Bruneau area, 1890-1991.

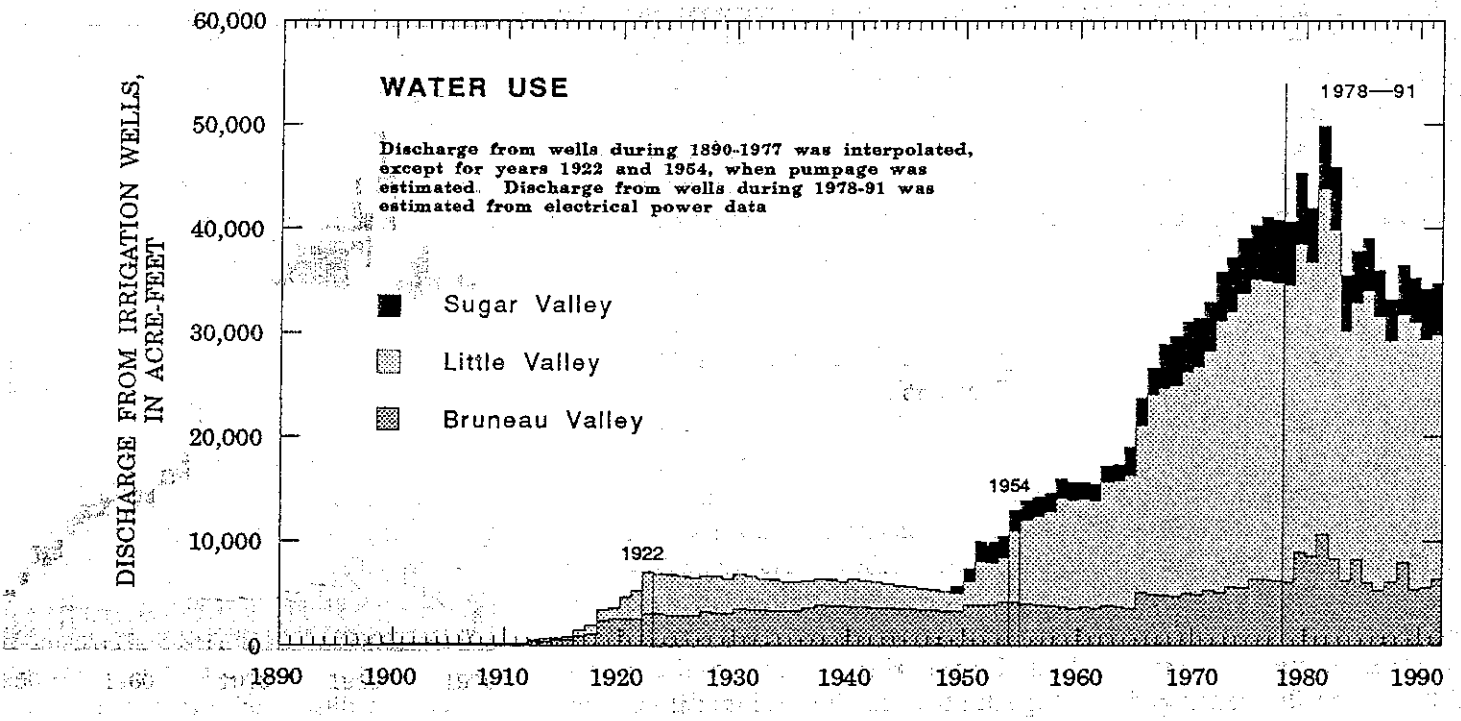



**Figure 9.** Distribution of annual discharge from irrigation wells in the Bruneau area, 1890-1991.

city of Bruneau, is one of the largest nonirrigation users of ground water in the study area. During 1977, 1978, and 1989, they used about 13, 13, and 25 acre-ft of water, respectively (Tom Moore, JUB Engineering, Inc., oral commun., 1991). Moore attributes the increase in pumpage from 1977 to 1989 to the conversion from individual septic-tank systems to a centralized sewage system in 1981. The quantity of water for nonirrigation use in the study area probably has been less than 100 acre-ft/yr since 1991 and was not further considered in this study.

A substantial quantity of water has discharged from the regional geothermal system from flowing and pumped wells. In 1922, discharge from irrigation wells was estimated to be about 7,150 acre-ft (fig. 9)—about 3,150 acre-ft from Bruneau Valley and 4,000 acre-ft from Little Valley (Piper, 1924, p. 39–46). These estimates were made by measuring the discharge from all flowing wells at least once and assuming that the flow remained constant throughout the year because artesian pressures in the aquifer remained relatively constant (Littleton and Crosthwaite, 1957, p. 183). The distribution of annual discharge from wells in Bruneau, Little, and Sugar Valleys during 1890 to 1991 is shown in figure 9. Annual well discharges prior to 1922 were determined by using a well's 1922 discharge value given by Piper (1924, table 10, p. 40–45) as a constant from the time of well construction to 1922. No attempt was made to account for annual variations in well discharge as noted by Piper (1924, table 10, p. 40–45) because accurate records of flow rates were not kept.

The number of wells drilled in the study area increased slowly from 1922 to 1954 (figs. 7 and 8). During that time, annual discharge nearly doubled (fig. 9). In 1954, Littleton and Crosthwaite (1957, p. 174) estimated that 81 wells discharged about 22,500 acre-ft of water, about three times as much as Piper's estimate for 1922. However, Piper's estimate was for Bruneau, Little, and Sugar Valleys, whereas Littleton and Crosthwaite's estimate included the Grand View area. For this report, Littleton and Crosthwaite's estimate was revised to exclude wells in the Grand View area, and the revised estimate of discharge from 51 wells in the Bruneau study area in 1954 was about 13,000 acre-ft. Twenty-eight of the wells were in Bruneau Valley, 19 in Little Valley, and 4 in Sugar Valley, and the wells discharged about 4,200, 6,800, and 2,000 acre-ft, respectively (fig. 9). Littleton and Crosthwaite (1957) used the same procedure as Piper (1924) to calculate well discharges, except for 24 wells that were pumped or that flowed only during the irrigation season. Discharge from these wells was estimated by multiplying the estimated daily discharge by 100, the average number of days wells flowed or were pumped in a year (Littleton and Crosthwaite, 1957, p. 174). Annual quantities of discharge for 1922–54 were determined by interpolating between 1922 and 1954 estimated values or by using the well's 1954 discharge value as a constant from the time of the well's construction to 1954. Discharge from wells with a reported discharge in 1922 but none in 1954 was interpolated between the estimated 1922 value and the zero 1954 value because information about when the well was abandoned, destroyed, or not in use was unavailable. This probably accounts for the declining trend in annual discharge from 1922 to 1950 in Little Valley (fig. 9).

Land use in the study area changed significantly between 1954 and 1978. Lindholm and Goodell (1986) indicated that, in 1945, no appreciable amount of land in the study area was irrigated with ground water; by 1966, about 13,000 acres were irrigated, and by 1980, about 20,000 acres were irrigated. Intensive use of geothermal water for irrigation began in the mid-1960's. Most of the increase in irrigated acreage since 1945 was in Little and Sugar Valleys. The number of wells drilled (73) also increased (figs. 7 and 8), although the dramatic increase in discharge from wells (fig. 9) during 1954–78 probably was caused by the addition of large-capacity pumps to increase well yields. Young and others (1979, table 2, p. 15) estimated that, in 1978, about 39,000 acre-ft of water was discharged from wells. Their estimate was based on total electrical consumption by pumps, depth to water, average water level, and well efficiency. The estimate by Young and others has been revised on the basis of more recent information and regrouping of wells. Total estimated discharge from wells in 1978 was about 40,600 acre-ft—6,200 acre-ft from Bruneau Valley, 28,300 acre-ft from Little Valley, and 6,100 acre-ft from Sugar Valley (fig. 9). Annual

quantities between 1954 and 1978 were interpolated as previously described.

Only two irrigation wells were drilled in the study area during 1978–91 (fig. 8). One reason for curtailed drilling was that in 1982, the Bruneau-Grand View area was declared a Ground-Water Management Area by the Idaho Department of Water Resources. Most irrigation wells are in Little Valley (figs. 7 and 8), where annual discharge has been greatest since 1954 (fig. 9). Annual variations in discharge from irrigation wells from 1978 through 1991 are shown in figure 9. Total well discharge declined from the maximum of 49,900 acre-ft in 1981 to 34,700 acre-ft in 1991. From 1981 to 1991, discharge from wells declined about 4,200 acre-ft in Bruneau Valley, 9,700 acre-ft in Little Valley, and 1,300 acre-ft in Sugar Valley. Declines are, in part, attributed to irrigated lands being idle as part of the "set-aside" program administered by the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service. In 1991, well discharges in Bruneau Valley totaled 6,500 acre-ft; in Little Valley, 23,400 acre-ft; and in Sugar Valley, 4,800 acre-ft.

Irrigation well discharges prior to 1979 were estimated by previous investigators. Discharges from 1979 through 1991 were estimated during this study from annual electrical power data obtained from Idaho Power Company. Annual discharge was estimated by one of three methods. The first method was used only when an instantaneous discharge measurement was made and electrical power data were available. Annual well discharge was calculated as the product of the measured discharge and the time the pump was on. Discharge was assumed to remain constant. The second method was used when water-level measurements were made and electrical power data were available. Annual well discharge was calculated using the following equation, as described by Young and others (1979, p. 5, eq. 1): $Q=kWh/[K(H+P)]$, where $Q$ is pumpage, in acre-feet, $kWh$ is kilowatthours used; $K$ is kilowatthours required to lift 1 acre-ft of water 1 ft; $H$ is the depth to pumping water level, in feet; and $P$ is the pressure head at the well, in feet of water. At 100-percent efficiency, $K$=1.02 $kWh$/acre-ft-ft; that is, it takes slightly more than 1 kilowatthour of electricity to lift 1 acre-ft of water 1 ft (Goodell, 1988, p. E19). A $K$ value of 1.8, developed from efficiency data by Young and others (1979, p. 5), was used for this study. The third method was used when electrical power data were not available. Annual well discharge was calculated as the product of the measured discharge and the number of days in the year if the well flowed continuously, or 100 days if the well flowed only during the irrigation season (Littleton and Crosthwaite, 1957, p. 175). Annual discharge from several wells powered by internal-combustion engines was estimated as the product of measured discharge and the average number of pumping hours of all other wells in the study area (Young and others, 1979, p. 5).

From 1896 through 1991, nearly 1,400,000 acre-ft of ground water discharged from wells in the study area. Of that quantity, about 546,000 acre-ft discharged from 1978 through 1991; 50 percent was from wells 10 to 15 mi from Indian Bathtub Spring (fig. 10 and table 5). During 1978–91, 85 percent of the discharge was from wells greater than 5 mi from Indian Bathtub Spring (fig. 10). The closest wells, 1 to 2 mi from this spring, discharged 2 percent (11,000 acre-ft) of the total during 1978–91, or about 790 acre-ft/yr. The percentage of annual well discharge for different distances from Indian Bathtub Spring did not change appreciably during 1978–91, although the distribution of pumpage in 1922 and 1954 was notably different (table 5). The percentage of pumpage in 1922 and 1954 was generally greater closer to Indian Bathtub Spring than at present, especially 2 to 3 mi from the spring, as shown in table 5. About 31 percent of the discharge from wells in 1922 was within 5 mi of Indian Bathtub Spring, about 21 percent in 1954, and 15 percent during 1978–91.

Ground-water discharge from wells is documented reasonably well; however, separating the quantity according to aquifer (sedimentary-rock or volcanic-rock) is difficult. If wells are open to both aquifers, there is no way to distribute stress except by assuming that most of the water comes from the volcanic rocks. This assumption is probably reasonable because water is transmitted through the volcanic rocks (higher hydraulic conductivity) more easily than through the sedimentary rocks. For example, if hydraulic conductivity is 16 ft/d for the sedimentary rocks and 360 ft/d for the volcanic rocks (see section, "Slug Tests"), if both rock types

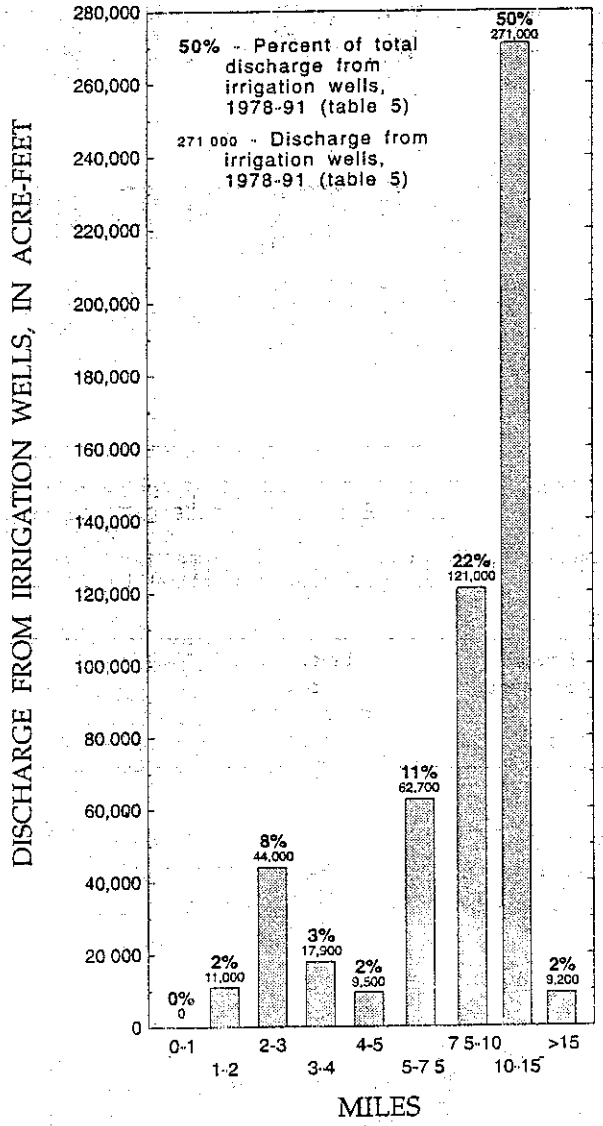



**Figure 10.** Discharge and percent of total from irrigation wells at various distances from Indian Bathtub Spring (8S-6E-3BDD1S), 1978-91. (Values are rounded)

**Table 5.** Areal distribution of discharge from irrigation wells in the Bruneau study area, 1922, 1954, and 1978–91, at specified radial distances from Indian Bathtub Spring (8S-6E-3BDD1S)

[acre-ft, acre-feet; %, percent; >, greater than. Values are rounded]

| | Radial distances, in miles, from Indian Bathtub Spring (8S-6E-3BDD1S) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0–1 | | 1–2 | | 2–3 | | 3–4 | | 4–5 | | 5–7.5 | | 7.5–10 | | 10–15 | | >15 | | |
| Year | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | (acre-ft) | (%) | Total |
| 1922 | 0 | 0 | 0 | 0 | 1,570 | 22 | 610 | 8 | 40 | 1 | 840 | 12 | 3,820 | 53 | 270 | 4 | 0 | 0 | 7,150 |
| 1954 | 0 | 0 | 180 | 1 | 2,010 | 15 | 450 | 3 | 320 | 2 | 2,410 | 18 | 5,120 | 39 | 2,550 | 20 | 0 | 0 | 13,000 |
| 1978 | 0 | 0 | 270 | 1 | 1,100 | 3 | 1,030 | 3 | 1,260 | 3 | 6,630 | 16 | 7,920 | 20 | 21,500 | 53 | 900 | 2 | 40,600 |
| 1979 | 0 | 0 | 560 | 1 | 3,160 | 7 | 1,770 | 4 | 1,230 | 3 | 6,730 | 15 | 9,590 | 21 | 21,400 | 47 | 970 | 2 | 45,400 |
| 1980 | 0 | 0 | 0 | 0 | 3,540 | 8 | 1,890 | 4 | 1,430 | 3 | 4,840 | 12 | 8,270 | 20 | 21,000 | 50 | 1,090 | 3 | 42,000 |
| 1981 | 0 | 0 | 570 | 1 | 4,290 | 9 | 1,800 | 4 | 1,620 | 3 | 6,320 | 13 | 8,890 | 18 | 25,000 | 50 | 1,400 | 3 | 49,900 |
| 1982 | 0 | 0 | 590 | 1 | 2,620 | 4 | 1,940 | 6 | 1,520 | 3 | 5,600 | 12 | 8,400 | 18 | 24,300 | 53 | 920 | 2 | 45,900 |
| 1983 | 0 | 0 | 840 | 2 | 2,130 | 6 | 1,360 | 4 | 780 | 2 | 4,490 | 13 | 7,740 | 22 | 17,300 | 49 | 920 | 3 | 35,600 |
| 1984 | 0 | 0 | 1,050 | 3 | 3,460 | 9 | 1,330 | 4 | 1,000 | 3 | 4,180 | 11 | 8,300 | 22 | 17,700 | 47 | 780 | 2 | 37,800 |
| 1985 | 0 | 0 | 960 | 2 | 4,130 | 11 | 750 | 2 | 40 | 0 | 3,150 | 8 | 8,350 | 21 | 20,700 | 53 | 1,070 | 3 | 39,200 |
| 1986 | 0 | 0 | 870 | 2 | 3,100 | 9 | 1,090 | 3 | 130 | 0 | 2,700 | 8 | 7,900 | 22 | 19,900 | 55 | 300 | 1 | 36,000 |
| 1987 | 0 | 0 | 930 | 3 | 4,160 | 13 | 620 | 2 | 180 | 1 | 2,450 | 7 | 7,980 | 24 | 16,900 | 51 | 0 | 0 | 33,200 |
| 1988 | 0 | 0 | 1,200 | 3 | 4,190 | 11 | 1,420 | 4 | 310 | 1 | 3,900 | 11 | 9,060 | 25 | 16,000 | 44 | 370 | 1 | 36,500 |
| 1989 | 0 | 0 | 900 | 3 | 2,470 | 7 | 1,080 | 3 | 0 | 0 | 3,700 | 10 | 9,510 | 27 | 17,200 | 49 | 430 | 1 | 35,300 |
| 1990 | 0 | 0 | 990 | 3 | 2,520 | 7 | 750 | 2 | 0 | 0 | 4,190 | 12 | 9,730 | 28 | 16,000 | 47 | 10 | 0 | 34,200 |
| 1991 | 0 | 0 | 1,270 | 4 | 3,150 | 9 | 1,040 | 3 | 0 | 0 | 3,830 | 11 | 9,590 | 28 | 15,800 | 46 | 0 | 0 | 34,700 |
| 1978–91 TOTAL | 0 | 0 | 11,000 | 2 | 44,000 | 8 | 17,900 | 3 | 9,500 | 2 | 62,700 | 11 | 121,000 | 22 | 271,000 | 50 | 9,200 | 2 | 546,000 |

**Table 6.** Monthly consumptive use estimates based on evapotranspiration by alfalfa at Bruneau

[Adjusted evapotranspiration data from Allen and Brockway (1983, table 12, p. 134–135); mm/d, millimeters per day]

| Month | Adjusted evapotranspiration (mm/d) | Estimated consumptive use (percent) |
|---|---|---|
| January | 0 | 0 |
| February | 0 | 0 |
| March | 2.52 | 5.34 |
| April | 4.97 | 10.53 |
| May | 6.56 | 13.90 |
| June | 8.28 | 17.54 |
| July | 8.58 | 18.17 |
| August | 7.13 | 15.10 |
| September | 5.41 | 11.46 |
| October | 3.76 | 7.96 |
| November | 0 | 0 |
| December | 0 | 0 |

are of equal thickness, and if hydraulic gradients in both rock types are the same, 96 percent of the discharge might be from the volcanic rocks. Thus, wells open to both the sedimentary- and volcanic-rock aquifers were treated as if they were completed solely in volcanic rocks. During 1978–91, about 70 percent of the well discharge in Little and Sugar Valleys was from wells open only to the volcanic-rock aquifer; about 90 percent of the well discharge in Bruneau Valley was from the volcanic-rock aquifer. Volcanic rocks are the main contributor of water to wells in the study area.

An attempt was made to estimate monthly discharge from irrigation wells, which varies throughout the year, especially during the irrigation season. Littleton and Crosthwaite (1957, p. 174) accounted for seasonal pumping in 1954 by using a 100-day well-pumping or flowing season; Young and others (1979) used the same procedure only for flowing wells that were shut off during nonirrigation periods. One widely used method of estimating discharge from irrigation wells incorporates crop consumptive water use. Allen and Brockway (1983) indicated that consumptive use is synonymous with evapotranspiration and determined the average monthly consumptive use for alfalfa. They adjusted the monthly consumptive use for station aridity at Bruneau and 97 other sites in Idaho. The consumptive use values determined for the Bruneau area by Allen and Brockway (table 6) are averages and representative of the study area where alfalfa, beans, corn, grain, and hay are grown. Hence, monthly well discharge can be estimated by multiplying each well's annual discharge by the monthly percentage of consumptive use (table 6). Only wells that had pumps were used for this analysis.

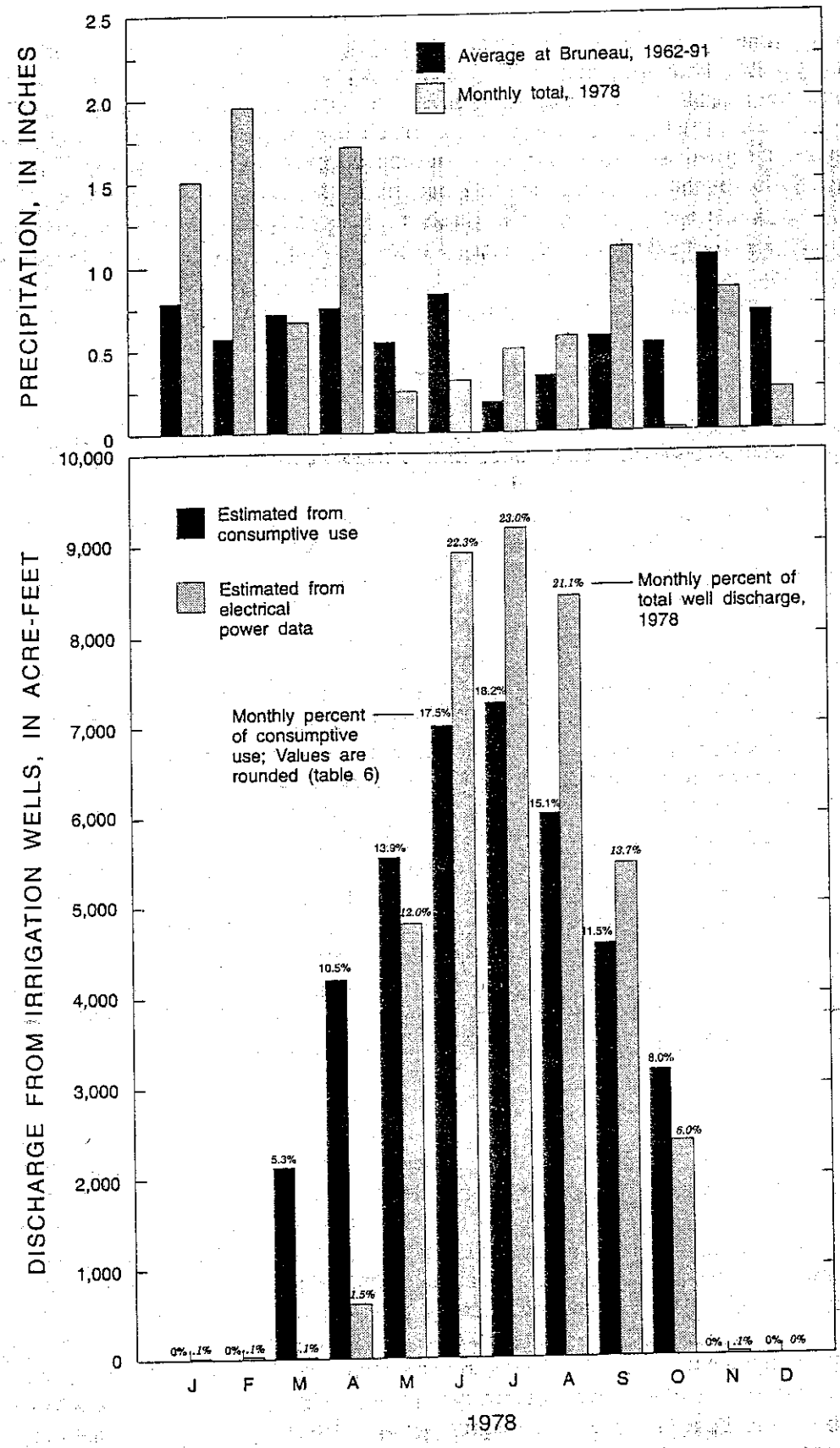



**Figure 11.** Average 1962-91 and monthly precipitation and monthly well discharge estimated from consumptive use and from electrical power data in the Bruneau area, 1978

Young and others (1979) calculated ground-water pumpage in 1978 by summing monthly discharges estimated from electrical power data. Only annual electrical power data were available for subsequent years. The relation between 1978 monthly discharge estimated from consumptive use and from electrical power data is shown in figure 11. Well discharge estimated by the consumptive use method generally was within 5 percent of that estimated from electrical power data. The largest discrepancies were in April and August. A possible explanation for these discrepancies is that precipitation was more than double the 1962–91 average in January, February, and April (fig. 11), and the need for irrigation water decreased. Under those conditions, well discharge estimated from electrical power data would be less than that estimated by the consumptive use method (fig. 11). Also, the lack of precipitation in June, compared to the average, created the need for more irrigation water throughout the summer than the amount estimated by the consumptive use method. Although there are some discrepancies between the two estimates, the consumptive use estimate generally followed the same trends as the electrical power data estimate, especially when precipitation was near normal.

The purpose of developing monthly estimates of ground-water pumpage by the consumptive use method was to help explain differences in hydraulic heads and spring flows in the last several years. Monthly electrical power data were not available. Since early 1989, water levels in 12 wells and test holes and flows from 5 springs in the study area have been measured monthly (Young and Parliman, 1989; Young and others, 1990). Since April 1990, six test holes near Indian Bathtub Spring have been equipped with continuous water-level recorders (Young and others, 1990). To estimate the total monthly ground-water discharge by irrigation wells in 1990–91, the consumptive use method was applied to pumping wells and added to the monthly quantities discharged by flowing wells. The monthly distribution of well discharge for 1990–91 is shown in figure 12. The abundance of precipitation during the last 10 days of May 1990 (1.04 in.), compared with the average, lessened the need for irrigation water in May and June. As a result, actual well discharges were probably less than those estimated by the consumptive use method. The decrease in well discharge corresponded to an increase in hydraulic heads, as shown by the water levels in well 8S-6E-3BDC1 (fig. 12). Conversely, the lack of precipitation during June through October 1990, March 1991, and July and August 1991, compared with the average, created the need for more irrigation water, and actual well discharge during those months was probably greater than that estimated by the consumptive use method. The lack of precipitation in July and August 1991 corresponded to greater water-level declines, as shown by the hydrograph for well 8S-6E-3BDC1, a well in the volcanic-rock aquifer open from 173.5 to 480 ft below land surface (fig. 12). Consumptive use estimates for September and October 1991 were probably representative of actual well discharges because of near-average precipitation that corresponded to rising water levels (fig. 12).

## Potentiometric Surfaces and Water Movement

Generally, ground water flows northward from areas of recharge along the mountains, through the volcanic-rock aquifer, and into the sedimentary-rock aquifer (Young and Lewis, 1982, p. J17). The potentiometric surface south of the study area was defined by Young and Lewis (1982, pl. 2) on the basis of water-level measurements made in spring 1979. That surface is considered representative of predevelopment conditions, probably unaffected by pumping. The potentiometric surface slopes steeply from an altitude of about 4,600 ft near well 14S-9E-2BAA1 (more than 40 mi south of Indian Bathtub Spring) to slightly less than 2,800 ft near Indian Bathtub Spring, an average gradient of about 40 ft/mi (Young and Lewis, 1982, pl. 2). The spring 1979 potentiometric contours in the Bruneau study area are not representative of predevelopment conditions; however, they indicate that water movement is generally northward, toward the Snake River. Even water levels measured in the early 1920's showed declines due to the discharge of wells in the study area; therefore, they too are not representative of predevelopment conditions (Piper, 1924, p. 48).

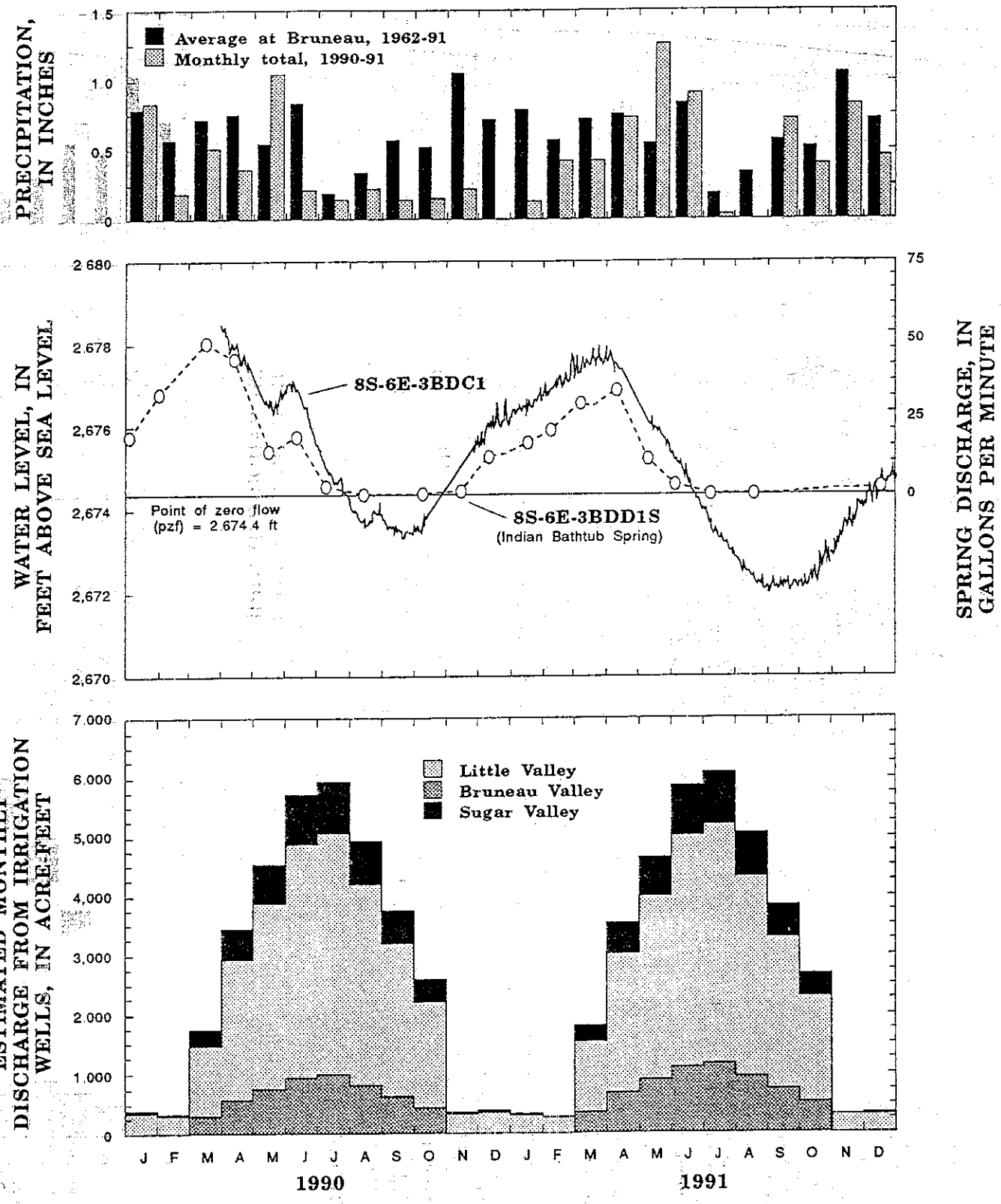



**Figure 12.** Relations among precipitation, water level in test hole 8S-6E-3BDC1, discharge from Indian Bathtub Spring (8S-6E-3BDD1S), and estimated monthly discharge from irrigation wells, 1990-91.

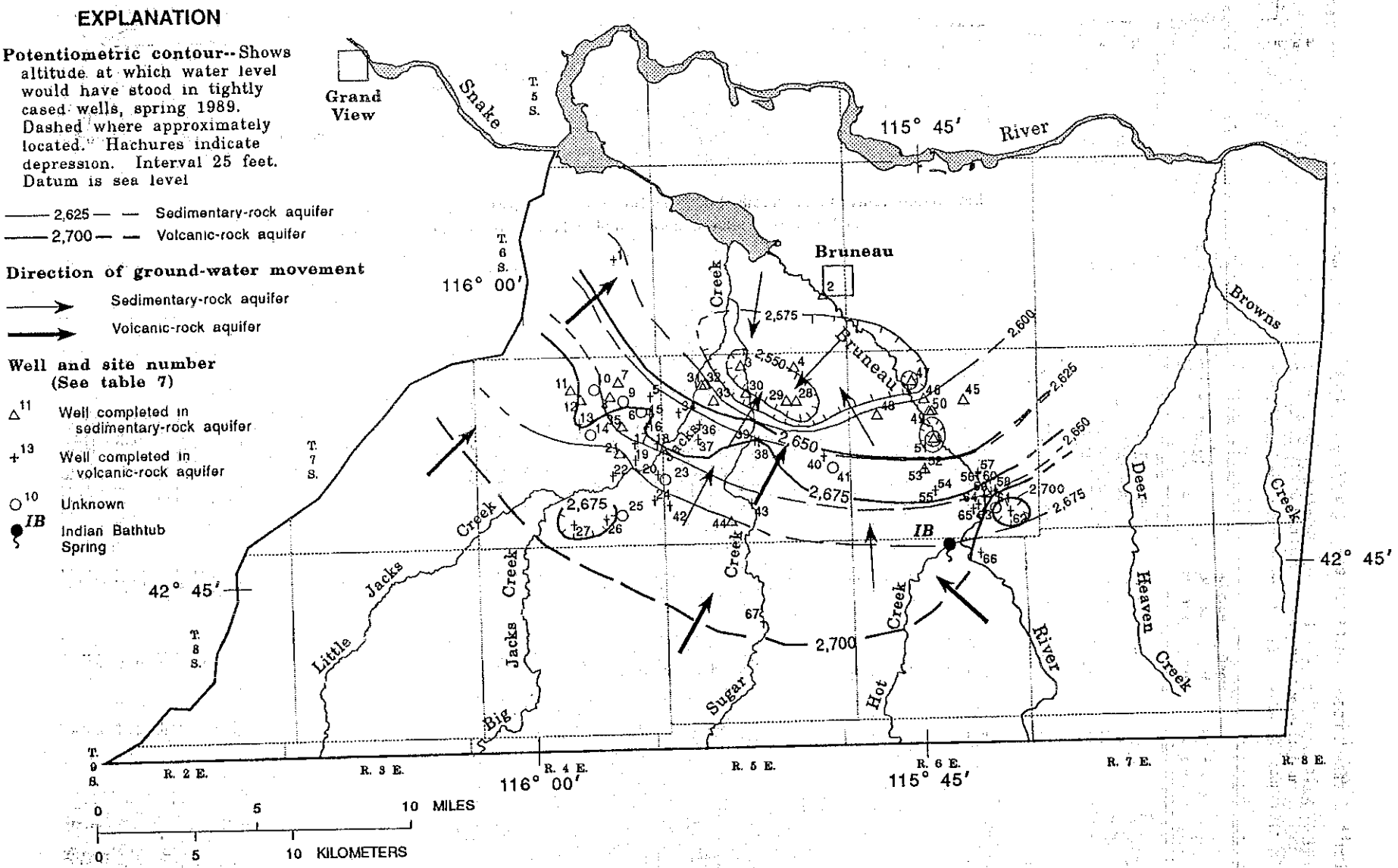



**Figure 13.** Potentiometric surfaces and directions of water movement in sedimentary-rock and volcanic-rock aquifers, spring 1989.

**Table 7.** Water-level measurements in selected wells, Bruneau study area, spring 1989

[Site No.: Indicates location of well in figure 13. Altitude of land surface and altitude of water level in feet above sea level. Depth of well, perforated interval, open hole, and depth to water in feet below land surface. Depth to water: F, well flowing above land surface; negative value indicates water level above land surface. Aquifer monitored: Sr, sedimentary-rock; Vr, volcanic-rock; U, unknown. Symbols: —, no data available]

| Site No. | Well No. | Altitude of land surface | Depth of well | Perforated interval | Open hole | Date measured (1989) | Depth to water | Altitude of water level | Aquifer monitored |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6S-4E-14ABC1 | 2 665 | 1,900 | — | — | 3-21 | 42.94 | 2,622.06 | Vr |
| 2 | 6S-5E-24BCA1 | 2,525 | 1,095 | — | 75 – 1,095 | 1-19 | -56.80 | 2,581 80 | Sr |
| 3 | 6S-5E-33DBB1 | 2,540 | 142 | — | — | 3-21 | 6.93 | 2,533 07 | Sr |
| 4 | 6S-5E-35CBD1 | 2,620 | 476 | 230 – 350 | 350 – 476 | 3-22 | 67.36 | 2,552.64 | Sr |
| 5 | 7S-4E- 1ACC1 | 2,655 | 1,800 | — | — | 3-23 | -8.02 | 2,663.02 | Vr |
| 6 | 7S-4E- 1CDC1 | 2,670 | — | — | — | 3-23 | -.72 | 2,670.72 | U |
| 7 | 7S-4E- 2ABB1 | 2,700 | 342 | — | 197 – 342 | 3-30 | 54 83 | 2,645 17 | Sr |
| 8 | 7S-4E- 2CAB1 | 2,675 | 890 | — | 330 – 890 | 3-22 | 31.17 | 2,643.83 | Sr |
| 9 | 7S-4E- 2DBA1 | 2,675 | — | — | — | 3-23 | -4.84 | 2,679 84 | U |
| 10 | 7S-4E- 3AAC1 | 2,730 | — | — | — | 3-22 | 70.82 | 2,659.18 | U |
| 11 | 7S-4E- 3BBC1 | 2,770 | 1,050 | 100 – 538 | 538 – 600, 780 – 1,050 | 3-22 | 107.29 | 2.662 71 | Sr |
| 12 | 7S-4E- 3CAB1 | 2,770 | 1,050 | 775 – 901 | 901 – 1,050 | 3-23 | 106 67 | 2,663 33 | Sr |
| 13 | 7S-4E-10BDB1 | 2,755 | 1.145 | 537 – 568 | 616 – 737, 738 – 1.145 | 3-21 | 81.20 | 2,673 80 | Vr |
| 14 | 7S-4E-10DBD1 | 2 740 | — | — | — | 3-21 | 72.55 | 2,667 45 | U |
| 15 | 7S-4E-12ABB1 | 2.660 | 1.600 | — | -- | 3-23 | -20 02 | 2,680.02 | Vr |
| 16 | 7S-4E-12BDD1 | 2,660 | 1,105 | — | 675 – 735 | 3-23 | -12.82 | 2,672 82 | Vr |
| 17 | 7S-4E-12CCC1 | 2,700 | 900 | — | 475 – 900 | 3-20 | 10.88 | 2,689 12 | Vr |
| 18 | 7S-4E-12DDC1 | 2,660 | 1,350 | — | 339 – 1,350 | 3-24 | F | — | Vr |
| 19 | 7S-4E-13BCC1 | 2,690 | 1,060 | — | 194 –1,060 | 3-20 | 12.92 | 2,677.08 | Vr |
| 20 | 7S-4E-13DCD1 | 2,670 | 1,000 | — | 194 –1,000 | 3-21 | -9 42 | 2,679.42 | Vr |
| 21 | 7S-4E-14ABC1 | 2,725 | 1,146 | -- | 223 –1,146 | 3-20 | 47.78 | 2.677.22 | Sr |
| 22 | 7S-4E-14CDC1 | 2,755 | 950 | — | 200 –950 | 3-20 | 75 94 | 2,679.06 | Vr |
| 23 | 7S-4E-24AAA1 | 2.660 | — | — | — | 3-20 | F | — | U |
| 24 | 7S-4E-24DCB1 | 2,690 | 750 | — | — | 3-20 | 21 85 | 2,668.15 | Vr |
| 25 | 7S-4E-26ACB1 | 2,730 | — | — | — | 3-22 | 56.82 | 2,673.18 | U |
| 26 | 7S-4E-26BCB1 | 2 750 | 867 | 130 –180 | 180 –867 | 3-22 | 72.35 | 2,677 65 | Vr |
| 27 | 7S-4E-27BCC1 | 2 770 | 1,390 | — | 19 –1.230 | 3-21 | 101 93 | 2,688 07 | Vr |
| 28 | 7S-5E- 2CBD1 | 2.650 | 300 | 100 –300 | -- | 3-22 | 115.67 | 2 534.33 | Sr |
| 29 | 7S-5E- 3DAD1 | 2,640 | 300 | — | — | 3-22 | 115 05 | 2,524.95 | Sr |
| 30 | 7S-5E- 4ACD1 | 2 575 | 1,100 | — | 700 –I,100 | 3-23 | 16.60 | 2,558.40 | Sr |
| 31 | 7S-5E- 5BAC1 | 2 579 | 906 | — | — | 3-23 | F | — | Sr |
| 32 | 7S-5E- 5BAC2 | 2,579 | 920 | — | — | 3-23 | F | — | Sr |
| 33 | 7S-5E- 5DBC1 | 2,600 | 2,405 | 160 –190 | 651 –747 | 3-23 | F | — | Sr |
| 34 | 7S-5E- 7ABB1 | 2.615 | 1,625 | — | 632 –1,625 | 3-24 | F | — | Vr |
| 35 | 7S-5E- 8BBC1 | 2 594 | 580 | — | 140 –580 | 3-23 | F | — | Sr |
| 36 | 7S-5E- 8BCC1 | 2,600 | 1 390 | — | 310 –1,390 | 3-23 | -60 06 | 2,660 06 | Vr |
| 37 | 7S-5E- 8CCC1 | 2,640 | 1,500 | — | 200 –555, 690 –1 500 | 3-23 | -12 32 | 2,652 32 | Vr |
| 38 | 7S-5E- 9DDC1 | 2,652 | 2,170 | — | 96 –2,170 | 3-22 | F | — | Vr |
| 39 | 7S-5E- 9DDD1 | 2,662 | 2.065 | — | 550 –984, 1,034–1,337, 1 624 –1,925 | 3-22 | -15 12 | 2,677.12 | Vr |
| 40 | 7S-5E-13CBB1 | 2,771 | 1 954 | 180 –710, 1,070–1,180, 1,560 –1,680 | 1,680 –1,950 | 3-22 | 118 80 | 2,652.20 | Vr |
| 41 | 7S-5E-13CDB1 | 2.790 | — | — | — | 3-21 | 126.82 | 2,663.18 | U |
| 42 | 7S-5E-19CCC1 | 2,720 | 760 | — | 309 –760 | 3-21 | 42.42 | 2,677.58 | Vr |
| 43 | 7S-5E-21CCA1 | 2,763 | 1,135 | 406 –706 | — | 3-22 | 77 25 | 2,685 75 | Vr |
| 44 | 7S-5E-28CBB1 | 2 800 | 245 | — | 18 –245 | 3-22 | 121 28 | 2,678 72 | Sr |
| 45 | 7S-6E- 3DCB1 | 2.675 | 1,510 | — | 304 –1,510 | 3-22 | 44.68 | 2,630.32 | Sr |
| 46 | 7S-6E- 4CDA1 | 2,598 | 1,040 | — | — | 3-21 | -2.12 | 2,600.12 | Sr |
| 47 | 7S-6E- 5AAD1 | 2,570 | 158 | — | 80 –158 | 3-21 | 30 08 | 2,539 92 | Sr |
| 48 | 7S-6E- 7AACI | 2,585 | 1,086 | — | 342 –1,086 | 3-22 | F | — | Sr |
| 49 | 7S-6E- 9BAD1 | 2 580 | 910 | — | 42 –910 | 3-20 | -32.12 | 2,612 12 | Sr |
| 50 | 7S-6E- 9BAD2 | 2,580 | 960 | — | 80 –960 | 3-20 | -32.12 | 2,612 12 | Sr |

Table 7. Water-level measurements in selected wells, Bruneau study area, spring 1989—Continued

| Site No. | Well No | Altitude of land surface | Depth of well | Perforated interval | Open hole | Date measured (1989) | Depth to water | Altitude of water level | Aquifer monitored |
|---|---|---|---|---|---|---|---|---|---|
| 51 | 7S-6E-16ABB2 | 2,553 | 1,980 | — | 158–190 | 3-21 | 5.00 | 2,548.00 | Sr |
| 52 | 7S-6E-16CDC1 | 2,595 | 513 | — | 389–513 | 3-20 | -73.52 | 2,668.52 | Vr |
| 53 | 7S-6E-16CDC2 | 2,606 | 353 | — | 80–353 | 3-20 | -12.92 | 2,618.92 | Sr |
| 54 | 7S-6E-21DBC1 | 2,631 | 760 | — | 167–760 | 3-20 | -36.94 | 2,667.94 | Vr |
| 55 | 7S-6E-21DBC2 | 2,635 | 611 | — | 167–611 | 3-20 | F | — | Vr |
| 56 | 7S-6E-22AADA1 | 2,648 | 1,410 | — | 400–1,410 | 3-21 | F | — | Vr |
| 57 | 7S-6E-22AADA2 | 2,645 | 585 | — | — | 3-21 | -19.42 | 2,664.42 | Vr |
| 58 | 7S-6E-23CAD1 | 2,675 | 1,300 | — | 40–900 | 3-22 | -19.72 | 2,694.72 | Vr |
| 59 | 7S-6E-23CCA1 | 2,625 | 460 | — | 107–460 | 3-21 | -17.62 | 2,642.62 | Sr |
| 60 | 7S-6E-23CDB1 | 2,635 | 1,030 | — | 341–1,000 | 3-22 | F | — | Vr |
| 61 | 7S-6E-23DCB1 | 2,710 | 1,220 | — | 365–1,220 | 3-22 | -7.92 | 2,717.92 | Vr |
| 62 | 7S-6E-26ADA1 | 2,700 | 1,000 | — | 171–1,000 | 3-24 | 16.84 | 2,683.16 | Vr |
| 63 | 7S-6E-26BDA1 | 2,655 | — | — | — | 3-20 | -42.72 | 2,697.72 | U |
| 64 | 7S-6E-27AAD1 | — | 350 | — | — | 3-22 | F | — | Vr |
| 65 | 7S-6E-27ADB1 | 2,626 | 400 | — | — | 3-22 | F | — | Vr |
| 66 | 7S-6E-34DAD1 | 2,725 | 300 | — | 46–300 | 4-11 | -9.18 | 2,734.18 | Vr |
| 67 | 8S-5E-16AAA1 | 3,010 | 410 | — | — | 5-16 | 321.40 | 2,688.60 | Vr |

Potentiometric contours for both the sedimentary- and volcanic-rock aquifers (fig. 13) were constructed from water-level measurements (table 7) made during nonpumping periods in spring 1989. Wells open to both the sedimentary- and volcanic-rock aquifers were treated as if they were completed in the volcanic-rock aquifer (see section, "Ground-Water Development").

Ground-water movement in both the sedimentary- and volcanic-rock aquifers in spring 1989 generally was from south to north toward the Snake River. The altitude of hydraulic head in the sedimentary-rock aquifer ranges from about 2,525 ft above sea level as indicated by the water level in well 7S-5E-3DAD1 to 2,680 ft above sea level as indicated by the water level in well 7S-5E-28CBB1. Hydraulic head in the volcanic-rock aquifer ranges from about 2,622 ft above sea level as indicated by the water level in well 6S-4E-14ABC1 to 2,735 ft above sea level as indicated by the water level in well 7S-6E-34DAD1 (table 7). The average water-surface gradient is about 20 ft/mi toward the north in the sedimentary-rock aquifer and about 10 ft/mi toward the north in the volcanic-rock aquifer.

Spring 1989 potentiometric surfaces for the sedimentary- and volcanic-rock aquifers show four distinct cones of depression. In the northern part of the study area, from Bruneau Valley to Sugar Valley, a cone of depression has developed around irrigation wells completed in the sedimentary-rock aquifer. The large areal extent of this depression may reflect a long-term water-level decline due to withdrawals. A smaller depression in Bruneau Valley is centered around well 7S-6E-16ABB2. In these depressions, well discharge caused water levels to decline below 2,550 ft in altitude and reversed the direction of ground-water movement from north to south (fig. 13). Two small cones of depression on the spring 1989 surface are related to withdrawals from the volcanic-rock aquifer (fig. 13), one in Bruneau Valley and the other in Little Valley. These two depressions are near the southern end of each valley, where volcanic rocks are close to land surface and sedimentary rocks are thin (fig. 3).

Water is under artesian pressure in both the sedimentary- and volcanic-rock aquifers. Hydraulic head is as much as 50 ft higher in the volcanic-rock aquifer than in the sedimentary-rock aquifer in parts of Bruneau Valley, although differences are typically about 25 ft in most of the study area (fig. 13). Water-level data from three paired wells (table 8) also are used to demonstrate hydraulic head increases with depth throughout the study area. In each pair, the water level in wells completed in the volcanic-rock aquifer is higher than the water level in wells completed in the sedimentary-rock aquifer. This water level indicates that hydraulic head increases with depth from the sedi-

Table 8. Hydraulic heads and potential for vertical ground-water movement in paired wells

[Altitude of land surface and altitude of hydraulic head in feet above sea level. Depth of well and perforated interval or open hole in feet below land surface. Aquifer monitored: Sr, sedimentary-rock; Vr, volcanic-rock]

| Well No. | Altitude of land surface | Depth of well | Perforated interval or open hole | Aquifer monitored | Date measured | Altitude of hydraulic head | Hydraulic head difference between units | Potential vertical direction of ground-water movement |
|---|---|---|---|---|---|---|---|---|
| **Bruneau Valley** | | | | | | | | |
| 7S-6E-16CDC1 | 2,595 | 513 | 389 – 513 | Vr | 3-20-89 | 2,668.52 | | |
| 7S-6E-16CDC2 | 2,606 | 353 | 80 – 353 | Sr | 3-20-89 | 2,618.92 | 39.60 | Upward |
| **Near Indian Bathtub Spring** | | | | | | | | |
| 7S-6E-29BBA1 | 2,832.5 | 760 | 415 – 760 | Vr | 5-23-90 | 2,675.83 | | |
| 7S-6E-29BBA2 | 2,832.5 | 364 | 246 – 364 | Sr | 5-23-90 | 2,646.95 | 28.88 | Upward |
| **Little Valley** | | | | | | | | |
| 7S-4E-10BDB1 | 2,755 | 1,145 | 537–568, 616 – 737, 738 – 1,145 | Vr | 3-21-89 | 2,673.80 | | |
| 7S-4E-2CAB1 | 2,675 | 890 | 330 – 890 | Sr | 3-22-89 | 2,643.83 | 29.97 | Upward |

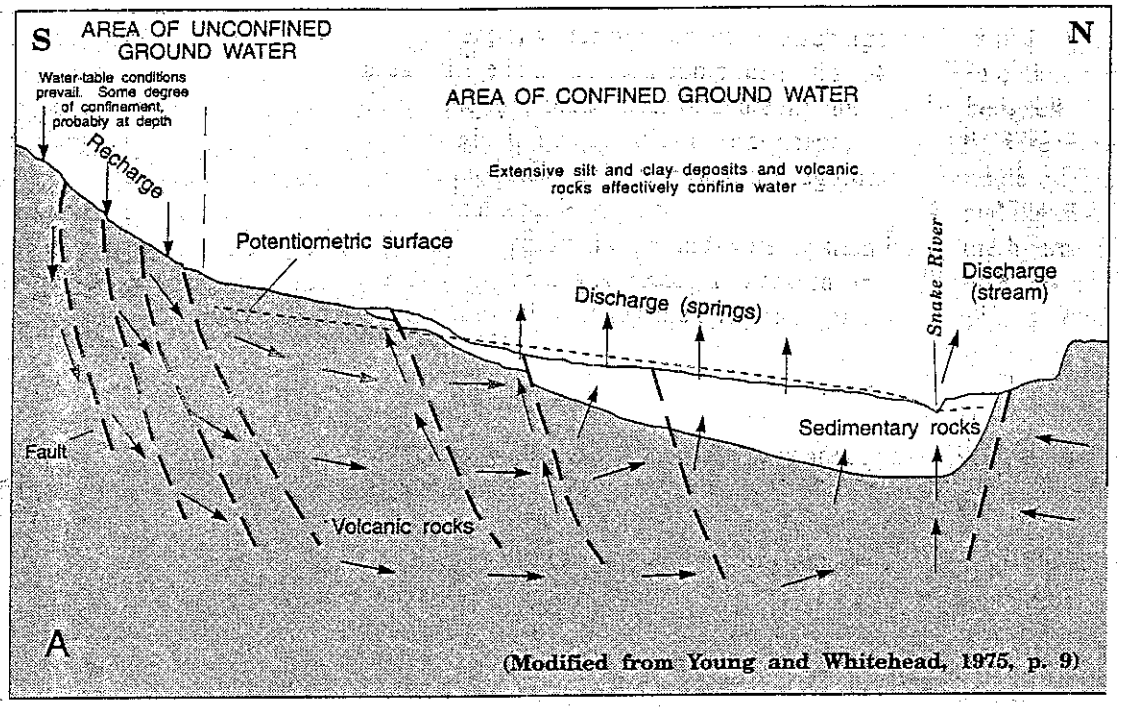
mentary-rock aquifer to the volcanic-rock aquifer, and water moves upward from the volcanic-rock aquifer into the sedimentary-rock aquifer.

The Bruneau area is intensively faulted, as indicated by geologic data (figs. 2 and 4). Previous investigators (Piper, 1924; Littleton and Crosthwaite, 1957; Young and Whitehead, 1975; Young and Lewis, 1982) believed that many faults and fractures are not barriers to water movement but instead provide conduits for ground-water flow, horizontally and vertically. Data collected during this study did not indicate abnormal water-level differences across any of the known faults in the study area. Additional study is needed to determine geologic controls on water movement in the study area.

## Conceptualization of the Geothermal Aquifer System

As described in preceding sections of this report, the ground-water system is a thick reservoir of sedimentary rocks (alluvial and lacustrine) and underlying volcanic rocks (fig. 14A). Sedimentary rocks are present in the northern and central parts of the study area and consist mainly of silt and clay with lesser amounts of sand. Sedimentary rocks are much less permeable than the volcanic rocks; their grain size and permeability decreases northward. The water table in these sediments is generally less than 100 ft below land surface and is shallowest near major streams. In most of the area, the water table is undefined. Water in the deeper parts of the sedimentary rocks is confined by interbedded silt and clay, and hydraulic head increases with depth due to regional discharge. Water-bearing properties of the volcanic rocks vary and are dependent largely on the amount of fracturing and faulting. Generally, volcanic rocks are more permeable than sedimentary rocks; their permeability decreases southward. Water in volcanic rocks is confined where the rocks are dense and fine-grained sedimentary interbeds are present. Water levels in wells in the volcanic rocks vary with depth of perforated interval or open section.

The ground-water reservoir underlying the Bruneau area functions as a three-dimensional flow system. Generally, water flows northward from the areas of recharge in and around the Jarbidge and Owyhee Mountains toward the study area, where it is discharged as springs and as seepage to streams or leaves the study area as ground-water underflow (fig. 14A). In recharge areas, there is a downward



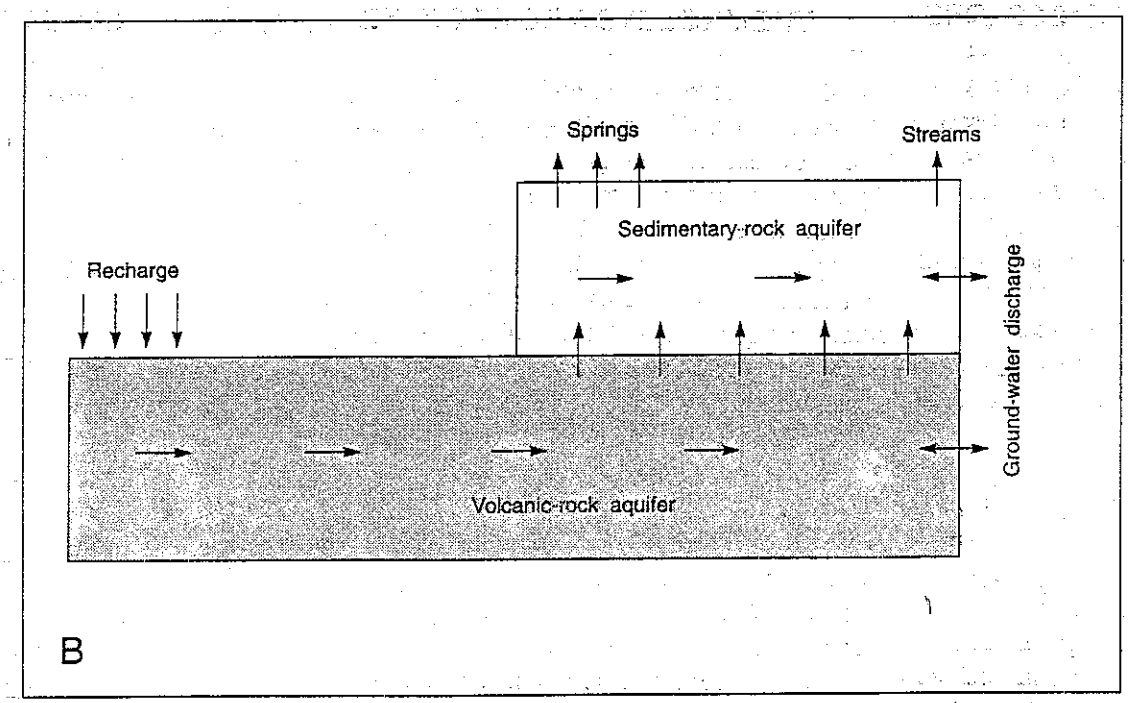




**Figure 14.** Conceptualization of the regional geothermal aquifer system in the Bruneau study area. A, Diagrammatic section. B, Conceptual model. (Arrows show direction of ground-water movement)

component of water movement; in discharge areas, there is an upward component (fig. 14). Consequently, head varies both areally and with depth, and a multiple-layer concept is required to reasonably represent the regional geothermal aquifer system.

In this study, the ground-water system in the Bruneau area was treated as a two-layer system consisting of sedimentary rocks and volcanic rocks, which together compose the regional geothermal aquifer system (fig. 14B). Sedimentary rocks predominate in the northern and central parts of the study area and generally extend from about 100 to 2,000 ft below land surface. Volcanic rocks predominate in the southern part of the study area and underlie sedimentary rocks in the northern part. Thickness of the volcanic rocks is not known but is probably 2,000 to 3,000 ft (Young and Lewis, 1982, p. J17).

## EFFECTS OF DEVELOPMENT

From the late 1890's through 1991, nearly 1,400,000 acre-ft of water was discharged from flowing and pumped wells completed in the geothermal system in the study area, and about 275,000 acre-ft discharged from Indian Bathtub Spring. Of these quantities, about 546,000 acre-ft was discharged by wells and 2,000 acre-ft was spring flow during 1978–91. Most water discharged from wells, about 339,000 acre-ft, was from the volcanic-rock aquifer. Of this quantity, about 78,000, 218,000, and 43,000 acre-ft were from wells in Bruneau, Little, and Sugar Valleys, respectively.

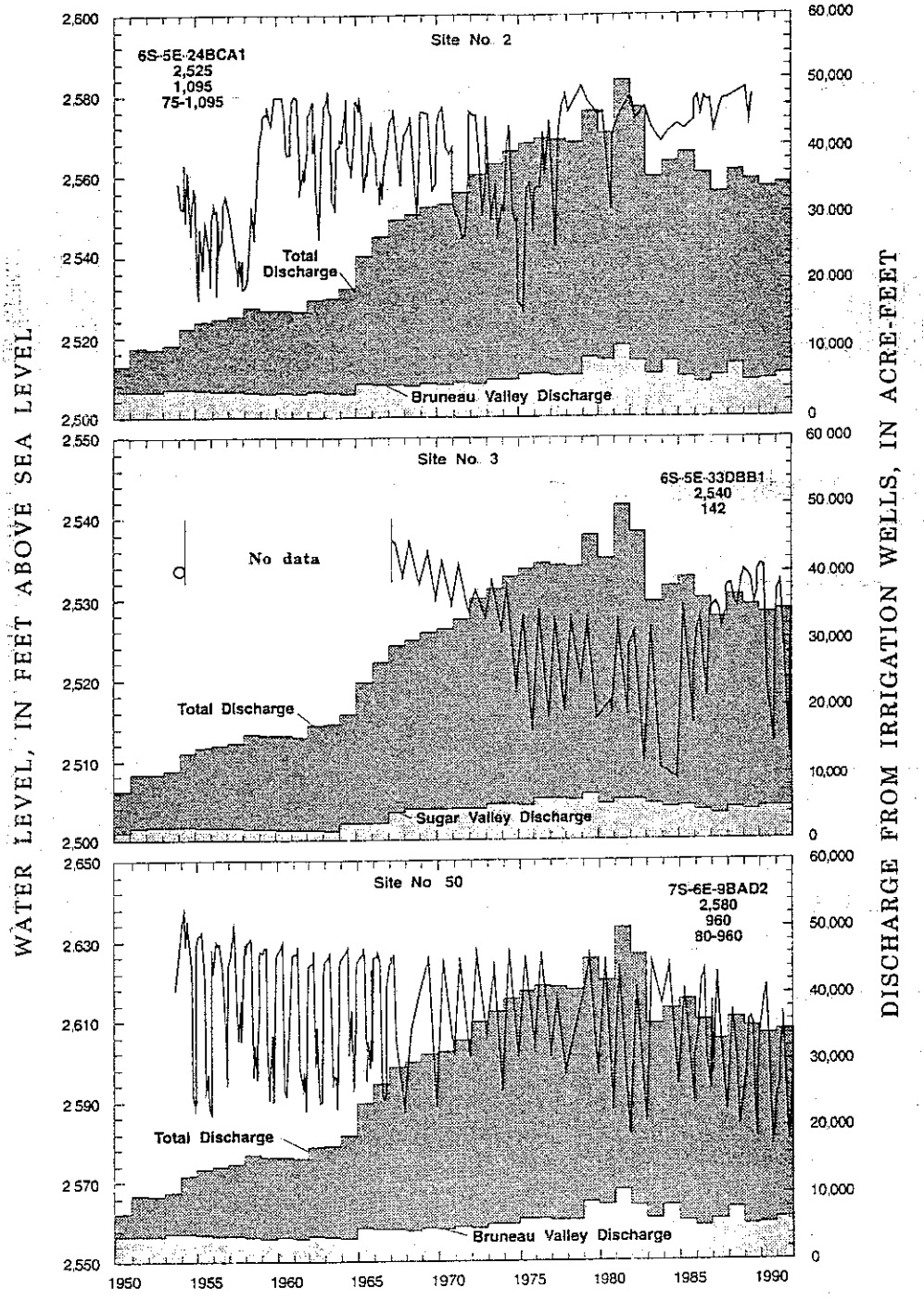
Response of the ground-water system to pumpage stress is complex. The two most apparent effects are declines in hydraulic head and declines in spring discharge.

### Declines in Hydraulic Head

Hydraulic heads in the geothermal aquifer generally have declined since measurements began in the mid-1950's. The annual rate of decline and the net change in head between 1977 and 1989, when measurements of water levels in a large number of wells were made, vary areally depending on the degree and distribution of pumpage (figs. 7 and 9) and the hydraulic properties of the aquifer (see section "Hydraulic Characteristics"). Hydrographs of head changes in eight wells illustrate typical rates and magnitudes of change in various parts of the study area. Hydrographs for wells open only to the sedimentary-rock aquifer are shown in figure 15; hydrographs for wells open to the volcanic-rock aquifer are shown in figure 16.

Hydrographs for wells completed in the sedimentary-rock aquifer indicate small long-term changes in water levels. Annual fluctuations in water levels are mainly aquifer response to pumpage for irrigation. The hydrograph for well 6S-5E-24BCA1 indicates that water levels declined slowly from the early 1960's to 1977, probably owing to a gradual increase in pumpage, and later rose as pumpage decreased. Thirty percent of the total discharge in Little and Sugar Valleys is from wells open only to the sedimentary-rock aquifer; most wells are in the northern part of the study area. During the 1990–91 nonirrigation season, the water level in well 6S-5E-33DBB1 declined about 6 ft. The large decline probably was due to pumping of this well or nearby wells. The water level in well 7S-6E-9BAD2 in Bruneau Valley declined slowly until 1986, then the rate of decline accelerated in spite of the decline in pumpage.

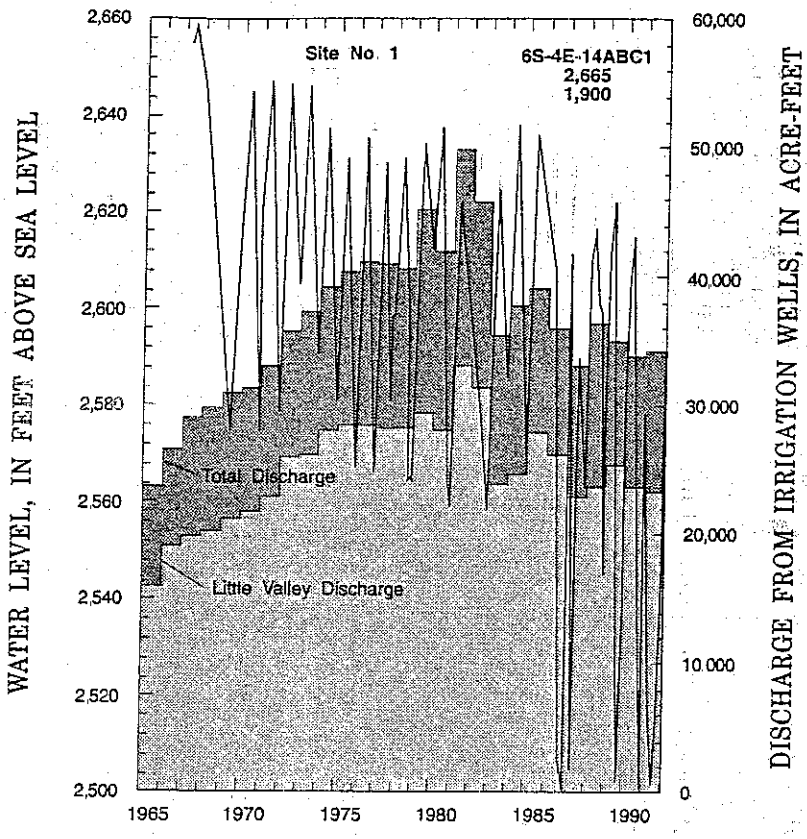
Hydrographs for wells completed in the volcanic-rock aquifer indicate large long-term changes (decreases) in hydraulic head in the aquifer (fig. 16). No long-term water-level data are available for such wells in Sugar Valley. Wells 6S-4E-14ABC1, 7S-5E-18BCD1, and 7S-5E-19CCC1 in Little Valley, where pumpage since 1954 has been the greatest, exhibit large water-level declines. The hydrograph for well 6S-4E-14ABC1, an irrigation well, shows that the water level declined about




EXPLANATION

| | | |
|---|---|---|
| Measured water level | 7S-6E-9BAD2 | Well number |
| | 2,580 | Altitude of land surface, in feet above sea level |
| Single water-level measurement | 960 | Depth of well, in feet below land surface |
| | 80-960 | Perforated interval and (or) open hole, in feet below land surface (no data for Site No. 3) |

**Figure 15.** Hydrographs for wells completed in the sedimentary-rock aquifer. (Site numbers refer to table 7 and fig 13)




## EXPLANATION

| | |
|---|---|
| ———— | Measured water level |
| o | Single water-level measurement |
| 7S-5E-19CCC1 | Well number |
| 2,720 | Altitude of land surface, in feet above sea level |
| 760 | Depth of well, in feet below land surface (no data for Site No. 63) |
| 309-760 | Perforated interval and (or) open hole, in feet below land surface (no data for Site Nos. 1 and 63) |

**Figure 16.** Hydrographs for wells completed in the volcanic-rock aquifer. (Site numbers refer to table 7 and fig. 13)

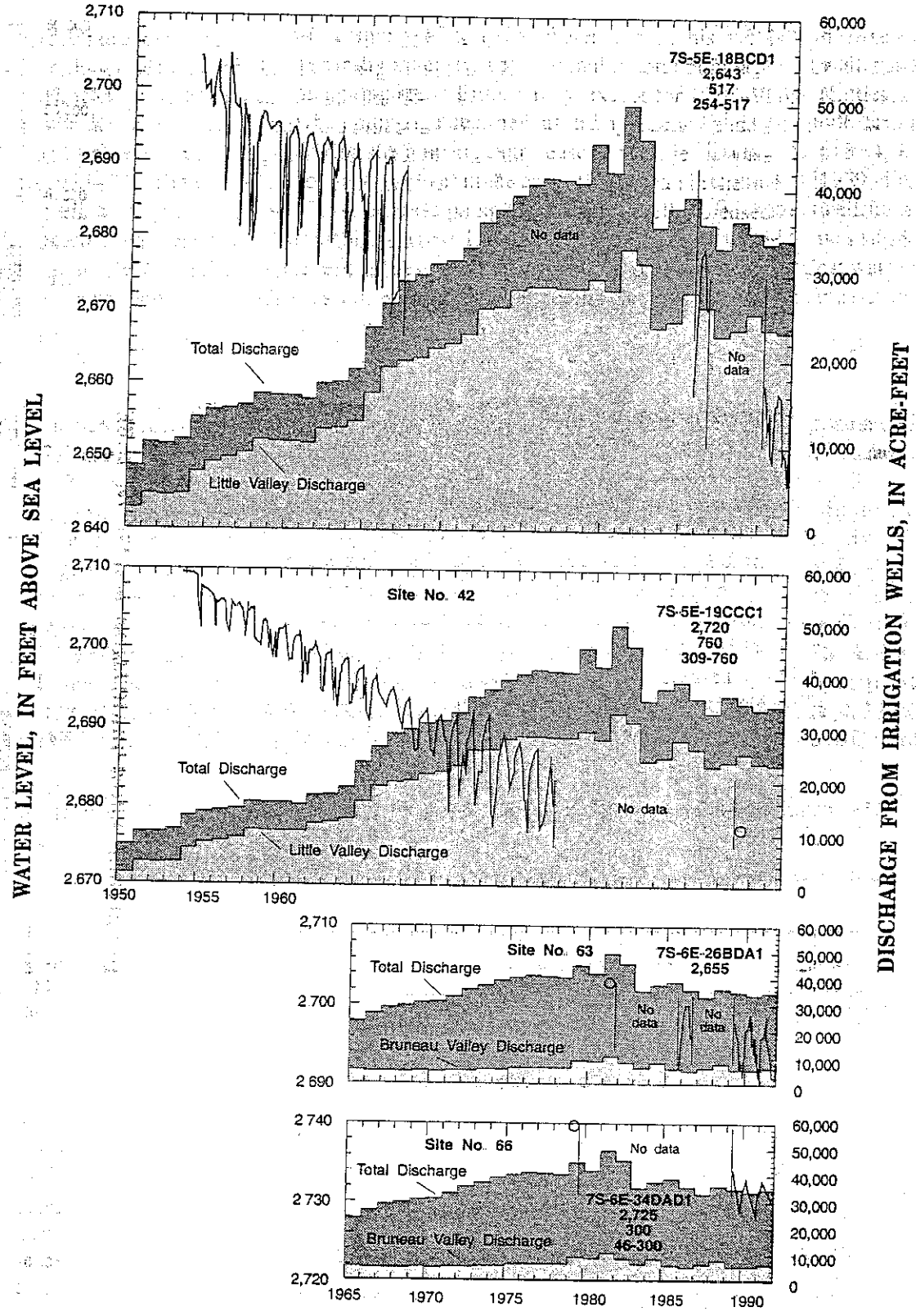



**Figure 16.** Hydrographs for wells completed in the volcanic-rock aquifer—Continued.

70 ft from 1967 to 1991. Water level in this well is generally inversely proportional to total pumpage and pumpage in Little Valley, except for 1986–91, when pumpage declined, as did hydraulic head. During the nonirrigation season, water level was about 30 ft lower in the early 1990's than in the late 1980's because pumpage from this well increased fourfold to about 1,400 acre-ft/yr. The large water-level changes between irrigation and nonirrigation seasons indicate that the specific capacity for this well is probably low and hydraulic conductivity of the volcanic rocks in this area is accordingly low. The water level in well 7S-5E-18BCD1 declined about 45 ft from 1954 to 1991. The rate of decline was about 0.8 ft/yr during 1954–85, compared with 4.0 ft/yr during 1986–91. These rates of decline were based on the highest water-level values in 1954, 1986, and 1991. The reason for the increased rate is unknown because discharge from wells in Little Valley and total discharge from flowing and pumped wells in the study area have been relatively constant since 1983. From 1950 to 1983, well discharge in Little Valley increased gradually. The water level in well 7S-5E-19CCC1, about 1.5 mi south of well 7S-5E-18BCD1, declined steadily after 1953. Pumpage from this well was estimated to be about 500 acre-ft in 1954 (Littleton and Crosthwaite, 1957, p. 174, 188); 400 acre-ft in 1978 (Young and others, 1979, p. 3–4, 12); and averaged about 300 acre-ft during 1979–91. The rate of water-level decline in this well, based on the highest levels in 1953 and 1977, was slightly less than 1 ft/yr. On the basis of highest water-level measurements in 1977 and a single measurement in 1989, the rate of decline has decreased; during that time, total pumpage decreased about 500 acre-ft/yr.

Two hydrographs are used to show the intermediate effects of ground-water development in Bruneau Valley, although the earliest data are for 1979. The hydrograph for well 7S-6E-26BDA1 (fig. 16), an irrigation well, shows that the water level declined about 5 ft, or about 0.5 ft/yr during 1981–91. The steady decline can be related to the relatively steady pumpage in Bruneau Valley during this period. The water level in irrigation well 7S-6E-34DAD1, about 1 mi from Indian Bathtub Spring, declined about 8 ft since 1979, or about 0.7 ft/yr. Although wells 7S-6E-34DAD1 and 7S-6E-26BDA1 are about 2 mi apart, water levels in both

**Table 9.** Spring 1979, 1989, and 1992 hydraulic head measurements and head declines since 1979 at selected wells in the Bruneau study area

[Altitude of land surface and altitude of hydraulic head in feet above sea level. Head declines since spring 1979 in feet. Symbols: —, no data available]

| | | Spring 1979 (Young and Lewis, 1982) | | Spring 1989 | | | Spring 1992 | | |
|---|---|---|---|---|---|---|---|---|---|
| Well No. | Altitude of land surface | Date measured | Altitude of hydraulic head | Date measured | Altitude of hydraulic head | Head declines since spring 1979 | Date measured | Altitude of hydraulic head | Head declines since spring 1979 |
| **Aquifer unknown** | | | | | | | | | |
| 7S-4E-1CDC1 | 2,670 | 3-31 | 2,676.82 | 3-23 | 2,670.72 | 6.10 | — | — | — |
| **Sedimentary-rock aquifer** | | | | | | | | | |
| 7S-6E-9BAD2 | 2,580 | 3-15 | 2,626.42 | 3-20 | 2,612.12 | 14.30 | 2-19 | 2,609.10 | 17.32 |
| **Volcanic-rock aquifer** | | | | | | | | | |
| 6S-4E-14ABC1 | 2,665 | 3-13 | 2,628.56 | 3-21 | 2,622.06 | 6.50 | 1-28 | 2,604.74 | 23.82 |
| 7S-4E-10BDB1 | 2,755 | 3-14 | 2,678.08 | 3-21 | 2,673.80 | 4.28 | — | — | — |
| 7S-4E-27BCC1 | 2,770 | 3-14 | 2,675.00 | 3-21 | 2,668.07 | 6.93 | 2-19 | 2,664.95 | 10.05 |
| 7S-5E-13CBB1 | 2,771 | 3-15 | 2,657.78 | 3-22 | 2,652.20 | 5.58 | 2-19 | 2,665.56 | 7.78 |
| 7S-6E-16CDC1 | 2,595 | 3-15 | 2,667 | 3-20 | 2,668.52 | 1.52 | 2-11 | 2,666.88 | .12 |
| 7S-6E-34DAD1 | 2,725 | 3-15 | 2,739.92 | 4-11 | 2,734.18 | 5.74 | 2-19 | 2,730.60 | 9.32 |

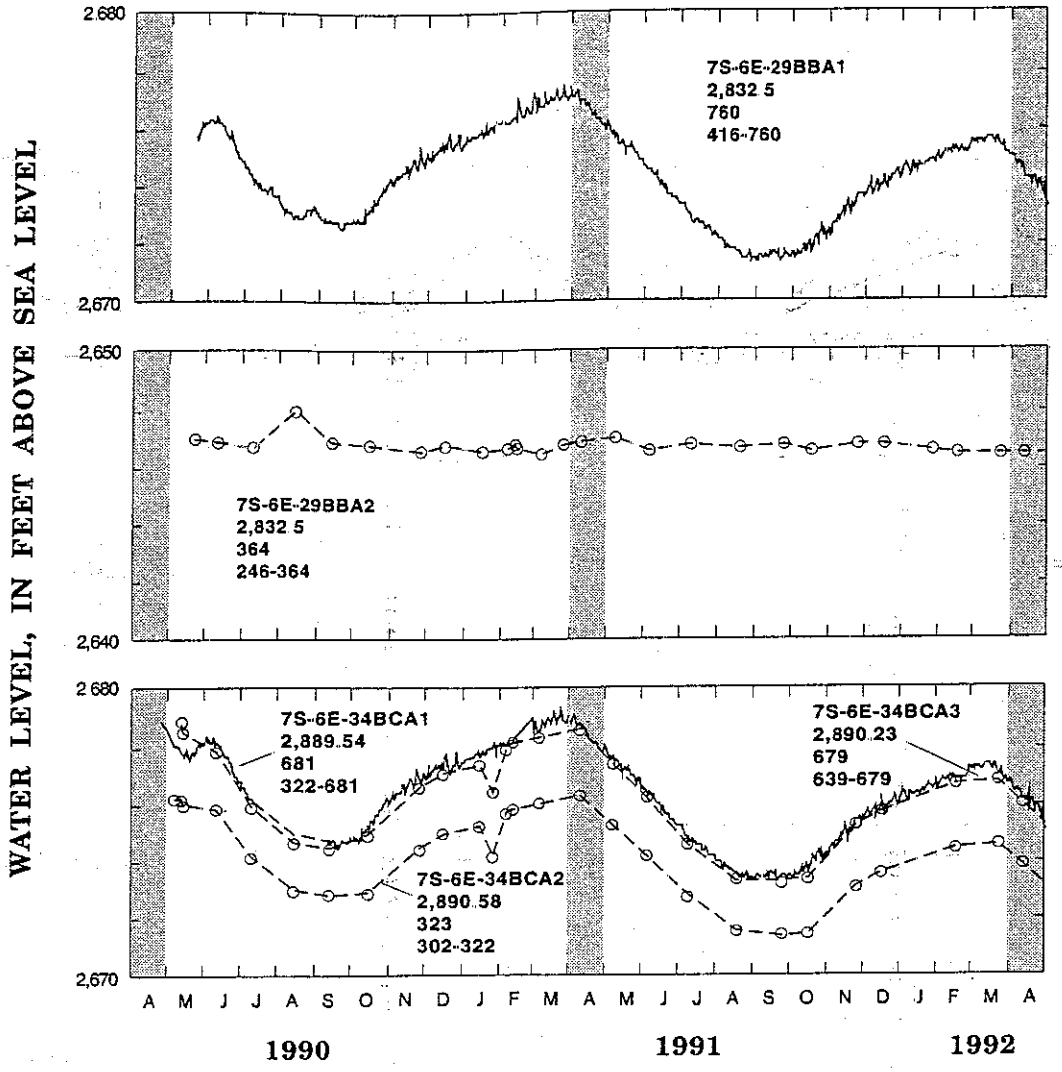
exhibited nearly the same rate of decline. Hydraulic heads in and around Indian Bathtub Spring probably decline at about the same rate as the water levels in wells 7S-6E-34DAD1 and 7S-6E-26BDA1, because these wells and the test holes near Indian Bathtub Spring have had about the same rate of decline since 1990. The only exception to the generally declining heads appears to be in wells open to the sedimentary-rock aquifer.

An attempt was made to remeasure water levels in all wells measured in 1979 by Young and Lewis (1982) to show the effects of recent ground-water pumpage on hydraulic heads. Only a general comparison between the 1979 (Young and Lewis, 1982, pl. 2) and 1989 (fig. 13) potentiometric surfaces was possible because of the 100-ft contour interval on the 1979 map and consequent differences in detail. Although more water levels were measured in 1989, control for both maps was still sparse in much of the study area. Many of the wells measured in 1979 could not be remeasured in 1989 because they had been destroyed or for some other reason were no longer measurable. Only eight wells measured in 1979 were remeasured during this study. Of these, one well, 7S-6E-9BAD2, is open only to the sedimentary-rock aquifer (table 9). The water level in that well, about 1 mi south of the depression on the potentiometric surface shown in figure 13, declined 14.30 ft and 17.32 ft during 1979–89 and 1979–92, respectively.

Six of the eight wells remeasured in 1989 are completed in the volcanic-rock aquifer (table 9). During 1979–89, the water levels in five of the wells declined more than 4 ft, and the water level in one well rose 1.52 ft. The water level in well 6S-4E-14ABC1 in the northern part of Little Valley declined 6.50 ft and 23.82 ft during 1979–89 and 1979–92, respectively. Declines were steeper between 1989 and 1992 when pumpage from this well increased fourfold. The water level in well 7S-6E-34DAD1 declined 5.74 ft by 1989 and 9.32 ft by 1992 (table 9), or about 0.7 ft/yr (fig. 16). The water levels in wells 7S-4E-27BCC1 and 7S-6E-16CDC1 declined 10.05 ft and 0.12 ft between 1979 and 1992, respectively. The water level in well 7S-5E-13CBB1 rose more than 13 ft between 1989 and 1992 because it was not pumped, as opposed to previous years of pumping.

During the second phase of this study, eight test holes at four sites near Indian Bathtub Spring were equipped with recorders to obtain continuous water-level measurements. The test hole at 7S-6E-29BBA1 was completed to monitor water levels at two different depths to determine the vertical distribution of hydraulic head. Hydrographs for the test holes are shown in figure 17. Water levels fluctuate seasonally and are highest in March-April and lowest in September-October. Seasonal fluctuations are, in part, due to irrigation pumpage. Water levels declined about 5 ft during the 1990 irrigation season, recovered to April 1990 levels prior to the start of the 1991 irrigation season, and declined about 6 ft during the 1991 irrigation season. Following the 1991 irrigation season, water levels did not recover to April 1990 levels and were 1 to 2 ft lower in spring 1992 than they were in spring 1991. Water levels changed less in test hole 7S-6E-29BBA2 because it is open only to the sedimentary rocks, and about 10 percent of the ground-water discharge in Bruneau Valley is from the sedimentary rocks. In test hole 8S-6E-3BDC3, water levels did not rise as high or decline as low as in the other test holes because this test hole is open to 20 ft of basalt between 10-ft intervals of fine-grained rocks. The fine-grained rocks confine water in the basalt and cause delayed and attenuated responses from pumpage in aquifers below or above such units (see sections, "Slug Tests" and "Potentiometric Surfaces and Water Movement"). Hydrographs for the test holes (fig. 17) show that hydraulic head, even in nonstressed areas, is highly sensitive to well discharge.

Throughout the study area, hydraulic head responds to stress in a similar manner. Declines in head are the result of regional




## EXPLANATION

— — — **Measured/estimated hydraulic head**—Solid line indicates head from continuous recorder. Dashed line indicates head measured at least monthly

○ **Single water-level measurement**

7S-6E-34BCA2 **Test hole**

2,890.58 **Altitude of land surface, in feet above sea level**

323 **Depth of well, in feet below land surface**

302-322 **Open hole, in feet below land surface**

**Figure 17.** Hydrographs for test holes near Indian Bathtub Spring, April 1990 through April 1992.

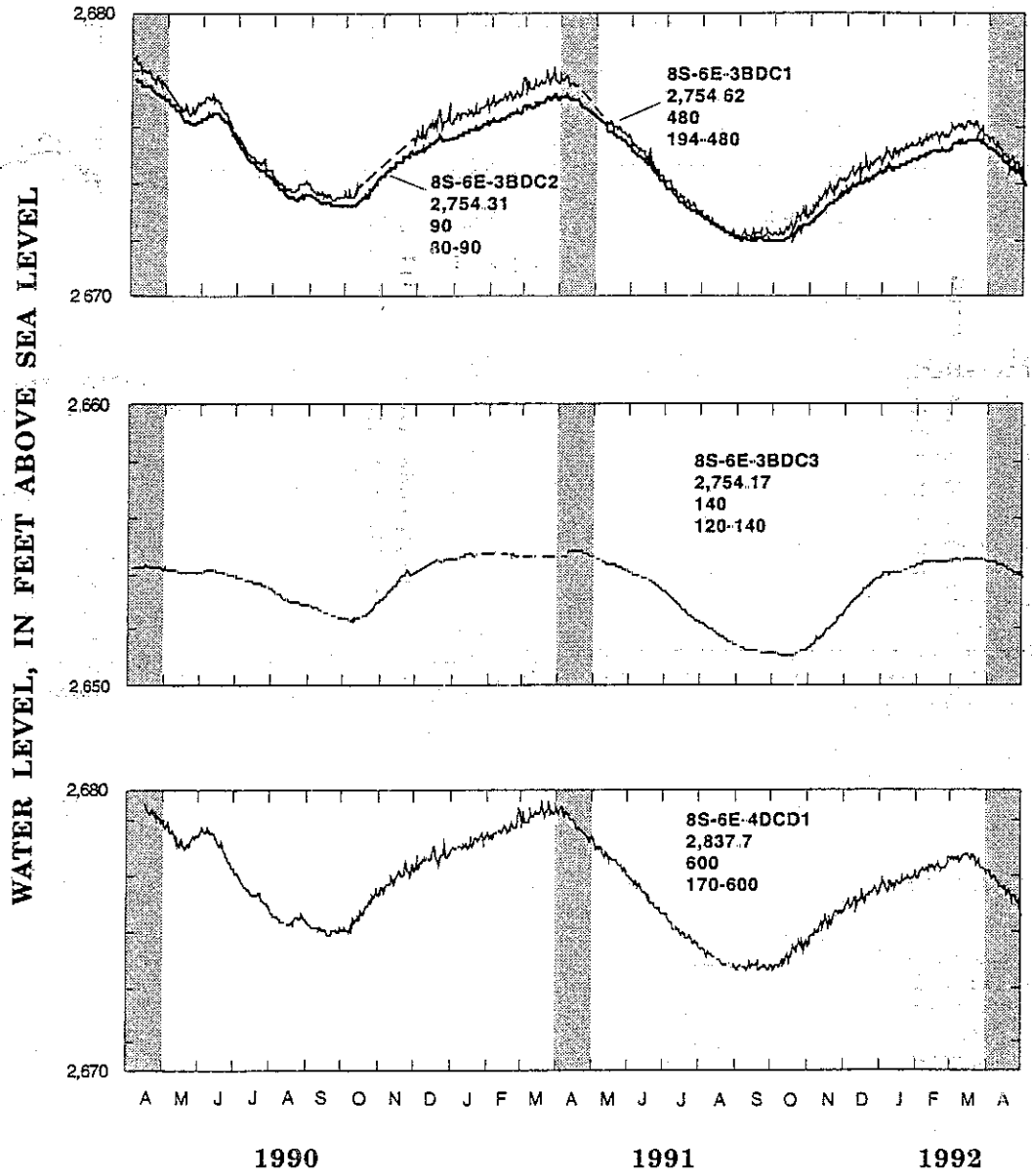
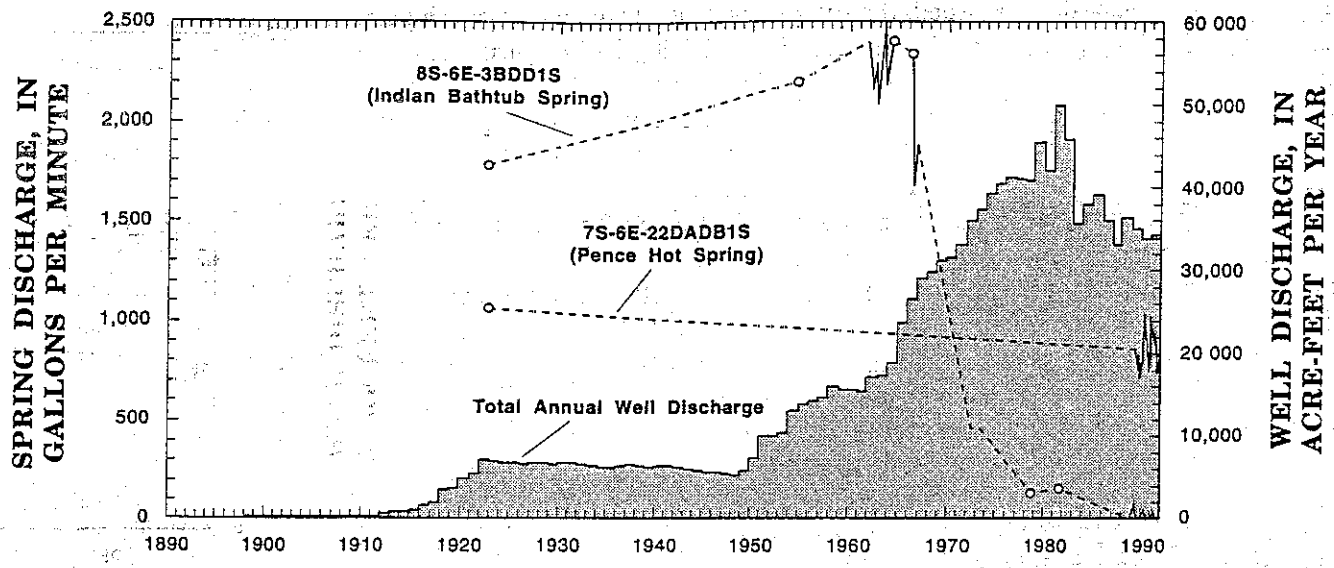



**Figure 17.** Hydrographs for test holes near Indian Bathtub Spring, April 1990 through April 1992—Continued.




**EXPLANATION**

——— ----- **Measured/estimated spring discharge**—Solid line indicates discharge measured at least annually. Dashed line indicates estimated discharge

o **Single spring discharge measurement**

**Figure 18.** Discharge of Indian Bathtub and Pence Hot Springs and total annual well discharge in the Bruneau study area, 1890-1991. (Spring locations shown on fig. 2)

effects of well discharges. Declines do not appear to be attributable to a single well or group of wells.

## Declines in Spring Discharge

Within the past 25 years, discharge from monitored springs along Hot Creek and the Bruneau River has declined, most notably from Indian Bathtub Spring (8S-6E-3BDD1S). In the last several years, Indian Bathtub Spring has ceased to flow during the summer and early fall (Young and others, 1990, p. 15). The decline in spring discharges probably has minimal effect on ranchers and farmers who, in large part, do not rely on spring water; however, the cessation of some springs may adversely affect the Bruneau Hot Springs snail.

Discharge from wells (flowing and pumped) has caused hydraulic head in the regional geothermal aquifer system to decline, especially in the volcanic rocks. Discharges from Indian Bathtub Spring (8S-6E-3BDD1S) and Pence Hot Spring (7S-6E-22DADB1S) and total annual well discharge in the study area are shown in figure 18. Prior to 1966, discharge from Indian Bathtub Spring ranged from about 1,700 to 2,500 gal/min, and discharge from wells was less than about 25,000 acre-ft/yr. After 1966, discharge from Indian Bathtub Spring began to decline and discharge from wells was greater than 25,000 acre-ft/yr, reaching a maximum of about 49,900 acre-ft in 1981. Discharge from Indian Bathtub Spring has continued to decline since 1981.

About 275,000 acre-ft of water has discharged from Indian Bathtub Spring since the first wells were drilled in 1896; only about 1,400 acre-ft was discharged during 1982–91. In contrast, discharge from Pence Hot Spring ranged from about 700 to 1,100 gal/min since 1922 (fig. 18) because the point of zero flow (pzf), or altitude of the point of discharge, is considerably lower than that of Indian Bathtub Spring. The pzf for Pence Hot Spring is about 2,585 ft, whereas the pzf for Indian Bathtub Spring is about 2,670 ft.

Changes in spring discharges are similar to changes in hydraulic heads, which fluctuate seasonally and are substantially less in late summer than in the spring (fig. 19). Discharges typically peak in March but were less during 1992 than during 1991, except for the spring at 7S-6E-34BCB1S. Monthly discharge measurements for four springs and the water level in test hole 8S-6E-3BDC1 during April 1990 to April 1992 showed corresponding decreases and increases (figs. 12 and 19). The water level in test hole 8S-6E-3BDC1 was used for comparison because it probably reflects the hydraulic head at Indian Bathtub Spring (8S-6E-3BDD1S, lower site; and 8S-6E-3BDD2S, vent) and continuous data are available since April 1990.

Because these springs discharge confined water (artesian springs), the quantity of discharge should follow Darcy's equation and be proportional to hydraulic head (see section, "Natural Recharge and Discharge"). If the length of the flowpath (length from the top of the confined aquifer to land surface), the cross-sectional area of the flowpath ($A$), and the hydraulic conductivity ($K$) are constant, spring discharge is linearly proportional to hydraulic head and can be plotted as a straight line on a rectangular grid. Data for 1990–92 were used to develop the hydraulic head/spring discharge relation. The relation between water level in test hole 8S-6E-3BDC1 and spring discharge is shown in figure 20. A hydraulic head/spring discharge relation probably exists because the data tend to follow some curve (figs. 20A and 20B). Data in figures 20C and 20D are more scattered and no one curve can reasonably represent the data, so no curves were developed. More data, especially in the upper and lower discharge ranges, are needed before a curve can be developed for these springs.

An important assumption made for the hydraulic head/spring discharge relation for springs at the lower (8S-6E-3BDD1S) and vent (8S-6E-3BDD2S) sites at Indian Bathtub Spring was that no deposition or scour occurred in the Indian Bathtub area during 1990–92, the period used to develop a hydraulic head/spring discharge relation. Depositing or scouring of sediments on the floor of Indian Bathtub could change the pzf, or altitude of the discharge, because of the change in the altitude of the sediments; thus, the hydraulic head/spring discharge could change. H.W. Young (U.S. Geological Survey, oral commun., 1992) indicated that in 1964, probably no sediments existed on the floor of Indian Bathtub. By 1992, sediments probably less than 10 ft thick covered the floor of Indian Bathtub.

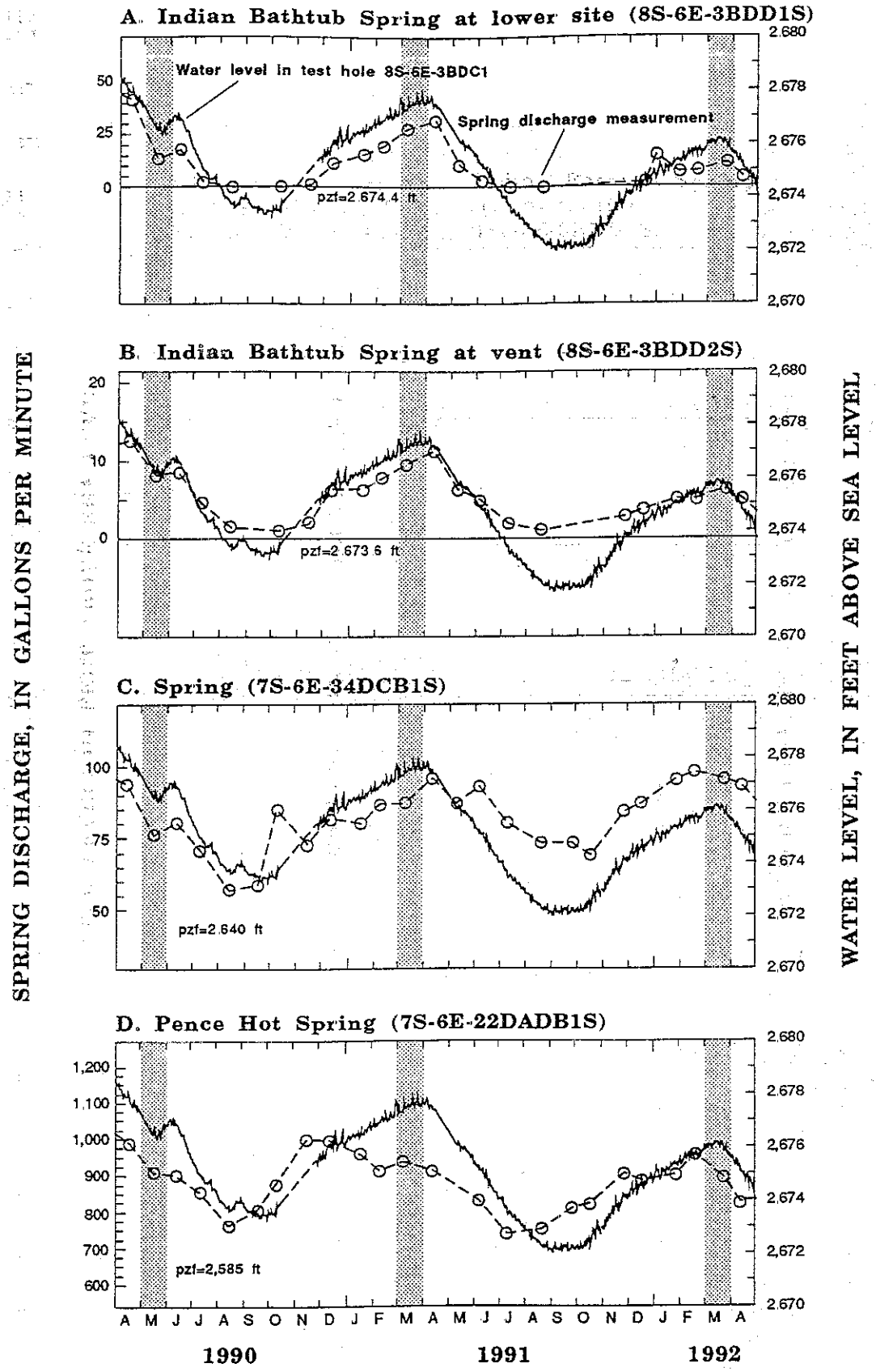



**Figure 19.** Hydrographs for test hole 8S-6E-3BDC1 and spring discharge at four sites. (pzf, point of zero flow)

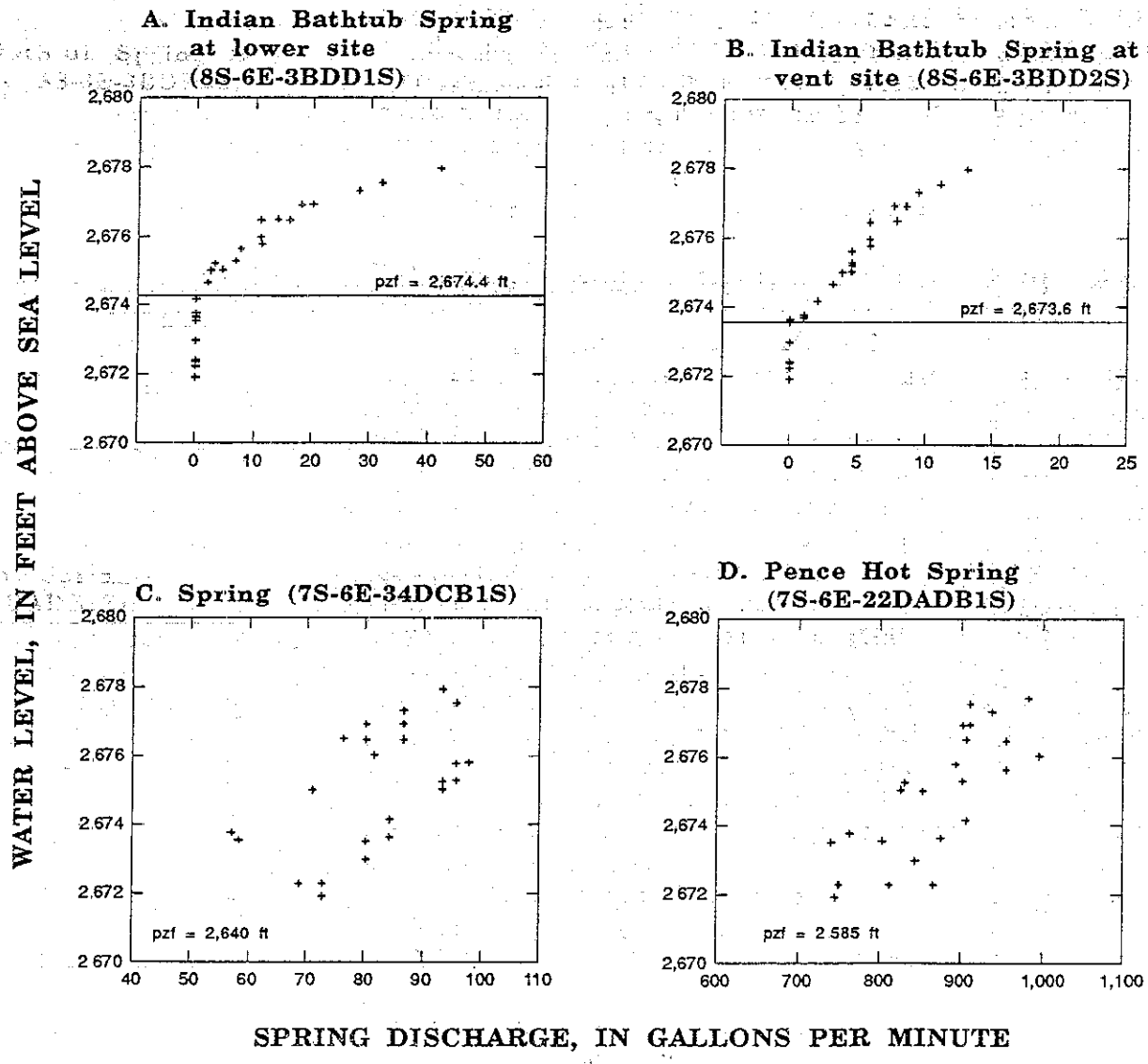



**Figure 20.** Relation between water level in test hole 8S-6E-3BDC1 and discharge at four springs. (pzf, point of zero flow)

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Field Guide

# BOISE GEOTHERMAL SYSTEM, IDAHO

by

WILL L. BURNHAM AND SPENCER H. WOOD




**38th Annual Meeting**

## ROCKY MOUNTAIN SECTION

**The Geological Society of America**

*with the*
Rocky Mountain Section of the
Paleontological Society

**April 22–24, 1985**
**Boise State University**
**Boise, Idaho**

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# FIELD TRIP GUIDE FOR

# GEOLOGY OF THE BOISE GEOTHERMAL SYSTEM

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## INTRODUCTION

Geothermal water presently used for space heating at Boise is drawn from wells which derive their principal yeilds from silicic volcanic rocks. Successful wells are along an 8-mile (13 km) reach of the northwest-trending range-front fault zone at the north margin of the Snake River Plain. The wells are within one-half mile (0.8 km) of this complex zone of normal faulting. Water temperature ranges from 190°F (84°C) at the southeast to about 150°F (63°C) at the northwest. This field trip will visit the sites of the principal wells; and three localities where rock units representative of the western plain and of the subsurface aquifers will be observed in outcrop. The route of the trip is given in Figure 1. The stratigraphic and lithologic sequence as drilled in the principal wells is given in Figure 2 (stop #1) and Figure #2 (stop #4). Figure 1 (stop #1) is a geologic map showing the distribution of geologic units throughout the field trip area.

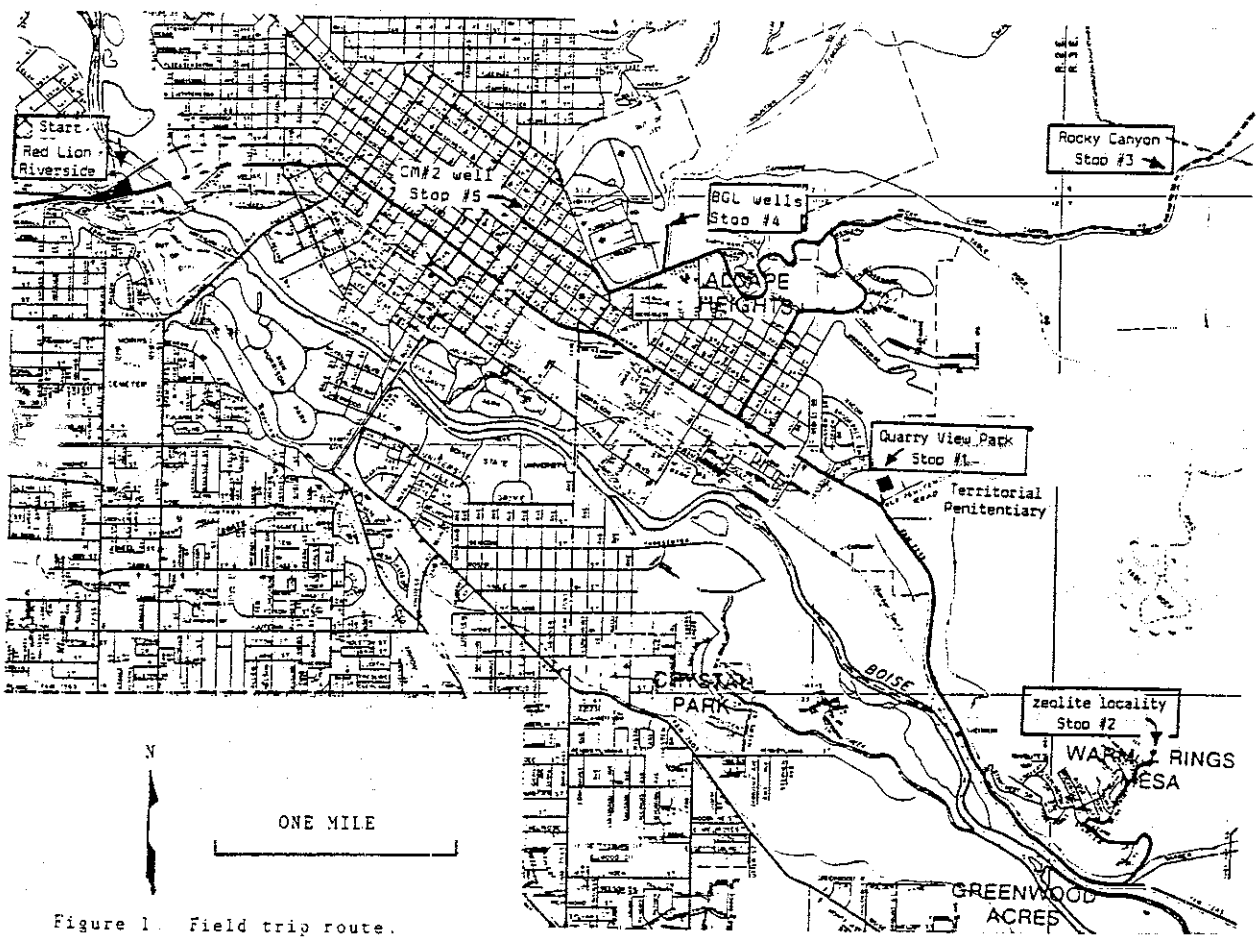



Figure 1. Field trip route.

STOP NO. 1

## PENITENTIARY HISTORIC AREA AND QUARRY VIEW CITY PARK, BOISE, IDAHO

### LOCATION

The Penitentiary historic area and Quarry View City Park are within the city limits of Boise, Idaho. The locality is accessable by city streets and by morning and evening city bus service. The area is 2 miles (3.2 km) southeast of the Idaho State Capitol building along Warm Springs Avenue (Fig. 1). Turn north from Warm Springs Avenue onto Old Penitentiary Road. Take the first left, about 200 ft (70 m) to Quarry View City Park. Parking and picnic areas are in the park. A major part of the area is a public park administered by the City of Boise and the Idaho Historical Society. The prominant outcrop of rhyolite, locally known as "Castle Rock" is in private land, but at the present time, access is not restricted.

### SIGNIFICANCE

Exposed in a long and narrow uplifted fault block that lies immediately north of the park area are representative rhyolite and basalt flow rocks and overlying lacustrine and fluvial sediments of the late Cenozoic strata associated with the western Snake River Plain. The site lies at the northern margin of the Snake River Plain. In the foothills to the north these rocks lap against Cretaceous granitic rocks of the Idaho Batholith (Hyndman, 1980). The volcanic and sedimentary strata are a part of the time-transgressive volcanic stratigraphy proposed by Armstrong and others (1975) and originally discussed by Malde and Powers (1962). Structure at the site is typical of the normal-fault boundaries of the 50-km-wide rift-like basin of the western plain. The fault system is the conduit for 65°C (170°F) geothermal groundwater that supplies the oldest geothermal heating district in the United States. On the site are the original 1892 geothermal well-pump house and the 1870 Idaho Territorial Penitentiary: both are on the National Register of Historic Places.

### SITE INFORMATION

#### Geology

The rocky cliffs north of the park area contain representative rock formations of upper Cenozoic volcanic and sedimentary rocks of the western Snake River Plain (Figs. 2 and 3). The oldest rock at this locality is the rhyolite of Castle Rock. It is onlapped by a 50-ft (15 m) basalt sequence. A poorly-exposed, red-and-green, layered, sandy-clay unit 0-50 ft (15 m) thick unconformably overlies the volcanic rocks. At the top of this sequence is a nearly continuous 20-ft (6 m) bluff of sandstone that extends for several miles along this lowest ridge of the foothills. The fault system that borders the northwest side of the western plain is a complex zone of normal faulting about two miles wide. Rocks at this locality lie in a NW-trending elongate fault block (Fig. 1) that at this locality is about 2000 ft (700 m ) wide. Major down-to-south faults also occur south of the "Castle Rock" locality that are now buried by sediment beneath the plain.

The sandstone bluffs appear to be upwarped by the rhyolite mass of Castle Rock (Fig. 4). Waldemar Lindgren (1898) originally reported this feature as a

"laccolith in miniature". To interpret this structure as a laccolith the rhyolite would have to be intrusive into the basalt and sediments exposed on the hill. The exposure is not good, and it is understandable how such an interpretation was entertained, especially when his collegue, G.K. Gilbert, had eloquently argued that intrusive bodies of shallow igneous rocks had produced bulges and arches in the roofing strata in the Henry Mountains of Utah (Gilbert, 1877 and 1896; Hunt, 1980). Laccoliths were fashionable in the 1890's, and Lindgren writes:

> "At this interesting locality, well visible from near the Natatorium, the intrusive mass appears as a knob a few hundred feet long and 150 ft high, covered by an arched stratum of sandstone, very clearly uplifted by the force of intrusion. In the cut at the hot-water reservoir the sandy strata near the contact are seen to be locally disturbed, dipping southeasterly at a steep angle. This intrusive appears to form a laccolith in miniature. The rock is dark and glassy, not holocrystalline as would be expected *, and consists of small porphyritic soda-lime feldspars (andesine) and small augite crystals in a brownish perlitic glass with many feldspar microlites."
>
> note* Lindgren did not recognize this rock as a rhyolite, but classified it as an andesite based upon the phenocryst content.

Except for the arched sandstone, as seen from a distance, there is no evidence that the rhyolite is intrusive. Nevertheless, most of Gilbert's criteria for an intrusive laccolith (Hunt, 1980) exist at this locality: 1) no fragments of the (igneous rock) have been discovered in the associated strata..., 2) the (igneous rock) is in no case vesicular .... or fragmental..., 3) inclination of the strata indicates that they have been disturbed...

Two criteria not met by the rhyolite structure here are: 4) .... a sheet (of igneous rock), which for a certain distance has continued between two strata, breaks through one of them and strikes across bedding to some new horizon, resuming its course between other strata..., and 5) the strata which overlie as well as those which underlie laccoliths and sheets, are metamorphosed in the vicinity of the (igneous rock), and the greatest alteration is found in the strata which are in direct contact with it...

The disturbed strata which Lindgren speaks of can be seen at this locality, but they are more clearly disturbed by faulting than by intrusion. The arching of the sandstone can be interpreted as subsequent tectonic warping. The truncation of the basalt against the rhyolite is interpreted as an onlap relationship, and not as an intrusive relationship.

It is a tragedy to slay a beautiful hypothesis with a few more ugly facts; however, the stratigraphy encountered in a number of recent geothermal exploratory wells invariably shows that the rhyolite is overlain by basalt, the clay unit and basaltic tuffs, and finally by the sandstone and siltstone of the lower Idaho Group.

Stratigraphic names of rocks of the western Snake River Plain generally follow Malde and Powers (1962). The interfingering of volcanic, fluvial, and lacustrine facies complicate the assignment of formational names to these rocks. Armstrong and others (1975) have shown a systematic progression of volcanic and sedimentary facies that has migrated from west to east. In that study it is

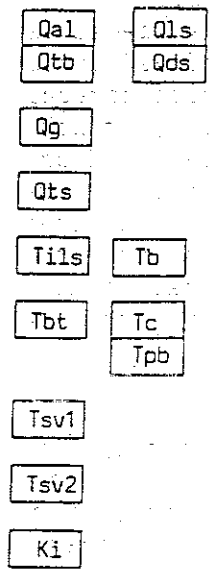
shown that at any one local section one sees (from oldest to youngest): (a) silicic volcanic rocks, mostly as ash-flow tuff deposits with minor basalt and sediment intercalations; (b) basalt flows with minor intercalated sediment and local silicic volcanic rocks; and (c) lacustrine and fluviatile sediments complexly interstratified with basalt flows. Associated with this facies progression is a systematic-age decrease of the rhyolite to the east that has been interpreted by many as a record of the continental lithosphere sliding over a fixed "hot spot" in the mantle at an average rate of 3.5 cm/yr (Morgan, 1972; Suppe and others, 1975; Leeman, 1982). A similar facies sequence is exhibited on a much compressed vertical scale at this locality. The oldest rock here is of the upper Miocene Idavada Group of silicic volcanic rocks. The overlying and overlapping porphyritic basalt is similar to rocks that have been mapped elsewhere as the the Banbury Formation, and the lacustrine clay and cross-bedded sandstone is typical of some units of the lower Idaho Group. Because of the age-and-facies progression now recognized across the plain, use of formation names such as the Banbury basalt has led to confusion, and has been discouraged by recent investigators (Wood and Anderson, 1981; Hart and others, 1984)

## Rhyolite of "Castle Rock"

The dark rhyolite outcrops on the hill are the upper part of a tabular body of rhyolite that is known from recent drilling to be at least 300 ft (90 m) thick It is encountered in drill holes at a depth of 850 ft (260 m) beneath the Park area and 2000 ft (610 m) deep

EXPLANATION

Correlation of map units




| | |
|---|---|
| Qal | Alluvial deposits within floodplain of modern streams. |
| Qtb | Alluvial deposits of a late Quaternary terrace of the Boise River. |
| Qls | Landslide deposits ranging in age from late Quaternary to active in historic time. |
| Qds | Sandstone layers, folded and disturbed by shallow landsliding prior to the Warm Springs Mesa landslide. |
| Qg | Gravel deposits of stream terraces generally 16 m (50 ft) above modern streams |
| QTs | Sandstone, sand, gravel high in the stratigraphic section, but considered part of the lower Idaho Group. |
| Tils | Sandstone and minor silt layers of the lower Idaho Group. |
| Tb | Basalt within sediment of the lower Idaho Group. |
| Tbt | Basaltic tuff, brown in color with interbedded basalt flows. |
| Tc | Clay, maroon and light green in color with interbedded thin arkosic sand. |
| Tpb | Basalt, typically contains one or more flows with large plagioclase phenocrysts. |
| Tsv1 | Rhyolite of "Castle Rock" |
| Tsv2 | Rhyolite of Rocky Canyon. |
| Ki | Granitic rocks of the Idaho batholith. |

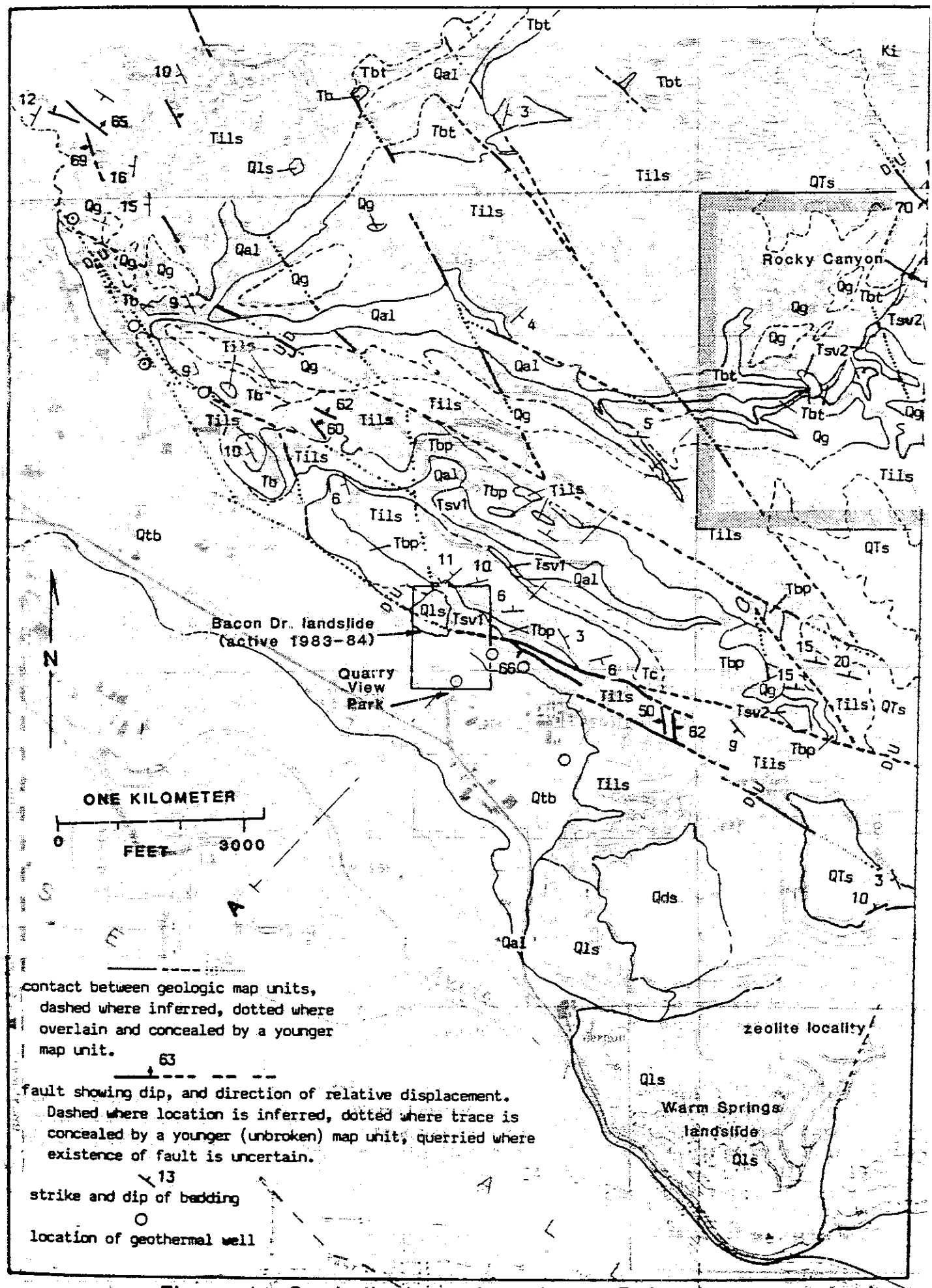



Figure 1. Geologic map of northeast Boise

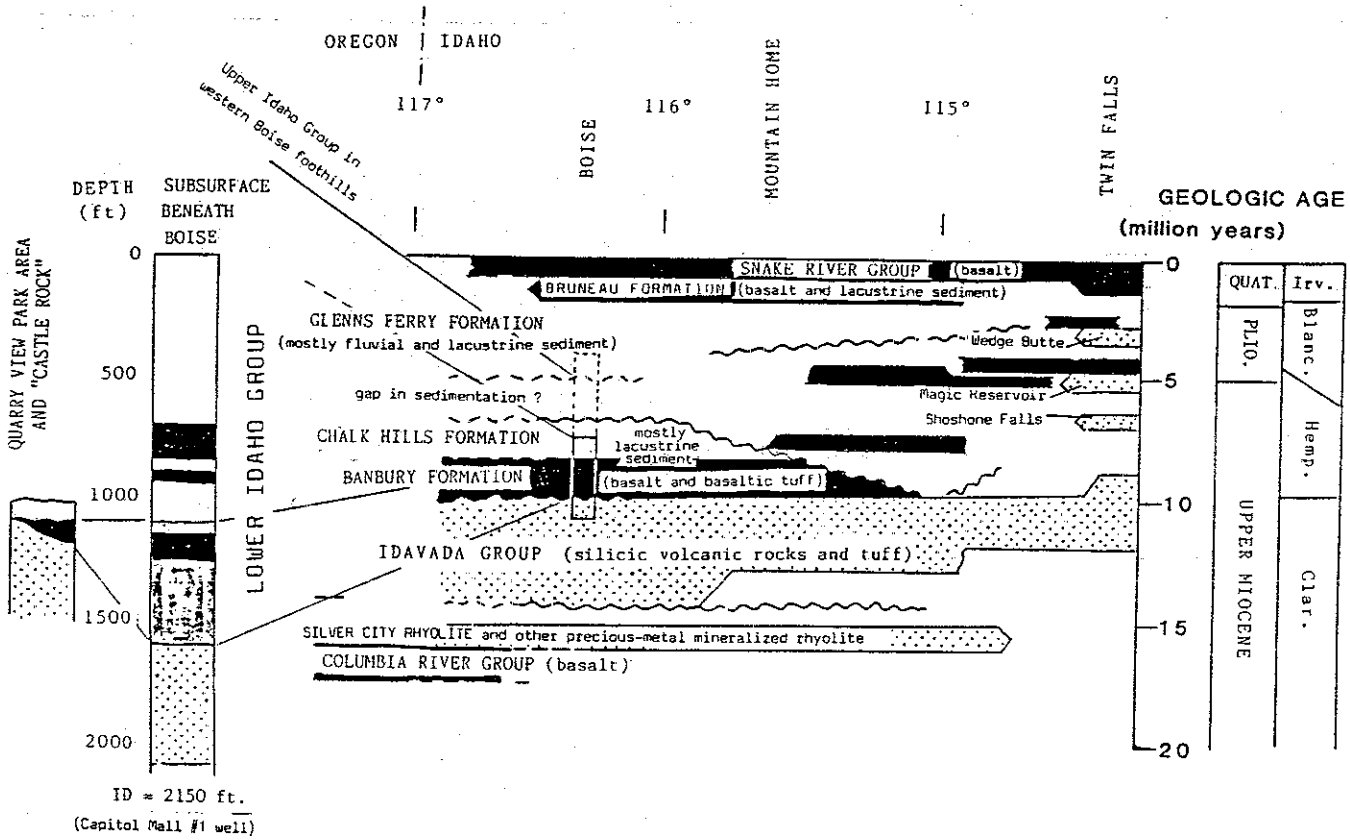



Figure 2. Stratigraphic section for the western Snake River Plain after Armstrong and others (1975), Struhsacker and others (1982), and Malde and Powers (1962), compared to units in the Boise foothills and in the subsurface beneath Boise.

beneath the State Capitol Building, about 3 km to the west.. Two lithologic types occur here. The eastern part of the outcrop is a dark-gray, flow-banded vitrophyre (Fig. 5). The western part and most of Castle Rock is a flow-banded, stony rhyolite with a sheeting parallel to flow banding that causes it to break into thin flaggy slabs (Fig. 6). Mineralogy of the two lithologies is identical. Plagioclase phenocrysts 0.2 to 2mm make up 10 to 15 per cent of the rock. The andesine plagioclase is zoned. In the vitrophyre it appears as transparent amber-colored crystals, but in the stony rhyolite, the andesine plagioclase is deteriorated to a chalky soft-white material. In some rocks the plagioclase has been totally leached away leaving a pitted surface (Fig.7). Minor amounts of magnetite and clinopyroxene (augite) occur as microphenocrysts. It has not been determined whether the stony rhyolite was originally a vitrophyre that has devitrified, or if it was originally crystallized as a stony rock.

Contact surfaces between the stony and glassy rhyolite are steeply dipping. At one locality is a 10-ft (3-m) wide dike of vitrophyre with well developed, horizontal, columnar jointing (Figs. 8 and 9). The dike appears to have invaded pre-exisiting vitrophyre, and may be material squeezed into the already chilled

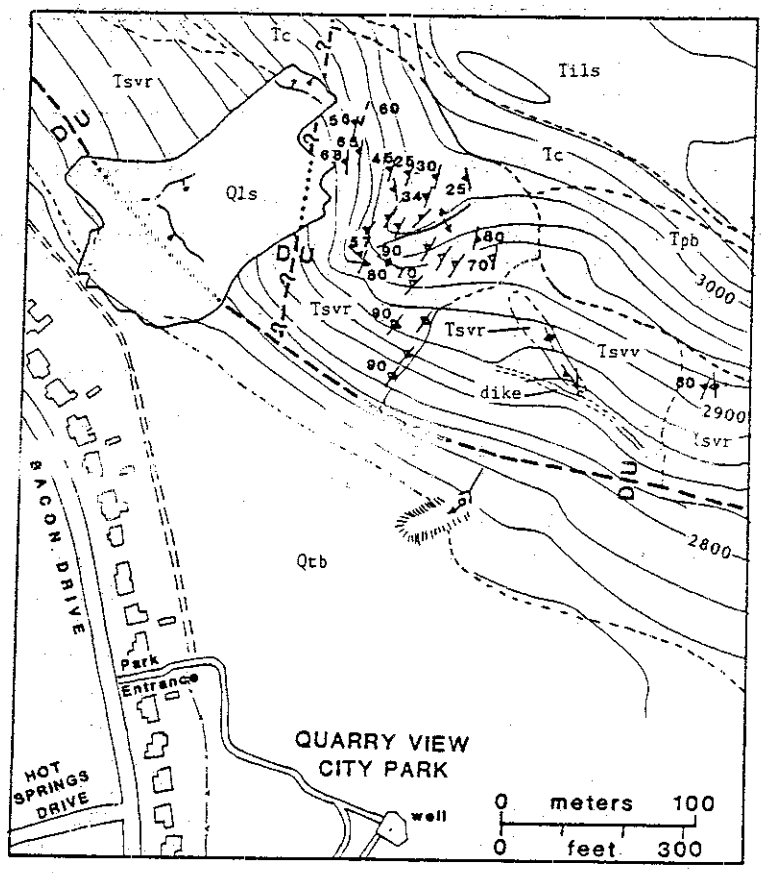



Figure 3. Geologic map of the Quarry View Park area. Foliation is on sheeting and flow banding in the rhyolite. Solid foliation symbol is considered right-side-up, and open sympbol is considered to be overturned. Tsvv is a dark rhyolite vitrophyre, Tsvr is a lavender-gray stony rhyolite, Tpb is porphyritic basalt, Tc is a lacustrine clay and sand unit, and Tils is quartz-cemented sandstone of the [illegible] Formation of the Group, and Qtb is Boise River terrace deposit of late Quaternary age.

upper part of the flow. Foliation of flow banding in the stony rhyolite maps into an asymmetric anticlinal structure at least 250 ft (80 m) wide. Because of the widespread and tabular nature of the rhyolite body, it has always been assumed it is a lava flow or a part of sheet of densely-welded ash-flow tuff, and not a dome. However one cannot rule out the possibility that it is a dome with a nearby source vent. It is difficult to distinguish between rhyolite lava flows and densely welded tuffs, particularly when the tuffs have completely remelted and remobilized as lavas. Ekren and others (1984) have shown that these problematic rhyolite lavas are common along the margins of the Snake River Plain. A distinctly different rhyolite body is encountered in drill holes beneath the outcrops (Fig. 12). This older and underlying rhyolite has conspicuous quartz phenocrysts in addition to plagioclase. It is similar to outcrops of stony rhyolite and perlite in Rocky Canyon about 1.5 miles (2.5 km) NW of this area and in the canyon immediately north of Table Rock, just 1 mile (1.6 km) SE of here

Porphyritic Basalt

A body of porphyritic basalt laps against and at places overlies the rhyolite of Castle Rock. It is well exposed in a small quarry area on the slope face about 500 ft (150 m) east of Castle Rock (Figs.3 and 9). The basalt is dark brown with large (3 x 15 mm) plagioclase phenocrysts that are transparent and amber-colored (Fig. 10). The basalt is partly vesicular. Many vesicles and

fractures are filled with a variety of zeolite minerals, calcite, clay , and chalcedony. Much of the basalt is discolored and has apparently been altered by geothermal water.

Red and Green Clay Unit

A unit of interbedded laminated green clay, red sandy clay, and arkosic sand locally overlies the basalt. The only good exposure of this unit is in an excavation over the top of the hill, about a 1000-ft(300 m) hike from the park. It can also be reached from Roanoke Drive (see map, Fig.1). In the wall of this pit is a 5-m sequence of bedded clay and sand layers

Sandstone

The clay un : and the basalt is overlain by a 20-ft (6-m) thick unit of cliff-forming arkosic and pebbly sandstone. Much of the sandstone displays cross bedded layers 0.3 to 1 m thick, suggesting that these basal sands were deposited under stream or river-bed conditions. Elsewhere, similar but possibly younger, sands are clearly deltaic in 6-m thick units indicating that water was up to 6-m deep as deltas prograded into a lake system that occupied the plain. A significant thickness of clayey siltstone originally overlaid this sand unit but has since been stripped off of the uplifted fault block by erosion. It is preserved in the subsurface beneath the park area, where wells penetrate about 200 m (Fig. 12). Much of the section of clastic sediments is thought to be preserved in the slopes of Table Rock to the east. Table Rock lies in the same down-dropped fault block as the park area. The capping sandstone of Table Rock is not the same sandstone that forms the cliff-line and the old prisoners' quarry along the skyline above the park. The Table Rock sandstone is much higher and stratigraphically younger, yet both of these well-cemented sandstones have a similar origin. These silica-cemented sandstones in the Boise foothills area always occur within 2000 ft (700 m ) of the major fault zones. Cementation is attributed to the percolation of geothermal water, bearing dissolved silica, into the permeable sand layers when they were still confined as aquifers within the less permeable siltstone section. As thermal ground waters migrated away from the faults, they cooled and precipitated silica in the voids of the arkosic sands. Only the relative stratigraphic age of the sandstone is known. It is similar in lithology and setting to the Chalk Hills Formation of the lower Idaho Group on the south side of the Snake River Plain where intercalated volcanic ash layers have been dated by the fission-track method as late Miocene (6.6 - 8.6 m.y.) by Kimmel (1982).

Structure

The site is at the border between the mountainous province to the north dominated by the Idaho Batholith, and the late Cenozoic basin of the Snake River Plain. The margin is characterized by a zone of normal faults several kilometers wide. The fault that runs along the base of the hill beneath Castle Rock offsets the top of the rhyolite unit 800 ft (270 m). Several fault planes can be observed in outcrops of sandstone along the hillside , and back of the Penitentiary Buildings to the east. One fault drops the sandstone datum down about 80 ft (25 m), to form a wedge-shaped plateau of sandstone to the east (Fig. 1). Dip of the fault plane is typically 60° south as measured in the sandstone outcrops. Geophysical evidence discussed by Wood (1984) indicates that other faults lie south of this area in the Boise River valley and have offset the volcanic units to depths of 4500 ft (1370 m).

## The Geothermal System

This area is the site of the oldest space-heating development using geothermal water in the United States (Lindgren, 1898; Wells, 1971). One may still observe warm water seeping from the toe of the ridge and from the marshy area of the flats late in the summer at the end of the non-pumping season. These seeps and springs were developed by drilling two wells to depths of 400 and 410 feet in 1890. Originally artesian flow of water at 172 F°(66°C) was piped to a Natatorium and to homes and businesses along Warm Springs Avenue. As artesian pressure declined, pumps were added to the wells. The pump house for the existing Boise Warm Springs Water District wells is built around the bases of the original wooden derricks used to drill the wells (Figure 9). The house was built in 1892 and restored in 1982. During the cooler 7 months of the year, the wells are pumped at an average rate of about 500 gallons per minutes. Maximum pumping rate for short periods of severe cold weather may reach 800 to 1,000 gallons per minute. The water maintains a near-constant temperature of 170 - 172°F. Seasonal drawdown during the heating season is about 80 feet by April, but recovery is rapid and artesian flow at land surface usually returns by late August. More than 250 homes are currently served: those of long standing being billed a flat rate that is about $400 per annum. Non-patrons of the original district are on metered service at a present charge of $0.57½ per 100 cubic feet.

The source of the heat and the important details of replenishment and circulation of the geothermal ground water have not been clearly identified. At all wells constructed to date the thermal water occurs under artesian pressure in fault zones or fractured parts of the rhyolite and closely associated granular clastic rocks. The basaltic flow rocks and tuffs that overlie the silicic volcanic rocks are invariably altered in major part to clay. This, combined with the overlying siltstone of the lower Idaho Group, forms a capping unit of small permeability for the artesian system.

A conceptual model of the geothermal ground-water systems has been proposed by Wood and Burnham (1983). It is known that some principal fault systems of the area are of regional extent, with cumulative displacement of several hundred meters or more. Many of these structural breaks must extend deep into the rocks of the batholith, thus creating fracture zones of sufficient permeability to permit deep circulation of ground water. The mountainous area north and east of the Boise area are infiltrated by snowmelt and rainwater, and the resulting ground-water system has a high driving head relative to the plain.

The region of the western Snake River Plain is one of high heat flow, thought to result from a thinning of the crust which gives rise to relatively shallow and hot mantle material. Heat flow from within the plain has been measured at 1.7 HFU (heat flow units, calories/cm sec) near the center and 3.0 HFU at the margins as compared with 1.5 HFU for the stable interior of North America (Brott and others, 1978; Lachenbruch and Sass, 1980, Mabey, 1982). The geothermal gradient is typically about 40°C/km over much of this region (Wood, 1984, Fig. 5) and the northern Basin and Range (Lachenbruch and Sass, 1980). Consequently, ground water would need to percolate to a depth of about 2 km to achieve a temperature of 65 C. Water infiltrating the 2,000-m-elevation mountains above the Boise area provides a high driving head relative to the 800-m elevation of the plain, and could concievably drive a deeply percolating ground-water system. The deep hot ground water would then rise along fracture zones and spread laterally through confined layers of silicic volcanic rock beneath the plain.

Although there are many occurrences of volcanic rocks within the area, it is thought unlikely that the source of heat is a shallow magma body in the crust beneath the geothermal area. Rhyolites are probably older than 8 m.y. and the associated basalts only a few million years younger (Fig. 2). Magma chambers in the shallow crust of that age would surely have lost all significant heat within a few million years (Smith and Shaw, 1979). Vents for Pleistocene Snake River Basalt lie within 30 km of Boise, but these appear to be fissure eruptions from deep sources and not evidence for shallow magma chambers.

Should such a conceptual model for the geothermal-water circulation system prove correct, one must accept a consequence of the very limited permeability at such depths within granitic rocks. Thus the volume of water per unit time within the circulating replenishment and discharge system is necessarily small as compared to more commonly developed ground-water systems in granular deposits.

## The Bacon Drive Landslide

On about April 2, 1983 the 4-acre landslide just west of "Castle Rock" began moving. Measured rates of movement were typically 0.1 ft/day. The slide stopped moving in July, 1983 and then recommenced about January 15, 1984. The slide stopped by the end of April, 1984 and has not moved again as of March, 1984 (Paul Warner, personal communication). Total lateral movement is about 20 feet. This slide mass had previously moved in prehistoric time, for a somewhat subdued bulge and closed depression were present here before 1983. The initiation of movement appears to have been caused by the saturated slope conditions in the espoecially wet year of 1983. The slide plane probably developed along the clay unit that overlies the rhyolite, however, the geology west of the slide is poorly exposed, and the configuration of contacts is known only from a few drill holes west of this area.

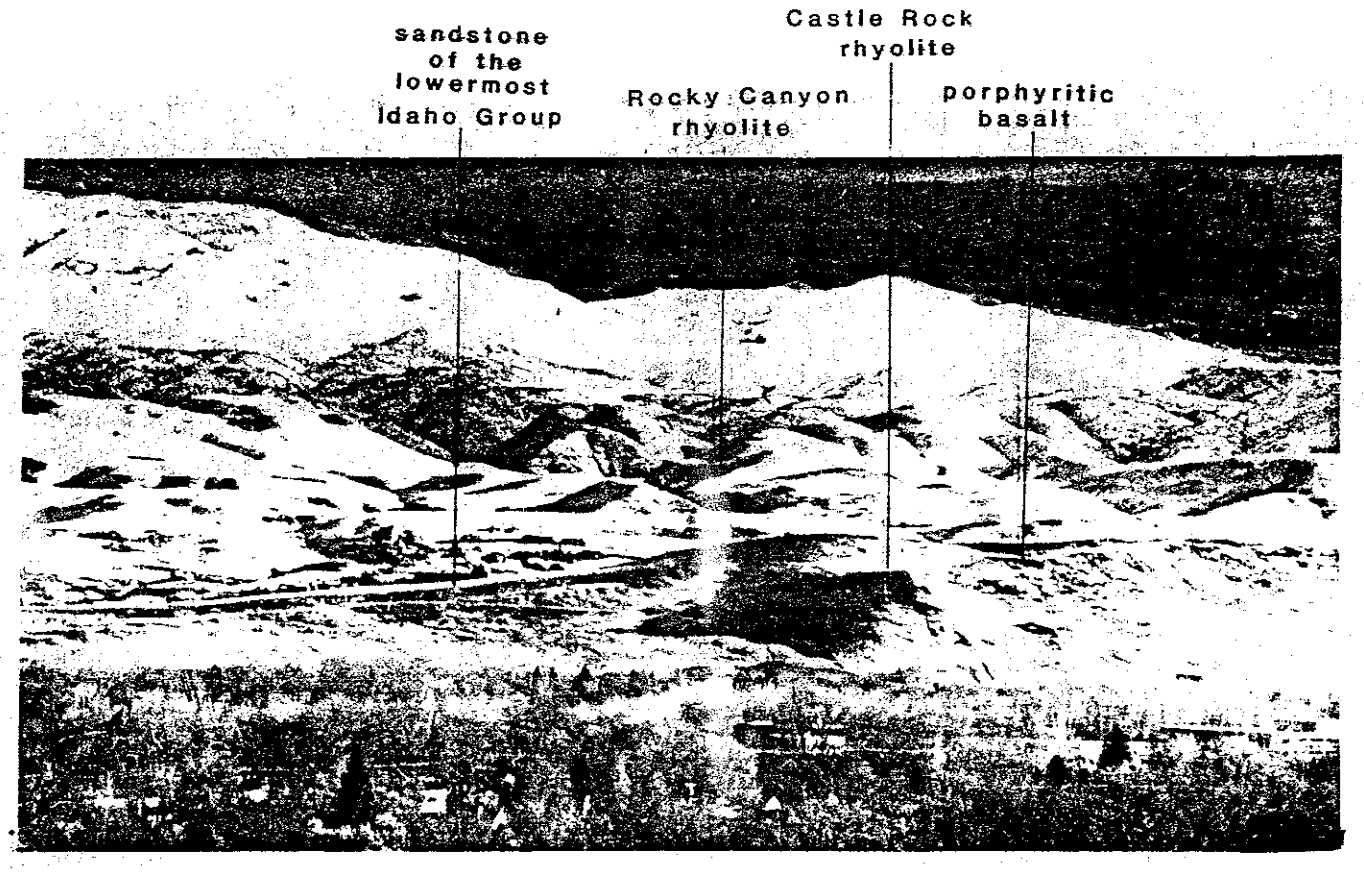



Figure 4. View to the northeast of the Castle Rock area. It is this view of the sandstone-draped rhyolite mass, that suggested the appearance of a laccolith structure to Lindgren in 1898.



Figure 5. Flow banding in the rhyolite vitrophyre.



Figure 6. Sheeting in the stony rhyolite.



Figure 7. Pitted surface of the hydrothermally altered rhyolite caused by solution and etching of plagioclase phenocrysts. The rock is brecciated, and fractures are filled with pale green chalcedony that appears dark in the photograph..



Figure 8. Horizontal columnar jointing in the vitrophyre suggesting this rock was emplaced as a dike-like sheet into pre-existing rhyolite and vitrophyre.

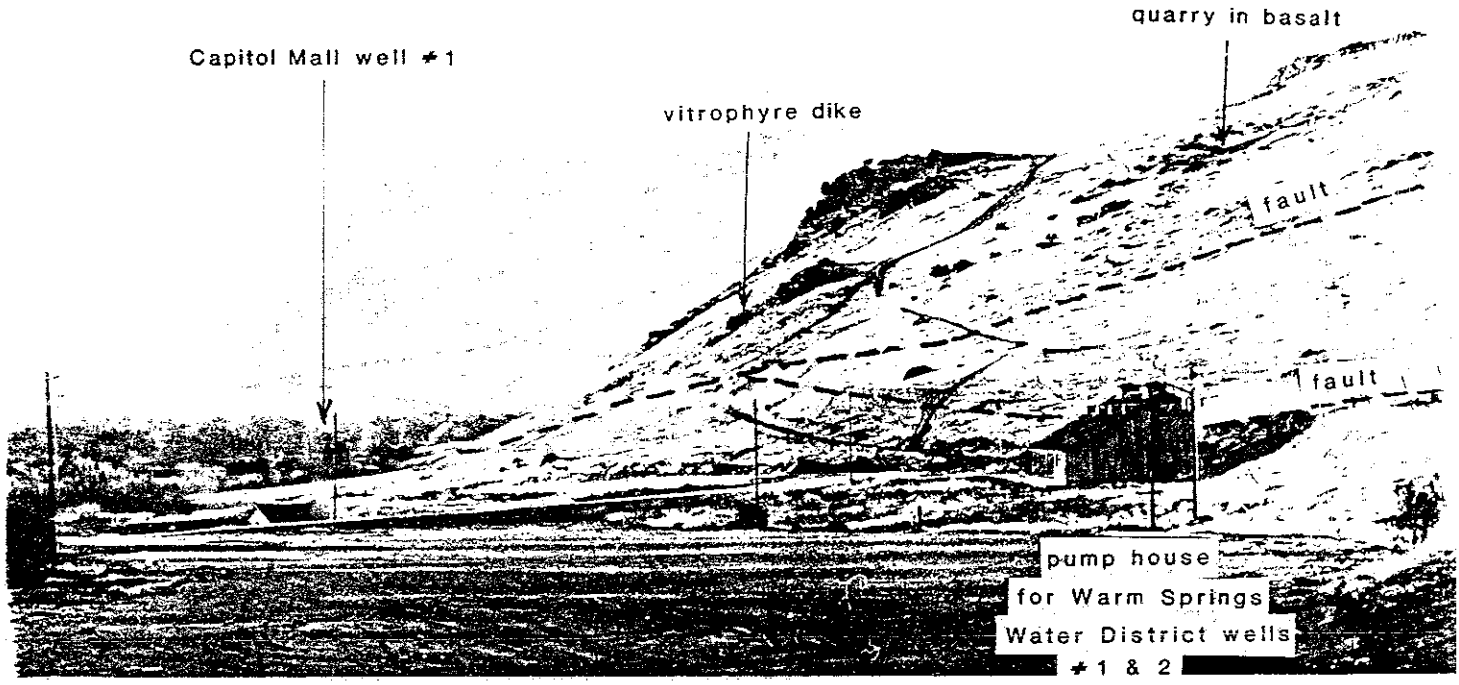



Figure 9. View to the northwest of the Boise Warm Springs Water District pump house, "Castle Rock", and in the background, downtown Boise.

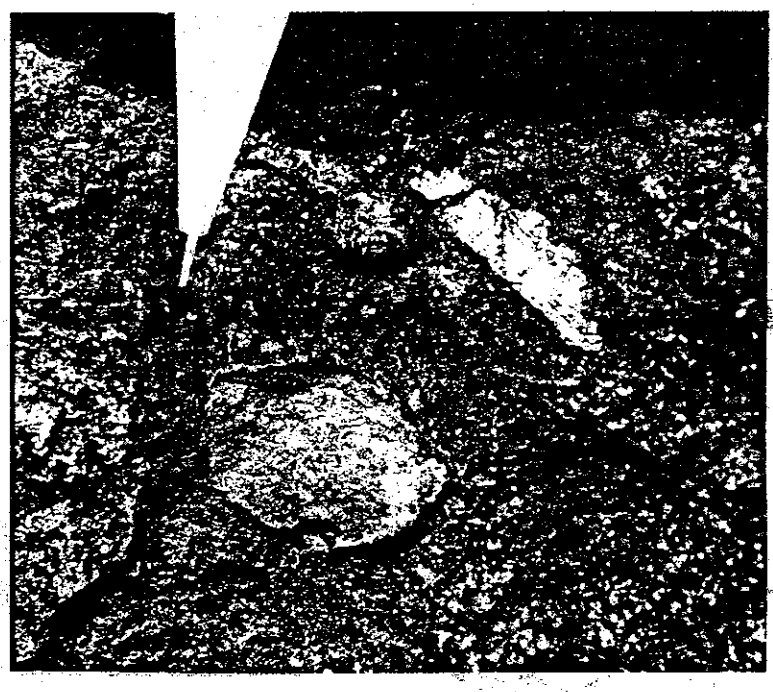


Figure 10. Porphyritic basalt from the "quarry" (Fig. 3) showing a large plagioclase phenocryst exhibiting striations of albite twinning. Pencil points to another plagioclase phenocryst. Spherical area is a clay-filled vesicle.



Figure 11. Basal sandstone of the lower Idaho Group showing cross bedding.

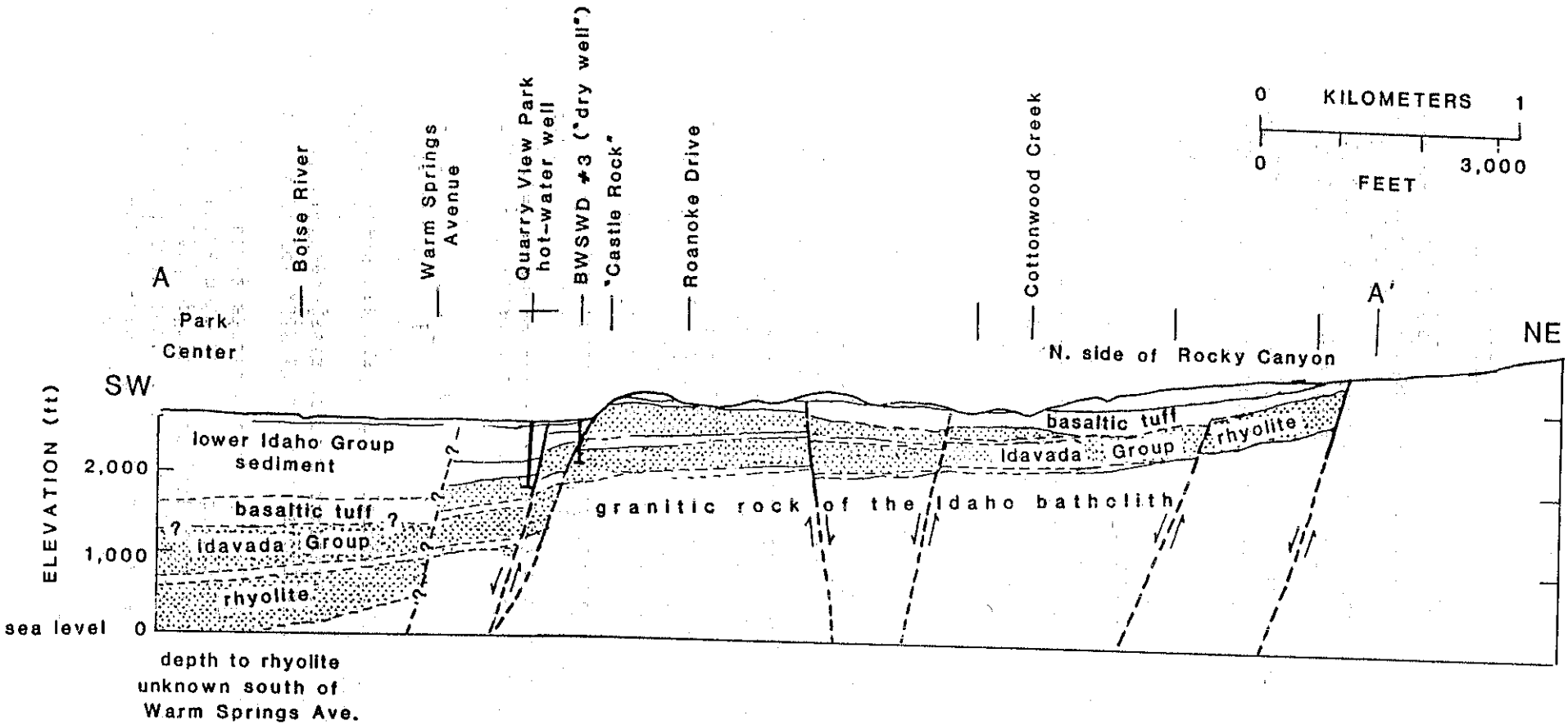



Figure 12. Geologic cross-section through the well at Quarry View Park. Location of section is shown as line AA' in Figure 1.

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STOP #2

Warm Springs Mesa and fossil hydrothermal effects on arkosic sediments.

LOCATION

Prominant hill crest 1,000 feet (305 m) east of the north limit of the Warm Springs Mesa Subdivision and 3,000 feet (915 m) southeast of Table Rock. The locality is accessible by Warm Springs Avenue and principal streets of Warm Springs Mesa Subdivision to the north edge of the development.

SIGNIFICANCE

Exposed in the westernmost high outcrops are arkosic sandstone, siltstone and conglomerate of the Idaho Group sediments that display effects of alteration and silica cementation by thermal fluids. Extensive open fractures and bedding-plane zones of weakness display erosional and depositional effects of thermal fluids. Large fault-controlled fractures contain massive zeolite deposits. The silicified sediments are thought to represent fluvial and shallow lacustrine Idaho Group units accumulating over a major fault zone in underlying granitic and volcanic rocks. Thermal fluids rising along the fault zone under large hydrodynamic pressure diffuse vertically and laterally through the permeable sediments and deposit silica cementation as temperature and pressure decline. The large fracture-fillings are ample evidence of the ability of certain zeolites to form under relatively low pressure-temperature conditions. The zeolites here have not been studied thoroughly but are believed to be mainly stilbite and heulandite. Most of the exposures in these outcrops show deposition as massive sand beds or as thick sequences of current-bedded fluvial sand, silt and conglomeratic sand later invaded by silica cement. There are exposures, however, which suggest granitic detritus being deposited in highly silicious hot spring pools.

The outcrops here are the result of erosion of a considerable thickness of Idaho Group sedimentary cover by the Boise River and its tributaries. The hydrothermal effects seen are fossil evidence of similar effects now going on within the thermal water circulation system of the Frontal Fault system to the north.

STOP #3

Rocky Canyon Gorge and Picket Pin Canyon Exposures of the basal volcanic rock units.

LOCATION

Three miles (4.8 km) east of the State Capitol by way of Shaw Mountain Road up Cottonwood Creek. The steep-walled bare rock gorge is cut in rhyolite flow and rhyolitic ash-flow tuff equivalent in mineralogy and character to

the deepest rhyolite found in the geothermal water wells. The locality is accessable by passenger car by county-maintained graded dirt road from Boise, or from State Route 21 near Robie Creek by way of Aldape Summit. The locality is on the route of the Boise-Idaho City Toll Road to the Boise Basin gold fields of more than 100 years ago.

## SIGNIFICANCE

Erosion by Cottonwood and Picket Pin Creeks here exposes the oldest of the rhyolites of the geothermal system; also its contact with the Idaho Batholith. Here also can be seen the depositional contact of both rhyolitic and basaltic tuff on the rhyolite and granite, as well as their relation to overlying Idaho Group sediments. The tuffs and associated basalts and sediments form the confining unit for artesian pressure in the geothermal system. Also here are displayed evidence for major normal faulting, and erosional-depositional features that document varying conditions during accumulation of the lower Idaho Group sediments. Figure 1 shows the distribution of the several geologic units exposed here.

## SITE INFORMATION

### Geology

The rhyolite of the gorge is the oldest of the volcanic rocks known in or near the Boise foothills. Complex flow banding and other flow features suggest it is a rhyolite flow, although some features are typical of densely welded ash-flow tuff. Fractures and jointing are intense on two sets; one trending about N 30°E with nearly vertical southeast dip, and the other about N 50°W and dipping southwest. The rock varies in color from dark glossy gray brown to a stoney lavendar-gray. It contains euhedral quartz and small phenocrysts of both plagioclase and alkali feldspar, and minor amounts of magnetite and possibly augite. The domestic water well at the house near the top of the outcrop is 420 feet (128 m) deep; 384 feet (117 m) through rhyolite, a few feet of sediment or weathered granite and the bottom in granite of the batholith. Rhyolite, with euhedral quartz and similar lithology, was drilled in wells in Freestone Canyon about one mile northwest and outcrops in a gully on the north flank of Table Rock one mile (1.6 km) to the south. Elsewhere it is known only from cuttings derived from the geothermal wells 2 to 3 miles (3 to 5 km) west.

Wherever seen, the rhyolitic rocks of the periphery of the Rocky Canyon outcrop are composed of pitchstone, perlite, pumicious tuff, rhyolitic ash or pumicious deposits containing spherules of pumicious glass and large lithophysae-like structures. The tuff and interbedded gray ash occur mainly to the east and southeast.

Basaltic tuff and/or a basaltic volcanic mudstone laps unconformably on the rhyolite and the granite of the batholith. Nowhere has evidence been seen in outcrop of sedimentation or significant weathering at the contact. In an abandoned mine adit on the northeast side of the rhyolite outcrop, tuff with slickensides is clearly in fault contact with the granite. More than 250 feet (75 m) of tuff section is exposed in the ridge dividing the two

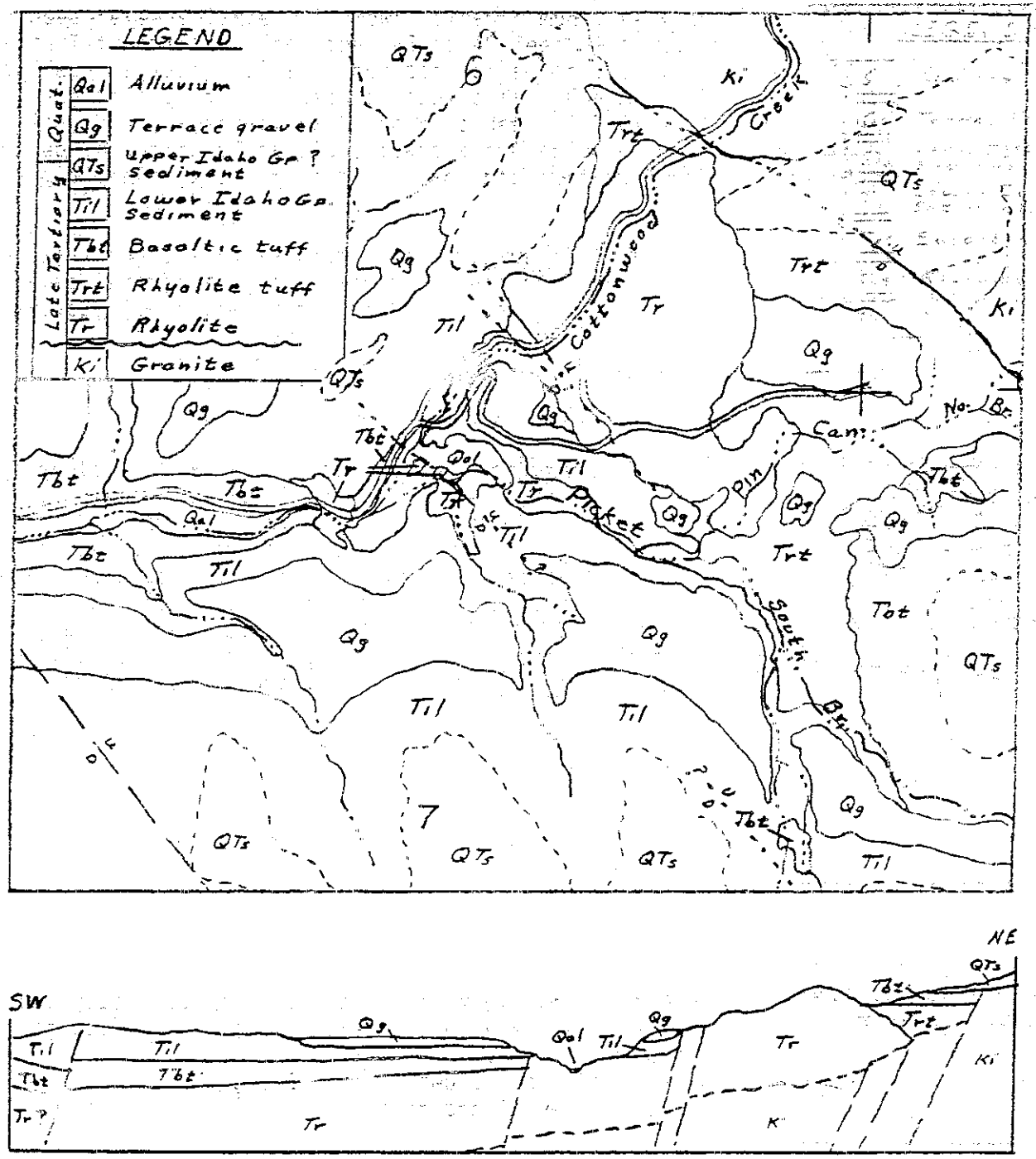



**Figure 1.** Map and diagramatic section of the Rocky Canyon area, showing outcrops and interpreted subsurface distribution of principal units.

branches of Picket Pin Creek, southeast of the outcrop of rhyolite. The basal 50 feet (15 m) exposed here is largely a brown volcanic mudstone with thin layers of basaltic tuff fragments. The upper 30 to 40 feet (9 to 12 m) is again fine-grained tuffaceous, ashy volcanic mudstone of a light brown color, with distinct bedding including thin beds of ashy clay. The main, central part of the section is well-bedded, dark brown to nearly black coarse-grained tuff made up of shards of basaltic glass and lithic fragments, subrounded basalt grains and rare lithic fragments derived from the granite.

Basaltic tuff is widespread along the Boise Front and contains flow basalt interbeds at some localities, principally near and northwest of Table Rock. There are no basalt interbeds within the tuff near Rocky Canyon. Unconformably on the volcanic rocks are fluvial sediments of the lower Idaho Group, Quaternary-Tertiary fanglomerate and colluvial sediments, and Quaternary gravels of an ancestral Cottonwood Creek drainage. The site lies on a zone of complex normal faulting that marks the northeast margin of the Boise Frontal Fault system. The zone contains several closely-spaced, subparallel faults trending about N 50°W with cumulative displacement of volcanic rocks of about 350 feet (105 m). There is good evidence here that the zone controlled the position of at least one of the principal streams and drainage systems of the region during the accumulation of lower Idaho Group sediments. Down-faulted basaltic tuff was deeply eroded to the southwest of the zone, and lower Idaho Group deposits display the basal boulder gravels grading upward through sands and finer-grained sediments typical of a basin-margin fluvial system. Figure 1 contains a diagramatic cross section drawn normal to the fault zone to illustrate stratigraphic and structural relations.

## Stop #4

Military Reserve and Capitol Mall geothermal well sites.

### LOCATION

City of Boise and Veterans Administration geothermal wells are within the Frontal Fault zone at the abrupt break in slope near the mouth of Cottonwood Creek. The three producing wells for the City are between Reserve Street and Mountain Cove Road, and the VA wells are several hundred feet toward the northwest (Figure 1). Also shown on Figure 1 are the two Capitol Mall wells along Washington Street some 3,000 feet (915 m) west of the City-VA well field.

### SIGNIFICANCE

These modern geothermal wells are the principal suppliers of thermal water for expansion of space heating and other heat energy uses in Boise. Data from their construction, testing and use since 1981 documents surface and subsurface geologic features and the hydrologic character of the hot-water aquifer system, and provides economic and ecological information for future management of the geothermal resource.

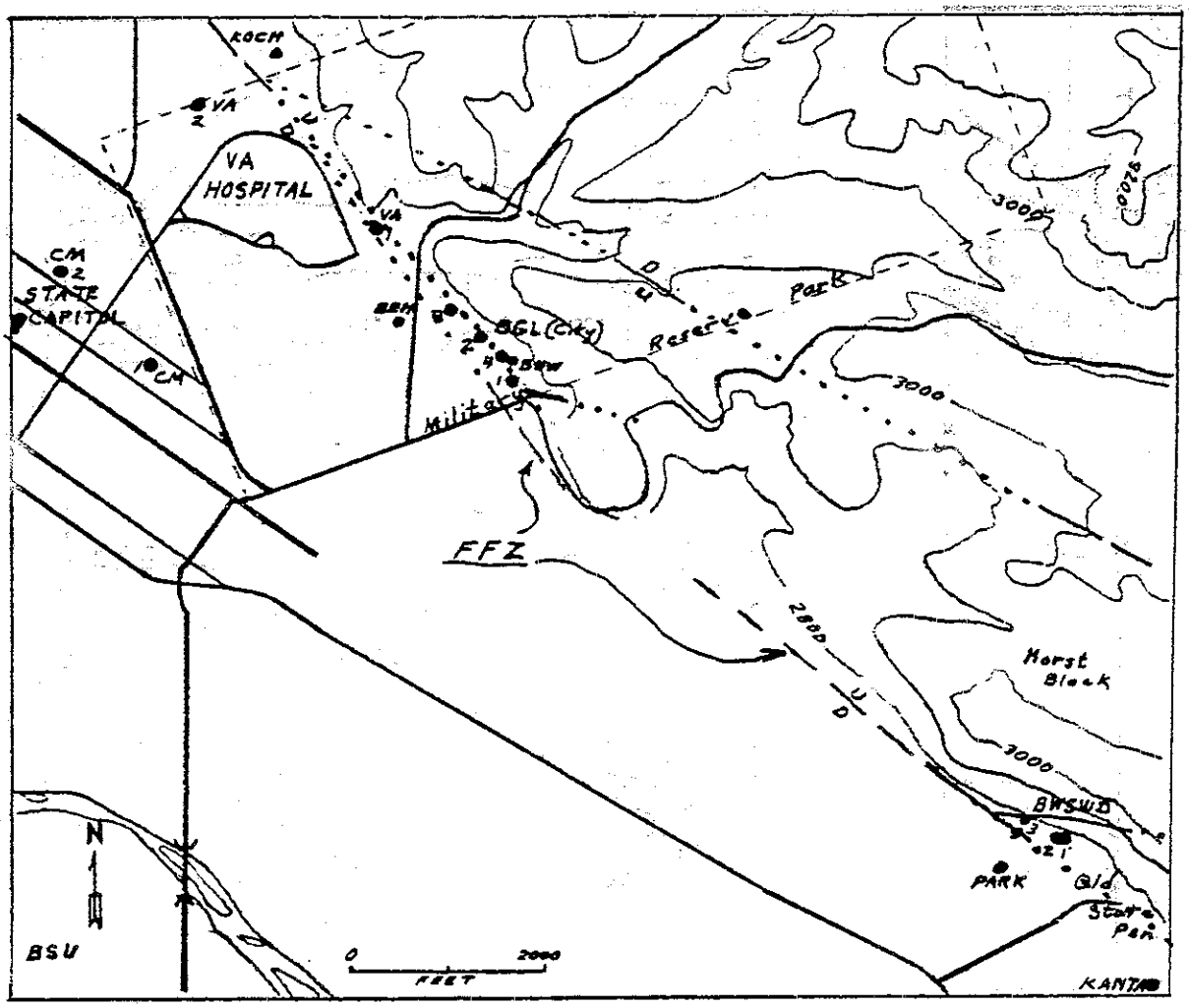



**Figure 1.** Map of Boise Front area showing location of principal geothermal wells and the Frontal Fault Zone (FFZ) of Hollenbaugh (1973). Capitol Mall (CM), Veterans Administration (VA), Boise Geothermal Limited (BGL-City), and Boise Warm Springs Water District (BWSWD) are the principal production and injection wells. BEH and BHW are test wells for design of BGL well construction. Koch is a small-yield well for space heating of two residences. Kanta is unused. Park is a Boise City Parks well. Only the principal boundary faults of the horst block are shown. See accompanying illustrations for areal structure pattern.

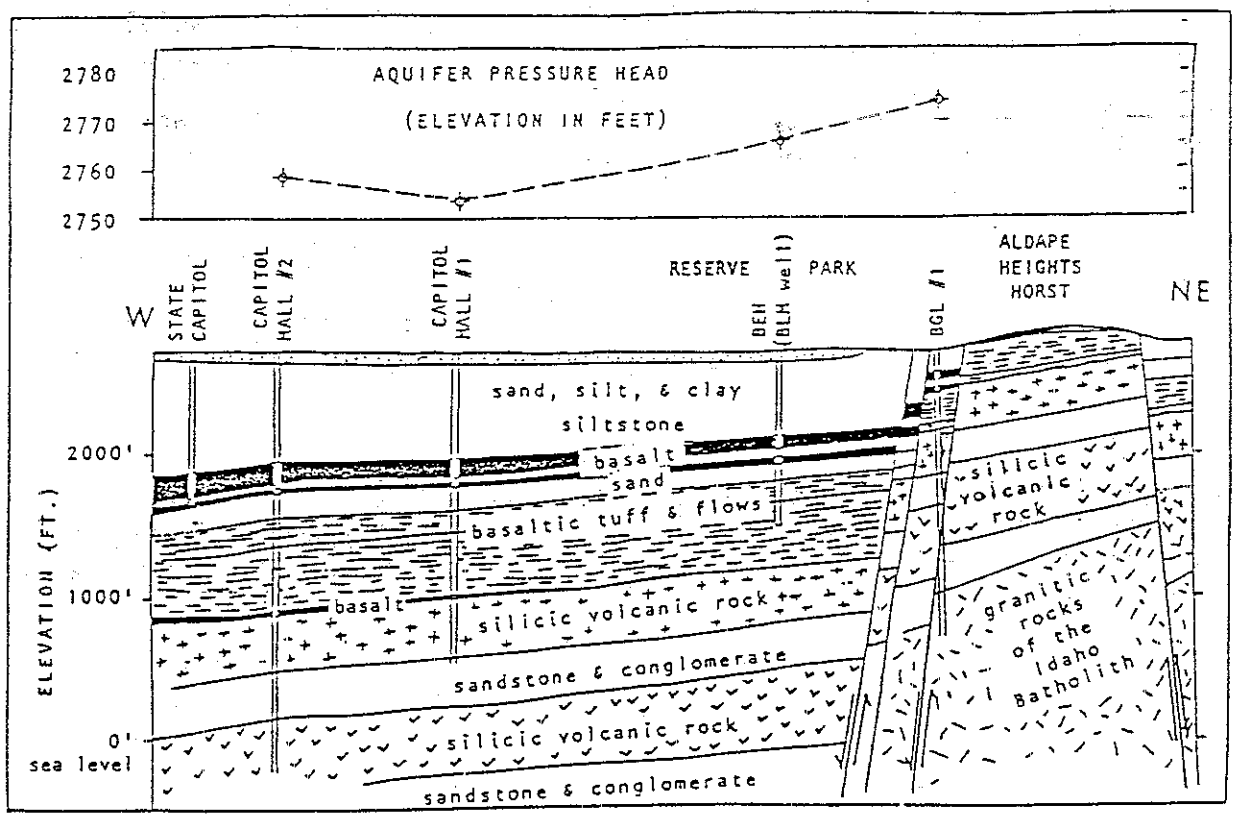



Figure 2. Diagramatic structure section showing correlation of geologic units. See Figure 1 for well locations Piezometric surface of water at time of well completion is shown above. Section at true scale.

## SITE INFORMATION

The Capitol Mall-Boise City-VA complex of wells are all drilled in the same stratigraphic sequence and are completed so as to use the upper silicic volcanic unit and associated sedimentary deposits for production and/or reinjection. The subsurface units and their relative positions are shown on the correlation section, Figure 2. Below a few feet of Holocene alluvium the wells all penetrate from 150 to 800 feet (45 to 240 m) of fluvial and lacustrine sand, silt and clay of the lower Idaho Group, the thickness increasing with distance from the Frontal Fault zone. Below these sediments all wells pass through approximately 400 to 600 feet (122 to 183 m) of basalt and basaltic tuff with interbeds of mixed volcanic and granitic sediment. The basal units of this sequence contain a downward-increasing proportion of hydrothermal alteration clays and generally abundant pyrite. Chalcedony and zeolites are often abundant also.

At more than half the well sites the basaltic sequence contained clean, coarse arkosic sand at the base several feet thick. Immediately beneath the sand (or basalt) all wells drilled a dense silicic volcanic rock from 200 to 400 feet (60 to 120 m) thick. Generally, this rock is intensely fractured, and the majority of the fractures healed with red-brown, orange or green chalcedony. The rock also contains much inter-granular and fracture-surface pyrite.

Arkosic medium-to-coarse sand, sometimes gritty and often stained red, underlies the upper silicic volcanics and is 150 to 400 feet (45 to 120 m) thick. Hydrothermal alteration of feldspars produces variable amounts of gray to white clay in this interval.

The sand unit is underlain by a second silicic volcanic rock that is more clearly rhyolitic, with pumicious and ashy components in the drill cuttings. The rock is more dense than the upper unit and contains euhedral quartz. Where wells drill through this unit the thickness is seen to be about 400 feet (122 m).

Arkosic sand, usually coarse to pebbly underlies the lower silicic volcanic, and at Boise Geothermal Well #1 this overlies granite. Boise City and VA wells are located so as to purposely be completed in or near a major normal fault plane or fault-fracture zone where vertical displacements on silicic volcanics of about 900 feet (275 m) can be shown (Figure 2).

## HYDROLOGY

Post-completion testing and production records thus far indicate that the geothermal water occurs and circulates primarily within the fault fracture zones, and the upper silicic volcanic rock and contiguous sand units. Recharge and deep circulation to acquire heat is believed to be as described in the Stop #1 discussion, with the principal upward convection of heated water occuring in or near the main fractures of the Frontal Fault zone. The wells are all completed in different parts of the structural zone and stratigraphic sequence such that regional gradient of static pressure heads

is difficult to assess. Indications are that regional movement is northwestward and that natural discharge is probably by upward seepage across the confining basaltic and fine-textured sedimentary layers over a broad area.

The attached illustrations and tables give data on water levels, temperature gradients, water quality and well testing and completion.

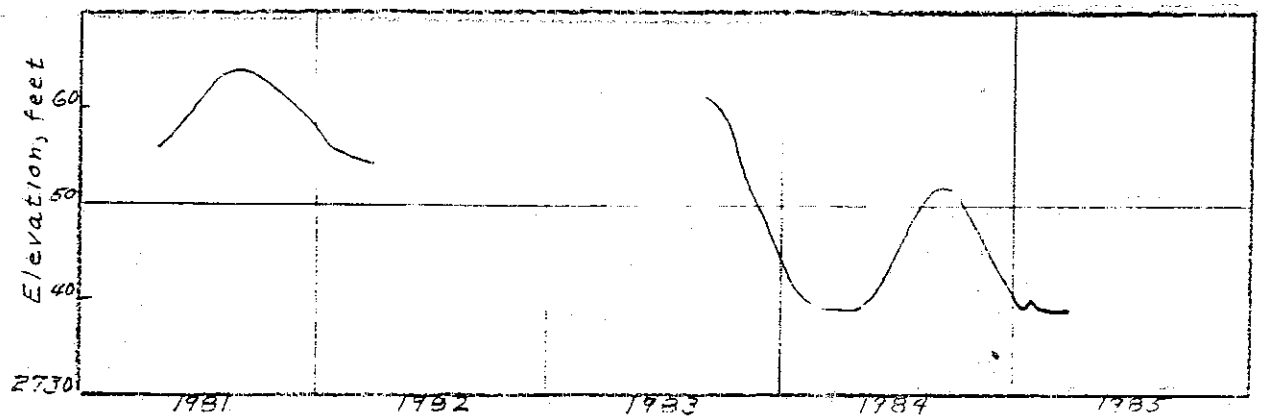



Figure 3. Elevation of static water level above sea level in representative observation well at Military Reserve Park.

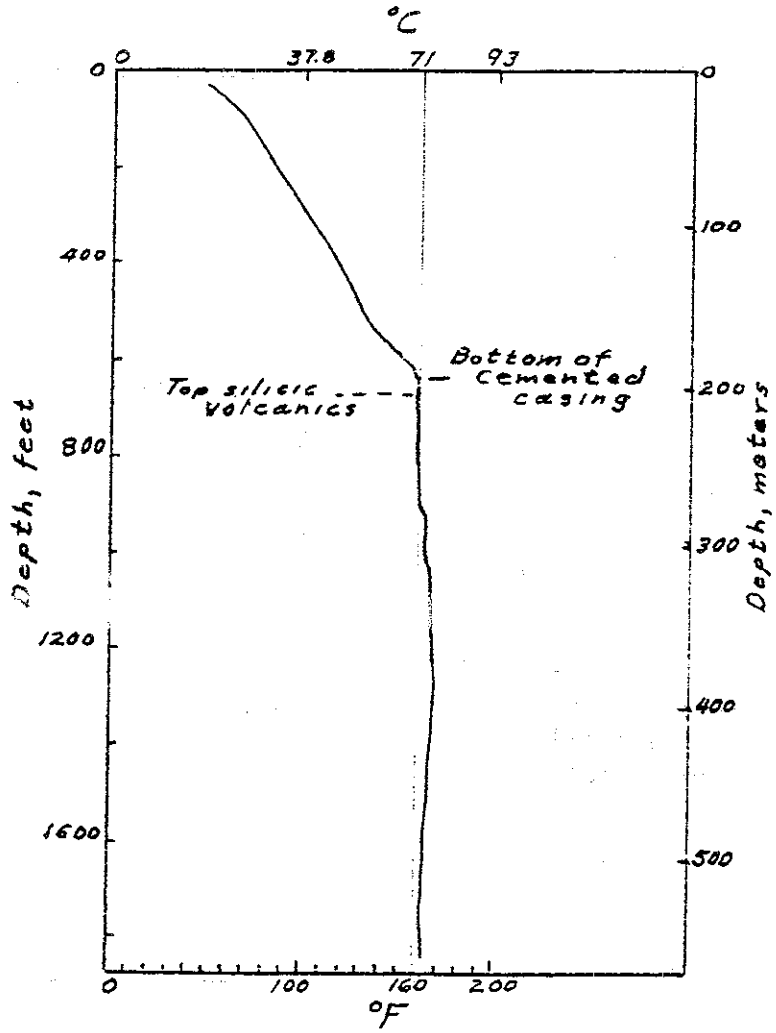
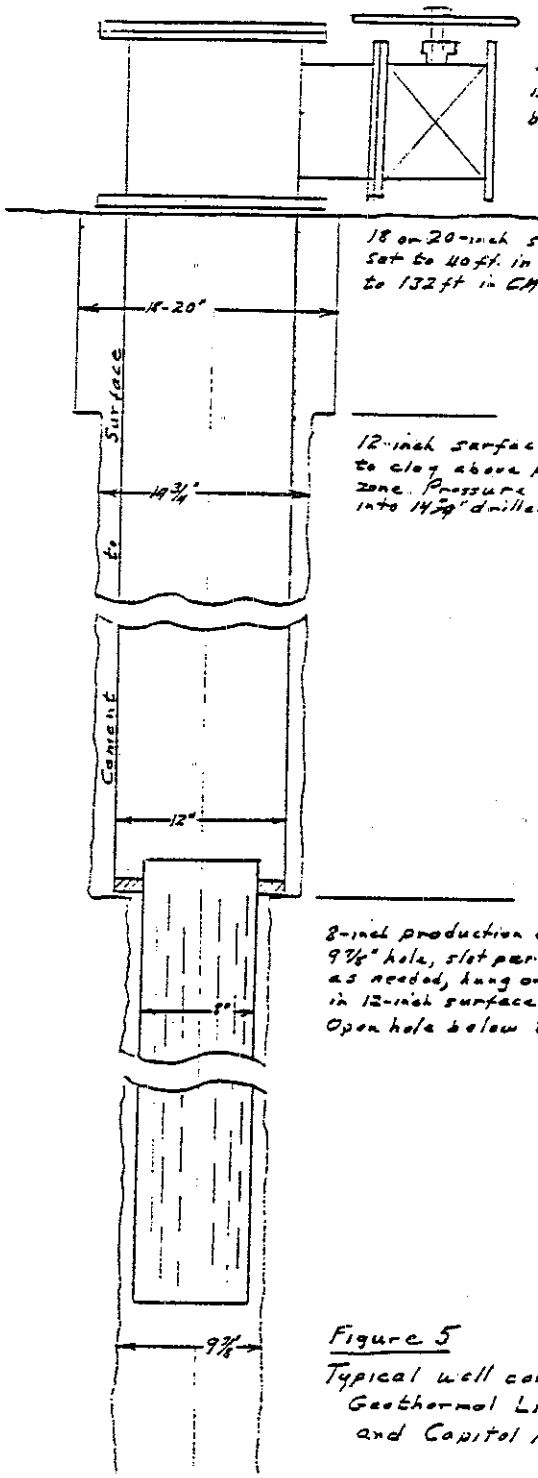



**Figure 4.** Temperature profile for BGL #3 after shut in for several months. Profile typical of all thermal water wells.




BGL-1

Depth = 2,008'
Surface casing to 857'
Perforations:
857–1017
1050–1070
1400–1500
1530–1560
1647–1657
Open hole from 1,660–2008'

BGL-2

Depth = 980'
Surface casing to 642'
Open hole from 642–980'

BGL-3

Depth = 1,899'
Surface casing to 680'
Perforations:
680–840
886–901
Open hole from 1,050–1,899'

BGL-4

Depth = 1,103'
Surface casing to 687'
Perforations:
720–800
850–870
900–1,040
No open hole

CM-2

Depth = 3,030'
Surface casing to 1,258'
Perforations:
1,260–2,550
Open hole from 2,550–3,030'

Figure 5

Typical well construction for Boise Geothermal Limited wells 1 thru 4 and Capitol Mall well 2.

Representative Water Quality

(Geothermal & Shallow Cold Water)

| | BWSWD (Westwell) | BGL-2 | VA Supply | Capitol Mall #2 | Barnes (Foothills) | BWCo. Centennial (Valley) | Boise River (Barber) |
|---|---|---|---|---|---|---|---|
| Specific Conductance (micromhos/cm) | 378 | 405 | | 415 | 157 | 208 | 85 |
| pH | 8.15 | 8.15 | 8.9 | 7.55 | 6.77 | 7.7 | 7.29 |
| Temperature, °C | 78 | 74 | 72 | 70.5 | 16 | (Cold) | 9 |
| Cations (mg/l) | | | | | | | |
| Calcium | 3.2 | 1.9 | | 1.3 | 16 | 21 | 10.4 |
| Magnesium | <0.1 | <0.1 | | 0.1 | 2.8 | 0.48 | 1.26 |
| Sodium | 82.6 | 88 | | 79.2 | 10.4 | 23 | 4.4 |
| Potassium | 1.4 | 1.1 | | 0.6 | 1.6 | 0.75 | 0.9 |
| Silica ($SiO_2$) | 73.5 | 74 | | 55.6 | 39.7 | 27 | 13 |
| Anions (mg/l) | | | | | | | |
| Bicarbonate | 137 | 138 | | 142 | 83 | -- | 46 |
| Chloride | 5.9 | 5.4 | 9 | 8 | 3.6 | 5 | 0.3 |
| Sulfate | 21.5 | 20 | 22 | 19 | 10 | 20 | 2 |
| Fluoride | 19.1 | 15.7 | 16.7 | 16 | 0.32 | 0.62 | -- |

**Table 1. Representative water Quality, Boise area.**

Table 2.

Table 2 gives representative values of transmissivity and storativity for Capitol Mall and Military Reserve wells as interpreted from discharge-drawdown data during flow tests.

| Well Ident. | Transmissivity gpd/ft | Storativity Dimensionless |
|---|---|---|
| BGL-2 | 261,000 | $1.8 \times 10^{-4}$ |
| BGL-3 | 260,000 | $2.8 \times 10^{-3}$ |
| BGL-4 | 264,000 | $4.0 \times 10^{-4}$ |
| VA-1 | 120,000-200,000* | ----- |
| CM-1 | 290,000 | $4.0 \times 10^{-4}$ |
| CM-2 | 271,000 | $5.0 \times 10^{-4}$ |
| BEH | 112,000 | $5.4 \times 10^{-4}$ |

*Estimated from drawdown effects of pumping BGL-2.

## MISCELLANEOUS INFORMATION

Most of the pertinent information on locations, well construction, yield, water temperature and quality, instrumentation, distribution system and uses is given in accompanying maps, diagrams, and table. A few additional facts on design, construction, testing, and completion follow:

1. Data from test holes BEH-1 (BLM) and BGH-1 (Beard) restricted location to near vicinity of interpreted faults striking NW along the toe of the break in slope of the Boise Front.

2. Right-of-way and access restricted locations to roadways and berm tops within Military Reserve Park.

3. Planned uses for Boise City wells determined a desired peak season yield of 2,000 gpm or greater. Test data from the BLM-Beard holes indicated individual well yields of 500 gpm with economically feasible drawdown. Consequently, four wells were needed, to be fitted into available locations.

4. Spacing to minimize drawdown interference between wells had to be matched to access and right-of-way, and to pipeline costs for the gathering system.

5. State and local laws and regulations related to geothermal wells required pressure grouting of surface casing to protect shallow cold-water aquifers, blow-out protection when drilling the thermal zone. Such requirements dictated size, type and capabilities of drilling equipment used. Design discharge and drawdown dictated size of pumps required. Size of pump dictated size of hole to be drilled to accept casing and the pressure-cemented annulus needed. Size of surface casing was further dictated by size of the production hole and casing needed, and by the possibility that at least two hole-size reductions might be needed below the surface casing. Such considerations further determined the size and type of drilling equipment.

6. Drilling deep, large diameter holes in or near fault zones anticipates hole-wall instability and loss-of-circulation problems. A carefully designed and controlled drilling mud is required. To minimize drilling mud effects on thermal water production, only bentonite clay mixed with fresh water was used where mud drilling was necessary. Conditioning additives were closely monitored and kept to a minimum. Wherever possible in the thermal water production zones, drilling was done with water only; with compressed air assistance in removing cuttings and maintaining circulation.

7. Only moderate thermal-water formation pressures were encountered, and as a rule the wells did not flow or make a significant amount of water during drilling. Each well was completed by circulating out the drilling fluid with clear water, then air lifting to reduce the column density sufficiently to intiate artesian flow. Flow was continued until the discharge was clear and stable. Well BGL-3 is located such that the

wellhead elevation is above artesian pressure head. That well was air-lift pumped for completion.

8. The wells were test flowed or pumped under a variety of procedures designed to determine both well and aquifer hydraulic characteristics under planned production schedules and use. Testing included long-term monitoring of water-level changes in the thermal water zones at the Koch well which is drilled in the fault blocks northeast of the Frontal Fault Zone. Also monitored was BWSWD well #3 which is in or near, the faults directly connected to the Frontal Fault Zone and the BLM test hole which is on the valleyward side of the Frontal Fault Zone. During flow tests, all wells in the vicinity completed in the thermal water zones were used as observation wells. Additionally, shallow cold-water wells nearby were monitored for possible drawdown effects.

9. Well and aquifer characteristics, as based on testing done to date may be summarized as follows:

   The wells in Military Reserve Park and valleyward in the Capitol Mall area display a seasonal static level fluctuation that matches closely both timing and magnitude of change in cold-water municipal, domestic and irrigation wells in and near Boise. BWSWD well #3 water level follows very closely the pumping times and magnitude at the two production wells near the Old Penitentiary. (See attached hydrographs.)

   The thermal water aquifer system at the Boise City wells is well confined, with indicated storage coefficients of $10^{-4}$ to $10^{-3}$. All wells have a barometric efficiency of about 80 to 90 percent. During the early, initial period of a test, the aquifer responds as a fault-fracture system with indicated transmissivity in the $10^6$ gpd/ft. range and no-flow boundary across the faults to the northeast. Toward the southwest, the Capitol Mall and BLM observation wells indicate the aquifer responds more in the character of a granular material with transmissivity values of the order of $10^5$ gpd/ft. and storativity of $10^{-3}$.

10. Capitol Mall well #2 was drilled by the same equipment and under essentially the same specifications as the four Boise City wells in Military Reserve Park. The well is 3,030 feet (924 m) deep and bottoms in quartz-rich rhyolite. Attached diagrams and correlative sections give the essentials of well construction and stratigraphic relations. In addition to the geolographic record and cuttings logging, logs were run for Natural Gamma, Caliper, Induction Electrical Resistivity, Borehole Compensated Sonic, Compensated Neutron-Formation Density, and Temperature. These were used to guide production casing, performation and completion programs. The drilling was done with fresh-water mixed with bentonite mud and/or just fresh water and air. Artesian flow was controlled by mud until wellhead valving was in place and disposal facilities were in order. Upon purging of mud from the column, flow of at least 950 gpm was obtained for initial cleanup and completion. Temperature discharge water stabilized at 160°F (171°C), and shut-in pressure of the hot water column was about 18 psig. The water quality is similar to that from other wells and, following flow tests for data

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# PRODUCTION, TEMPERATURE AND WATER LEVEL DATA FOR THE FOUR HEATING SYSTEMS IN THE BOISE FRONT LOW TEMPERATURE GEOTHERMAL RESOURCE AREA, 1977-1997

by

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**Open File Report**
**June, 1998**

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# PRODUCTION, TEMPERATURE AND WATER LEVEL DATA FOR THE FOUR HEATING SYSTEMS IN THE BOISE FRONT LOW TEMPERATURE GEOTHERMAL RESOURCE AREA, 1977-1997

*By* Kenneth W. Neely

## ABSTRACT

Water level declines in the Boise Front Low Temperature (85 to 212° Fahrenheit) Geothermal Resources Area (Boise Front geothermal area) prompted the Idaho Department of Water Resources (IDWR) to create a Ground Water Management Area in 1987 to discontinue the routine issuances of permits for geothermal development. Further restrictions were added to the Boise Front geothermal area in 1988 when the IDWR issued a five-year moratorium. The moratorium was extended for another five years in 1993. The moratorium is due to be reviewed in June, 1998.

Water level declines in the Boise Front geothermal area began to occur when the State of Idaho and City of Boise heating systems came on line in the mid-1980's. Prior to 1983, the Boise Warm Springs Water District was the only geothermal district heating system in the Boise area. The Veterans Administration Regional Hospital was permitted to begin withdrawing geothermal water in 1988 because substantial development of their system had been completed when the moratorium was issued. Production from the Boise Front geothermal system has increased from about 300 million gallons in water year 1984 to the current level of about 670 millions gallons per water year.

Currently, discharge does not appear to be exceeding recharge in this part of the Boise Front geothermal area based on water level data from the Bureau of Land Management (BLM) observation well and production data from the four heating systems. Water levels in the BLM well for the past 10 years indicate that the geothermal system has probably reached a new equilibrium, despite some minor fluctuations. The reasons for the new equilibrium are not fully understood but are probably related to: 1) stabilized withdrawal rates since the rapid increases of the 1980's, and 2) induced recharge which can occur when withdrawals from an aquifer increase.

The City of Boise's new injection well, which is scheduled to be operational for the 1998-1999 heating season, is expected to cause positive pressure effects in the geothermal aquifer. A modeling scenario by Montgomery Watson (1994) predicted that injection of spent

geothermal water near the new injection well location would result in no net changes to the water level at the BLM well assuming a 20 percent increase in production at the City and Boise Warm Springs Water District well fields.

Based on the current data, it is unknown whether production increases, if allowed by the IDWR, will adversely impact the water levels in this part of the Boise Front geothermal system, especially in combination with the new injection well. The historic data show that water level declines did occur after the State and City systems came on line. However, there were no observable water level declines with the addition of the VA production in the late 1980's

# INTRODUCTION

The four geothermal district heating systems in the Boise Front Low Temperature (85 to 212° Fahrenheit) Geothermal Resources Area (Boise Front geothermal area) are the: 1) Boise Warm Springs Water District (BWSWD), 2) State of Idaho Capitol Mall (State), 3) City of Boise (City), and 4) Veterans Administration Regional Hospital (VA). The BWSWD, which is the oldest heating district in the United States, has been supplying hot water to customers for space heating since 1892 (Rafferty, 1992). The State and City systems began producing geothermal water to heat public buildings in 1983. The VA system came on line in 1988 to heat the buildings on the VA complex. Combined, these systems provide clean and cost-efficient heat for several hundred private and public buildings. The cost savings of geothermal heat over conventional fossil fuel or hydropower electric heating for the four systems is at least one million dollars per year.

Water level declines in the Bureau of Land Management (BLM) observation well in the mid 1980's suggested that discharge may have been exceeding recharge in the Boise Front geothermal area. The Idaho Department of Water Resources (IDWR) created the Boise Front Low Temperature Geothermal Resource Ground Water Management Area (Boise Front GWMA) in 1987. The conditions of the Boise Front GWMA curtailed additional development of the geothermal resource in the Boise area. In 1988, a five-year moratorium was put in place by IDWR to further restrict withdrawals from the geothermal system. The moratorium was extended in 1993 for five more years. The moratorium is scheduled for review in June, 1998.

## PURPOSE OF REPORT

The purpose of this report is to publish a summary of the production, temperature and water level data for the four heating systems in the Boise Front geothermal area for the years 1977 through 1997. The data in this report include: 1) annual production totals for each system by water year (October 1 of the previous year through September 30 of the designated water year), 2) cumulative annual production totals for the four systems, 3) monthly production graphs for each system, 4) cumulative monthly production totals for the four systems, 5) water level records, 6) water supply and return temperatures for the State of Idaho Capitol Mall system, 7) precipitation records for the Boise Airport rain gauge, and 8) heating day records for the Boise area. This report was written so that the Idaho Department of Water Resources, with input from the four major users and other interested parties, could determine whether the moratorium should be extended, modified or canceled in 1998.

## WELL-NUMBERING SYSTEM

The well-numbering system used in this report is identical to the system used by the USGS in Idaho (Figure 1). The system indicates the location of wells within the official rectangular subdivision of the Public Land Survey System (PLSS) with reference to the Boise baseline and meridian. The first two segments of the number designate the township and range. The third segment gives the section number followed by three or four letters and a number. The letters indicate the ¼ section (160 acre tract), ¼-¼ section (40 acre tract), ¼-¼-¼ section (10 acre tract), ¼-¼-¼-¼ section (2 5 acre tract), and the serial number of the well within the tract. Quarter sections are lettered A, B, C, and D in counterclockwise order beginning in the northeast quarter of the section. Successively smaller tracts are lettered in the same manner. For example, well 01N 01E 11DBA1 corresponds to the PLSS location: NE¼, NW¼, SE¼, Section 11, Township 1 North, Range 1 East, and it was the first well inventoried by the USGS in that tract.

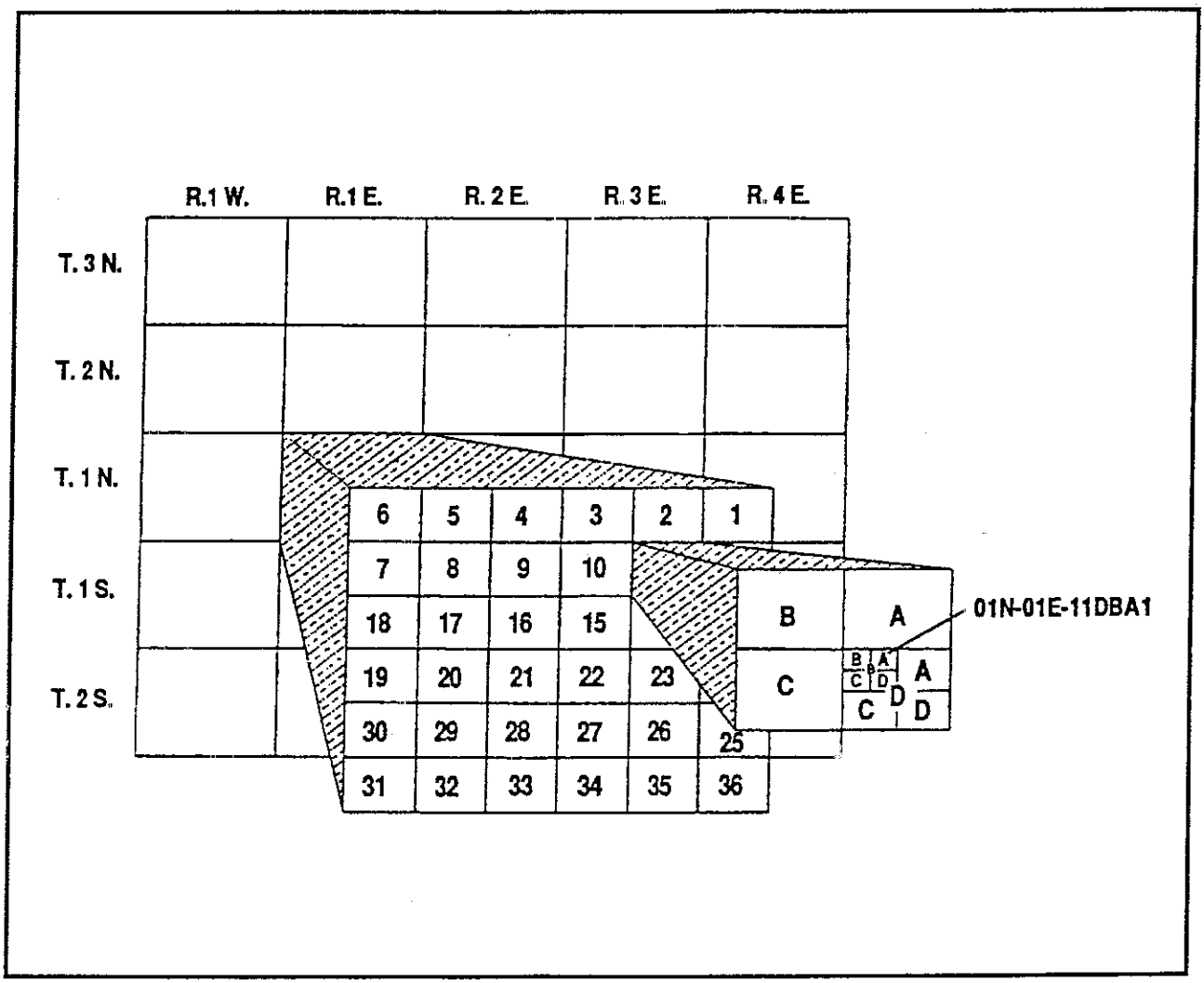



**Figure 1.** Well-numbering system.

## STUDY AREA

The Boise Front geothermal area is located along the northern edge of the Treasure Valley in the western part of the Snake River Plain of southwestern Idaho. The Treasure Valley trends northwest-southeast with the Boise Mountains located to the northeast. The Boise and Snake Rivers dissect the Treasure Valley as they flow to the northwest. A band of hills known as the Boise Front Foothills lie between the Boise Mountains and the valley floor. The Boise Front geothermal area occurs in Ada county primarily along the toe of the Boise Front Foothills and extends a short distance into the Treasure Valley (Figure 2). Part of the Boise Front geothermal area is within the Boise City limits; the remainder of the area is located north, northeast and east of the city limits. The study area for this report is the relatively small portion of the Boise Front geothermal area that contains the four district heating systems.

## PREVIOUS STUDIES

Numerous papers and reports have either described the geologic setting for the Boise Front geothermal system, documented the development of the four district heating systems or chronicled the production, water level and temperature data. Reports that provided overviews of geothermal resources in Idaho, including the Boise Front geothermal area, are Mitchell and others (1980) and Dansart and others (1994).

Mink and Graham (1977) described the geothermal potential in the western part of the Boise Front geothermal area. Anderson and Kelly (1983) evaluated the ground water flow conditions for the Boise Front geothermal aquifer. Waag and Wood (1987a and 1987b) discussed in detail the physical setting of the Boise geothermal hydrogeologic system, the chemical data and the analysis of drawdown and production data. Wood and Burnham (1987) described the geological framework of the Boise Front geothermal system and developed a conceptual model.

Reports and articles that provided information about the exploration and development history of the Boise Front geothermal resources included Stoker and others (1977), Nelson and others (1980), Worbois (1982), Higginson and Barnett (1987), and Neely (1996). Lithologic, hydrologic and chemical data were documented in reports by Young and others (1988), and Parliman and Young (1992). Burnham and Wood (1983) provided a field trip guidebook and road log for the Boise Front geothermal area.

A detailed aquifer study in the area of the four heating systems was conducted by the Berkeley Group, Inc. (1990). A two-part study was conducted by the City and the BWSWD in the early 1990's. The first part developed a conceptual model of the geothermal system (Montgomery, 1992). The second part described the hydraulic modeling of the aquifer which used the USGS MODFLOW and TST3D flow models (Montgomery Watson, 1994). A follow-up study used the numerical modeling results to evaluate potential sites for the City system's injection well (Montgomery Watson, 1996).

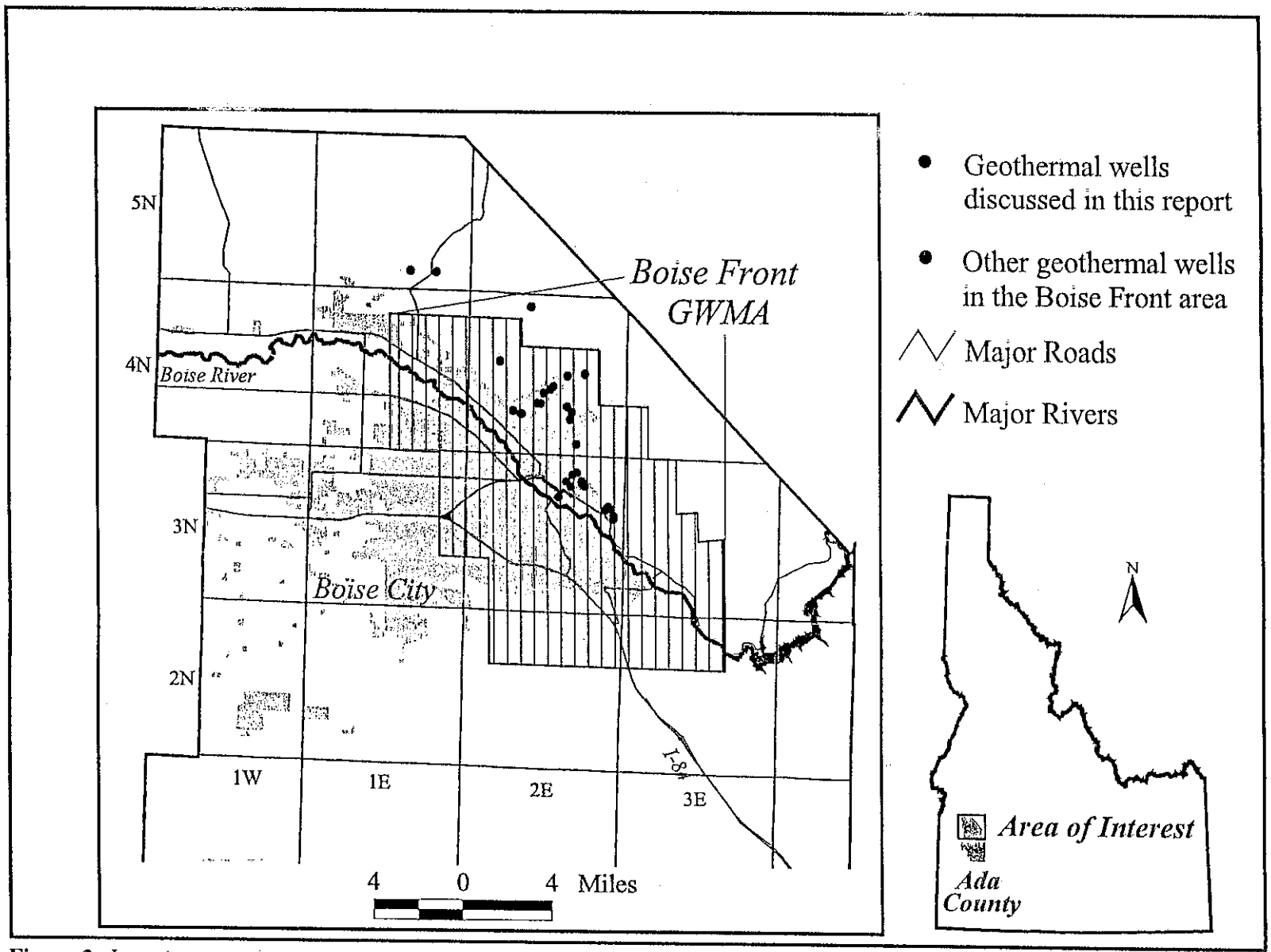



**Figure 2.** Location map showing geothermal wells in the Boise Front area and the Boise Front Low Temperature Geothermal Resource Ground Water-Management Area (Boise Front GWMA).

Some reports have been written specifically about one of the systems. The geothermal production for the BWSWD from 1977 through 1989 was documented by Robert Griffiths (Boise Warm Springs Water District, 1989). Rafferty (1992) presented the history of the BWSWD system. Mink (1976) summarized the testing of the Statehouse well which is located beside the State Capitol building. Austin (1978) described a demonstration project for the State of Idaho which used geothermal water from the BWSWD to heat three buildings in the State Laboratory complex. Anderson and Kelly (1981) reported the drilling and testing of the State Capitol Mall #2 well. Neely (1995) reported production and temperature data for the State system for 1983 through 1994.

## CLIMATE AND HEATING DATA

The 30-year average precipitation (water years 1968 through 1997) for the Boise Airport rain gauge station was 12.19 inches (National Oceanic and Atmospheric Administration) (Figure 3). The data for the last 20 water years, which is the time period that we have monitoring data for the Boise Front geothermal system, show that: 1) water years 1978 through 1986 were

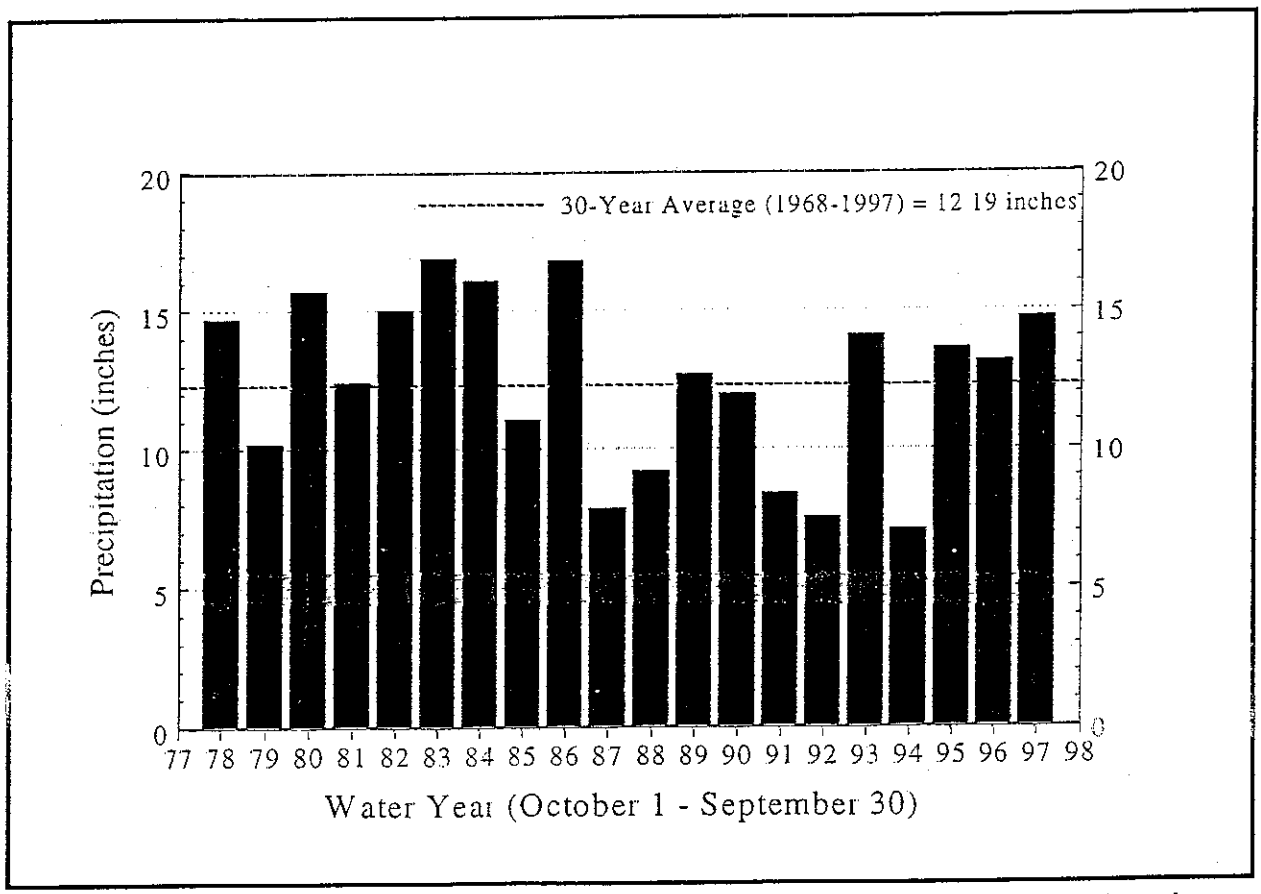



**Figure 3.** Precipitation records for the Boise Airport rain gauge station for water years 1978 through 1997.

generally wetter than average, 2) water years 1987 through 1994 were generally dryer than average, and 3) water years 1995 through 1997 were slightly wetter than average (Figure 3)

The 30-year heating degree day average (heating years 1968 through 1997) for Boise was 5757 heating degree days (National Oceanic and Atmospheric Administration). The data for the last 20 years show that: 1) annual heating degree days were generally less than the 30-year average for heating years 1978 though 1983, 2) annual heating degree days were significantly more than the 30-year average for heating years 1984 through 1986, and 3) annual heating degree days were generally less than the 30-year average for heating years 1987 through 1997 (Figure 4)

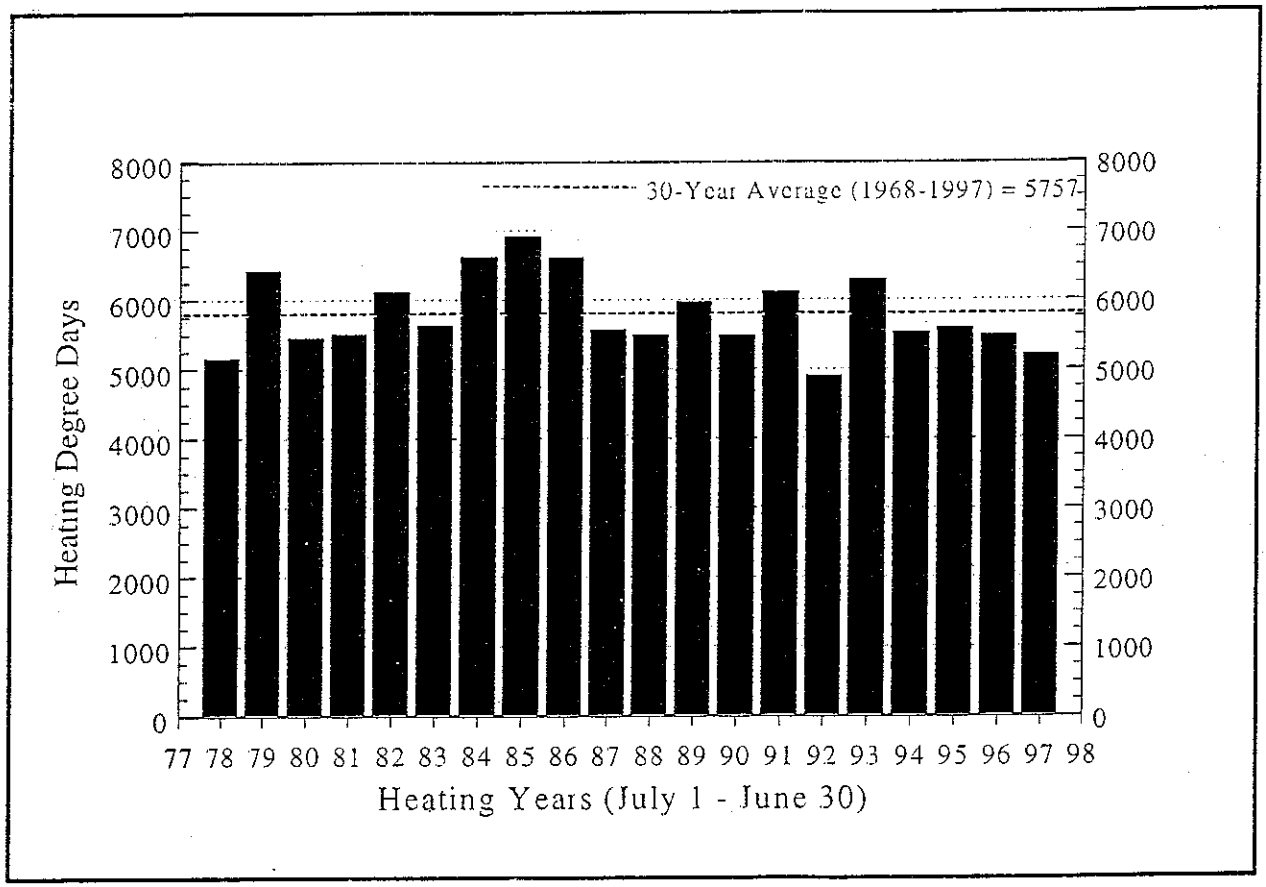



**Figure 4.** Heating degree day data for Boise for heating years 1977 through 1997

# GEOTHERMAL DEVELOPMENT IN THE BOISE AREA

The first two geothermal wells in the United States were drilled near Boise, Idaho, in 1890 and 1891 (Boise City Public Works, 1993). The wells were completed near some thermal springs located about two miles east of Boise (Figure 5). Both wells were drilled to depths of 400 feet (Table 1). Although there are no well driller's reports for the two wells, it is assumed that the wells were completed in the rhyolite rocks of the Idavada Group. The wells are believed to have been drilled through a major down-to-the-southwest normal fault that trends northwest/southeast along the toe of the Boise Front Foothills. This fault and other associated faulting are interpreted to be the conduits for upward migration of geothermal water along the Boise Front.



**Figure 5.** Original well house for the Boise Warm Springs Water District's two geothermal production wells (from Burnham and Wood, 1983).

By 1892, the water from the wells was being used to heat homes, businesses and a 15,000 square foot Natatorium in east Boise. The Natatorium no longer exists but the

geothermal water is still being used to heat 226 homes and 36 commercial buildings on and near Warm Springs Avenue and in part of the downtown Boise area (Figure 6). Today, the Boise Warm Springs Water District (BWSWD) maintains the production wells and delivers the water to the customers. The used geothermal water is discharged to the Boise River through the city sewer system (Berkeley Group, Inc., 1990). BWSWD drilled a third well in 1981 about 650 feet northwest of the two production wells. The well, which is believed to be on the upthrown side of the fault, did not encounter sufficient quantities of geothermal water for production. The well is being used for monitoring water levels.

**Table 1.** Selected wells in the Boise Front geothermal area.

| System | Well Name | Location | Reported Depth (feet below land surface) | Year Drilled | Use[1] |
|---|---|---|---|---|---|
| Boise Warm Springs Water District (BWSWD) | BWSWD West | 3N 2E 12CDDD1 | 400 | 1891 | A |
| | BWSWD East | 3N 2E 12CDDD2 | 400 | 1891 | A |
| | BWSWD #3 | 3N 2E 12CDDC1 | 587 | 1981 | U,M |
| State of Idaho Capitol Mall (State or CM) | CM #1 | 3N 2E 10AADA1 | 2,152 | 1981 | I |
| | CM #2 | 3N 2E 10AABB1 | 3,030 | 1981 | A |
| City of Boise (previously owned by Boise Geothermal Limited (BGL)) | BGL #1 | 3N 2E 11ABCA1 | 2,008 | 1981 | U |
| | BGL #2 | 3N 2E 11ABBC1 | 880 | 1981 | A |
| | BGL #3 | 3N 2E 11BAAA1 | 1,897 | 1981 | A |
| | BGL #4 | 3N 2E 11ABCB2 | 1,103 | 1981 | A |
| Veterans Administration Regional Hospital (VA) | VA #1 | 3N 2E 02CDCD1 | 1,666 | 1983 | A |
| | VA #2 | 3N 2E 02CBCC2 | 1,840 | 1983 | U |
| | VA #3 | 3N 2E 02CBCC3 | 2,300 | 1987 | I |
| Other | BLM | 3N 2E 11BABD1 | 1,222 | 1976 | M |

[1] Use codes: A = heating; I = injection; M = monitoring; U = unused.

In the mid-1970's, the increasing cost of heating created new interests in alternate heat sources such as geothermal. In 1976, EGG /INEL drilled the Bureau of Land Management (BLM) and Beard exploration wells, along with three geothermal test holes, in the downtown Boise area. At about the same time, the State of Idaho Capitol Mall complex was expanding. This development prompted then-Governor Andrus to request a federal study to determine the feasibility of geothermal heat for the State's building in downtown Boise (Austin, 1978).

The State Health Laboratory was retrofitted for geothermal heat as a pilot project in 1977. The success of the State Health Laboratory project motivated the State of Idaho to drill

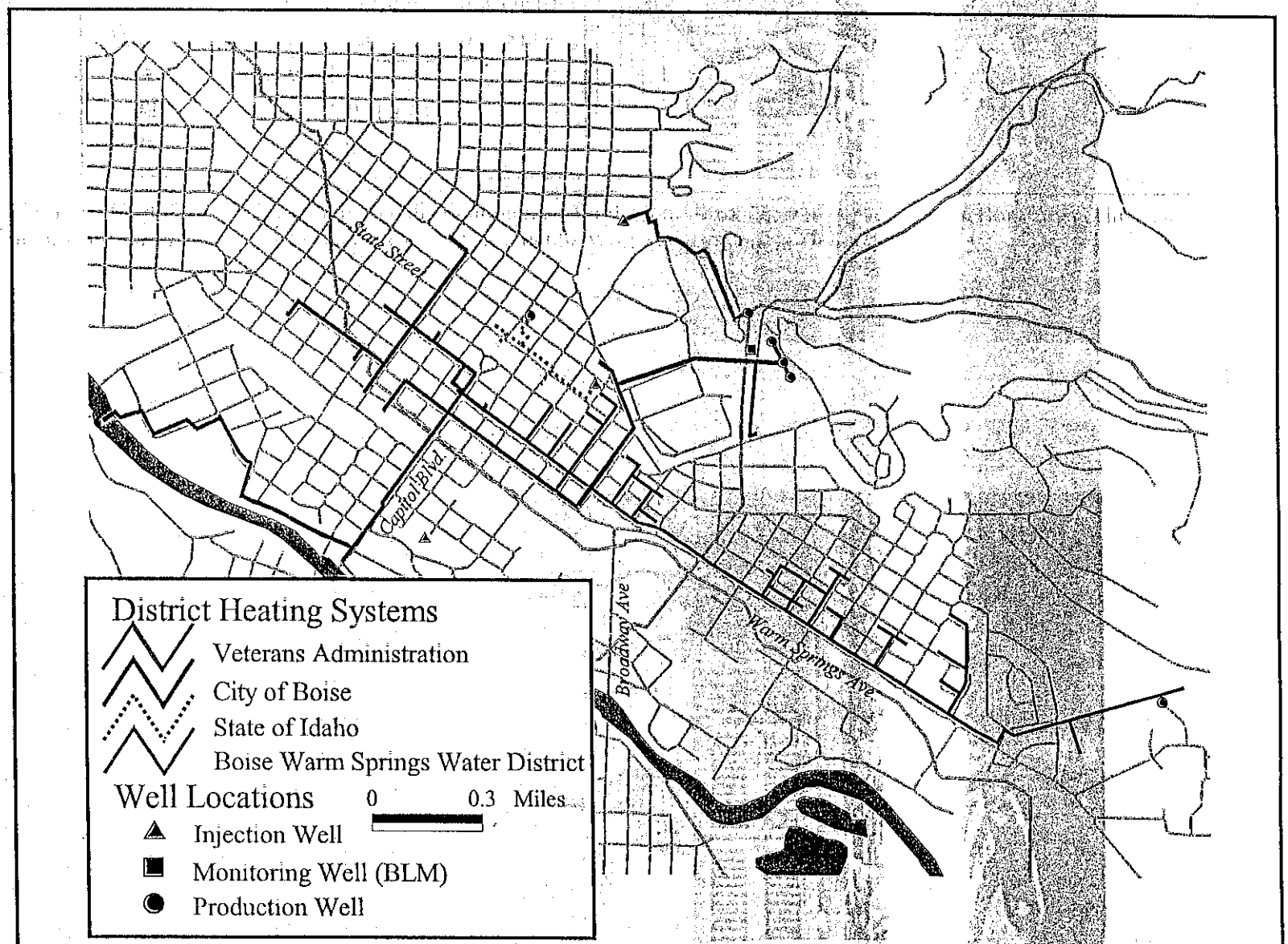



**Figure 6.** Geothermal well locations and distribution lines for the four district heating systems in the Boise area (This map was modified from a map received from the City of Boise Public Works Department in 1996).

the Capitol Mall #1 exploration well about three blocks from the State Capitol in 1981. Capitol Mall #2 was drilled about two blocks north of the Capitol (Figure 7). Capitol Mall #2, which is 3,030 feet deep, is being used as the production well; Capitol Mall #1 is 2,150 feet deep and is used as the injection well (Figure 6). The wells were completed in volcanic rock and sand (Idavada Group) according to the well driller's reports. By 1982, the State of Idaho geothermal system was suppling heat to eight building in the Capitol Mall complex, including the State Capitol. The Alexander House was added to the system in about 1992. Currently, the system is used to heat about 1,500,000 square feet.

In 1981, a company named Boise Geothermal Limited (BGL) had four geothermal wells drilled an area northeast of downtown Boise and along the edge of the Boise Front Foothills (Figure 6). The well names and well depths are: 1) BGL-1, 2,008 feet, 2) BGL-2, 880 feet, 3) BGL-3, 1,897 feet (Figure 8), and 4) BGL-4, 1,103 feet. The wells were completed in the rhyolite and interbedded sandstones of the Idavada Group.

BGL began supplying geothermal water for space heating to downtown Boise customers in 1983 (Berkeley Group, Inc., 1990). In 1988, the City of Boise purchased BGL. Today, the City geothermal system is used to heat about 1.8 million square feet which includes the City

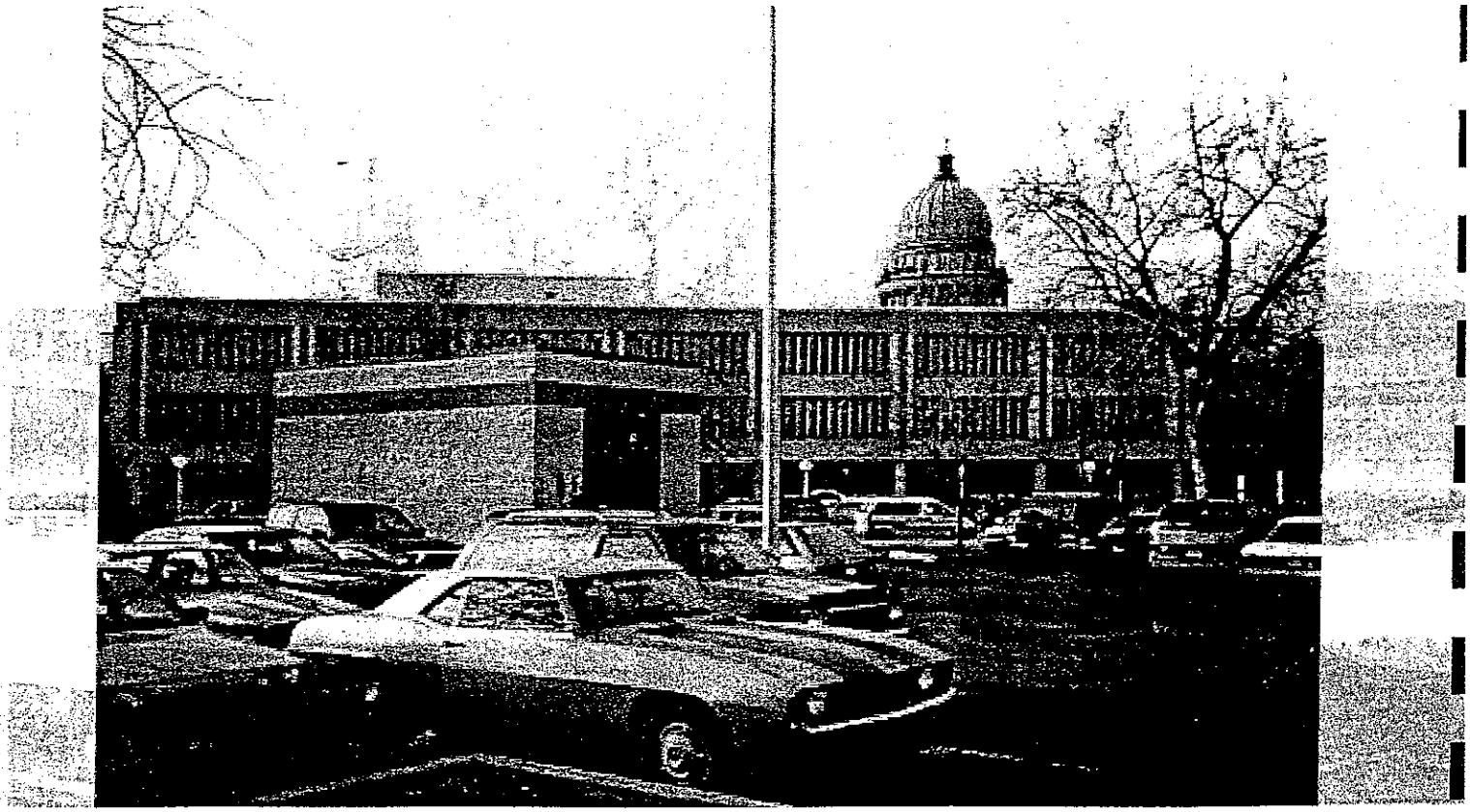


**Figure 7.** Well house for the State of Idaho Capitol Mall #2 geothermal production well. The top of the State Capitol building is in the background.

Hall and 42 customers (Tensen, 1996, personal communication). Used geothermal water is currently disposed of in the Boise River. However, the City of Boise has recently completed a 3,200-foot well in Julia Davis Park which will be used for injecting spent geothermal water (Figure 9). The well is to be operational by the beginning of the 1998-1999 heating season

Two geothermal wells were drilled for the Veterans Administration (VA) Regional Hospital on their properties in 1983. A third geothermal well was drilled for the VA in 1986. The production well, which was the first well drilled for the VA, is 1,666 feet deep (Figures 6 and 10). The injection well, which was the third well drilled for the VA, is 2,300 feet deep (Figure 6). The second well, which was drilled primarily for exploration, is currently unused. The wells were completed in rhyolite, tuff, basalt and sand (Idavada Group) according to the well driller's report. The VA geothermal system provides heat to about 400,000 square feet in 22 buildings on the hospital grounds which include patient care, clinical support, outpatient and ancillary support facilities.

Several other deep geothermal wells have been drilled in the Boise Front geothermal area (Berkeley Group, Inc., 1990; Neely, 1995). The names of the wells located nearest to the four

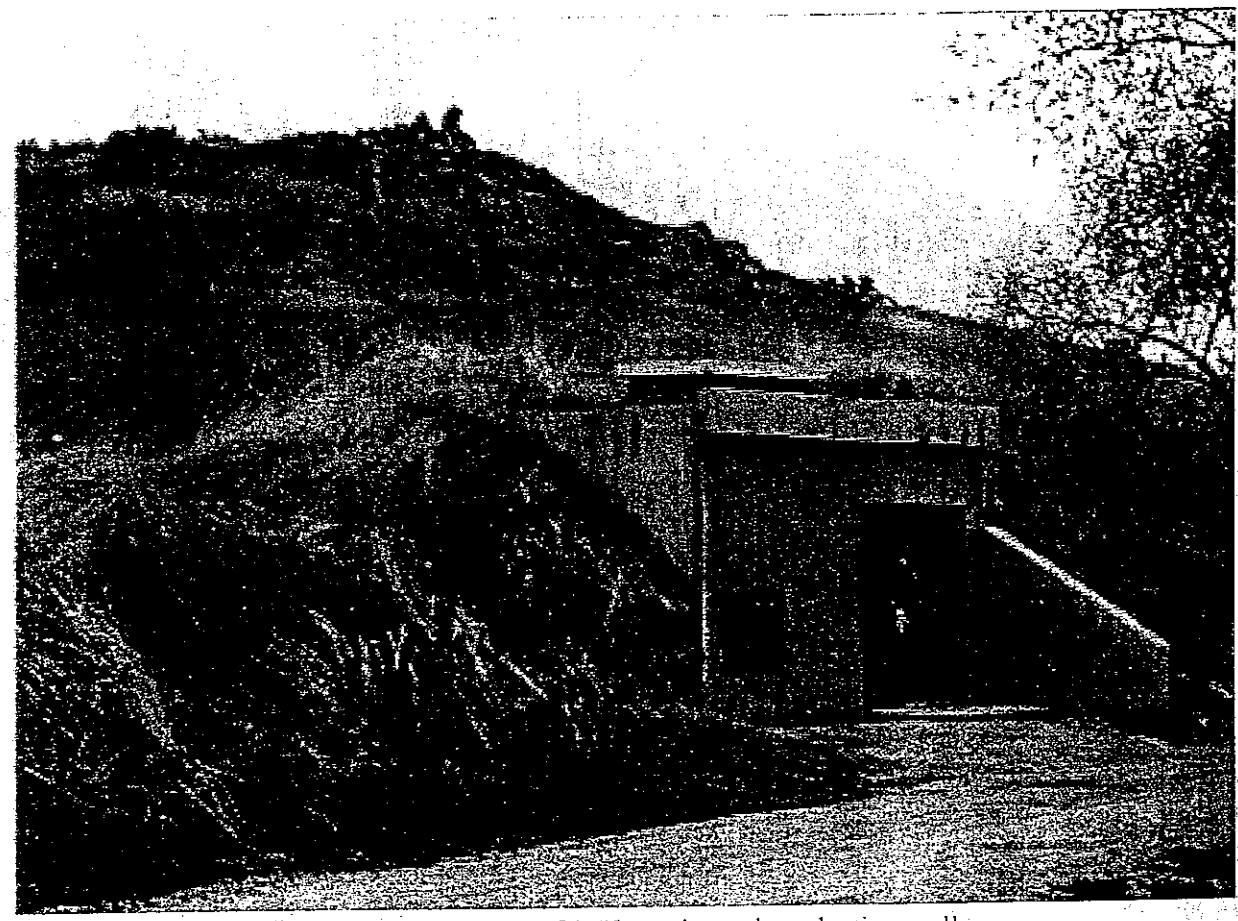


**Figure 8.** Well house for the City of Boise's BGL #3 geothermal production well

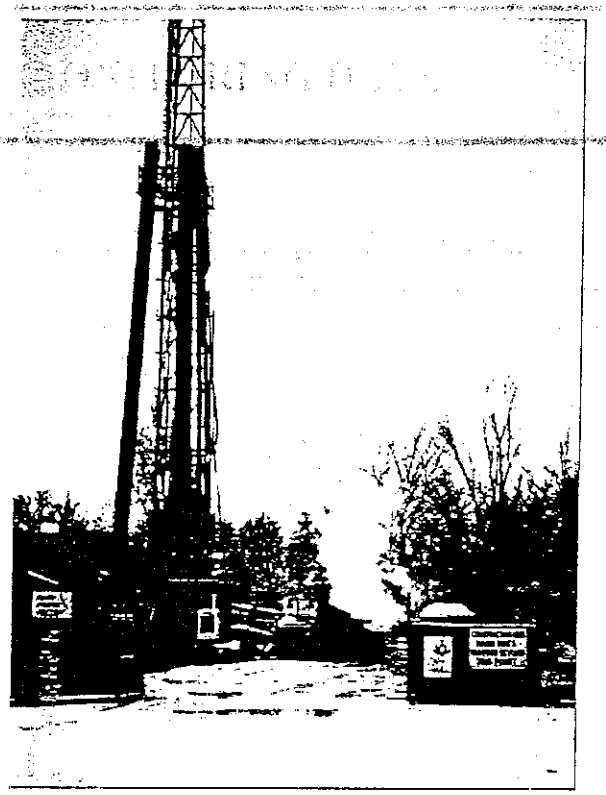


**Figure 9**. Drilling the injection well for the City of Boise, April 1998.

heating systems are: Behrman, BLM, Fort Boise Park, Kanta, Koch, Old Penitentiary (Botanical Gardens) and Quarry View. The Fort Boise Park and Koch wells produce small quantities of geothermal water; the other wells are not being used for withdrawals. The BLM well, located close to the VA and City of Boise production wells, is the primary observation well for the Boise geothermal system.

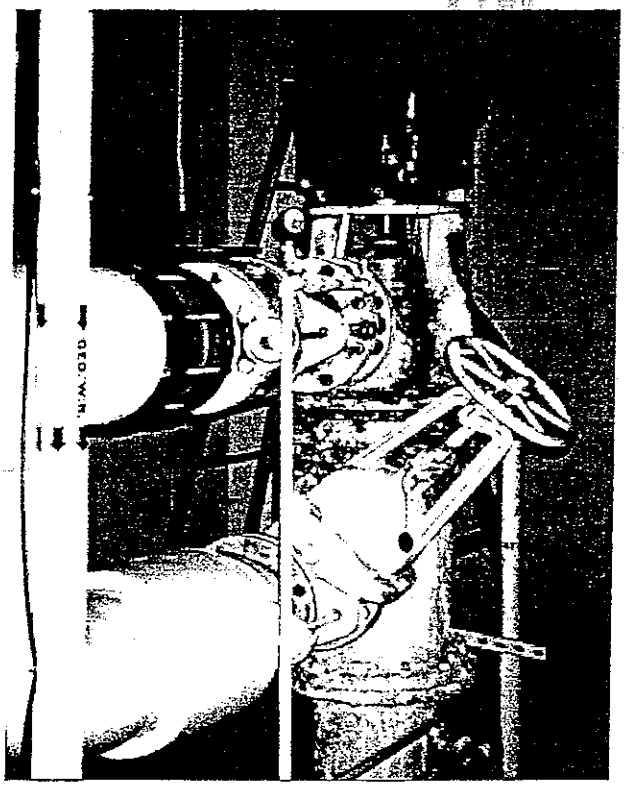


**Figure 10**. Production well for the Veterans Administration Regional Hospital.

# GEOTHERMAL MONITORING DATA

Data collection for the four systems is accomplished through manual readings and computer data loggers. The BWSWD and the State systems currently use electronic devices to capture monitoring data. Automation of data collection using data loggers has been discussed for the City and Va systems but has not been implemented yet.

The BWSWD began recording production data in September, 1977 (Boise Warm Springs Water District, 1989). Production data are currently being recorded using two methods: 1) hand-written daily logs, and 2) a data logger. The BWSWD submits a summary of the hand-written logs to IDWR that lists production by month and by year. The data logger captures a production value once every 10 minutes. IDWR downloads the datalogger every three months.

Maximum monthly production for the BWSWD has decreased over the past 20 years from almost 50 million gallons per month to about 30 million gallons (Figure 11). Annual production by water year for the BWSWD has decreased from a peak of over 300 million gallons to about 220 million gallons (Table 2; Figure 12). The reasons for the decline are: 1) better heating efficiencies because of the addition of new pipe insulation on main and service

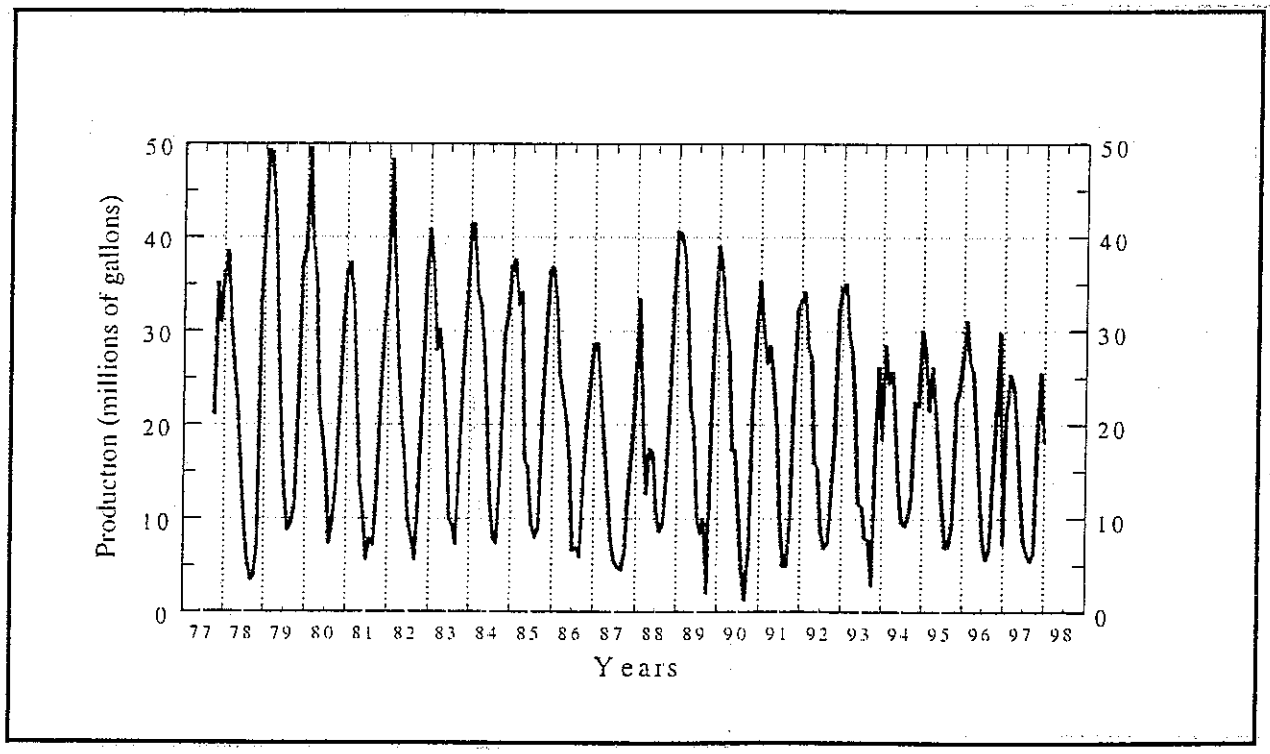



**Figure 11.** Monthly production for the Boise Warm Springs Water District heating system, 1977-1997

**Table 2.** Production By Water Year[1] For The Four Heating Systems In The Boise Front Geothermal Area.

| PRODUCTION IN MILLIONS OF GALLONS | | | | | |
|---|---|---|---|---|---|
| **Water Year** | **BWSWD** | **State** | **City** | **VA** | **Total** |
| 1978 | 256.0 | | | | 256.0 |
| 1979 | 312.2 | | | | 312.2 |
| 1780 | 308.1 | | | | 308.1 |
| 1981 | 239 4 | | | | 239 4 |
| 1982 | 276 0 | | | | 276.0 |
| 1983 | 283.5 | | | | 283.5 |
| 1984 | 300 1 | 162.9 | 166 7 | | 629 7 |
| 1985 | 281.1 | 175 4 | 121 4 | | 577.9 |
| 1986 | 253.2 | 192.0 | 176 8 | | 622.0 |
| 1987 | 183.3 | 169.1 | 188 9 | | 541 3 |
| 1988 | 199 4 | 138.8 | 123.8 | | 462.0 |
| 1989 | 278 0 | 120 0 | 158.0 | | 556 0 |
| 1990 | 244.6 | 68.3 | 122 3 | 118.2 | 553 4 |
| 1991 | 245.7 | 177 6 | 121.3 | 115.4 | 660 0 |
| 1992 | 243.3 | 139 0 | 123.3 | 116.7 | 622 3 |
| 1993 | 239.3 | 177 6 | 156.0 | 137.0 | 709.9 |
| 1994 | 214 7 | 179 6 | 122.5 | 137 4 | 654.2 |
| 1995 | 221 2 | 150 8 | 129.9 | 151.4 | 653.3 |
| 1996 | 226.6 | 119.6 | 132.1 | 186.2 | 664.5 |
| 1997 | 212 8 | 112 2 | 130.7 | 203.6 | 659.3 |
| Average production | 250 9 (1978-1997) | 155.0 (1984-1997, minus 1990) | 141.0 (1984-1997) | 145.7 (1990-1997) | 660.5 (1991-1997) |

[1]Water year runs from October 1 to September 30. For example, water year 1978 started on October 1, 1977 and ended on September 30, 1978.

lines, 2) reduced demand by some of the service units, and 3) reduction in the number of service units. The addition of new pipe insulation is considered the primary factor for the reduction in withdrawals. Water supply temperatures have remained constant at about 175° Fahrenheit (F).

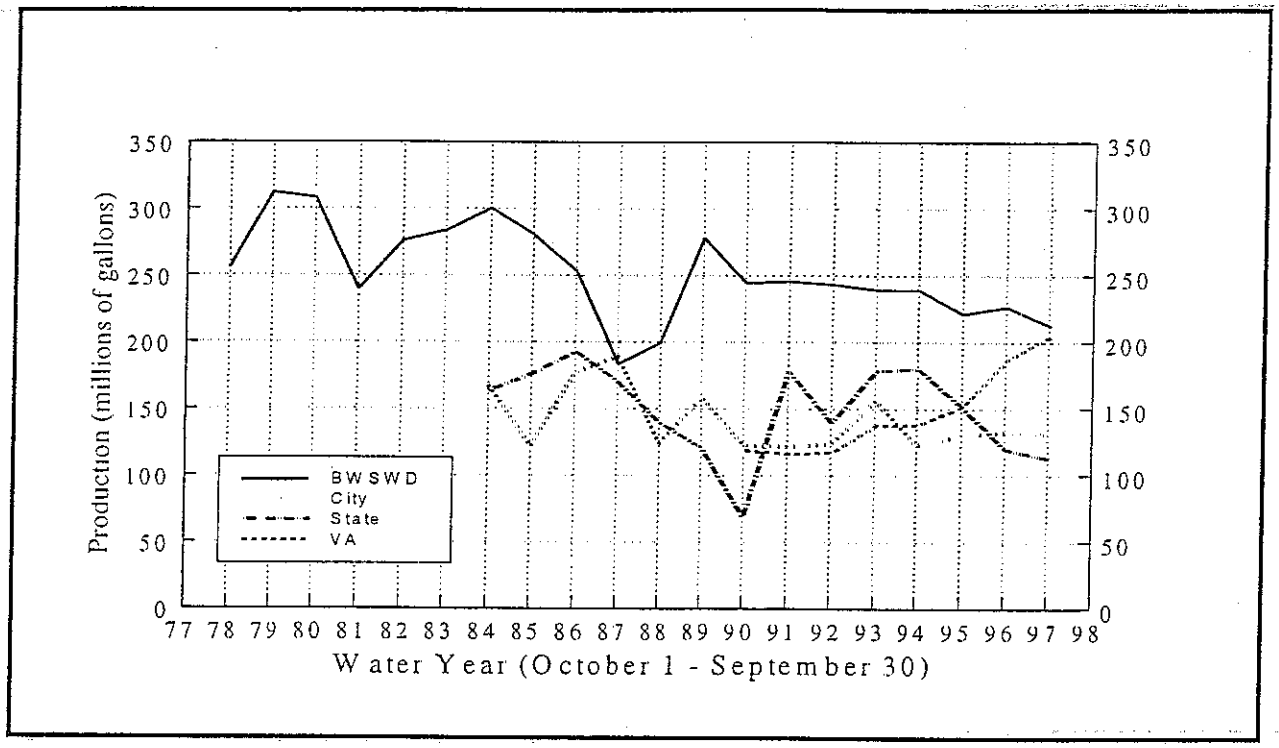



**Figure 12.** Geothermal production by water year for the Boise Warm Springs Water District (BWSWD), City of Boise (City), State of Idaho Capitol Mall (State) and Veterans Administration Regional Hospital (VA) heating systems

The State of Idaho geothermal system went on line in November, 1982. The first production data recorded for the system were from May, 1983. Monitoring data were initially recorded by hand on daily logs with only one entry for each day. Data were usually recorded in the mornings (between 5:00 and 8:00 am). The Berkeley Group, Inc., (1990) reported that the daily logs reflect higher than average discharges because the readings were taken during peak flow times. Data have been recorded on computer trend logs since 1991. Data were initially recorded once every six hours; since 1995, data have been recorded once every two hours.

Maximum monthly production for the State of Idaho geothermal system was about 30 million gallons in 1985, 1986 and 1993 (Figure 13). Production data for half of water year 1990 was missing; therefore, the total of 68.3 million gallons is considerably too low.

Production appears to have declined in 1996 and 1997 (Table 2; Figures 12 and 13). However, there are missing data intervals in the computer trend logs during those years due to equipment failure and data capture errors. To minimize data loss in the future, the State Department of Administration is now submitting data updates to IDWR once every three

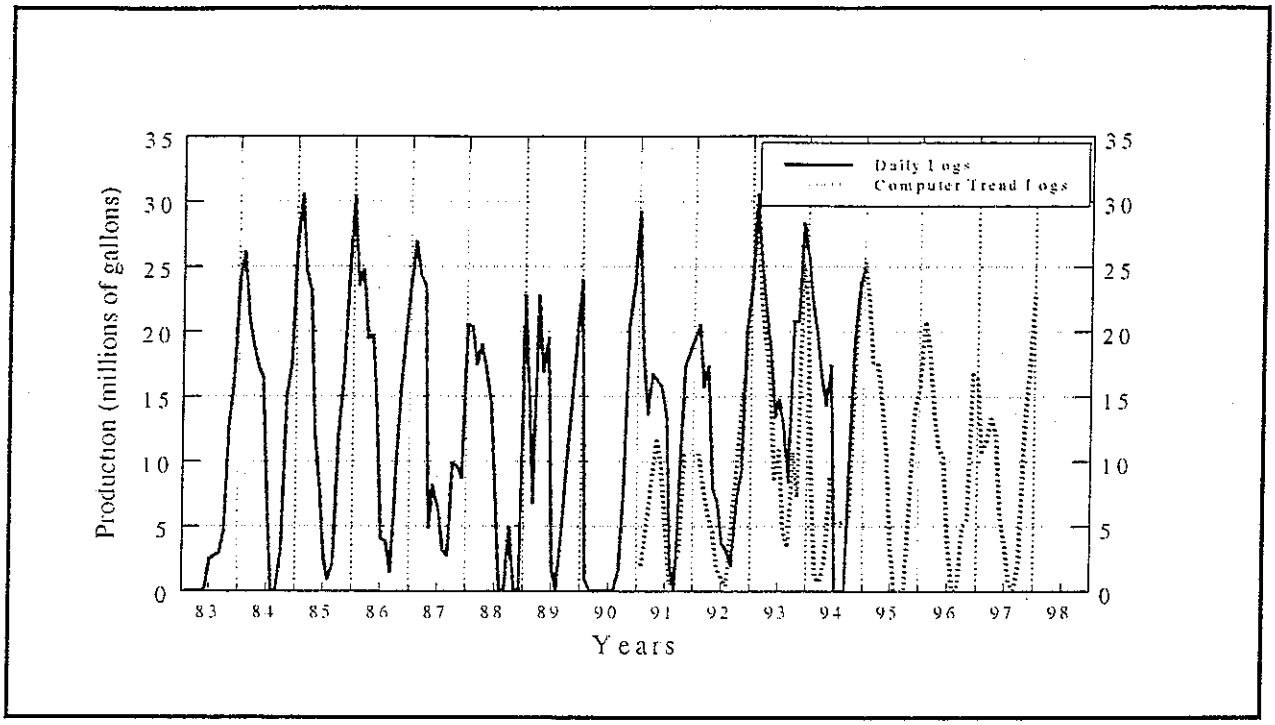



**Figure 13**. Monthly production for the State of Idaho Capitol Mall heating system, 1983-1997

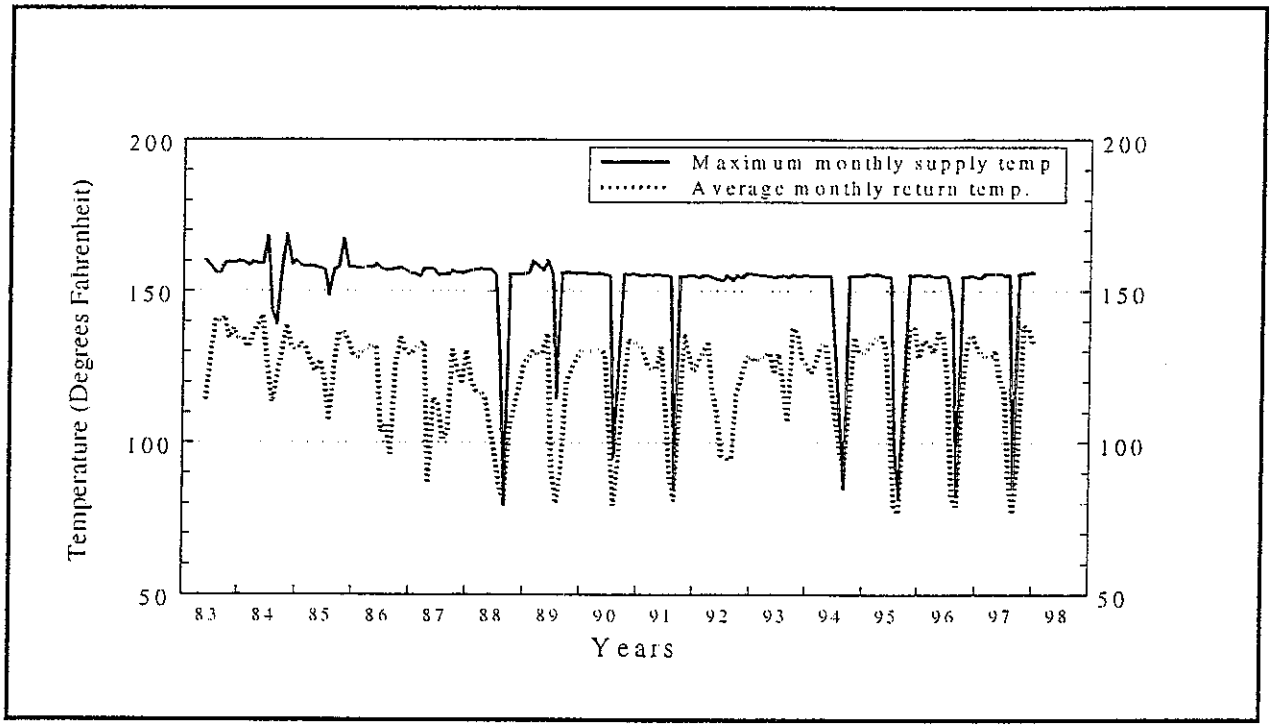



**Figure 14**. Maximum monthly supply and average monthly return temperatures for the State of Idaho Capitol Mall heating system, 1983-1997

months Maximum monthly supply temperatures decreased from about 160° F in 1983 to about 155° F in 1992 and have since risen slightly (Figure 14)

The City of Boise records monitoring data using flow rate and temperature charts. The City also has a totalizer meter that is read weekly. Since 1988, the City has supplied the IDWR with a production total for each month. Production data prior to 1988 were documented in the Berkeley Group, Inc., (1990) and Montgomery (1992) reports

Production for the City of Boise geothermal system was variable from water years 1984 through 1989 (Table 2; Figure 12). Beginning in water year 1990, production has been consistently in the 121-130 million of gallons per year range with the exception of a slight

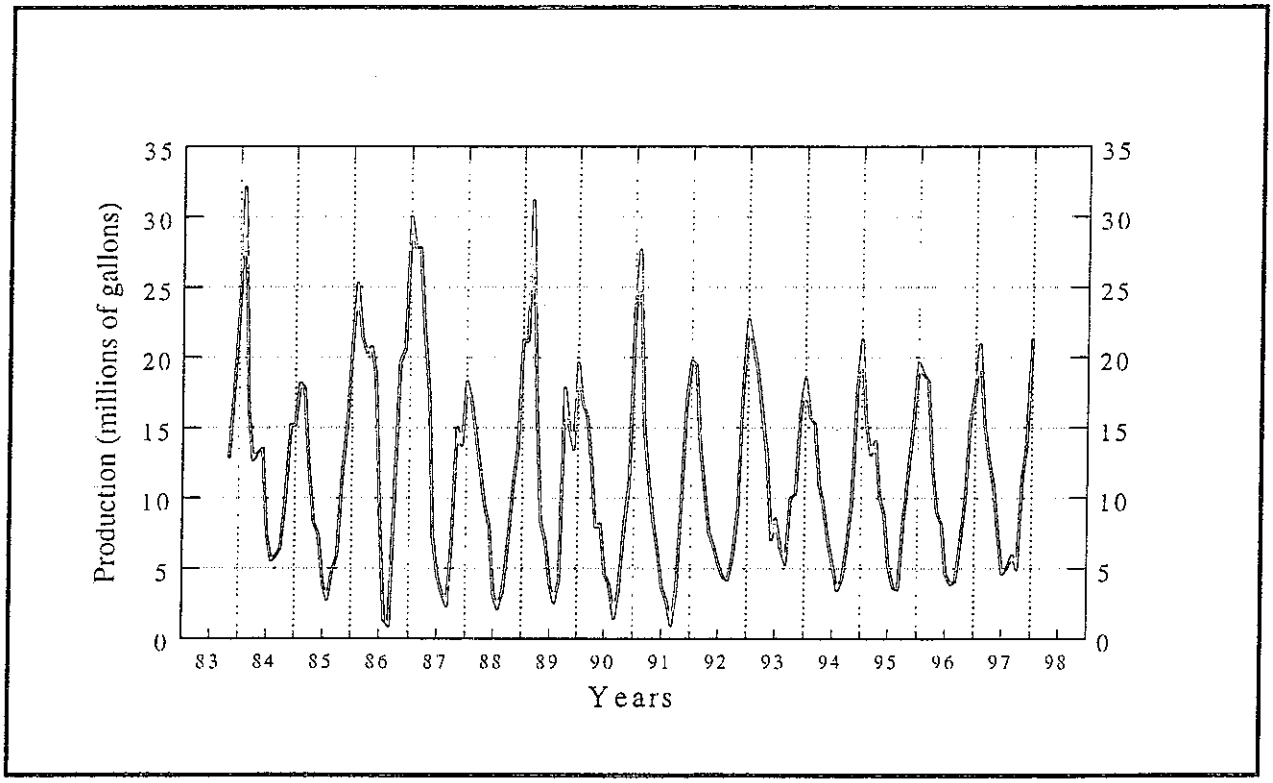



**Figure 15**. Monthly production for the City of Boise heating system, 1983-1997.

increase in water year 1993 (Figure 12) Maximum monthly production was generally higher during the 1980's than it was in the 1990's (Figure 15). Supply temperatures have remained constant at about 175° F.

VA technicians record totalizer, instantaneous discharge, temperature and water level data daily (except for weekend days and holidays) on handwritten log sheets. Production has increased steadily from water years 1990 through 1997 (Table 2; Figure 12). Maximum monthly production has increased during this time period from about 16 million gallons to about

25 million gallons (Figure 16) The reason(s) for the increase is unknown (Doug Lamb, VA; personal communication) Supply temperatures have remained constant at about 162° F.

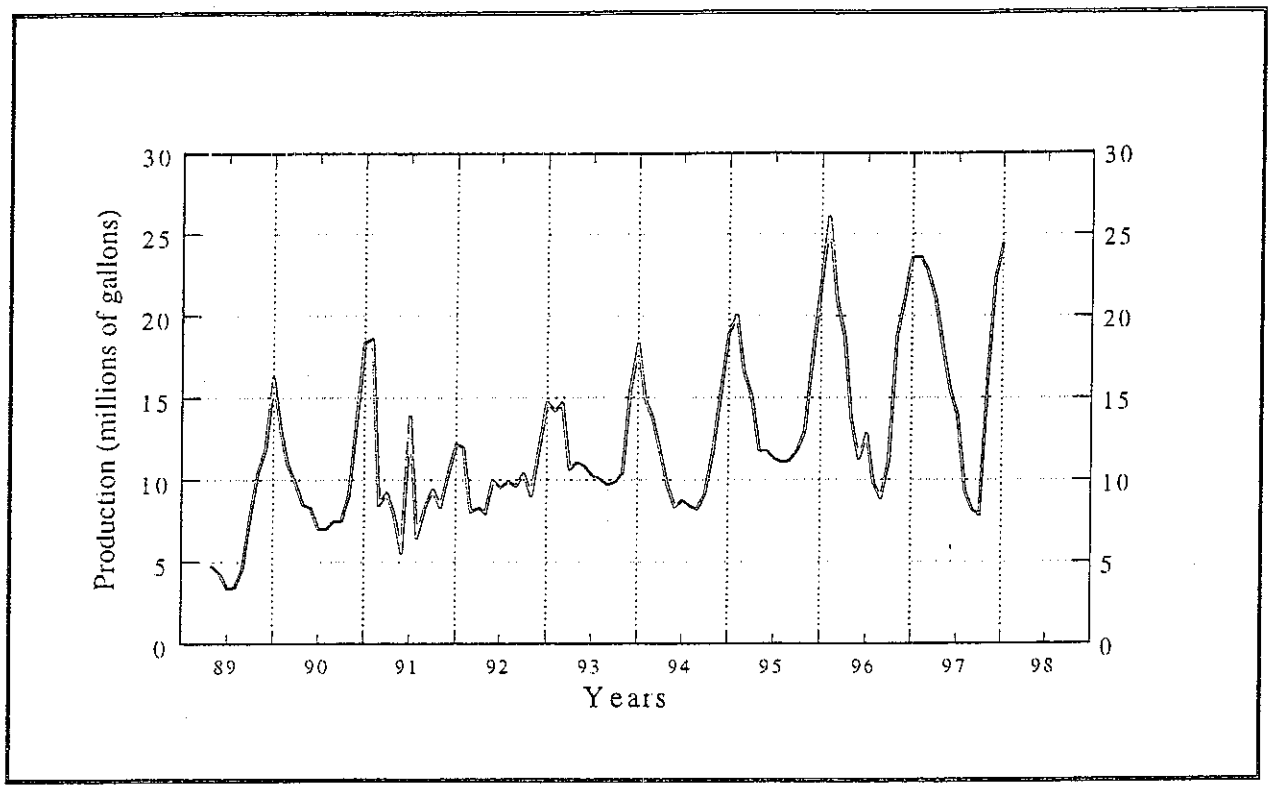



**Figure 16**. Monthly production for the Veterans Administration Regional Hospital heating system, 1989-1997.

Figure 17 shows that total production for the four geothermal heating systems jumped dramatically in water year 1984 when the State and City systems came on line. The average annual production for water years 1978 through 1983, when the BWSWD was the only system withdrawing geothermal water, was 279 million gallons The average annual production for water years 1984 through 1989 was 565 million gallons. A second but smaller increase occurred in the early 1990's water years when the VA began production. The average annual production for water years 1991 through 1997, when all four systems were on line, was 661 million gallons (Calculations did not include 1990 because a considerable amount of data were not available for the State system that year) The average for 1991-1997 is estimated to be 670 million gallons after adding in the estimated amount of withdrawals that are missing from the State system in 1996 and 1997.

Overall, production has more than doubled since the time when only the BWSWD was withdrawing geothermal water. Maximum monthly production, which occurs in January, for the

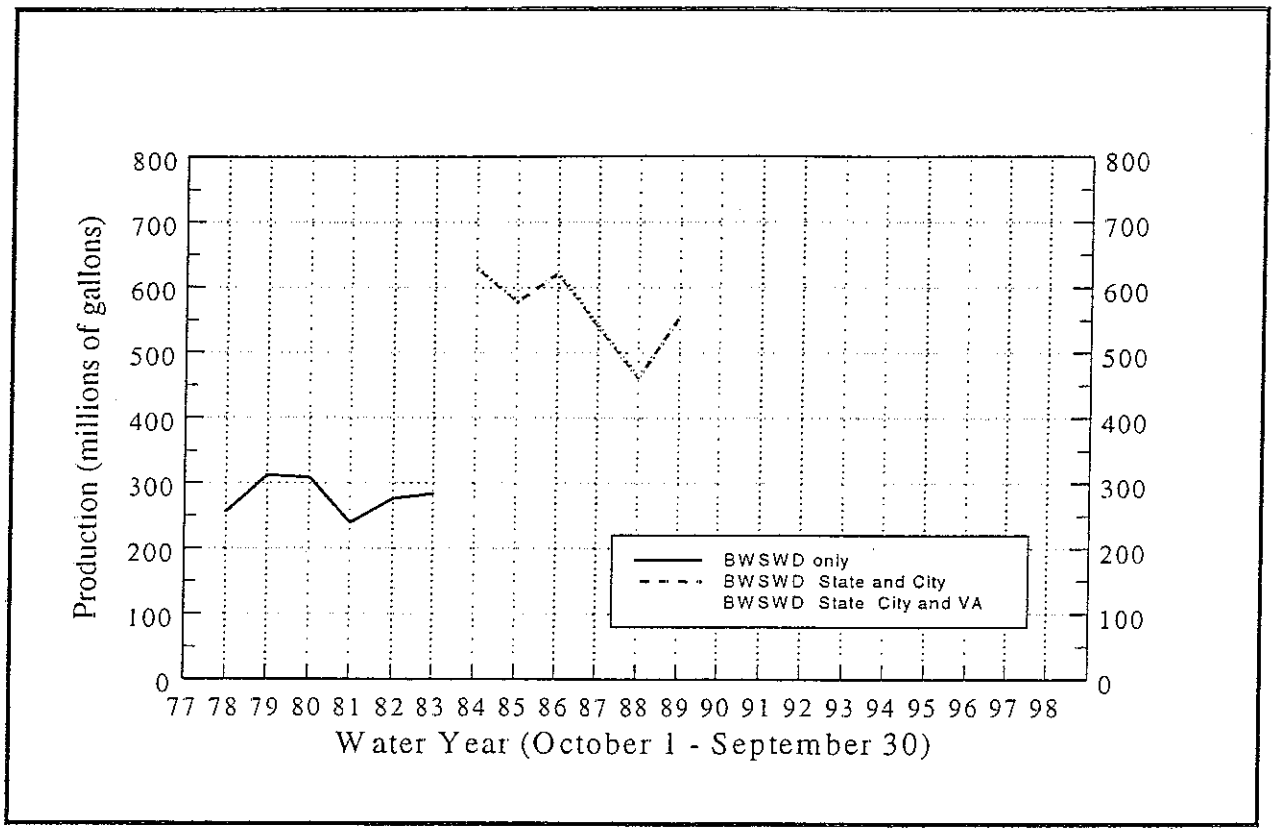



**Figure 17**. Total production by water year for the four heating systems in the Boise Front geothermal area, 1978-1997

four systems, has been as much as 106 million gallons (Figure 18). Figure 19 shows the average annual production and percentage of total for each heating system for water years 1991-1997

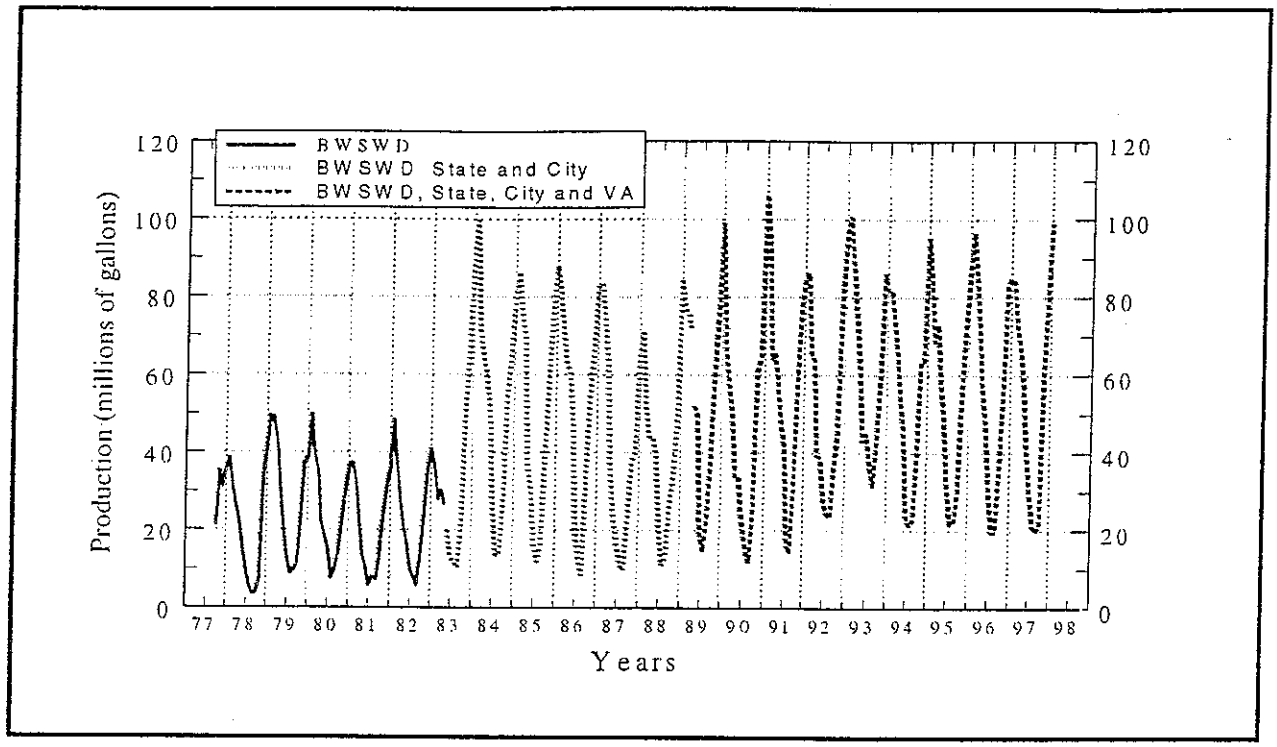



**Figure 18**. Monthly production for the four heating systems in the Boise Front geothermal area, 1977-1997.

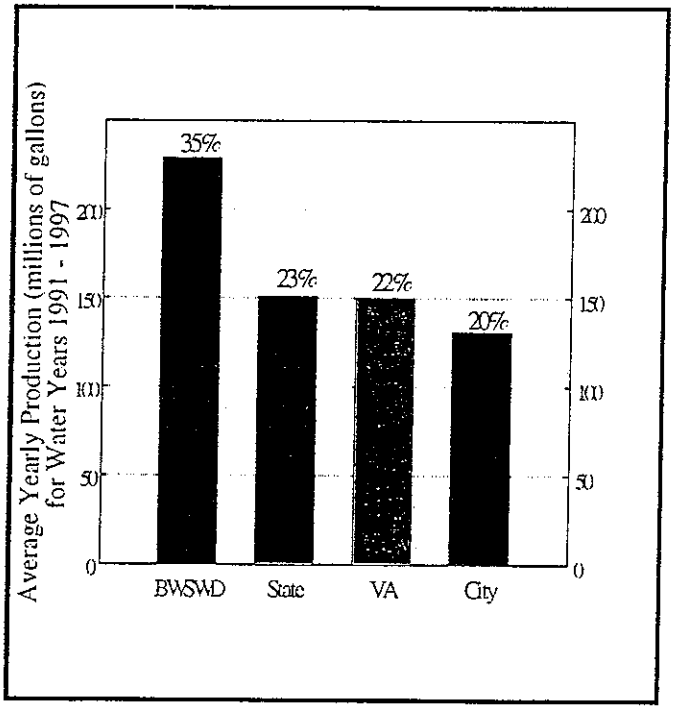



**Figure 19**. Average yearly geothermal production for the four heating systems in the Boise area for water years 1991 through 1997. Individual percentages of the total production are given for each system.

# GROUND WATER MANAGEMENT AREA AND MORATORIUM

Water levels in the BLM well, which is the primary monitoring well for the Boise Front geothermal area, declined about 25 feet from 1984 to 1989 (Figure 20). Comparing Figures 17 and 18 to Figure 20 shows that the plummeting levels in the mid to late 1980's were related to new production from the State and City heating systems. Geothermal production in this portion of the Boise Front geothermal area increased about 100 percent when these two systems went on line. The addition of the VA system in 1989 did not cause observable declines in the BLM well despite a 15 percent increase in total production. The VA production well and the BLM well are believed to be in the same fault zone based on similar water level responses (Berkeley Group, 1990).

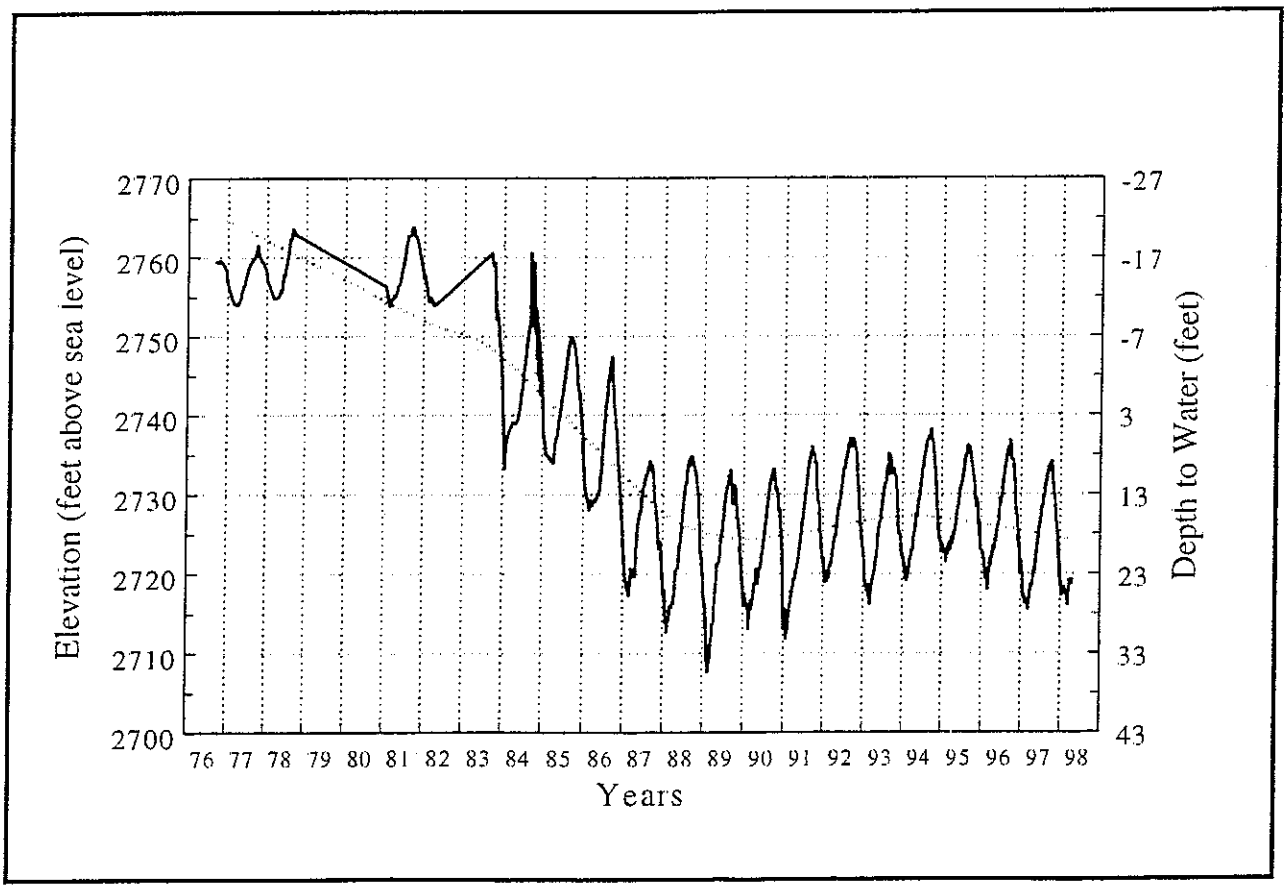



**Figure 20.** Hydrograph for the BLM observation well, 1976-1998. The solid line connects actual data points. The dotted line was added using the locally weighted scatterplot smoothing (LOWESS) method to show the general middle trend of the data (Helsel and Hirsch, 1992)

On June 15, 1987, the IDWR designated the Boise Front Low Temperature Geothermal Resource Ground Water Management Area (Boise Front GWMA) which stopped routine issuances of permits for geothermal development in the designated area (Figure 2) The description of the Boise Front GWMA is:

> From a point of beginning at the Northeast corner of Sec 8, T4N, R2E; thence southerly 1 mile to the southeast corner of Sec. 8; thence easterly approximately 3 miles to the northeast corner of Sec 14; then southernly 2 miles to the southeast corner of Sec. 23; then easterly 2 miles to the northeast corner of Sec. 30, T4N, R3E; thence southerly 2 miles to the southeast corner of Sec 31; thence easterly approximately 1 mile to the southeast corner of Sec. 32; thence southerly approximately 2 miles to the northwest corner of Sec 16, T3N, R3E, thence easterly 1 mile to the northeast corner of Sec 16; thence southerly 1 mile to the southeast corner of Sec. 16, thence easterly 1 mile to the southeast corner of Sec 15; thence southerly approximately 5 miles to the southeast corner of Sec 10, T2N, R3E; thence westerly approximately 9 miles to the southwest corner of Sec. 8, T2N, R2E; thence northerly 4 miles to the southwest corner of Sec 20, T3N, R2E; thence westerly approximately 2 miles to the southwest corner of Sec. 24, T3N, R1E; thence northerly approximately 4 miles to the southwest corner of Sec. 36, T4N, R1E; thence westerly 2 miles to the southwest corner of Sec. 34; thence northerly approximately 5 miles to the northwest corner of Sec 10; thence easterly approximately 5 miles to the point of beginning (Idaho Department of Water Resources, 1987).

On June 10, 1988, the IDWR issued a five-year moratorium for the Boise Front GWMA whose main conditions were: 1) the prohibition of further development or additional use pursuant to undeveloped or partially developed permits (unless certain information is provided), and 2) the rejection of pending and future applications (unless certain information is provided)(Idaho Department of Water Resources, 1998) The Veterans Administration Regional Hospital was allowed to bring their system on line in 1988 because substantial development had been completed when the moratorium was issued. In 1993, the IDWR extended the moratorium for another five years (Idaho Department of Water Resources, 1993). The moratorium is due to be reviewed in June, 1998. The dramatic water level declines in the BLM well ceased in 1989 Water levels rose slightly from 1989 to 1994 and have decreased a small amount since 1994 (Figure 20).

# DATA ANALYSES

The following observations are based on reviewing and analyzing the geothermal monitoring data and other ancillary data for the Boise Front GWMA:

1. The rapid water level declines that occurred in the BLM well in the mid-1980's ceased after early 1989. Water levels increased in the BLM well from 1989 through 1994 (Figure 20). Since 1994, water levels have declined slightly.
2. Average annual total production for the four heating systems for water years 1991-1997 was 661 million gallons (Figure 17). The data from 1990 were not used because much of the State data for that year was missing. Some data were also missing from the State records for 1996 and 1997. The adjusted average total production for 1991-1997 was estimated to be 670 million gallons after the State records were modified with estimated values for the missing data intervals in 1996 and 1997.
3. Some correlations occurred between heating degree days and production data during water years 1991 through 1997 (Figures 4 and 17). For example, the number of heating degree days for water year 1993 was slightly higher than both the preceding and succeeding years. Total production was also higher in 1993. Both the number of heating degree days and the total production have remained fairly constant since 1994. However, missing State data for 1996 and 1997 make these correlations less reliable.
4. Correlations between water levels in the BLM well and total production are not clear. Water levels increased from 1990 through 1992 despite total production increases during these years. Water levels declined slightly in 1993 when heating degree days and total production were at their highest in the last 10 years. Water levels in the BLM well declined 3-4 feet from 1994 through1997 despite the apparent flat trend in total production. However, if we assume that total production was slightly higher in1996 and 1997 than shown in Figure 17 (based on the adjustments for missing data), then water level declines may be related to production increases for those years. In any event, fluctuations in water levels and total production have been minor in the last five years.
5. The average precipitation at the Boise Airport rain gauge station for water years 1987 through 1997 was about 10 percent lower than the 30 year average for water years 1968 through 1997 (Figure 3). These data suggest that recharge from precipitation to the ground water systems in the Boise area has been slightly less than average during the last decade. However, it is uncertain how fluctuations in precipitation affect water levels in the deep geothermal aquifer. Water levels in the BLM well did not responded immediately to precipitation fluctuations. For example, water levels in the BLM well increased slightly from 1990 through1992

despite below average precipitation during these years. Water levels declined slightly in the BLM well from 1994 through 1997 despite above average precipitation in water years 1995-1997. Presently, it cannot be determined if the water level declines in the 1994-1997 interval were related to below average precipitation in some of the mid 1980's and early 1990's water years or to slight increases in total production.

In conclusion, discharge does not appear to be exceeding recharge based on the water level data in the BLM well and the production data from the four geothermal heating systems. Water levels in the BLM observation well for the past 10 years indicate that the geothermal system has probably reached a new water level equilibrium, despite some minor fluctuations. The reason(s) for the new equilibrium is not fully understood but it is probably caused by: 1) stabilized withdrawal rates since the rapid increases of the 1980's, and/or 2) induced recharge related to the increase in production from the geothermal system.

A model developed by Montgomery Watson (1994) predicted that water levels will decline if production is increased at the City and Boise Warm Springs well fields. However, the City of Boise recently completed an injection well that is expected to reduce or completely offset the predicted water declines caused by increased withdrawals. The new well will inject most of the City's spent geothermal water that is currently being disposed in the Boise River. This well, which is to be operational for the 1998-1999 heating season, is predicted to cause positive pressure effects assuming there is hydraulic connectivity between it and the geothermal aquifer (Montgomery Watson, 1996). A modeling scenario by Montgomery Watson (1994) predicted that injection of spent geothermal water near the new injection well location would result in no net changes to the water level at the BLM well assuming a 20 percent increase in production at the City and Boise Warm Springs Water District well fields.

Based on the current data, it is uncertain how production increases, if allowed by the IDWR, will adversely impact the water levels in this part of the Boise Front geothermal system, especially in combination with the new injection well. The historic data show that water level declines did occur after the State and City systems came on line. However, there were no observable water level declines with the addition of the VA production

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# PRODUCTION HISTORY
# FOR THE STATE OF IDAHO
# CAPITOL MALL GEOTHERMAL SYSTEM
# 1983-1994

by

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Boise, Idaho

December, 1995

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# INTRODUCTION

The State of Idaho Capitol Mall geothermal system has operated in downtown Boise since 1982. The system supplies about ninety percent of the heat required for nine buildings, including the State Capitol. The primary components of the system are: 1) a production well, 2) heat exchangers, 3) underground delivery and collection pipes, and 4) an injection well. Production, temperature and system operation data have been recorded manually on Daily Logs since May, 1983. In 1991, the Department of Administration-Building Services made this data available through computer Trend Logs which capture information every six hours. The Idaho Department of Water Resources has compiled the Daily Logs and Trend Logs from 1983-1994.

## Purpose and Scope

The purpose of this report is to publish a complete record to date of the geothermal production history for the State of Idaho Capitol Mall geothermal system. This report presents annual and monthly production totals, daily discharges, average monthly discharges, maximum monthly discharges and maximum monthly supply temperatures. The data in this report were compiled from the handwritten Daily Logs, the computer Trend Logs and previously published reports. Data are presented using Julian year dates.

The data in this report were used by the Idaho Department of Water Resources for the water right licensing of the State of Idaho geothermal production well in 1995.

## Previous Studies

Several papers and reports describe either the development of the Capitol Mall geothermal system or document some of the production history (Mink, 1976; Anderson, 1981; Anderson and Kelly, 1981; Worbois, 1982; Berkeley Group Inc., 1990; Higginson, 1987; Waag and Wood, 1987; Boise Warms Springs Water District, 1989; Montgomery, 1992; Dansart and others, 1994; Montgomery Watson, 1994). Prior to this report, the most complete production history was presented in the Berkeley Group, Inc. (1990) report which contains records of annual production from 1982 through June 1989. The Montgomery (1992) and Montgomery Watson (1994) reports contain some production data for 1990 and 1991.

## Well-Numbering System

The well-numbering system used in this report is identical to the system used by the U.S. Geological Survey (USGS) in Idaho (Figure 1). The system indicates the location of wells within the official rectangular subdivision of the Public Land Survey System (PLSS) with reference to the Boise baseline and meridian. The first two segments of the number designate the township and range. The third segment gives the section number followed by three or four letters and a number. The letters indicate the ¼ section (160 acre tract), ¼-¼ section (40 acre tract), ¼-¼-¼ section (10 acre tract), ¼-¼-¼-¼ section (2.5 acre tract),

and the serial number of the well within the tract. Quarter sections are lettered A, B, C, and D in counterclockwise order beginning in the northeast quarter of the section. Successively smaller tracts are lettered in the same manner. For example, well 04N 01E 04CDA1 corresponds to the PLSS location: NE¼, SE¼, SW¼, Section 4, Township 4 North, Range 1 East, and it was the first well inventoried by the USGS in that tract.

Acknowledgements

The author would like to thank several people who helped compile the data for this report. Monty Leinberger and Bill Hudson, Idaho Department of Administration-Building Services and Tom Markland, Idaho Department of Lands, provided copies of the Daily Logs for the State Geothermal system. Cody Kinney, Idaho Department of Water Resources (IDWR), entered the data from the Daily Logs into computer spreadsheets. Wayne Haas, Hal Anderson, Paul Castelin and Steve Lester (all employees at IDWR) provided technical review for this report. I appreciate all of your efforts in this project.

## GEOTHERMAL DEVELOPMENT IN BOISE

In late 1890, investors from the Boise Water Works Company decided to drill a hot water well in a swampy area about two and a half miles east of Boise. This tract of land was swampy because of seepage from natural geothermal springs. By early 1891, two geothermal wells (now known as Boise Warms Springs Water District (BWSWD) #1 and #2) had been successfully completed (Figure 2).

In May, 1892, the Boise Natatorium, a 15,000 square foot structure which included a 65 x 125 foot geothermal swimming pool, was open for business. In the same year, the Artesian Hot and Cold Water Company (which had purchased the Boise Water Works Company in 1891) began supplying geothermal water to private residences and businesses along Warm Springs Road. The Natatorium remained in business until 1934. From 1892 until the 1970's, there was no significant exploration for geothermal resources in the downtown Boise area.

In the early 1970's, the State of Idaho began expanding the Capitol Mall office complex. Rising heating costs prompted Governor Cecil Andrus to request a study of the Boise geothermal resources. The study, conducted by the U.S. Energy Research and Development Administration, recommended a pilot project. Consequently, the heating system for the State Health Laboratory on Penitentiary Road was converted to geothermal space heating in 1977. The State of Idaho realized the cost-saving benefits immediately. By 1979, the State was ready to take the next step in geothermal heating.

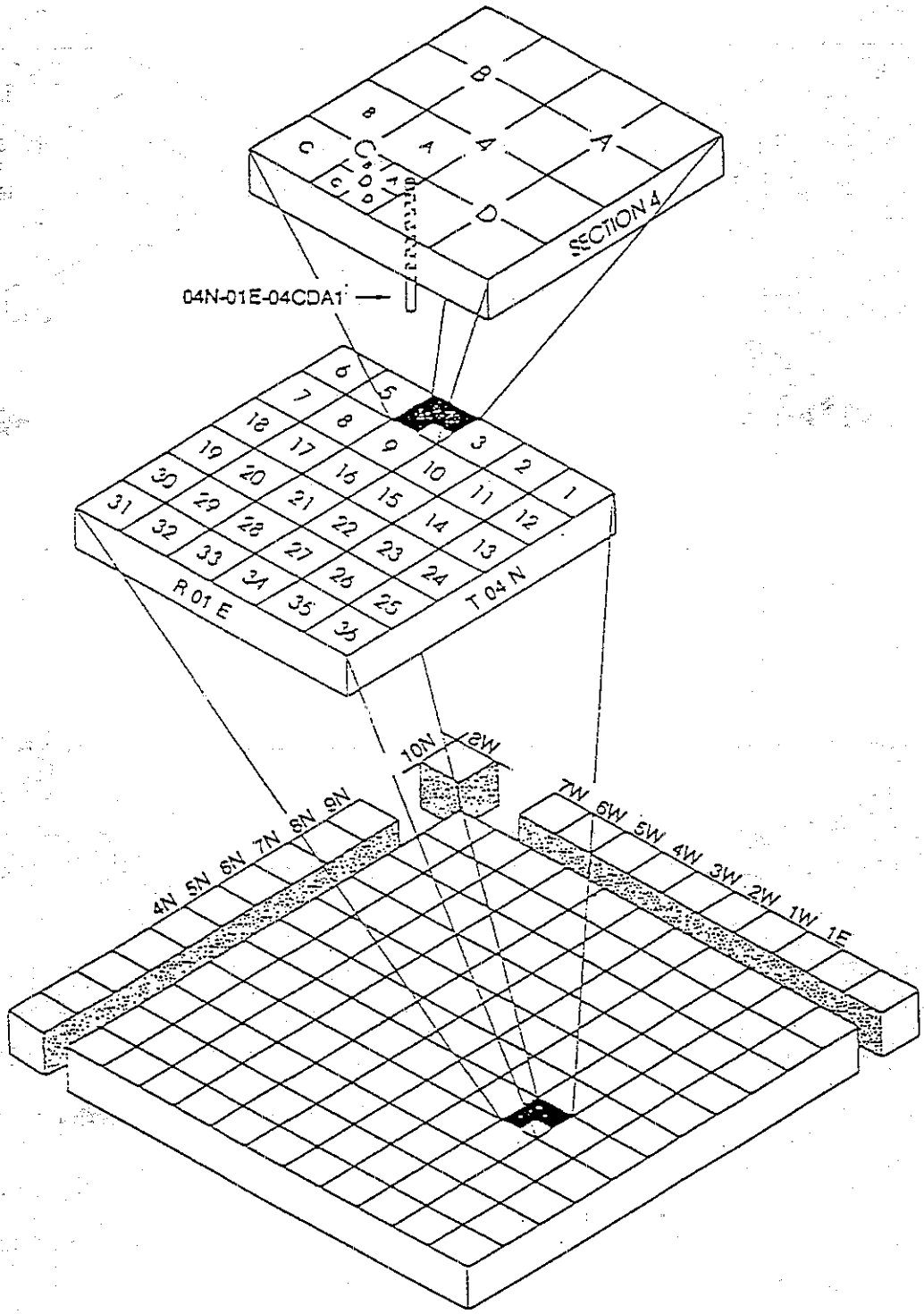



Figure 1. Well-numbering system.

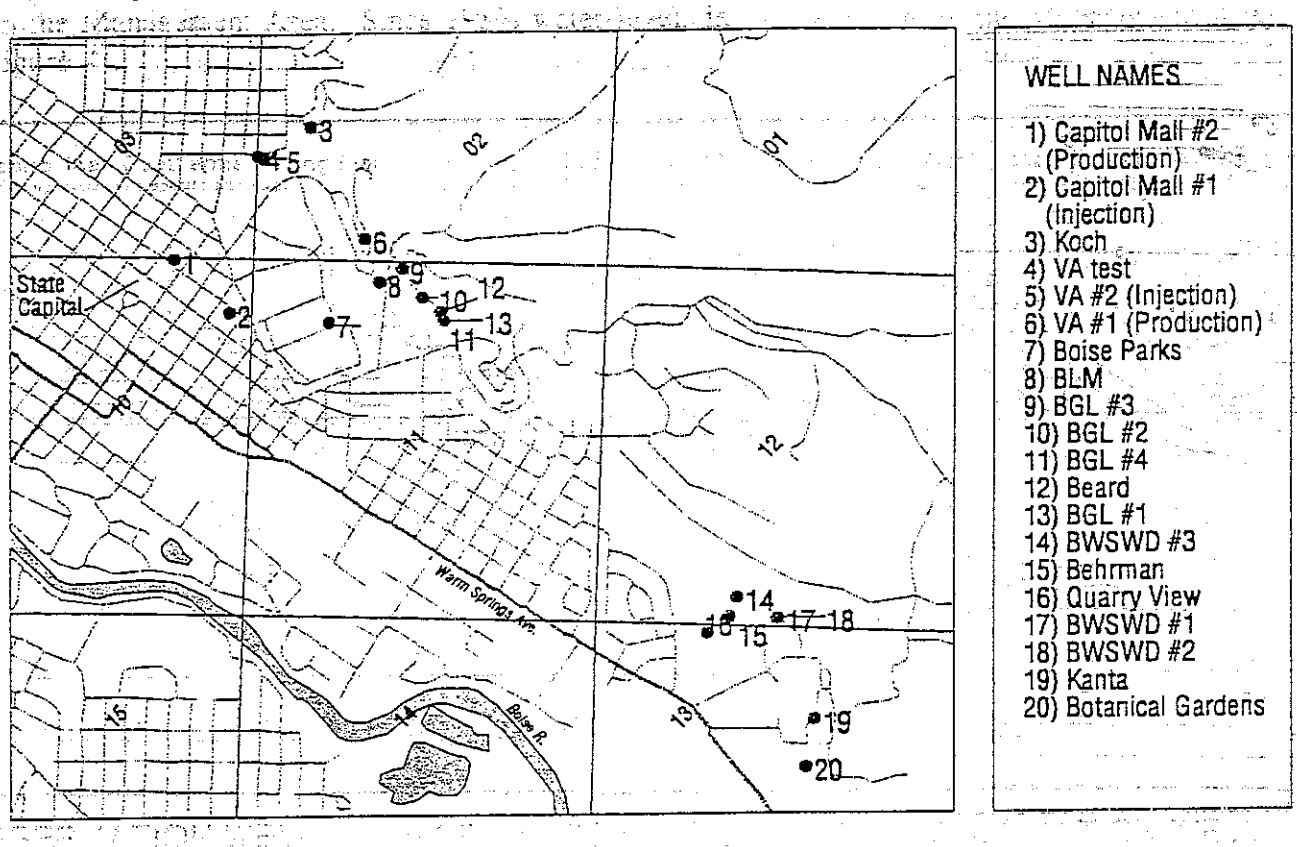



Figure 2. Location map of geothermal wells in the downtown Boise and Boise Warm Springs Water District areas. The map area is within Township 3 North, Range 2 East. The numbers appearing diagonally are the section numbers.

In 1981, the Capitol Mall #1 and #2 wells were completed to the east and northeast of the State Capitol, respectively (Figure 2). Capitol Mall #1 (03N 02E 10AADA1) is 2,152 feet deep and is used as the injection well. Capitol Mall #2 (03N 02E 11AABB1) is 3,030 feet deep and is the production well. Capitol Mall #2 is capable of flowing at over 900 gallons per minute. The original water temperature for Capitol Mall #2 was 160° Fahrenheit. By 1982, nine buildings in the Capitol Mall complex were being heated by the geothermal resource (Figure 3).

In the early 1980's, Boise Geothermal Limited drilled four production wells and the Veterans Administration drilled a test well followed by a production and an injection well (Figure 2). In 1988, the City of Boise purchased Boise Geothermal Limited.

In the mid 1980's, water levels in the Bureau of Land Management (BLM) observation well, located east of the Capitol Mall wells (Figure 4), began declining rapidly. In 1987, IDWR created the Boise Front Low Temperature Geothermal Resource Ground

Water Management Area because of the declining water levels. Further development of the geothermal resource was discontinued in the Management Area. Since 1987, water levels in the BLM well have ceased declining (Figure 4).

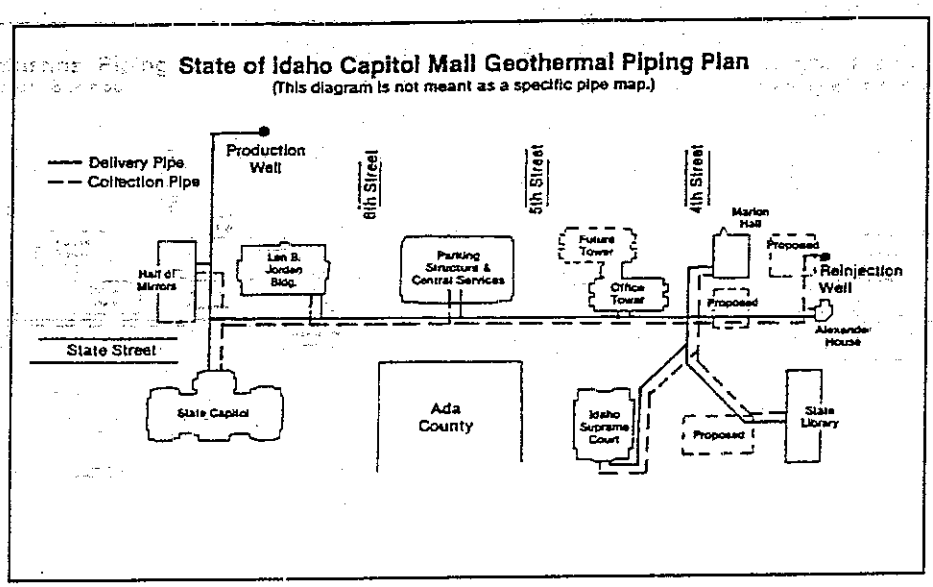



Figure 3. State of Idaho Capitol Mall geothermal piping plan (from Worbois, 1982).

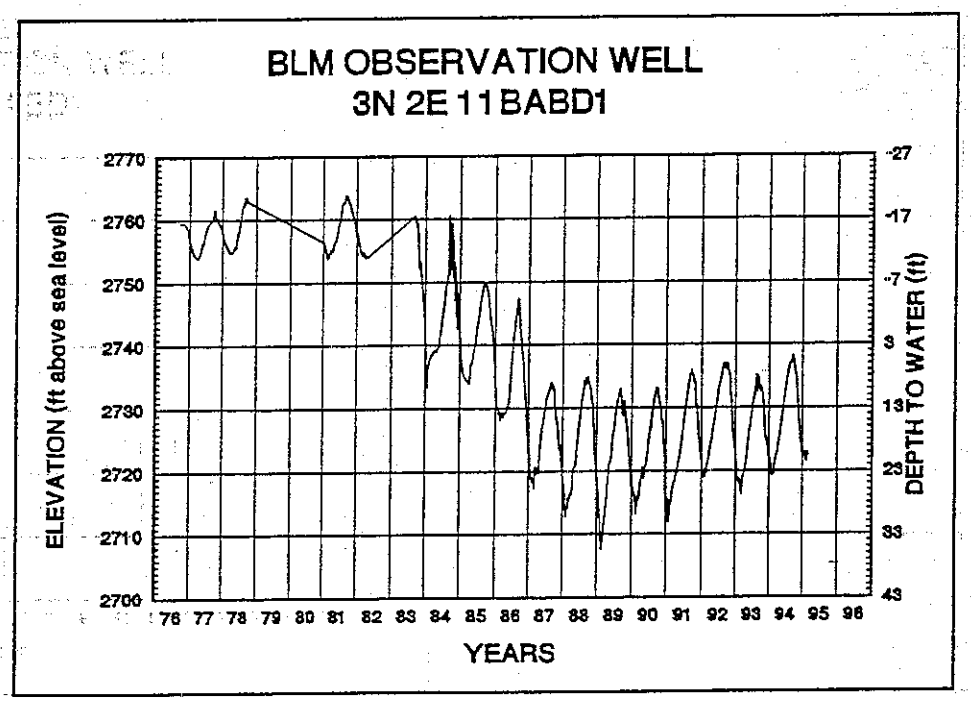



Figure 4. Hydrograph for the BLM observation well (03N 02E 11BABD1).

## CAPITOL MALL DATA

Data are collected in two formats for the Capitol Mall system. The first format is handwritten Daily Logs on which discharge, temperature, pressure and other system operations are recorded. Data have been entered on Daily Logs since May, 1983. The Berkeley Group, Inc. (1990) report noted that the Daily Log data usually reflect higher than average discharges because the readings are taken during peak flow times (i.e. 5:00 - 8:00 a.m.). Data from the Daily Logs were entered into computer spreadsheet files at IDWR.

The second format is Trend Logs where data are recorded every six hours using a computer system. Data have been recorded on Trend Logs since 1991. Unfortunately, Trend Logs for 1991 and 1992 are incomplete primarily due to data capture mistakes by the author. Trend Log data for 1993 are considered to be complete. Trend Log data for 1994 are incomplete because the flowmeter was not working for several months.

The raw data from both the Daily Logs and the Trend Logs were used to calculate and graph annual and monthly production, daily and monthly discharges and average monthly supply temperatures.

### Annual Production

Annual production for the State Geothermal system was obtained using three sources: 1) Berkeley Group Inc. (1990) report, 2) Daily Logs, and 3) Trend Logs. The Berkeley Group Inc. (1990) report used calculated average flowrates instead of the flowrates reported on the Daily Logs. In this study, the annual production totals using the Daily Logs (1983-1994) were calculated by multiplying each daily discharge reading (in gallons per minute) by 1,440 to obtain a daily volume, and summing the daily volumes. The annual production totals for the Trend Logs were calculated by computing an average discharge for each day, multiplying each average daily discharge by 1,440 to produce a daily volume, and summing the daily volumes. Table 1 lists the reported and calculated annual production totals for 1983-1994. Low values in 1983, 1990, 1991, 1992 and 1994 are caused by missing data. Figure 5 shows the range in annual production for 1983-1994.

Additional calculations were performed on the data for 1993 because of the differences between the annual production calculations from the Trend and Daily Logs (1993 was selected because the Trend Log data in that year was considered to be the more complete than the Trend Log data collected in 1991, 1992 and 1994). The maximum daily discharge was extracted from each set of four daily readings from the Trend Logs. The maximum daily discharge was multiplied by 1,440 to obtain a maximum daily volume. The sum of the maximum daily volumes was 240.4 million gallons essentially equal to the annual production calculated from the Daily Logs (240.2 million gallons). This result confirms the Berkeley Group Inc. (1990) assertion that the values from the Daily Logs are too high because they were recorded during peak production times.

Table 1. Annual production for the Capitol Mall geothermal system, 1983-1994 (in millions of gallons).

| Year | Berkeley Group Inc. (1990) | Daily Logs | Trend Logs |
|---|---|---|---|
| 1983 | 79.1 | 65.8 | |
| 1984 | 204.8 | 169.5 | |
| 1985 | 196.4 | 187.5 | |
| 1986 | 188.6 | 179.7 | |
| 1987 | N/A | 148.6 | |
| 1988 | 212.6[a] | 122.7 | |
| 1989 | 106.3[a] | 155.6 | |
| 1990 | | 83.4 | |
| 1991 | | 159.4 | 43.6 |
| 1992 | | 136.3 | 75.3 |
| 1993 | | 240.2 | 180.3 |
| 1994 | | 167.9 | 96.3 |

[a] Estimated from Totalized value of 3.10 x 10 gallons for the period from January, 1988 through June, 1989 (Berkeley Group Inc. (1990)).

## Monthly Production

Figure 6 shows the total monthly production for 1983 to 1994 as calculated from the Daily and Trend Logs. Monthly production ranged from 0 to 30.5 million gallons. Appendix A lists the monthly production data.

## Daily Discharges

Figures 7 through 18 show the daily discharge readings from the Daily Logs for 1983-1994. The average daily discharge readings from the Trend Logs for 1991-1994 are included in Figures 15-18. The X axis for each figure is incremented by Julian days in the respective calendar year (Day 1 = January 1; Day 365 = December 31)

Daily discharges fluctuate from about 600 to 800 gallons per minute during the peak heating season (approximately days 1-90 and 300-365), to about 300-500 gallons per minute during the non-peak heating season (approximately days 91-180 and 240-299), to 0-300 gallons per minute during the summer (approximately days 181-239). Clearly, some years have more complete data than other years. Figures 9, 10, and 17 appear to be the most complete. Therefore, the annual production as calculated from the Daily and Trend Logs may be the most accurate for 1985, 1986 and 1993 (Table 1).

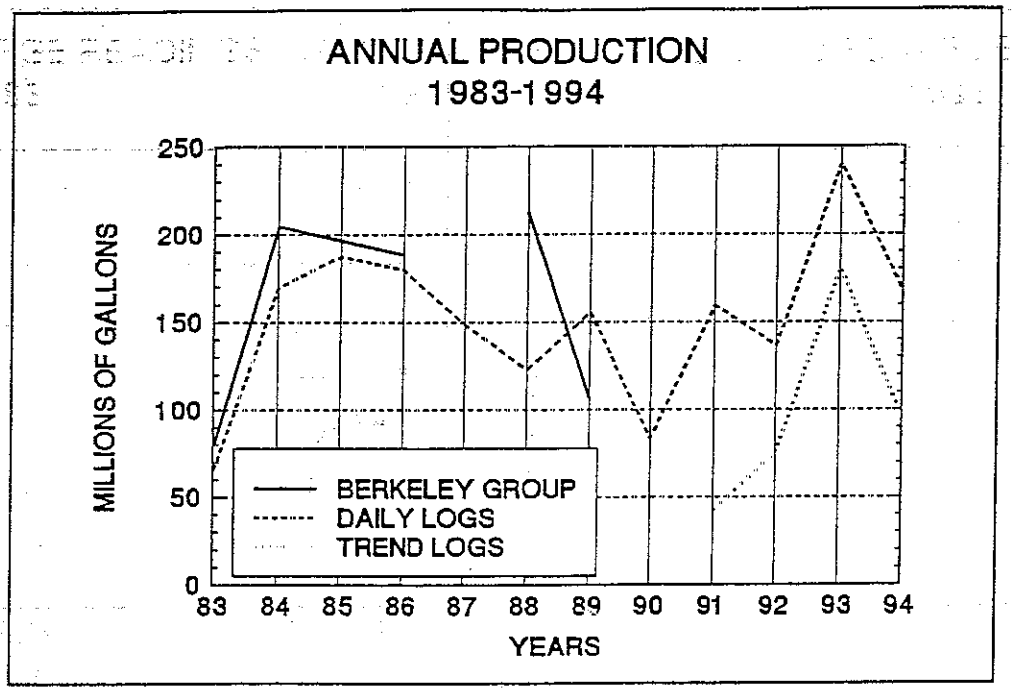



Figure 5. Annual production for the Capitol Mall geothermal system, 1983-1994.

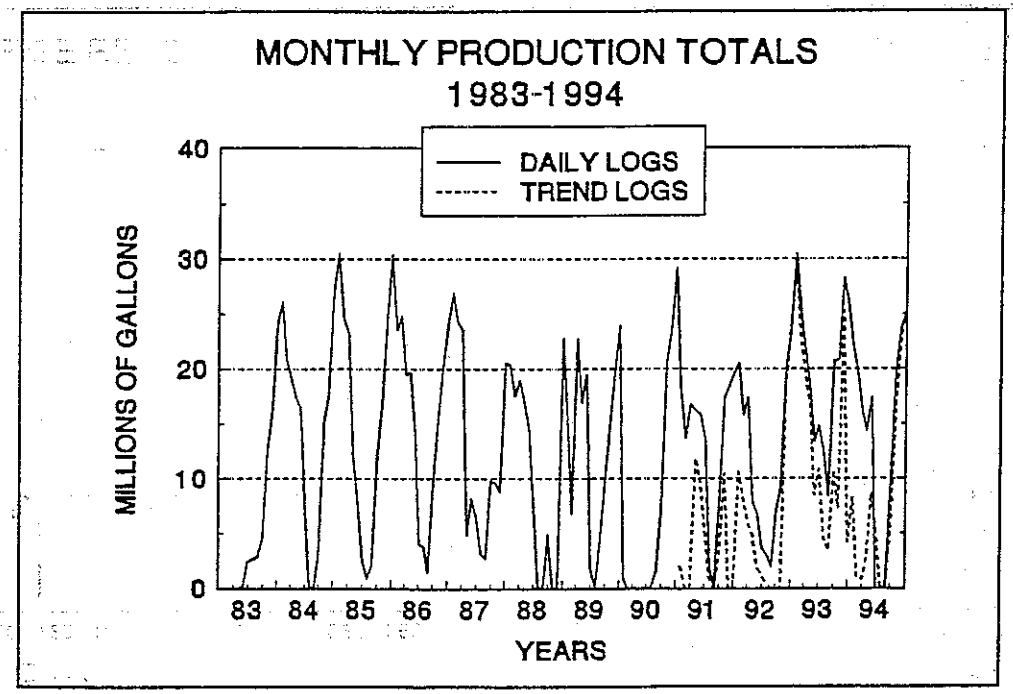



Figure 6. Monthly production for the Capitol Mall geothermal system, 1983-1994.

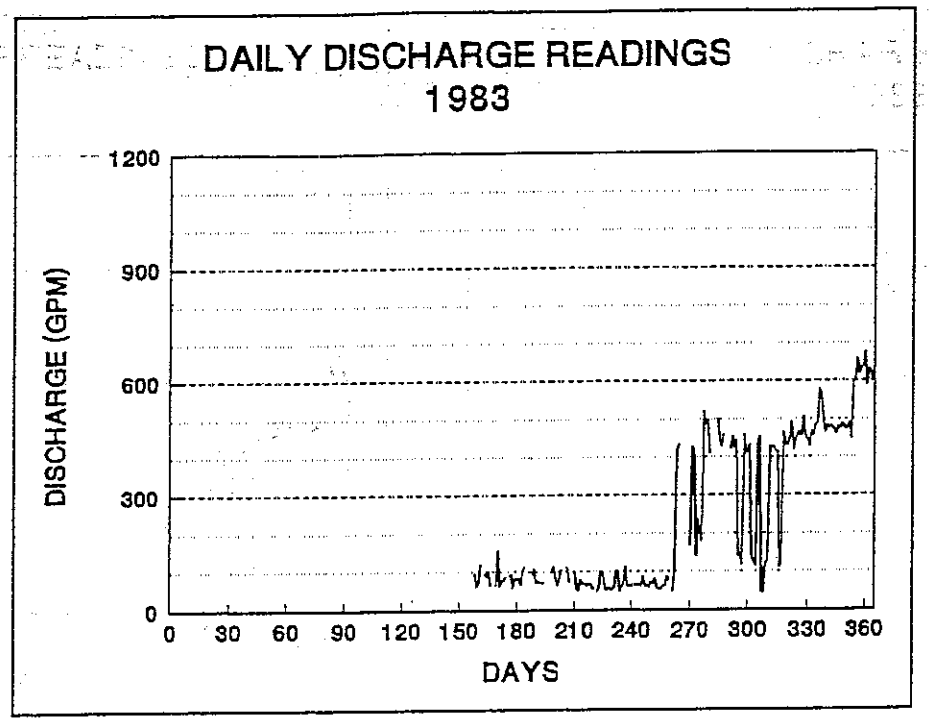



Figure 7. Daily discharge readings for the Capitol Mall geothermal system, 1983.

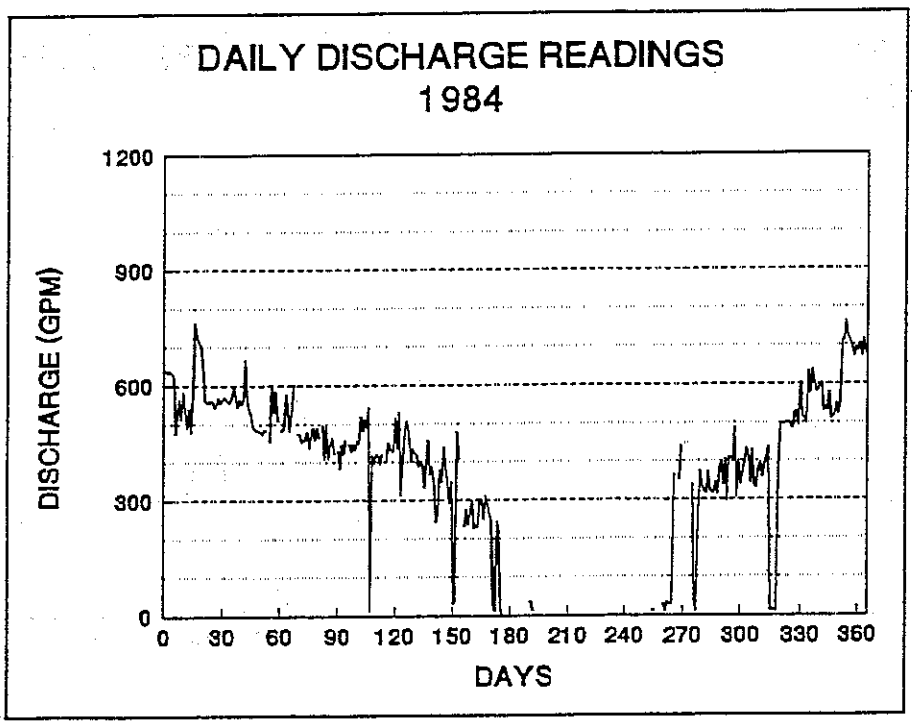



Figure 8. Daily discharge readings for the Capitol Mall geothermal system, 1984.

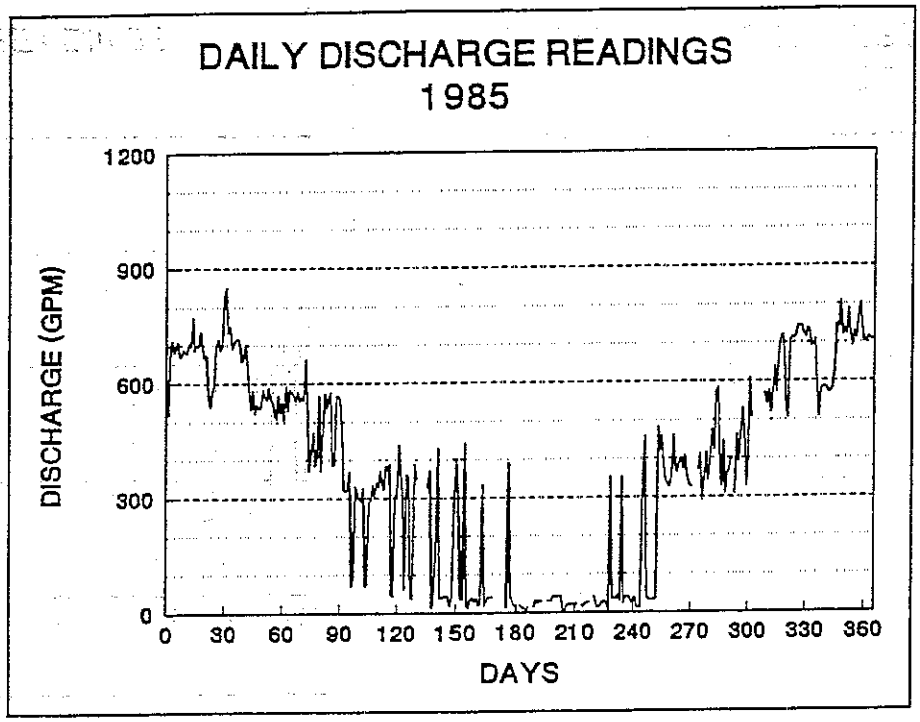



Figure 9. Daily discharge readings for the Capitol Mall geothermal system, 1985.

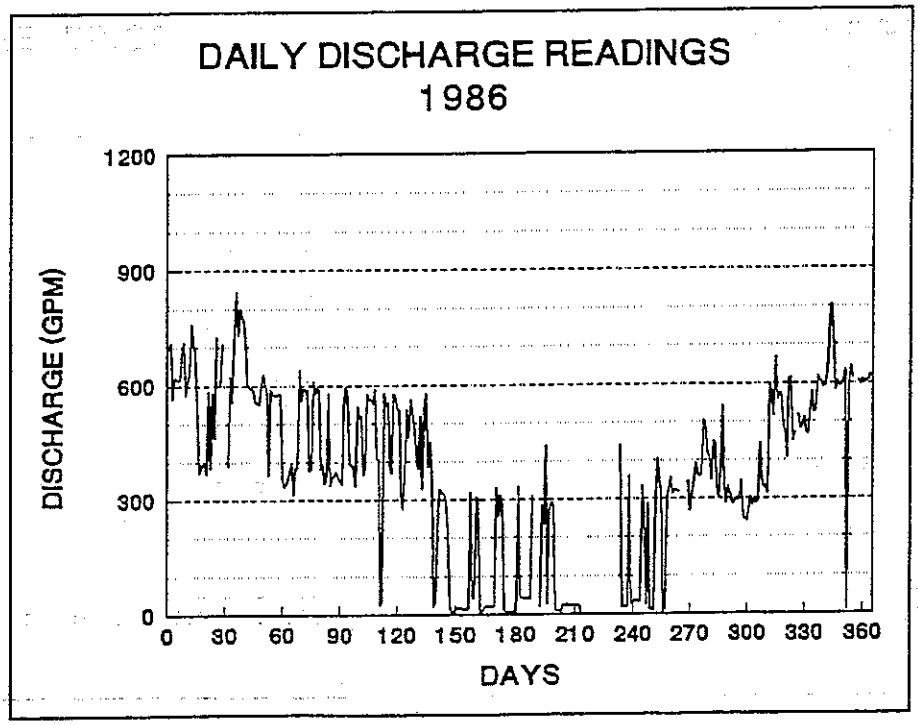



Figure 10. Daily discharge readings for the Capitol Mall geothermal system, 1986.

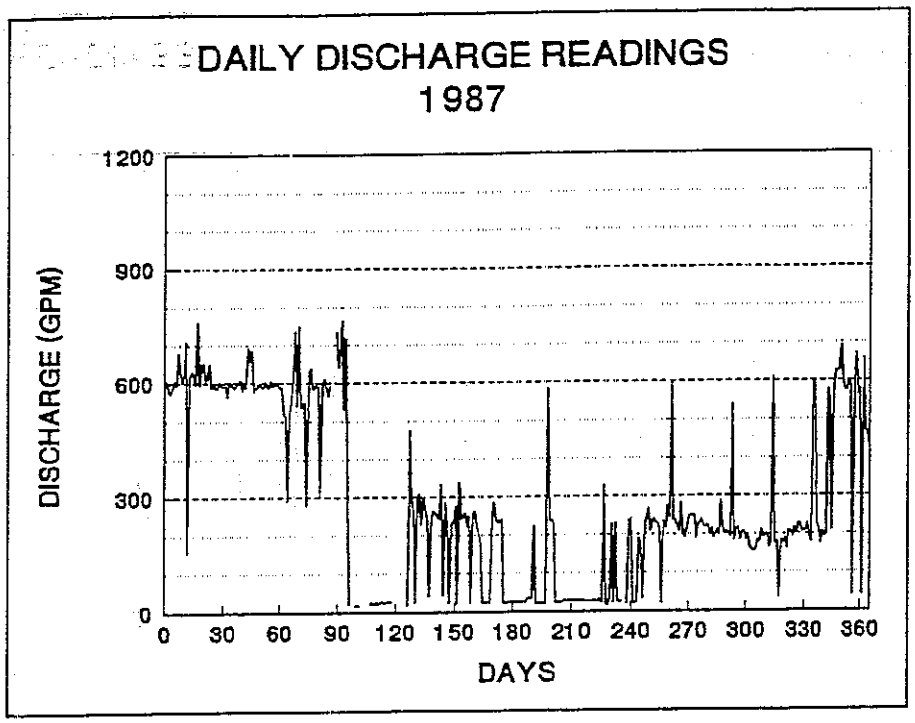



Figure 11. Daily discharge readings for the Capitol Mall geothermal system, 1987.

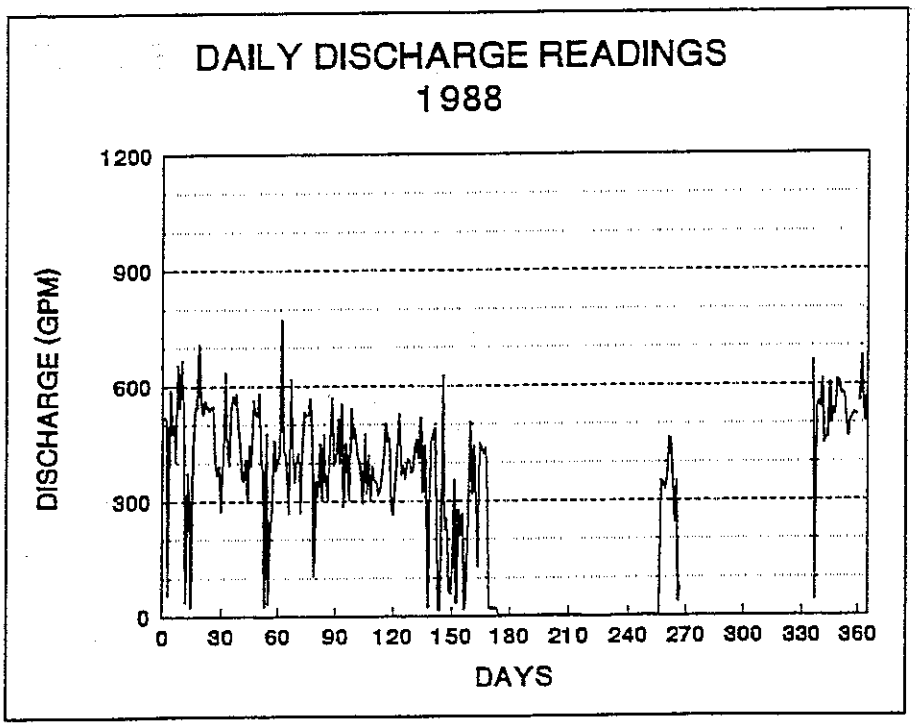



Figure 12. Daily discharge readings for the Capitol Mall geothermal system, 1988.

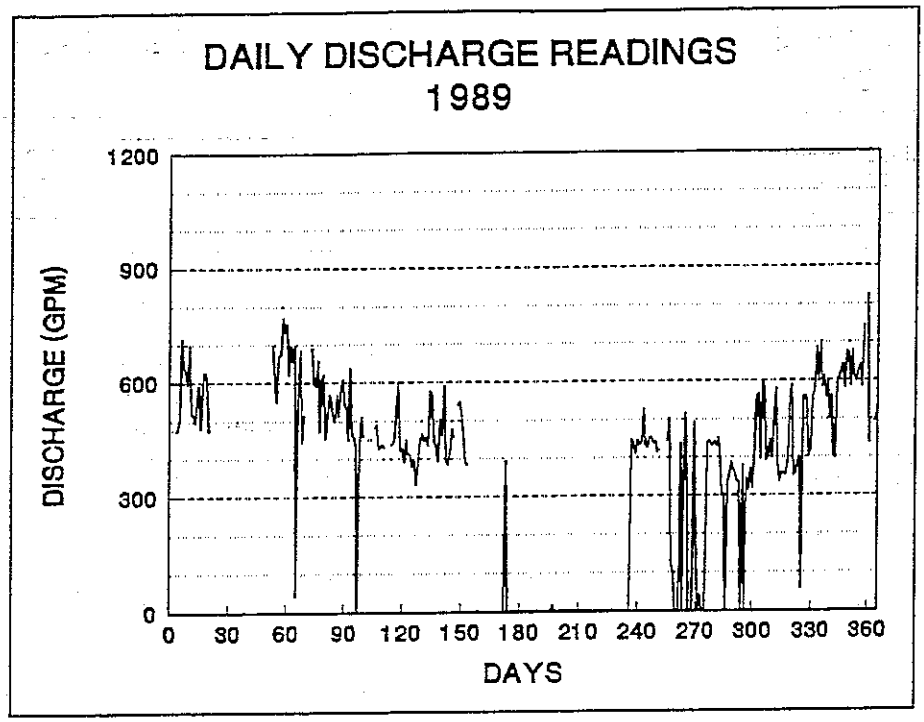



Figure 13. Daily discharge readings for the Capitol Mall geothermal system, 1989.

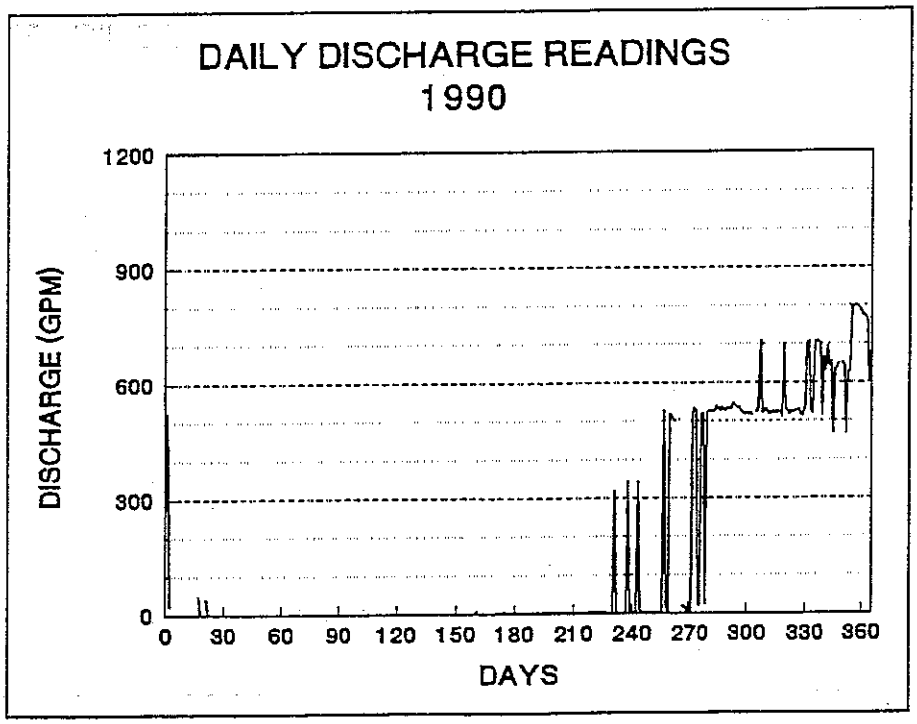



Figure 14. Daily discharge readings for the Capitol Mall geothermal system, 1990.

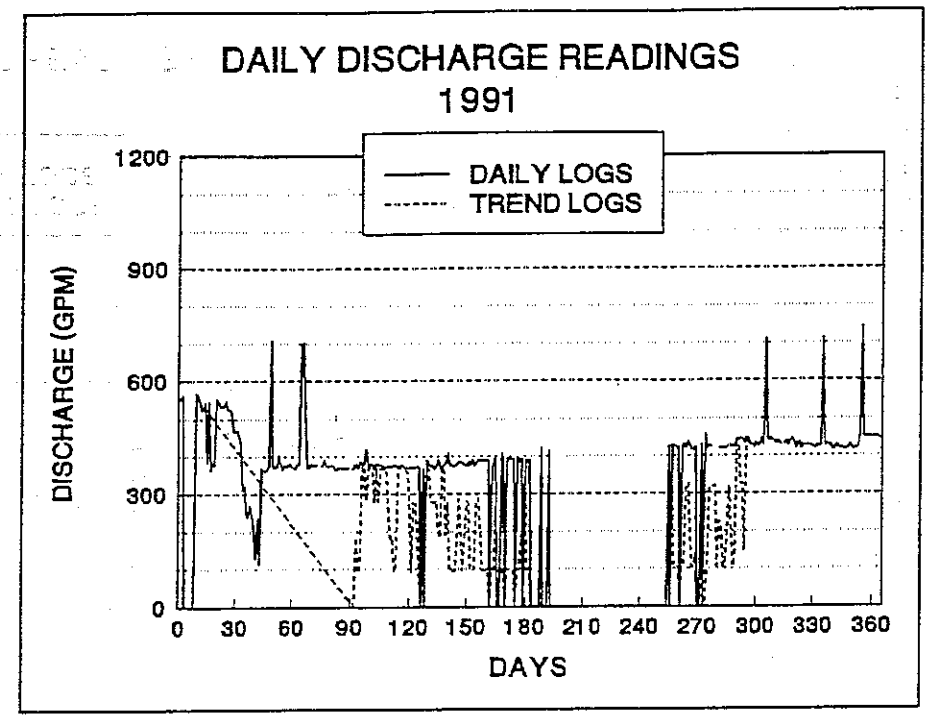



Figure 15. Daily discharge readings for the Capitol Mall geothermal system, 1991.

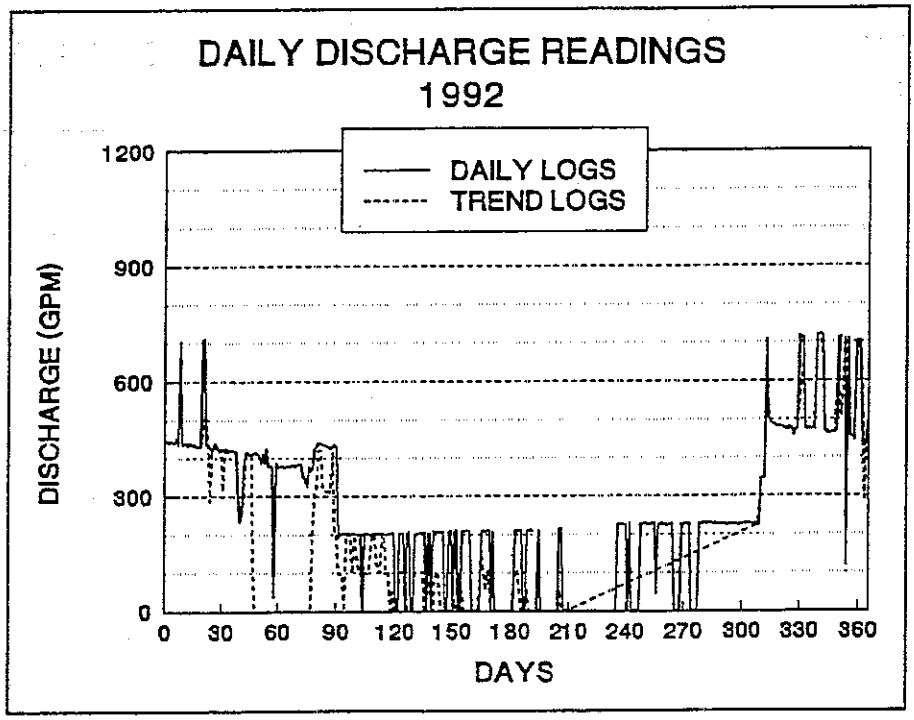



Figure 16. Daily discharge readings for the Capitol Mall geothermal system, 1992.

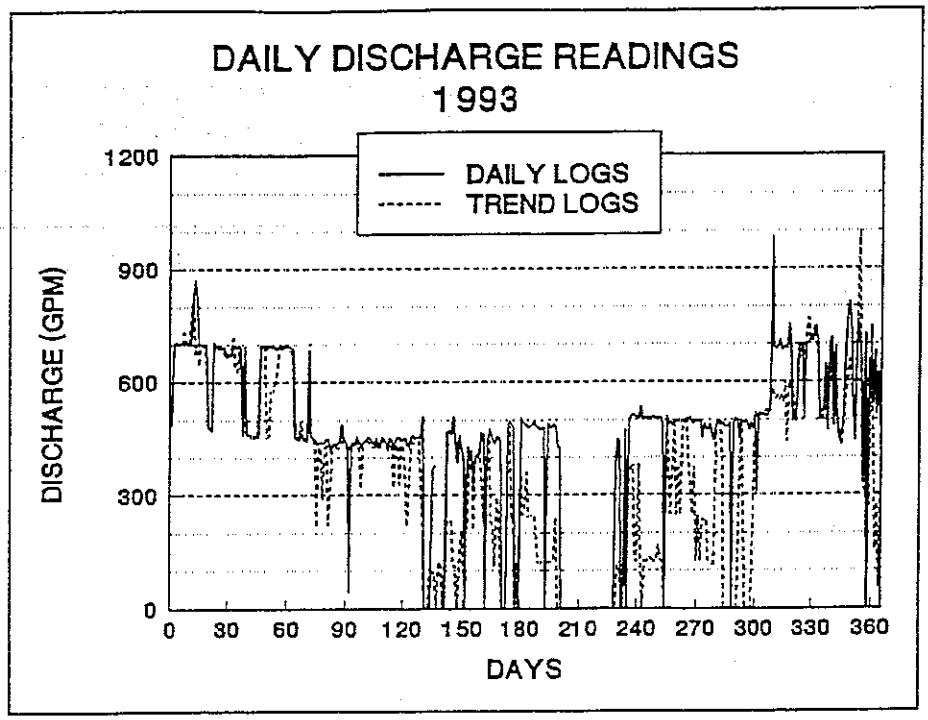



Figure 17. Daily discharge readings for the Capitol Mall geothermal system, 1993.

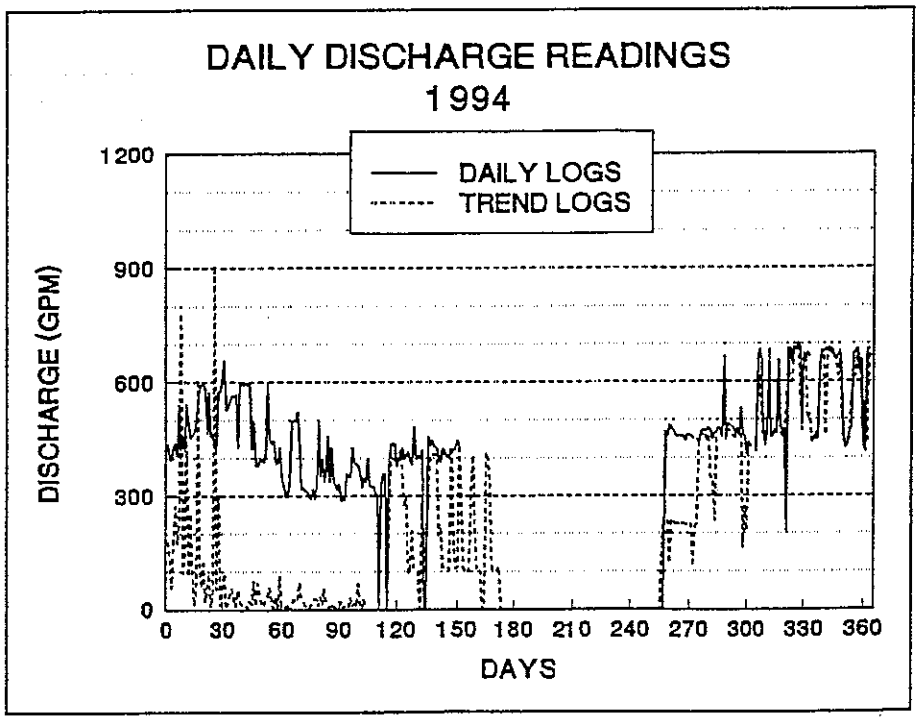



Figure 18. Daily discharge readings for the Capitol Mall geothermal system, 1994.

## Monthly Discharges

The average monthly discharges ranged from 0 to 683 gallons per minute (Figure 19). Maximum monthly discharges were about 800-850 gallons per minute (Figure 20). The highest discharge rate was 982 gallons per minute in November, 1993.

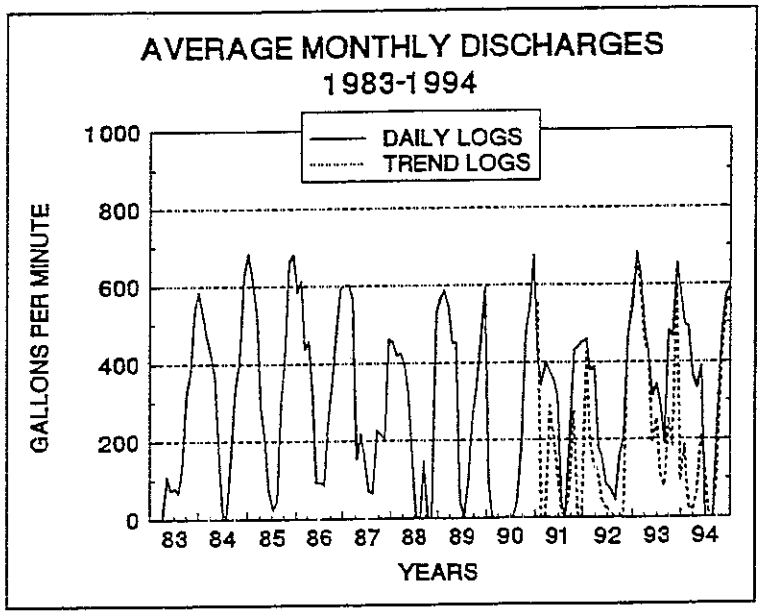



Figure 19. Average monthly discharges for the Capitol Mall geothermal system, 1983-1994.

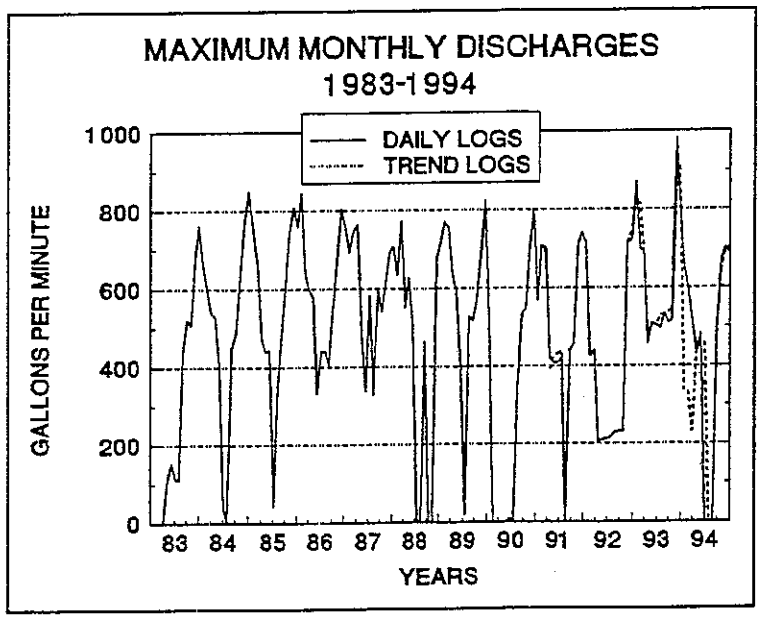



Figure 20. Maximum monthly discharges value for the Capitol Mall geothermal system, 1983-1994.

Supply Temperatures

Figure 21 shows a decline of about 5° Fahrenheit in the maximum monthly supply temperatures from 1983 to 1994. The decline may have been caused by a gradual thermal breakthrough related to nearby reinjection in Capitol Mall #1.

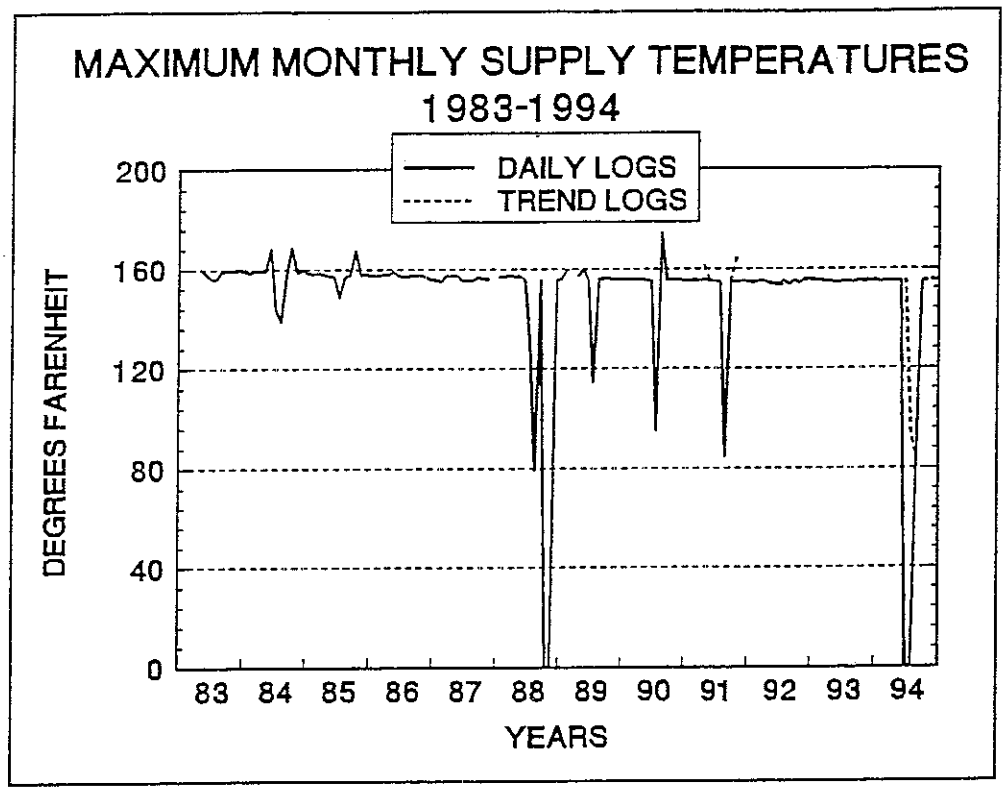



Figure 21. Maximum monthly supply temperatures for the Capitol Mall Geothermal system, 1983-1994.

## CONCLUSIONS AND RECOMMENDATIONS

The State of Idaho Capitol Mall geothermal system heats nine buildings in the Capitol Mall complex. The system has been in operation since 1982. Annual production was computed to range from 65.8 to 240.2 million gallons during the time period from 1983 to 1994 (no records could be found for 1982). The computed value of 240.2 million gallons (1993 Daily Logs) is too high because the calculation is based on peak daily discharges as opposed to average daily discharges. The computed value of 65.8 (1983 Daily Logs) is too low because of missing data. Based on all of the data, the annual geothermal production for the Capitol Mall system probably ranged from 160 to 205 million gallons. A credible average annual production cannot be calculated because data records for several years are incomplete. The highest monthly production was 30.5 million gallons in January, 1985. The highest average monthly discharge rate was 683 gallons per minute in January, 1985. The maximum discharge rate was 982 gallons per minute in November, 1993. The maximum monthly supply temperature decreased about 5° Fahrenheit from 1983 to 1994.

Continued and improved monitoring is critical for the Capitol Mall system as well as for the other geothermal systems in the downtown Boise and Boise Warm Springs Water District areas. Efforts should be expanded to prevent data gaps caused by equipment failure and data capture mistakes.

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# APPENDIX A.

| MONTHLY PRODUCTION FOR THE CAPITOL MALL GEOTHERMAL SYSTEM | | | |
|---|---|---|---|
| Year | Month | Production in gallons (Daily Logs) | Production in gallons (Trend Logs) |
| 1983 | January | NA | |
| | February | NA | |
| | March | NA | |
| | April | NA | |
| | May | 158,400 | |
| | June | 2,441,952 | |
| | July | 2,688,192 | |
| | August | 2,914,128 | |
| | September | 4,604,400 | |
| | October | 12,642,192 | |
| | November | 16,281,360 | |
| | December | 24,102,864 | |
| 1984 | January | 26,069,904 | |
| | February | 20,765,808 | |
| | March | 19,024,992 | |
| | April | 17,335,728 | |
| | May | 16,408,368 | |
| | June | 6,986,448 | |
| | July | 97,488 | |
| | August | NA | |
| | September | 3,192,336 | |
| | October | 15,059,952 | |
| | November | 17,584,416 | |
| | December | 26,996,400 | |
| 1985 | January | 30,486,960 | |
| | February | 24,515,280 | |
| | March | 23,126,976 | |
| | April | 12,104,352 | |
| | May | 8,037,360 | |
| | June | 2,485,584 | |
| | July | 862,272 | |
| | August | 2,048,112 | |
| | September | 12,060,864 | |
| | October | 16,672,032 | |
| | November | 24,705,648 | |
| | December | 30,388,752 | |

| MONTHLY PRODUCTION FOR THE CAPITOL MALL GEOTHERMAL SYSTEM | | | |
|---|---|---|---|
| Year | Month | Production in gallons (Daily Logs) | Production in gallons (Trend Logs) |
| 1986 | January | 23,485,392 | |
| | February | 24,713,568 | |
| | March | 19,460,448 | |
| | April | 19,732,608 | |
| | May | 14,113,584 | |
| | June | 4,015,440 | |
| | July | 3,804,912 | |
| | August | 1,478,448 | |
| | September | 9,465,696 | |
| | October | 15,321,888 | |
| | November | 20,062,944 | |
| | December | 23,996,448 | |
| 1987 | January | 26,843,760 | |
| | February | 24,236,496 | |
| | March | 23,514,048 | |
| | April | 4,835,088 | |
| | May | 8,163,936 | |
| | June | 6,458,832 | |
| | July | 3,140,352 | |
| | August | 2,680,992 | |
| | September | 9,832,147 | |
| | October | 9,590,400 | |
| | November | 8,711,136 | |
| | December | 20,545,056 | |
| 1988 | January | 20,283,552 | |
| | February | 17,454,528 | |
| | March | 18,954,576 | |
| | April | 16,864,272 | |
| | May | 14,381,712 | |
| | June | 7,103,664 | |
| | July | 74,592 | |
| | August | 6,336 | |
| | September | 4,873,104 | |
| | October | NA | |
| | November | NA | |
| | December | 22,732,272 | |

| MONTHLY PRODUCTION FOR THE CAPITOL MALL GEOTHERMAL SYSTEM | | | |
|---|---|---|---|
| Year | Month | Production in gallons (Daily Logs) | Production in gallons (Trend Logs) |
| 1989 | January | 15,411,024 | |
| | February | 6,759,648 | |
| | March | 22,694,400 | |
| | April | 16,857,936 | |
| | May | 19,484,352 | |
| | June | 1,701,792 | |
| | July | 88,128 | |
| | August | 4,557,024 | |
| | September | 9,763,344 | |
| | October | 14,638,896 | |
| | November | 19,700,064 | |
| | December | 23,902,704 | |
| 1990 | January | 909,648 | |
| | February | NA | |
| | March | NA | |
| | April | NA | |
| | May | NA | |
| | June | 53,056 | |
| | July | 65,808 | |
| | August | 1,499,184 | |
| | September | 7,517,088 | |
| | October | 20,564,640 | |
| | November | 23,629,680 | |
| | December | 29,185,344 | |
| 1991 | January | 18,211,392 | 1,989,104 |
| | February | 13,621,968 | NA |
| | March | 16,704,288 | NA |
| | April | 16,199,136 | 11,787,606 |
| | May | 15,713,712 | 9,509,605 |
| | June | 13,411,872 | 4,903,862 |
| | July | 1,765,296 | 454,892 |
| | August | NA | 1,989,104 |
| | September | 8,554,608 | 3,061,955 |
| | October | 17,361,648 | 10,468,839 |
| | November | 18,400,752 | NA |
| | December | 19,489,824 | NA |

| MONTHLY PRODUCTION FOR THE CAPITOL MALL GEOTHERMAL SYSTEM | | | |
|---|---|---|---|
| Year | Month | Production in gallons (Daily Logs) | Production in gallons (Trend Logs) |
| 1992 | January | 20,499,696 | 10,557,900 |
| | February | 15,725,808 | 8,175,694 |
| | March | 17,325,360 | 5,995,368 |
| | April | 7,840,944 | 4,797,475 |
| | May | 6,790,896 | 1,874,974 |
| | June | 3,606,912 | 1,055,038 |
| | July | 3,049,776 | 381,575 |
| | August | 1,955,376 | NA |
| | September | 6,929,136 | NA |
| | October | 9,161,136 | NA |
| | November | 19,996,992 | 18,264,697 |
| | December | 23,412,816 | 24,173,503 |
| 1993 | January | 30,446,640 | 29,216,599 |
| | February | 25,213,968 | 22,915,361 |
| | March | 21,644,208 | 19,416,082 |
| | April | 18,493,589 | 16,610,861 |
| | May | 13,382,352 | 8,429,695 |
| | June | 14,780,160 | 10,848,560 |
| | July | 12,329,568 | 4,561,290 |
| | August | 8,352,144 | 3,359,905 |
| | September | 20,727,792 | 10,691,201 |
| | October | 20,737,296 | 7,234,027 |
| | November | 28,243,440 | 25,207,402 |
| | December | 25,850,160 | 21,795,714 |
| 1994 | January | 22,115,808 | 8,284,003 |
| | February | 19,691,136 | 1,007,734 |
| | March | 16,226,640 | 683,525 |
| | April | 14,303,952 | 2,681,849 |
| | May | 17,355,456 | 8,656,128 |
| | June | NA | 5,155,506 |
| | July | NA | NA |
| | August | NA | NA |
| | September | 9,947,088 | 5,374,422 |
| | October | 19,640,160 | 16,083,684 |
| | November | 23,774,112 | 23,009,472 |
| | December | 24,817,680 | 25,344,295 |

# PRODUCTION HISTORY FOR THE STATE OF IDAHO CAPITOL MALL GEOTHERMAL SYSTEM 1983-1994

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Boise, Idaho

## INTRODUCTION

The State of Idaho Capitol Mall geothermal system has been in operation since 1982. The system extracts geothermal water to supply about ninety percent of the heat required for nine buildings in the downtown Boise area including the State Capitol. The cost savings over natural gas heating are estimated to be $400,000 per year. The primary components of the system are: 1) a production well, 2) heat exchangers, 3) underground delivery and collection pipes, and 4) an injection well. Production, temperature and system operation data have been recorded manually on Daily Logs since May, 1983. In 1991, the Department of Administration-Building Services made this data available through computer Trend Logs which capture information every six hours.

The Capitol Mall geothermal system is located within the borders of an administrative district called the Boise Front Low Temperature Geothermal Resource Ground Water Management Area (GWMA) in Ada County of southwestern Idaho (Figure 1). The GWMA was established by the Idaho Department of Water Resources (IDWR) in 1987 in response to declining water levels in geothermal wells along the edge of the Boise foothills. In addition to the Capitol Mall system, the other major geothermal users in the Boise area are: 1) City of Boise, 2) Veterans Administration, and 3) Boise Warm Springs Water District. Collectively, these four users extract about 600 million gallons of geothermal water annually. Capitol Mall geothermal production accounts for about 160 to 205 million gallons of water annually. The supply temperature for the Capitol Mall system is currently about 155° Fahrenheit.

## GEOTHERMAL DEVELOPMENT IN BOISE

In 1890, the Boise Water Works Company drilled an exploration well for hot water in an area about two and a half miles east of Boise where some natural geothermal springs existed. By 1891, two geothermal wells had been completed successfully (Worbois, 1990). In 1892, the Boise Natatorium, a 15,000 square foot structure which included a 65 x 125 foot geothermal swimming pool, was open for business. In the same year, the Artesian Hot and Cold Water Company (which had purchased the Boise Water Works Company in 1891) began supplying geothermal water to private residences and businesses along Warm Springs Road. The Natatorium remained in business until 1934. From 1892 until the 1970s, there was no significant exploration for geothermal resources in the downtown Boise area.

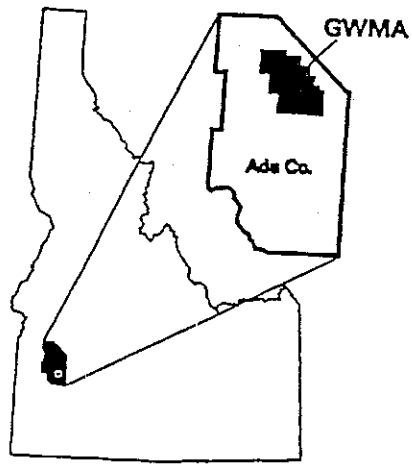



**Figure 1. Location map for the Boise Front Low-Temperature Geothermal Ground Water Management Area (GWMA).**

In the early 1970s, the State of Idaho began expanding the Capitol Mall office complex. Rising heating costs prompted Governor Cecil Andrus to request a study of the Boise geothermal resources (Worbois, 1990). The study, conducted by the U.S. Energy Research and Development Administration, recommended a pilot project. Consequently, the heating system for the State Health Laboratory was converted to geothermal space heating in 1977. The State of Idaho realized the cost-saving benefits immediately. In 1981, the Capitol Mall #1 and #2 wells were completed to the east and northeast of the State Capitol, respectively (Figure 2). Capitol Mall #1 is 2,150 feet deep and is used as the injection well. Capitol Mall #2 is 3,030 feet deep and is the production well (Figure 3). Capitol Mall #2 is capable of flowing at over 900 gallons per minute. The original water temperature for Capitol Mall #2 was 162° Fahrenheit. By 1982, nine buildings in the Capitol Mall complex were being heated by the geothermal resource.

In the early 1980s, Boise Geothermal Limited drilled four production wells and the Veterans Administration drilled a test well followed by a production and an injection well. In 1988, the City of Boise purchased Boise Geothermal Limited. In the mid 1980s, water levels in a geothermal observation well began declining rapidly. In 1987, IDWR created the Boise Front Low Temperature Geothermal Resource Ground Water Management Area because of the declining water levels. Further development of the geothermal resource has been discontinued in the management area.

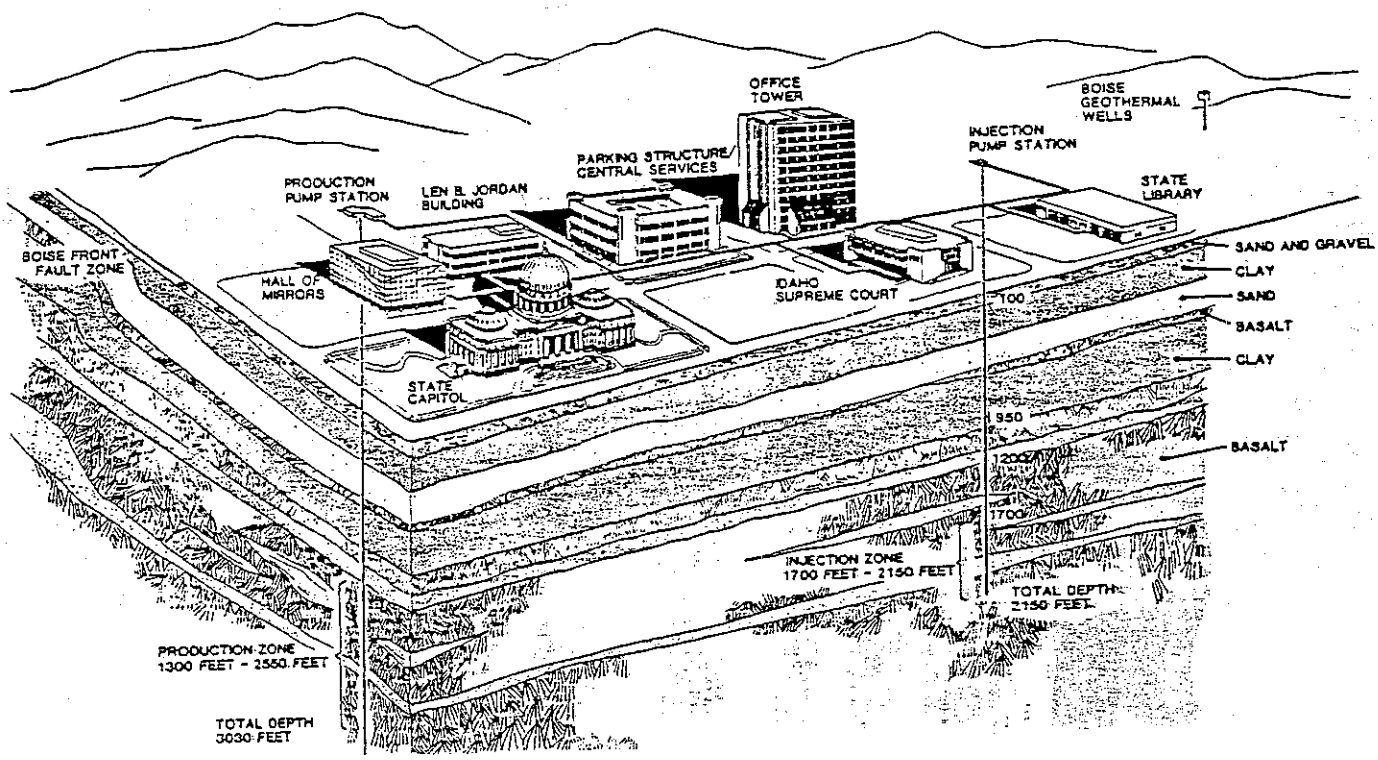



Figure 2. Production and injection wells and the distribution system for the State of Idaho Capitol Mall geothermal system (from "The Capitol Mall Geothermal Energy Project" published by the State of Idaho, Department of Administration).



Figure 3. Pump station for the Capitol Mall production well with the top of the State Capitol building in the background.

## CAPITOL MALL DATA

Monitoring data are collected in two formats for the Capitol Mall system. The first format is handwritten Daily Logs on which discharge, temperature, pressure and other system operations are recorded once per day. Data have been entered on Daily Logs since May, 1983. The Berkeley Group, Inc. (1990) report noted that the Daily Log data usually reflect higher than average discharges because the readings are taken during peak flow times (i.e. 5:00 - 8:00 a.m.). The second format is Trend Logs where data are recorded every six hours using a computer system. Data have been recorded on Trend Logs since 1991. Unfortunately, Trend Logs for 1991, 1992 and 1994 are incomplete due to data capture mistakes by the author and to equipment failure with the flowmeter. Trend Log data for 1993 are considered to be complete. The raw data from both the Daily Logs and the Trend Logs were used to calculate and graph annual and monthly production, daily and monthly discharges and average monthly supply temperatures (Neely, 1995).

### Production Calculations

Production for the State Geothermal system was obtained using three sources: 1) Berkeley Group, Inc. (1990) report, 2) Daily Logs, and 3) Trend Logs. The Berkeley Group, Inc. (1990) report used calculated average flowrates instead of the flowrates reported on the Daily Logs. For the study described in this article, the quantity of water extracted daily was calculated from the Daily Logs by multiplying each daily discharge reading (in gallons per minute) by 1,440 (minutes per day). Daily production quantities were calculated from the Trend Logs by computing an average discharge for each day (from the four daily readings) which was then multiplied by 1,440. Daily volumes from the Daily and Trend Logs were summed to provide monthly and annual totals.

### Annual, Monthly and Daily Production

Table 1 lists the reported and calculated annual production totals for 1983-1994. Low values in 1983, 1990, 1991, 1992 and 1994 are caused by missing data. Figure 4 shows the range in annual production for 1983-1994. Additional calculations performed on the data for 1993 revealed that the Daily Logs contained peak discharge values as indicated by in the Berkeley Group, Inc. (1990) report. Therefore, the 1993 value of 240.2 million gallons in Table 1 (Daily Logs column) is too high.

Figure 5 shows the total monthly production for 1983 to 1994 as calculated from the Daily and Trend Logs. Monthly production ranged from 0 to 30.5 million gallons; however, the most reliable maximum value is 29.2 million gallons for January, 1993, based on the Trend Logs. The average monthly discharges ranged from 0 to 683 gallons per minute (Figure 6). Maximum monthly discharges were about 800-850 gallons per minute with the highest reliable discharge rate being 982 gallons per minute in November, 1993.

Figures 7 shows the daily discharge readings for 1993 which was selected as an example because it contains the most complete record of Trend and Daily Log data. Daily discharges fluctuate from about 600 to 800 gallons per minute during the peak heating season (approximately days 0-90 and 300-364), to about 300-500 gallons per minute during the non-peak heating season (approximately days 91-180 and 240-299), to 0-300 gallons per minute during the summer (approximately days 181-239).

**Table 1. Annual Production for the Capitol Mall Geothermal System, 1983-1994 (in millions of gallons).**

| Year | Berkeley Group Inc. (1990) | Daily Logs | Trend Logs |
|---|---|---|---|
| 1983 | 79.1 | 65.8 | |
| 1984 | 204.8 | 169.5 | |
| 1985 | 196.4 | 187.5 | |
| 1986 | 188.6 | 179.7 | |
| 1987 | N/A | 148.6 | |
| 1988 | 212.6[a] | 122.7 | |
| 1989 | 106.3[a] | 155.6 | |
| 1990 | | 83.4 | |
| 1991 | | 159.4 | 43.6 |
| 1992 | | 136.3 | 75.3 |
| 1993 | | 240.2 | 180.3 |
| 1994 | | 167.9 | 96.3 |

[a] Estimated from Totalized value of $3.10 \times 10^6$ gallons for the period from January, 1988 through June, 1989 (Berkeley Group Inc. (1990)).

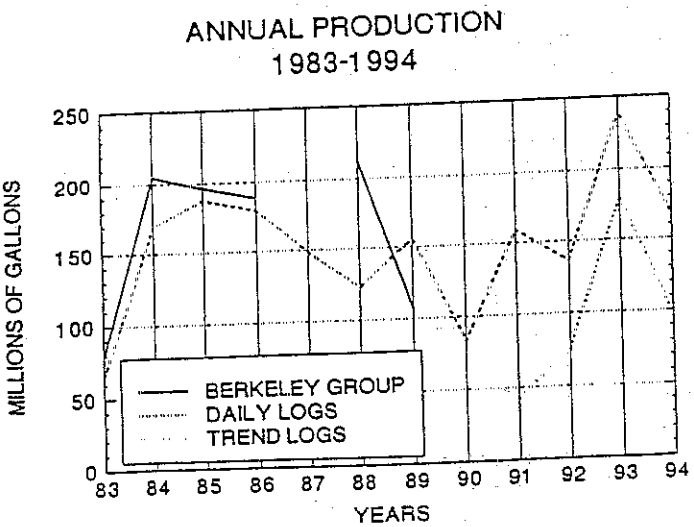



**Figure 4. Annual production for the Capitol Mall geothermal system, 1983-1994.**

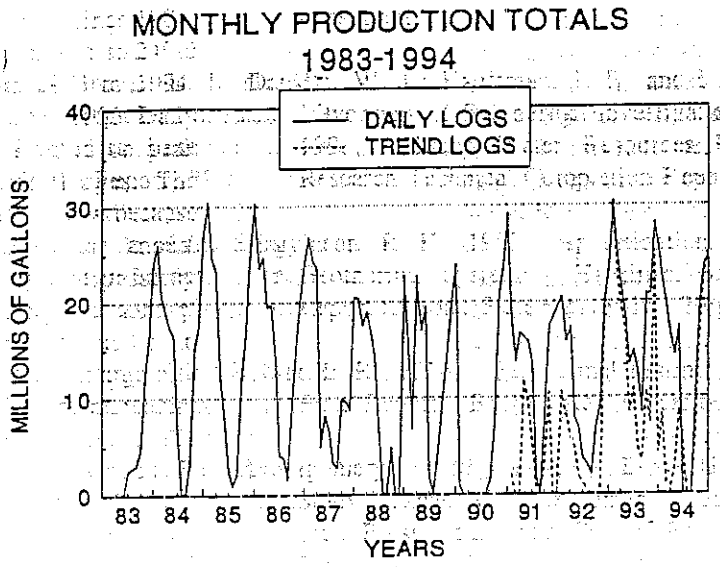



**Figure 5.** Monthly production for the Capitol Mall geothermal system, 1983-1994.

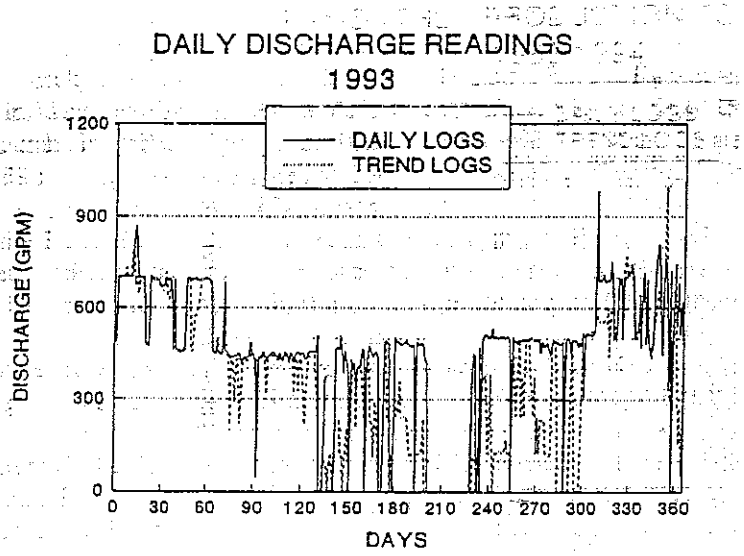



**Figure 7.** Daily discharge readings for the Capitol Mall geothermal system, 1993 (Day 0 = January 1; Day 364 = December 31).

Supply Temperatures

Figure 8 shows a decline of about 5° Fahrenheit in the maximum monthly supply temperatures from 1983 to 1994. The decline may have been caused by a gradual thermal breakthrough related to nearby reinjection in Capitol Mall #1, although this interpretation is speculative at this time.

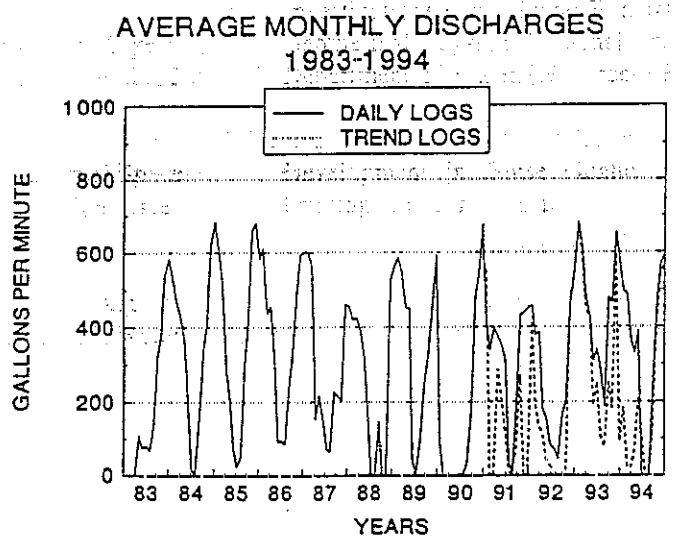



**Figure 6.** Average monthly discharges for the Capitol Mall geothermal system, 1983-1994.

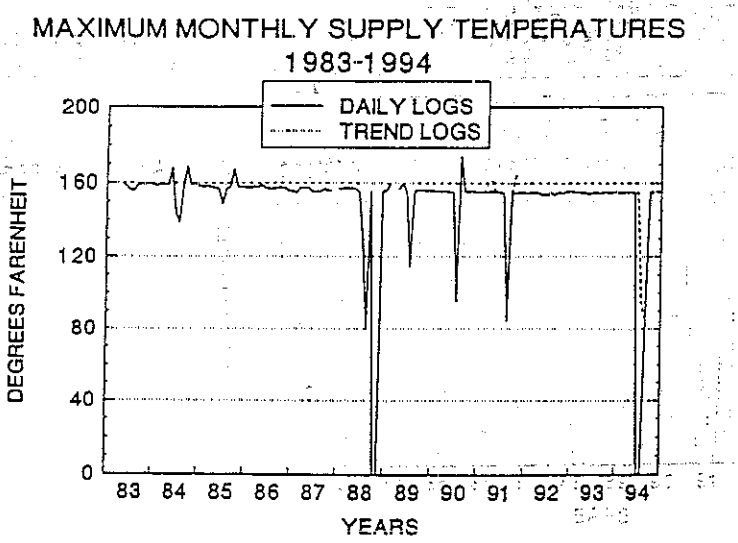



**Figure 8.** Maximum monthly supply temperatures for the Capitol Mall Geothermal system, 1983-1994.

## CONCLUSIONS

The State of Idaho Capitol Mall geothermal system has heated nine buildings in the Capitol Mall complex since 1982. Annual production was computed to range from 65.8 to 240.2 million gallons during the time period from 1983 to 1994. The computed value of 240.2 million gallons (1993 Daily Logs) is too high because the calculation is based on peak daily discharges as opposed to average daily discharges. The computed value of 65.8 (1983 Daily Logs) is too low because of missing data. Based on all of the data, the annual geothermal production for the Capitol Mall system probably ranged from 160 to 205 million gallons. The highest monthly production, based on Trend Logs, was 29.2 million gallons in January, 1993. The highest average monthly discharge rate was 683 gallons per minute in January, 1985. The maximum discharge rate was 982 gallons per minute in November, 1993. The maximum monthly supply temperature decreased about 5° Fahrenheit from 1983 to 1994.


## ACKNOWLEDGEMENTS

I would like to thank Wayne Haas, Hal Anderson and Paul Castelin with the Idaho Department of Water Resources for their technical review of this paper. Thanks also to Gerry Galinato, Idaho Department of Water Resources, for encouraging me to submit this article. Most of the information in the "Geothermal Development in Boise" section came from Worbois (1982). Finally, I thank everyone at the Idaho Department of Administration, Public Works Division, who faithfully collected monitoring data for the Capitol Mall system over the past 13 years.


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# INVESTIGATION OF HYDROGEOLOGIC CONDITIONS AND GROUND WATER FLOW IN THE BOISE FRONT GEOTHERMAL AQUIFER (EXECUTIVE SUMMARY)

*Prepared for:*

**City of Boise, ID**

*and*

**National Renewable Energy Laboratory, Golden, CO**

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PENCAD-Bayonne, N. J.

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# 1. INTRODUCTION

This report summarizes a study of hydrologic conditions in the Boise Front geothermal aquifer system conducted for the City of Boise, Idaho and the National Renewable Energy Laboratory. The summary is based on the following two reports:

1. "Hydrogeologic Conditions in the Boise Front Geothermal Aquifer" (Petrich, 2003).
2. "Simulation of Ground Water Flow in the Boise Front Geothermal Aquifer" (Zyvoloski et al., 2003).

This study arose from a request by the City of Boise to expand current levels of production (with corresponding re-injection) under existing water right permits. This production increase would be used to meet projected demand for geothermal heat in the downtown area. The proposed production increase led to concerns about possible water level and/or temperature changes in the geothermal system by other users. The City of Boise and other major users therefore sought additional hydraulic, thermal, and hydrogeologic information about the geothermal aquifer system, and the development and implementation of a monitoring plan.

The purpose of this study was to provide insight and tools for the long-term management of the Boise geothermal aquifer system. Specific objectives included the following:

1. Review and refine the current conceptual understanding of the Boise Front geothermal aquifer system.
2. Consolidate existing hydrogeologic and production data into a single database
3. Conduct a mass measurement[1] of water levels and/or pressures in selected geothermal wells throughout the system.
4. Construct a numerical model capable of simulating hydraulic heads and water temperatures in the Boise Front area.
5. Calibrate the model on the basis of hydraulic head and temperature observations using methods that quantify calibration confidence.
6. Evaluate potential hydraulic and thermal effects of increased production and re-injection by the City of Boise on wells in the downtown Boise – Table Rock[2], Harris Ranch, and Stewart Gulch areas.

[1] The term mass measurement refers to collecting "simultaneous" measurement of multiple wells over a short period of time. Data from such measurements are used to estimate hydraulic gradients.
[2] Referred to hereafter as the "downtown – Table Rock" area.

The primary focus of this study was on three areas within the geothermal system: Harris Ranch, downtown – Table Rock, and Stewart Gulch (Figure 1). Wells in these areas generally represent the warmest geothermal wells, share a common use (space heating), and have more available data than geothermal wells in other areas along the Boise Front. Users in these three areas expressed concern about possible effects associated with proposed increases in thermal water withdrawals (with re-injection) by the City of Boise

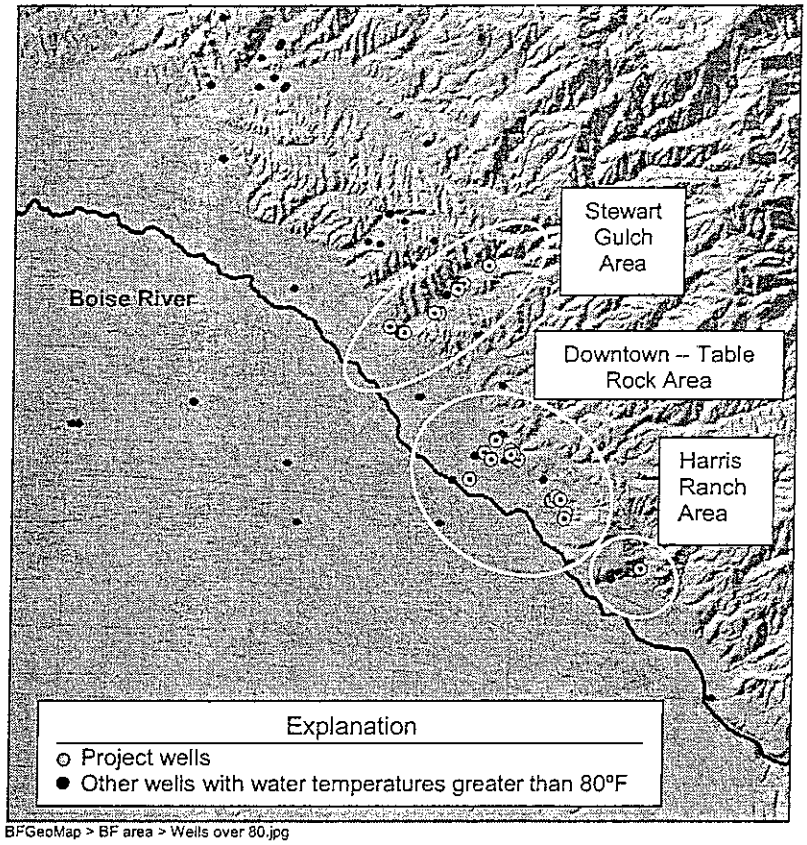



Figure 1: Map of the Boise Front area showing primary production areas.

This project has been guided by, and the above-listed reports have been reviewed by, a project Technical Committee. The committee agrees that this and the two reports referenced above represent a general understanding of the committee based on the present level of hydrologic information. The committee consists of the following individuals:

- Chuck Brockway, Brockway Engineering (on behalf of the Boise Warm Springs Water District)
- Paul Castelin, Idaho Department of Water Resources
- Sherl Chapman / Steve Hannula, ERO Resources (on behalf of Harris Ranch)

- Kent Johnson, City of Boise
- Ken Neely, Idaho Department of Water Resources
- Deb Parliman, U.S. Geological Survey
- Clarence Robison, University of Idaho
- Terry Scanlan, Scanlan Engineering (on behalf of the City of Boise)
- Ed Squires, Hydro Logic, Inc. (on behalf of the Terteling Family)

## 2. PROJECT COMPONENTS

The project included the following tasks:

1. Review applicable hydrogeologic and geologic literature.
2. Develop MS Access database of geothermal data.
3. Document consistent water level and/or pressure measurement point locations for selected geothermal wells.
4. Survey selected geothermal well locations, ground surface elevations, and measuring point elevations.
5. Conduct a simultaneous measurement[3] of water levels/pressures in selected geothermal wells.
6. Review and summarize the current understanding of the hydrogeologic framework.
7. Develop chronology of geothermal development in the Boise Front area.
8. Prepare and review hydrographs from available geothermal well data.
9. Evaluate water level and temperature trends.
10. Construct and calibrate a three-dimensional numerical model to simulate flow in the Boise Front geothermal aquifer.
11. Use the model to evaluate potential hydraulic and temperature impacts associated with increased geothermal withdrawals and re-injection proposed by the City of Boise.

## 3. OVERVIEW

An extensive "low temperature" geothermal aquifer system underlies the Boise area along the Boise Foothills – an area known as the Boise Front. The lateral extent of the aquifer along the northwest-southeast orientation of the Boise Front is unclear,

[3] Measurement of water levels and/or pressures in wells conducted over a period of two days.

although thermal ground water is known to exist further west in the Dry Creek area, further east near Mayfield, and to the south near the Snake River.

Development of hot ground water began in the Boise area in 1891. Geothermal wells with elevated water temperatures are clustered along the Boise Front in several areas, including Harris Ranch, downtown – Table Rock, and Stewart Gulch (Figure 1). Thermal water from these wells is withdrawn for space heating, irrigation, and domestic purposes by a variety of private, commercial, and government users.

The Boise Front geothermal aquifers reside in a complex series of igneous rocks and interbedded sediments (Wood and Burnham, 1987; Wood and Clemens, *in press*). Geothermal water is associated with fractures along a northwest trending fault zone along the Boise Foothills. Thermal water in the downtown – Table Rock area is drawn from Cretaceous-aged granite of the Idaho Batholith, Tertiary-aged rhyolite and associated sediments, and/or Tertiary-aged basalt. The temperature of thermal water in wells used for space heating typically ranges from about 135°F to 175°F. Geothermal water in the Harris Ranch area resides in fractured granite. Two Tertiary-aged basalt layers appear to be the primary source of 90°F to 125°F thermal water in the Stewart Gulch wells. Potentiometric surface maps based on the 2002 mass measurements suggest a westerly or southwesterly horizontal hydraulic gradient in all three of these areas.

The downtown – Table Rock and Stewart Gulch areas have experienced a number of water level decreases and increases since the early 1980s. Despite these observations, it is not possible to conclude that water levels in the Stewart Gulch area have (or have not) been affected by the geothermal withdrawals in the downtown area (or vice versa). Conceptually, faulting along the Boise Front would provide a basis for hydraulic connection between these areas. Although geothermal water in these areas has different chemistry characteristics and residence times (Mariner et al., 1989), the water shares a common source (Idaho Batholith granitics). It is conceivable that stresses from the downtown area could influence water levels in the Stewart Gulch area, or vice versa, depending on the magnitude and duration of the stress. However, such effects (if present) were not discernible in the available data from these two areas.

Simulations of the Boise area geothermal aquifer were conducted to determine if increased injection at the City of Boise injection well would affect the temperatures and/or water levels at other primary geothermal wells. The simulations were conducted using the FEHM computer code (Zyvoloski et al., 1997) and the PEST parameter estimation code (Doherty, 2000). The model area included the Harris Ranch, downtown – Table Rock, and Stewart Gulch areas. Recharge was simulated as upward flow in fault areas and lateral flow across the northeast boundary. Outflow included lateral flow across the southwest model boundary and discharge to wells. The model grid represented a 3-dimensional flow system, with the finest discretization in

the downtown – Table Rock area. The model was calibrated to selected 1984 through 1992 water level and temperature data, and checked against 1984 through 2002 water level and temperature data.

Scenario simulations were run for 30 and 100 years from present, and consisted of (1) current pumping rates (base case), (2) a 50% increase in City of Boise withdrawals (with all increased withdrawals being re-injected), and (3) a 100% increase in City of Boise withdrawals (with all increased withdrawals being re-injected). Simulation results suggest that the hydraulic impact of increased pumping/injection, if any, will be minimal. Simulations did not predict appreciable water level declines at the observed wells associated with the increased City of Boise pumping and withdrawals over the base-case simulations. Simulations of increased withdrawals and injection showed minimal impact on inter-annual head fluctuation at the Boise Warm Springs wells. The simulations indicated a possibility of some long-term temperature declines (as much as 3°C, or 6°F, in thirty years). Of the wells included in the model, the only wells showing any thermal changes were the Capitol Mall injection (CM#1) and Veterans Administration (VA) Production wells.

## 4. CONCLUSIONS

The primary conclusions from this study are that:

1. The Boise Front geothermal aquifer(s) appears adequate for supplying current levels of thermal withdrawals (with accompanying injection).
2. Improved monitoring and reporting of water levels, pressures, temperatures, and flow rates is needed to better track responses of current and future withdrawals and re-injection.
3. It is unlikely that the proposed increases in production and re-injection by the City of Boise will decrease water levels, or will decrease temperatures appreciably, in the downtown – Table Rock, Stewart Gulch, or Harris Ranch areas.

Specific conclusions drawn from the hydrologic analysis and model simulations include the following:

1. Water levels in the downtown – Table Rock area decreased beginning in 1984, apparently in response to new net withdrawals by the City of Boise in 1984.
2. Water levels in the BLM monitoring well appear to provide a good indication of water levels in the downtown – Table Rock area, based on intermittent water level data from other wells in this area.

3. Water levels in the Boise area stabilized somewhat beginning in the late 1980s, based on observations in the BLM well. The stabilization of water levels presumably was, at least in part, in response to stabilization of net production following the production increase of 1984

4. Water levels in the downtown – Table Rock area have been recovering since 1999, based on observed water level increases in the BLM, VA, BWSWD, Kanta wells. The recovery appears to be in response to the City's re-injection of a portion of its withdrawals since 1999.

5. Water temperatures in the CM #2 well declined from approximately 1983 – 1990, which may reflect the time to reach temperature equilibrium in the Capitol Mall couplet.

6. Water levels in the Edwards well also decreased beginning in approximately 1984, but at least part of the decrease appears to have been caused by the start of production from Quail Hollow (Golf Course) Upper well.

7. Several Stewart Gulch wells (e.g., Edwards, Quail Hollow Lower, Terteling Windsock, Terteling Pool, and Terteling Motorcycle) experienced water level increases in the mid to late 1990s. These increases began between approximately 1992 through 1996. Water levels in the Quail Hollow Lower, Terteling Windsock, Terteling Pool, and Terteling Motorcycle began to stabilize (or drop slightly) beginning in about 1999 (although August 2002 levels were slightly higher than in previous years). Water levels in the Flora Silkey and Flora Tiegs wells decreased between 1994 and 1998, and increased between about 1998 and 2002.

8. Faulting that connects the Harris Ranch, downtown – Table Rock, and Stewart Gulch areas provides the basis for hydraulic connection between these areas. There appears to be some evidence for hydraulic connection between the downtown – Table Rock, and the Harris Ranch areas. Thermal water in the downtown – Table Rock, and Stewart Gulch areas appears to share a common source, although there are clear differences in water chemistry, residence times, and temperature. The current water level/pressure and production data are insufficient to describe the degree of hydraulic connection between the downtown – Table Rock area and Stewart Gulch areas.

9. It appears from the simulations that the hydraulic connection between the City production and injection wells is sufficient for the proposed amount of increased water production and re-injection.

10. The simulation results suggest that the average head in the downtown – Table Rock production area will be increasing for the near future, even if the City increases production and re-injection as proposed. This is because the net production has decreased in recent years, and the increased

production and re-injection by the City of Boise will not result in an increase of net withdrawals.

11. The City injection well is far enough removed from other users in the downtown area that the simulated thermal perturbation caused by the injected water does not appear to propagate to the other wells in the downtown – Table Rock area. However, the increased injection may produce local hydraulic changes that in turn could change the temperature mix entering individual wells.

12. Two alternative conceptual models were implemented in the numerical model: partial hydraulic connection and no hydraulic connection. Neither model accurately reproduced measured hydrographs at the Edwards well. It is unclear whether this result is because of conceptual model errors or the paucity of production data in the Stewart Gulch area. It is unlikely that modeling or data analysis can be used to definitively determine the influence (or lack thereof) of withdrawals in the downtown – Table Rock area on wells in the Stewart Gulch area (or vice versa) given the current level of hydrologic and production data.

There are a number of assumptions, limitations, and potential errors associated with the model developed for this study, or with any numerical ground water flow model (see Zyvoloski et al., 2003). The resulting uncertainty may be exacerbated when making predictions into the distant future (e.g., 30 or 100 years).

## 5. RECOMMENDATIONS

The primary recommendation of this study is to improve the monitoring of water levels/pressures, temperature, and flow in geothermal wells. The improved monitoring would enable better tracking of hydrologic conditions in the Boise Front geothermal aquifer. Improved monitoring should include the following:

1. Inspect, check, and calibrate installed water level/pressure, temperature, and flow instrumentation on a regular basis (quarterly or semi-annually).
2. Continue to add monitoring data from these measurements to the database created for this project; consider ways to facilitate standardized data collection and reporting.
3. Consider expanding monitoring to selected additional thermal wells within the geothermal system.
4. Conduct another mass measurement with all wells under uniform temperature conditions. One approach for this would be to create enough flow in each well to allow temperature equilibration within the well prior to measuring water levels and/or pressures. This approach could be first

tested in a limited number of individual wells to check the differences between static and flowing water levels.

In addition, the following recommendations might be considered to improve the general understanding of the geothermal aquifer system:

1. Quantify aquifer and/or fault characteristics through multi-well aquifer tests using existing wells.
2. Quantify aquifer and/or fault characteristics through geophysical methods (e.g., seismic surveys).
3. Conduct field-based and/or simulated tracer tests. Bromide may be a tracer candidate depending on existing background concentrations.
4. Conduct capture zone simulations to provide insight into potential well interference.
5. Conduct flowing and non-flowing temperature logs in wells to provide more insight into temperatures and ground water flow associated with individual aquifer zones.
6. Consider exploratory drilling to help quantify hydraulic and temperature characteristics in primary faults.

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## ACKNOWLEDGEMENTS

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Clement's File

#1

All footages & samples referenced to Table ht 4' above LSD

Hull Log - Clements

0-30 - Tuff/congl

31- - poorly cons SS gty - chale 116°f

41-47 - larger gvl - pebbly, cong - 114°f - chunky

48-53 - poorly consol SS w/ gray ash, red particles

53-58 - poorly consol SS w/ limy clay 125°f - good T

58-72 - coarse sand - poorly consol SS gty & bas fgmts 138°f

72-74 - coarse gty sa

74-83 - loose gty sa w/ charcoal, ash

83-93 - gty sa uncons, basalt, pebbles 148°f

93-98 - [illegible] gty sa w/ bas fgmts

98-113 - fine gty sa 162°f

113-120 - gty sa w bas pebbles, water good +

120-127 - gty sa fine - w bas @ 200-300

127-133 - do 181°f

133-143 - coarse gty sa - bas pebbles

143-153 - " charcoal 183°f

153-160 do

160-163 gty sa w/ phyllite or schist - bas pebbles - water ch

166 water back

165-170 - gty sa w/ phyllite fgmts

170-173 - 60% phyllite 40% gty sa mod cons 185°f

173-181 phyllite w some gty

181-193 mod/phyllite sd

193 about 50% phyllite 50% gty sa 187°f

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P2

Reference - table 4 + 5

Begin day 2 — 152°f no strike

203 - rhyolite ± qtz sa - possible coal 155 ±

213 - vole ash silicic 50% ± qtz cont 157° ±
high % F qtz sa cont silica ash cement

238 & 233 - qtz sa w/ash ± charcoal/pyrite 162 ±
✓ pyrite/pyrite - subrounded/rotted qtz

237 coarse qtz sa, muscovite, charcoal pyrite
subrded to sub & grains T = 1500 ft lbs
color change ± [illegible] gray

240 — qtz sa w/ash - coarse

245 — do gray color of discharge 164°f ±
300-400 gpm

253 — qtz sa w/ash pyrite - med - coarse gr 165°f ±
gray discharge - sub rounded

260 do - increase in muscovite — 165°f

290 — ~~Qtz~~ Sa 164°f

294 — do

300 — fine - med qtz sa - muscovite 164°f

313 - coarse qtz sa & gvl - lots of rhyolite/pyrite
very coarse sa & fine gvl washing out around
surface - 164° ± Plan on well washing out
~~the~~ severely - putting bentonite around
Slotted pipe T = 170 ±

Rel Tabb
Wt

3-26-80

DTW 250 ft below TOC - TOC rp @ 15' + LSD

T = 186 f

316 - qty sa w/ [illegible] 186

323 do 190°

329 qty sa [illegible] vol ash/pyrite 190°

340 qty sa [illegible] 190° Tc pyr

350 qty sa - meal - ≠ w/ [illegible]

360 qty sa - [illegible] - Possible

[illegible] ref. 56° C

366 - [illegible] qty sa [illegible]

& su[illegible] Temp 85° C

380 qty [illegible]

190°±

386-39 - clay [illegible]

397 - qty sa [illegible] 190°±

403 qty sa w/ [illegible]

419 do [illegible] T @ 160± cent, Therm

415 [illegible] 55 - @ 2000 lbs [illegible] - qty [illegible] some pyrite (2%) - gneissic [illegible] - [illegible] (2%)

423 170° f 55 - [illegible] qty 90% pyrite

430 166° f 55 do [illegible] 1500 down 3000 Torque

432 - 162° f

434 - qty [illegible]

Re'-Table
+4 above LSD

435 - ~~174~~ 167°f - cem ss - qtz - some bas pebbles occ slow drilling
438 - ~~174~~ 166°f do
442 - do - muscovite - /mica - slow drilling
[illegible] qtz - ∅ - some rounded pgmts
/ [illegible]
443 - ~~174~~ 166°f pulling up added water
443 - change rod & Thermo 174°f - correct pre-reading
455 - coarse ∅ qtz, glassy; rolled pgmts w/ green & black ∅ ash
metamorphics; muscovite; no kspar ; pyrite (2-5%)
176° (80°c)
463 - 176°f - 50% multi-color qtz - ∅ - occ ~~∅~~ subang
50% [illegible] ash ∅). some
muscovite - slow [illegible]
475 182°f do w/ some ash
[illegible] - 55% ash 182°F
483 - 182°f - [illegible] altered rock
qtz ∅

3 - 2 ½ - 50
179°F

500 - altered [illegible] qtz ∅ rounded, clay
pyrite (2%) some pebbles (mafic) (1%) 176°f
503 178 at startup.
509 - 176°f
513 - pink angular qtz - coarse - mica - occ sm pyrite (qtz) ash
[illegible] - altered rock

3-28-80 Rig Table + 4

* 514 - 183°f - coarse-med qtz - pyrite coating altered green ash - fast drilling zone

520 - 182°f

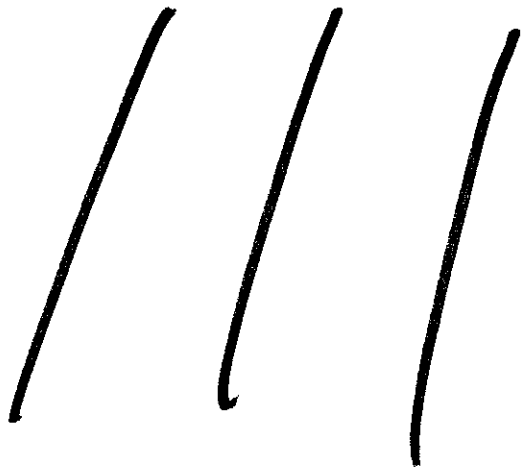
522 - back to cemented qtz ss

531 cem qtz ss w/ altered ash frgts, brassy pyrite v coarse glassy sub-ang qtz T = 177°f

535 - T = 181°f cem qtz ss - soft spot high alt ash content

543 qtz ss sub-ang qtz - glassy 3-8mm altered frgmts; brassy pyrite (10%) some muddy qtz 3000 torque 1450 pull/down 177°f

TD 3-25-80



July 14, 1983
Owner of Well: Larry Hellhake Well No.: GEO-1 Location: Roystone Hot Springs
Measuring point for water levels (MP) IOC – airline set at 226' PL=226-(2.31xPSI)

| Date And/or Time | Depth to water below M.P. | Discharge Measurement | Hours well was on since last notation | Person making this observation | Special Notes: |
|---|---|---|---|---|---|
| 7/14/83, 1510 | 32 | 0 | - | SLC | airline length 226' before test |
| 1535 | 62 | Corrected 250 | Probably not a full pipe | | Meter totalizer at start 1036 |
| 1607 | 62 | Corrected 250 | | | Sec x 32 60 / 500 60 200 x 71psi |
| 1642 | Raised RPM | | | | |
| 1644 | 67 | 359 | | | T=158°F pipe @ .85 full 800 rpm |
| 1735 | 71 | 344 | | | 67psi 23sec 200 gal 160°f |
| 1750 | 69 | 350 | | | 68psi k=.66 |
| Raised Q 1750 | | | | | |
| 1754 | 73.5 | 420 | | | K=.7 |
| 1819 | 73.5 | 420 | SLC | | K=.7 |
| 1820 | 80.5 | 570 | SLC | 30.8 | K=1.0 fullpipe |
| 1859 | 85 | 545 | | 23.7 | K=1.0 |
| 1900 | Raised Q | | | | |
| 1901 | 89.5 | 631 | | 22.9 | |
| 1938 | 94 | 600 | | | Increase Q at 2000 |
| 2001 | 106 | 750 | | 18.75 | 1325 RPM |
| 2006 | 108 | 750 | | | |
| 2010 | 110.5 | 750 | | SLC | |
| 2034 | 115.12 | 750 | | CWB | |
| 2105 | 115.12 | 750 | | | 180°F 1325 RPM |
| 2125 | 115.12 | 750 | | | |
| 2146 | 119.74 | 750 | 13.15 | | |
| 2215 | 122.05 | 706 | | | |
| 2243 | 128.98 | 706 | | | RPM Surging slightly: 1300-1350RPM |
| 2318 | 126.67 | 667 | | | RPM Surging slightly less than @2243 |
| 2356 | 128.98 | 667 | | | 2330 175°F: Note hard to measure due to steam |

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July 15, 1983
Owner of Well: Larry Hellhake Well No.: GEO-1 Location: Roystone Hot Springs
Measuring point for water levels (MP) IUC – airline set at 226' PL=226-(2.31xPSI)

| Date And/or Time | Depth to water below M.P. | Discharge Measurement | Hours well was on since last notation | Person making this observation | Special Notes: |
|---|---|---|---|---|---|
| 07/15/83 2432 | 131.29 | 667 | 9.67 | | |
| 0100 | 131.29 | 667 | | | 1400RPM |
| 0133 | 154.39 | 750 | | | |
| 0202 | 154.39 | 750 | | | |
| | | | | | |
| 0234 | 156.70 | 706 | | | |
| 0302 | 159.01 | 706 | | | |
| 0404 | 159.01 | 706 | | | 1500 |
| 0432 | 177.49 | 750 | | | |
| 0450 | 179.80 | 750 | | CWB | |
| 0510 | 179.80 | 750 | | | |
| 0600 | 182.11 | 750 | | | |
| 0658 | 182.11 | 706 | 5.89 | | 0715-84°C (183°F) Sc=4.71gpm/ft |
| 0748 | 193.66 | 800 | | | 1600RPM |
| 0755 | 202.90 | 800 | | | |
| 0809 | 202.90 | 800 | | | 84°C |
| 0824 | 212.14 | 857 | | | 1700 RPM |
| 0840 | 212.14 | 800 | | | |
| 0854 | 216.74 | 800 | | | |
| 0927 | 216.74 | 750 | 4.87 | | Pump shut down 1755 Ending Totalizer |
| 0935 | 126.67 | | | | |
| 0936 | 122.05 | | | | |

July 14, 1983
Owner of Well: Larry Hellhake Well No : 2
Location: Roystone Hot Springs – Original Well
Measuring point for water levels (MP) IOC

| Date And/or Time | Depth to water below M.P. | Discharge Measurement | Hours well was on since last notation | Person making this observation | Special Notes: |
|---|---|---|---|---|---|
| 7/14/83 1220 | 43.0 | 0 | months | SLC | Unused unpumped well So of GEO#1 about 30-40 feet |
| 1544 | 43.96 | 0 | | | |
| 1645 | 46.20 | 0 | | | |
| 1740 | 47.48 | | | | |
| 1939 | 47.6 | | | | |
| 2015 | 50.58 | | | | |
| 2040 | 54.12 | | | CWB | |
| 2109 | 55.01 | | | | |
| 2129 | 55.71 | | | | |
| 2148 | 56.30 | | | | |
| 2217 | 56.92 | | | | |
| 2246 | 57.48 | | | | |
| 2321 | 57.98 | | | | |
| 2358 | 58.42 | | | | |
| 7-15-83 2434 | 58.73 | | | | |
| 0108 | 59.15 | | | | M-scope malfunctioned. Tip repaired by removing ½" from tip |
| 0135 | 59.36 | | | | |
| 0204 | 59.60 | | | CWB | |
| 0304 | 59.95 | | | | |
| 0406 | 60.64 | | | | |
| 0513 | 60.83 | | | | |
| 0603 | 61.04 | | | | |
| 0701 | 61.31 | | | | |
| 0753 | 61.52 | | | | |
| 0830 | 61.65 | | | | |
| 0859 | 61.68 | | | | |
| 0930 | 61.78 | | | | Pump test shut down 0927 |
| 0938 | 61.77 | | | | 1424 0926 4Hrs 58min |

| Date And/or Time | Depth to water below M.P. | Discharge Measurement | Hours well was on since last notation | Person making this observation | Special Notes: |
|---|---|---|---|---|---|
| 0947 | 61.69 | | | | |
| 0955 | 61.55 | | | | |
| 0959 | 61.47 | | | | |
| 1011 | 61.28 | | | | |
| 1027 | 61.05 | | | | |
| 1044 | 60.73 | | | | |
| 1102 | 60.42 | | | CWB | |
| 1118 | 60.09 | | | | |
| 1132 | 59.99 | | | | |
| 1145 | 59.69 | | | | |
| 1228 | 59.00 | | | | |
| 1305 | 58.80 | | | | |
| 1424 | 58.10 | | | | End of Test |
| | | | | | |

Field Notes 7/14/83 - Spring
Owner of Spring: Larry Hellhake Well No.: Spring
Location: Roystone Hot Springs – swimming pool spring
Measuring point for water levels (MP): outlet above spring

| Date And/or Time | Parshall Flume Head | Discharge Measurement | Hours well was on since last notation | Person making this observation | Special Notes: |
|---|---|---|---|---|---|
| 7/14/83 925 | 042 | | | | Slight leakage beneath flume |
| 1555 | 062 | | | | Flume reset |
| 1706 | 062 | | | | |
| 1742 | 060 | | | SLC | |
| 2020 | 0.60 | | | CBW | |
| 2042 | 0.60 | | | | |
| 2131 | 0.60 | | | | |
| 2221 | 0.60 | | | | |
| 2325 | 0.60 | | | | |
| 7-15-83 2401 | 0.60 | | | | |
| 0137 | 0.60 | | | | |
| 0207 | 0.60 | | | | |
| 0306 | 0.60 | | | | |
| 0412 | 0.60 | | | | |
| 0516 | 0.60 | | | | |
| 0606 | 0.60 | | | | |
| 0703 | 0.60 | | | | |
| 0812 | 0.60 | | | CBW | |
| 0900 | 0.60 | | | | |
| 0934 | 0.60 | | | | |

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CPF3 - GEO #1
ROYSTONE HOT SPRINGS
April 1, 1980

LITHOLOGIC LOG

TEMP GRADIENT
DEGREES F

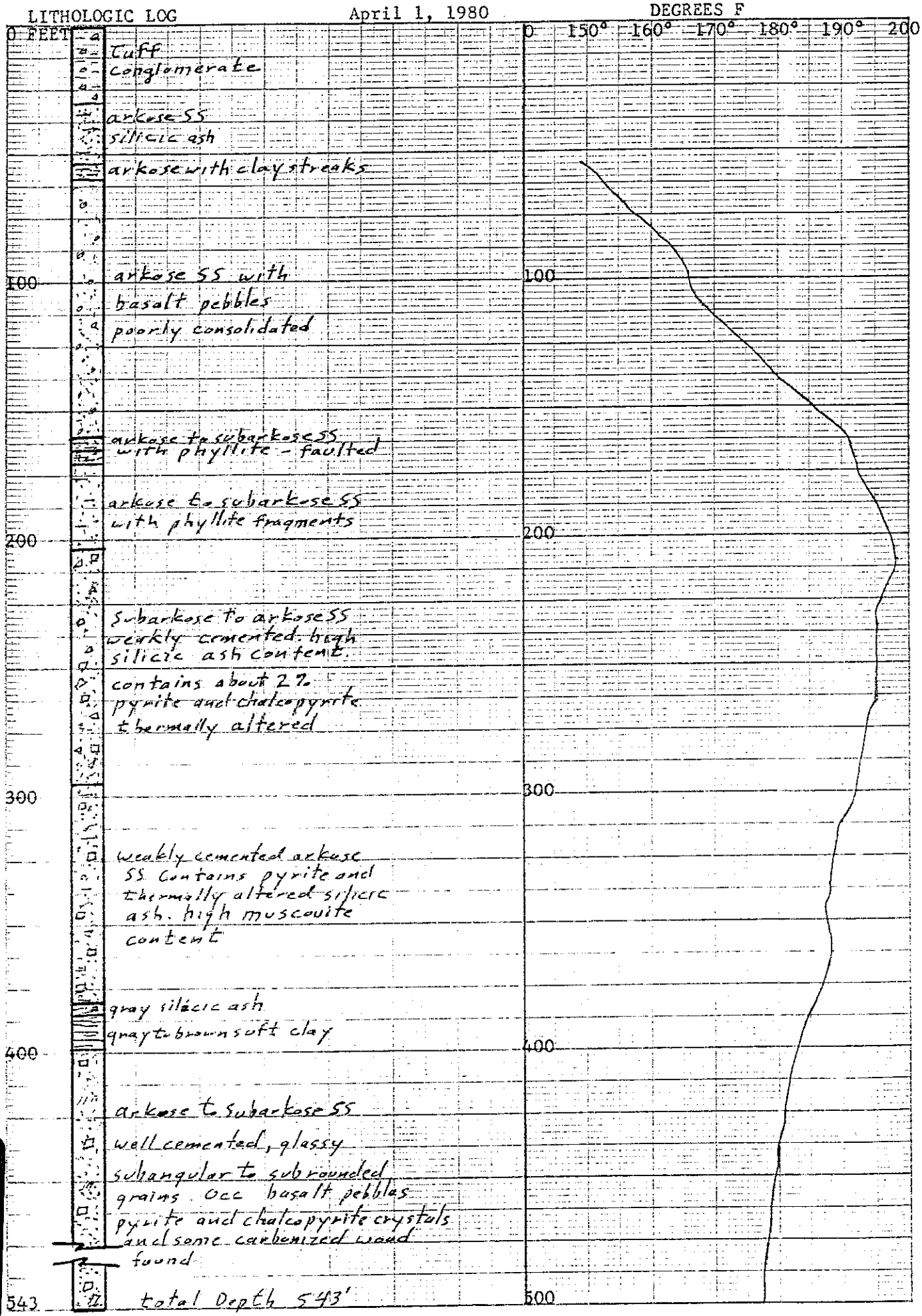
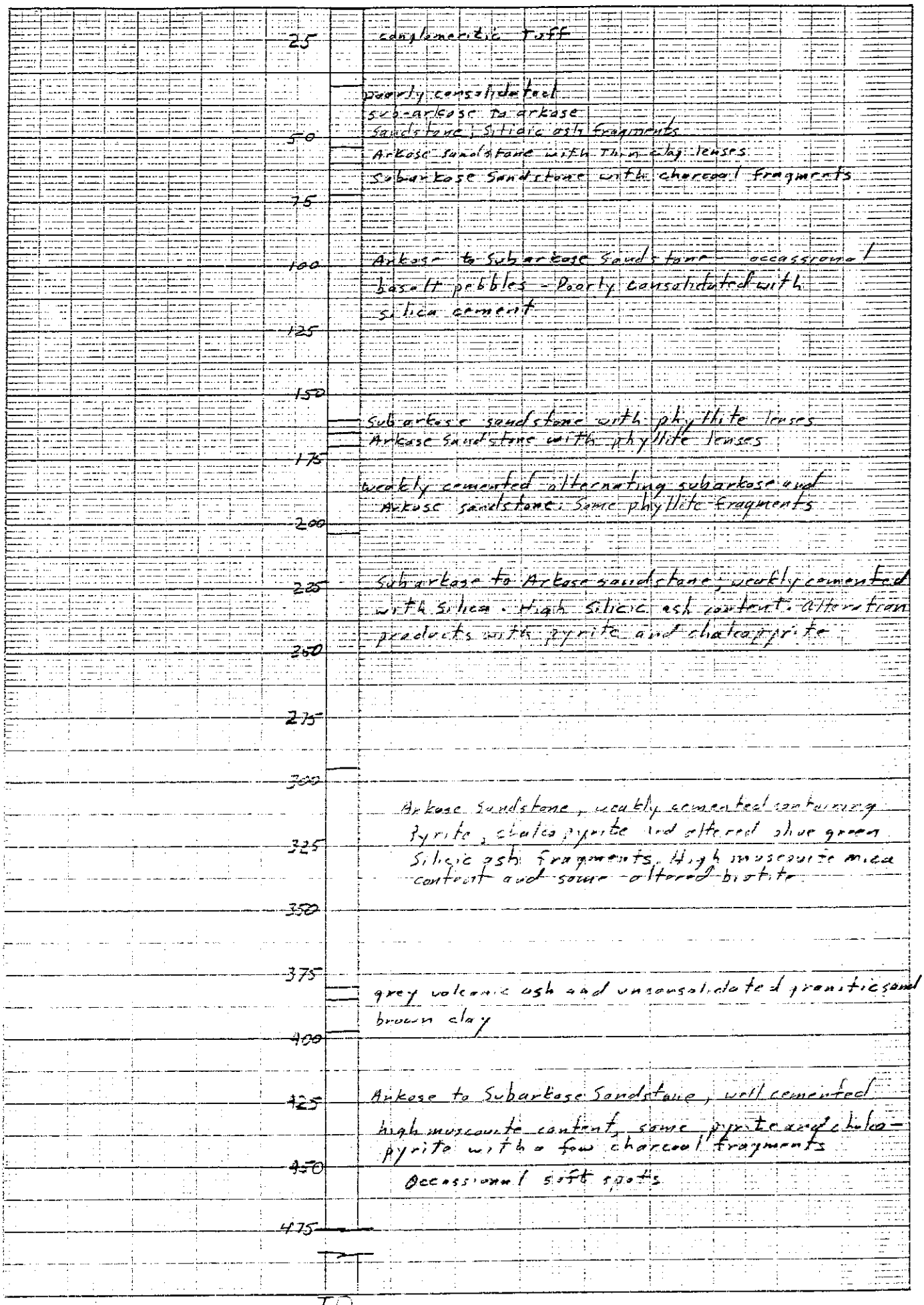



FIGURE 2 - Lithologic Log and Temperature Gradient, CPF3 - GEO #1 Well on April 1, 1980

April 1, 1980




20 X 20 TO THE INCH 46 1240
7 X 10 INCHES
KEUFFEL & ESSER CO.

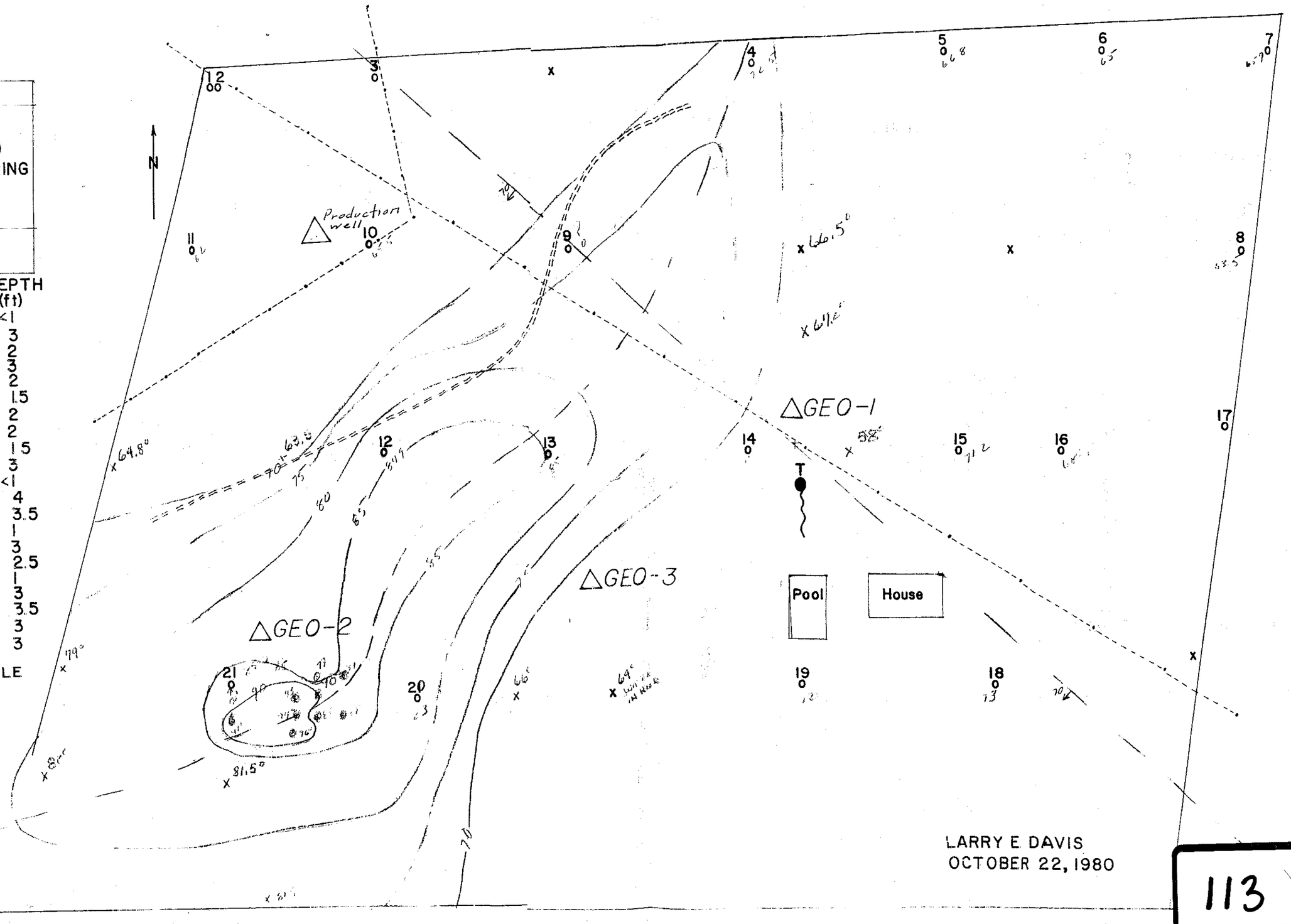
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# ROYSTONE HOT SPRINGS

| LEGEND |
|---|
| 13 o TEST HOLE |
| X STAKE (No Hole) |
| THERMAL SPRING |
| ==== ROAD |
| ---- POWER LINE |
| SCALE 1"≈100' |

| HOLE NO. | TEMP. (°F) | DEPTH (ft) |
|---|---|---|
| 1 | 58 | <1 |
| 2 | 62.5 | 3 |
| 3 | 61.5 | 2 |
| 4 | 72.5 | 3 |
| 5 | 66.8 | 2 |
| 6 | 65 | 1.5 |
| 7 | 65.9 | 2 |
| 8 | 63.5 | 2 |
| 9 | 59.4 | 1.5 |
| 10 | 65.5 | 3 |
| 11 | 62 | <1 |
| 12 | 84.9 | 4 |
| 13 | 85 | 3.5 |
| 14 | 68.9 | 1 |
| 15 | 71.2 | 3 |
| 16 | 68.5 | 2.5 |
| 17 | 61.4 | 1 |
| 18 | 73 | 3 |
| 19 | 72 | 3.5 |
| 20 | 83.5 | 3 |
| 21 | 85.5 | 3 |

1. WATER IN HOLE
AIR TEMP 65°




LARRY E. DAVIS
OCTOBER 22, 1980

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# Semi-Annual Review of the Monitoring Data for the Boise Front Geothermal System, January – June, 2003

**Ken Neely**
**Technical Hydrogeologist**
**Idaho Department of Water Resources (IDWR)**
**September 26, 2003**

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PENGAD-Bayonne, N. J.
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# 1. DOWNTOWN BOISE AND HARRIS RANCH

## 1.1. Production

In the first six months of 2003, the four downtown district heating systems extracted 386 million gallons, and re-injected 254 million gallons (66%). This amount is estimated to be eight million gallons (two percent) more than the first six months of 2002. Volumetric calculations for the Boise Warm Springs Water District (BWSWD) wells are based on data from the Sparling meter in 2003 because they are similar to the Signet meter readings in 2000 and 2001. Missing data in 2000 – 2002, and a difference of 12 million gallons between the Sparling and Signet meters in 2003 make it difficult to accurately determine the production amount at BWSWD.

## 1.2. BLM Water Levels

The BLM well is located on the U. S. Geological Survey (USGS) property; data are collected by the USGS. Water levels in the BLM well have risen steadily since early 1999 (Figure 1). The "trough" value (i.e., the low value which occurs between late January and early March each year) has increased almost 25 feet in the last 5 years. The "peak" value (i.e., the maximum value which occurs in late September to early October each year) has increased at least 15 feet in the last 5 years. However, the "peak" values for the last three years are either: 1) unusual, as in 2001 when the BLM well flowed causing a high spike, 2) missing as in 2002, or 3) not yet recorded as in 2003.

## 1.3. Data Summaries by Water System

### 1.3.1 Boise Warm Springs Water District West, East, and #3

Monitoring data for BWSWD West, East, and #3 were submitted in hardcopy by Rod Baldwin. Log sheets contain one entry per day for flow, water levels, temperature, and other data. Flow and total volume are measured using Signet flow meters on the East and West wells, and a Sparling meter that recorded a combined flow from the two wells. Boise Warm Springs Water District also provided monthly production summaries to IDWR. Table 1 shows 2003 data for January through June in comparison with the same time periods for 2000, 2001, and 2002.

**Table 1.** Production at BWSWD for January through June, 2000-2003.

| Year | Signet Meter | Sparling Meter |
|---|---|---|
| 2000 | 119 million | Incomplete |
| 2001 | 117 million | Incomplete |
| 2002 | Incomplete | No data |
| 2003 | 131 million | 119 million |

It is difficult to determine the mostly likely production total for this time period because data are missing for several of the years.

Water levels in the West well were markedly different in late 2002 and early 2003 than they were in previous years. The low reading was almost 50 feet higher in February 2003 than in February 2002 (Figure 2). The east well, which is the main producing well, actually had a slightly lower "trough" value in 2003 than in 2002.

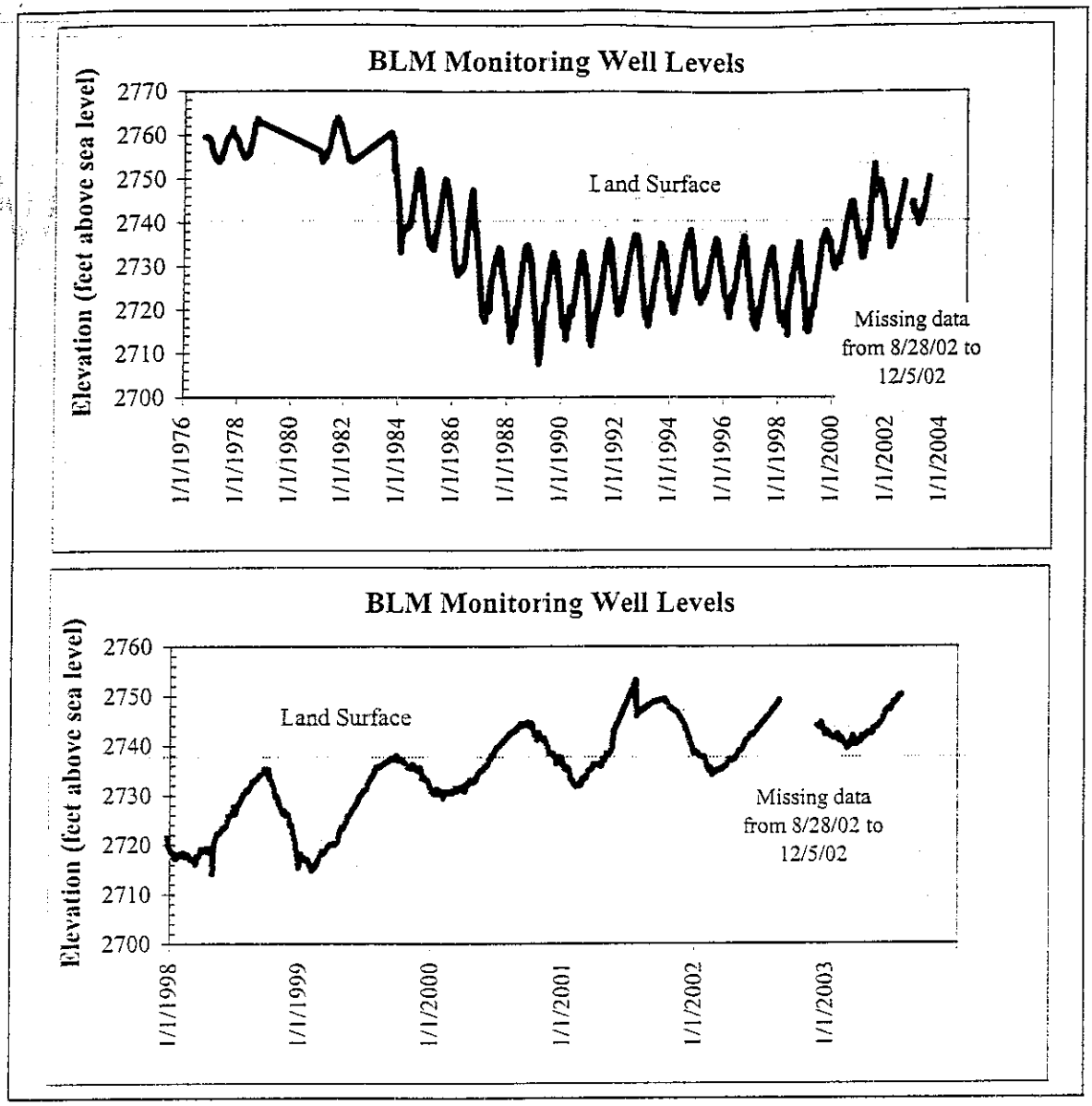



**Figure 1.** Water levels in the BLM Monitoring well.

1.3.2. State of Idaho Capitol Mall Production and Injection wells

Monitoring data for the Capitol Mall system were submitted in Dbase® files by Bill Hudson. The data files contain one reading for every two-hour interval, which was recorded by a computerized data logging system. Files containing discharge data were imported into Excel®, and monthly production summaries were calculated. Production for January through June was about 77 million gallons. In 2002, production was about 73 million gallons during this time period, but this figure is based on some estimates for May and June because of missing data. Water temperatures, system pressure readings, and other data were also submitted on Dbase® files

Maximum daily water supply temperatures rose slightly from 1994 through 1998, and then dropped about 1.5 degrees Fahrenheit from 1998 to 2003 based on a visual inspection of the data (Figure 3).

Maximum monthly temperature readings from January 1991 through June 2003 were determined and then transformed to remove seasonal effects[1]. The Spearman rho test was used in order to calculate a Pearson product moment correlation coefficient. The resulting coefficient[2] was –0.33, which indicates that there was a significant decreasing trend in the de-seasonalized monthly maximum water temperatures from 1991 through June 2003 at the 95 percent confidence level. The Spearman test yielded a coefficient of –0.8 for the data from 1997 through June 2003, which is the portion of the graph with the steepest decline since the mid 1980s.

1.3.3. City of Boise – BGL #1, #2, #3, and #4, Injection, Kanta, and Quarry View Park wells

Production, injection, and other data for the City wells were submitted in an Excel® spreadsheet and handwritten data sheets by Kent Johnson. The frequency of the data on the production spreadsheet was approximately once-a-week. The City also records the amount of water discharged to the Boise River on a weekly basis.

The City supplied data for their Injection well in an Excel® file, which included flow, pressure, and temperature data. The data were recorded on an hourly basis. Injection flow, temperatures, and pressures graphs showed regular cycles since mid-1999. The injection rates and operating pressures had longer durations of high values in the first half of 2003 than in the previous two years (Figure 4). The injection temperatures in late May, 2003 were unusually high.

The City's total production as calculated from the BGL #2 and #4 wells was about 104 million gallons for the first half of 2003, which was nearly identical to the amount during this time interval in 2002. About 90.5 million gallons (87 percent) were re-injected.

Wellhead pressure and water temperature data were submitted for the BGL #1 well in an Excel® file. Data are recorded six times a day by a computerized data recorder. Water pressure dropped about five pounds from late September, 2002, to late February, 2003 (Figure 5).

Manually-recorded shut-in pressures for the BGL #1, #2, and #4, and water levels for the BGL #3 were submitted in hardcopy. Slightly less than one year of data is available for these four wells (Figure 5). According to Table 2 of Exhibit 1 of the Order signed in July, 2002, the City is to collect weekly data at the BGL #2, #3, and #4 wells during the time periods from February 1 through March 14, and from September 1 through October 12. This would equate to 18 readings total for the three wells during each of these two time periods. However, only six readings were taken during the February-March six week time period (four in the #2, one in the #3, and one in the #4)

[1]The average value for each month was calculated (For example, the January values for 1991 through 2003 had an average of 154.84 degrees Fahrenheit). Adjusted monthly values were calculated by subtracting the average monthly value from the individual monthly values (For example, the January average of 154.84 was subtracted from the January, 1991, average of 155.0 degrees Fahrenheit, and so forth for all of the January readings). An overall average for all of the data was calculated and added to each adjusted monthly value

[2]Correlation coefficients range from – 1 to 1 with zero indicating no trend between the two variables.

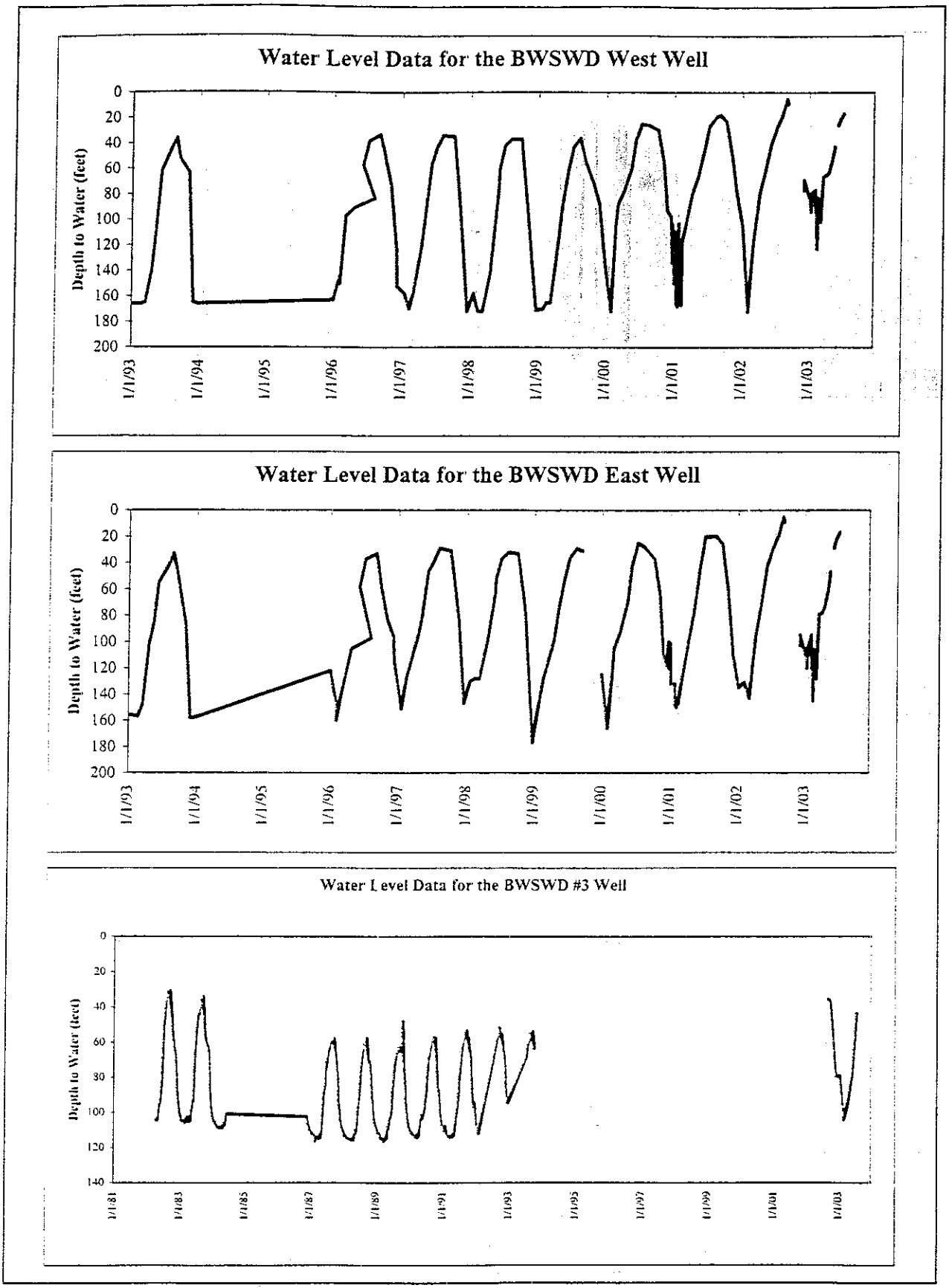



**Figure 2.** Water levels in the BWSWD East, West, and #3 wells

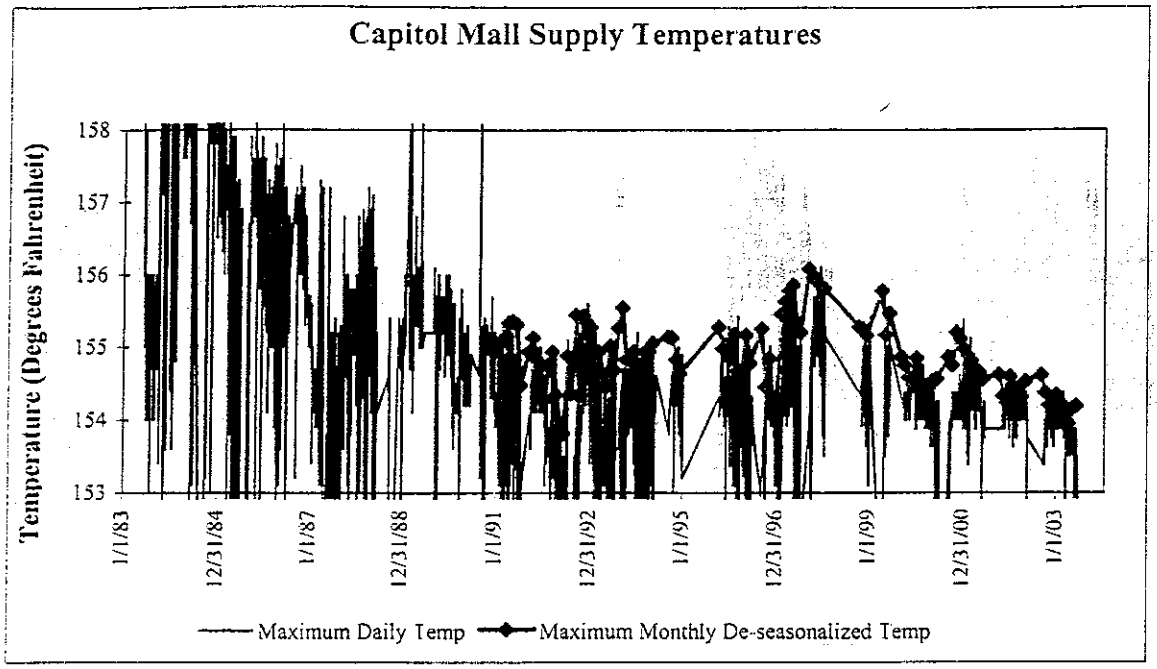



**Figure 3.** Water supply temperatures for the Capitol Mall system.

Monitoring data for the Kanta well after March 17 were discarded because of an equipment problem. Water levels at the Quarry View well were submitted in hardcopy. Data were recorded monthly during the first half of 2003. The maximum water level, which occurred in April, 2003, was 1.07 feet higher than the maximum peak in April 2002.

1.3.4. Veterans Administration (Production, Injection and Test Injection)

Monitoring data for Veterans Administration were submitted on monthly hand-recorded log sheets for the production and injection wells by Larry Post. The data include totalizer readings, discharges, supply and return temperatures, water levels, pump information and injection line pressures. According the Table 4 of Exhibit 1 of the Signed Order, the VA is requested to submit weekly data for two six-week time periods in the year, and specific data for the injection and test injection well, in addition to the production well data. Water level/pressure data for the test injection well, flow rates for the injection well, and the February data sheet for the production well were not received by IDWR. There was only one entry in the March 1- 14 time period for the production well.

Water levels were graphed when the pump was on "low" speed. The data for 2002 and 2003 appear to be questionable because a manual measurement in the summer of 2002 was about 80 feet higher than the low speed pumping water levels (Figure 6).

1.3.5. Old Penitentiary Well

Water level data for the Old Penitentiary well were submitted by Sharon Murray (Idaho Department of Lands, in a Word® file. Water levels are collected on a monthly basis. Water levels fluctuated less than 1.5 feet in the first half of 2003 (Figure 7).

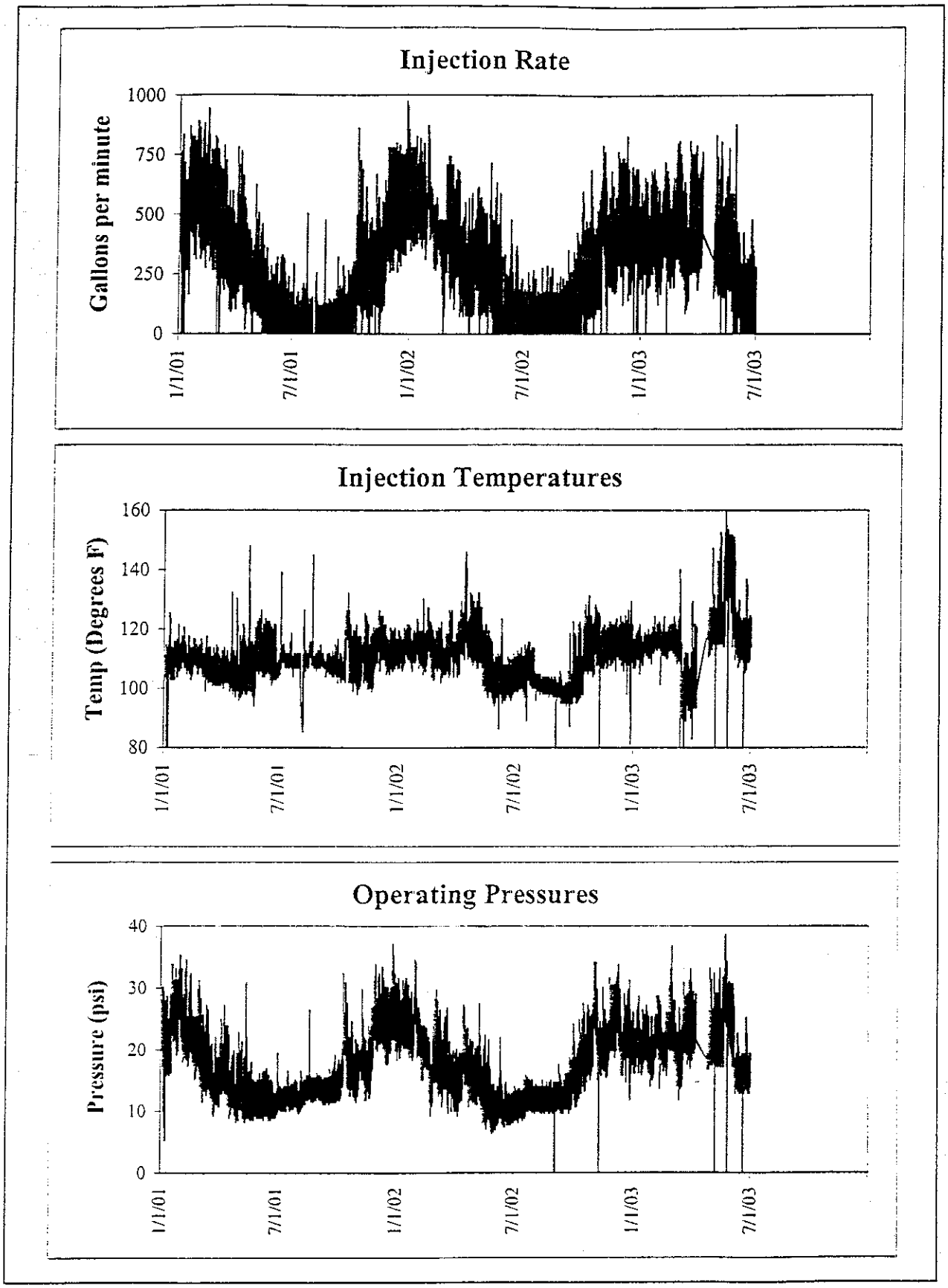



**Figure 4.** Monitoring data for the City of Boise's injection well.

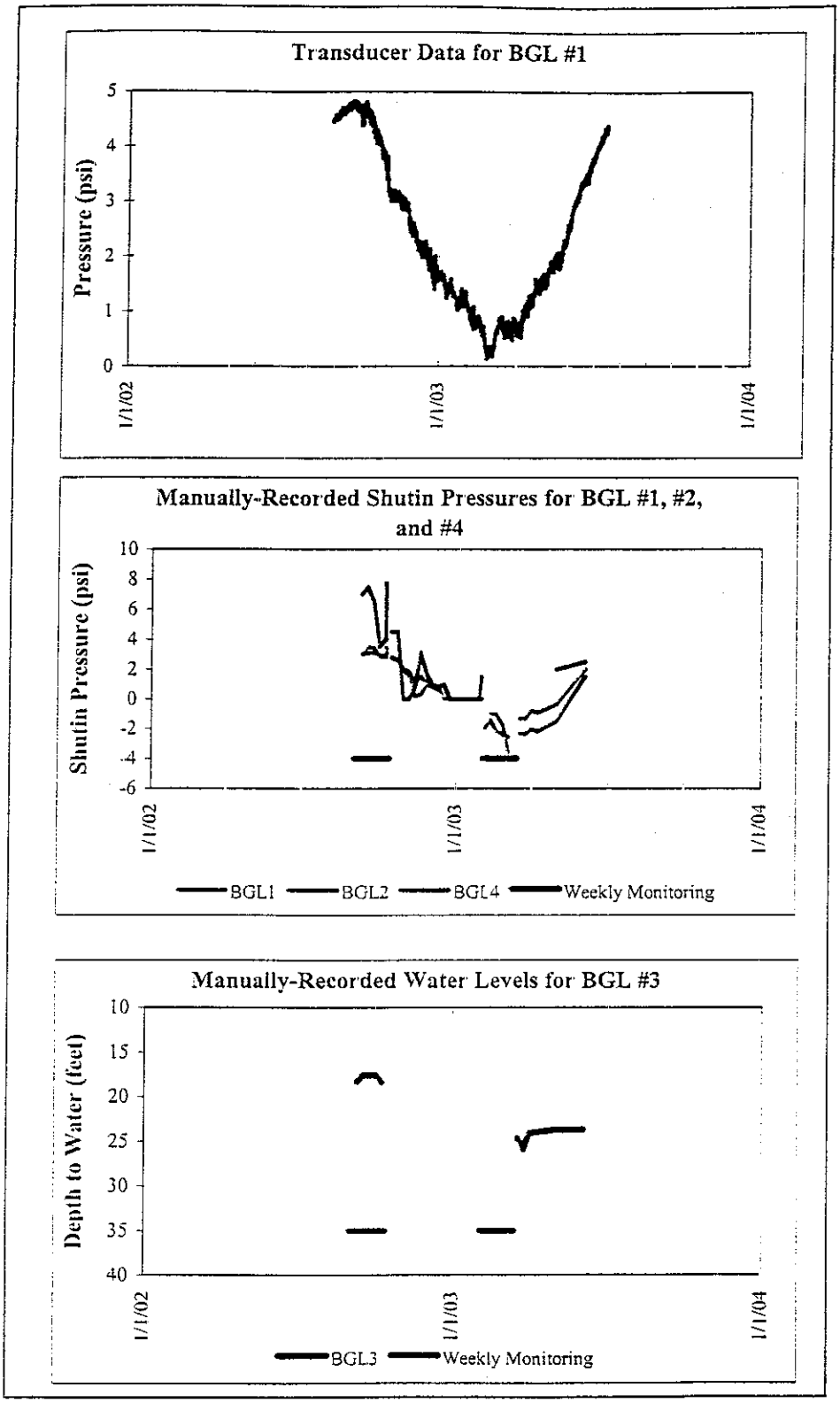



**Figure 5.** Monitoring data for the City of Boise's BGL #1, #2, #3, and #4.

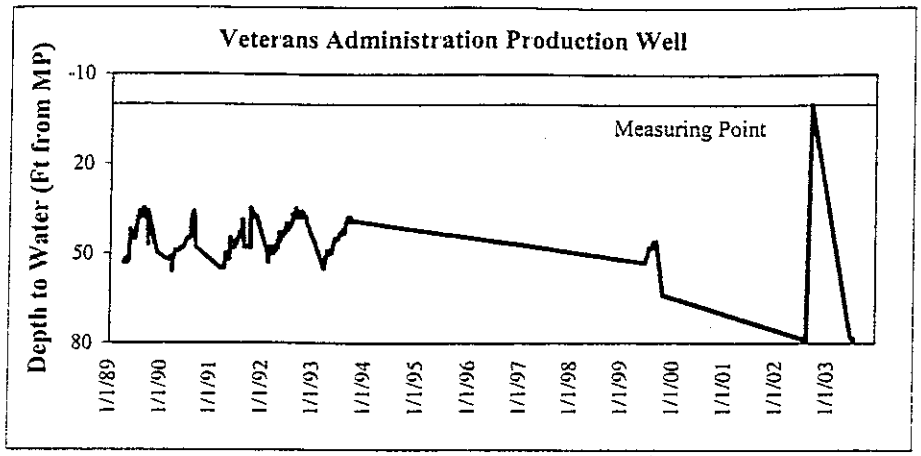



**Figure 6.** Water levels in the VA Production well when the pump was on the low setting (The highest reading was taken during the mass measurement in August, 2002).

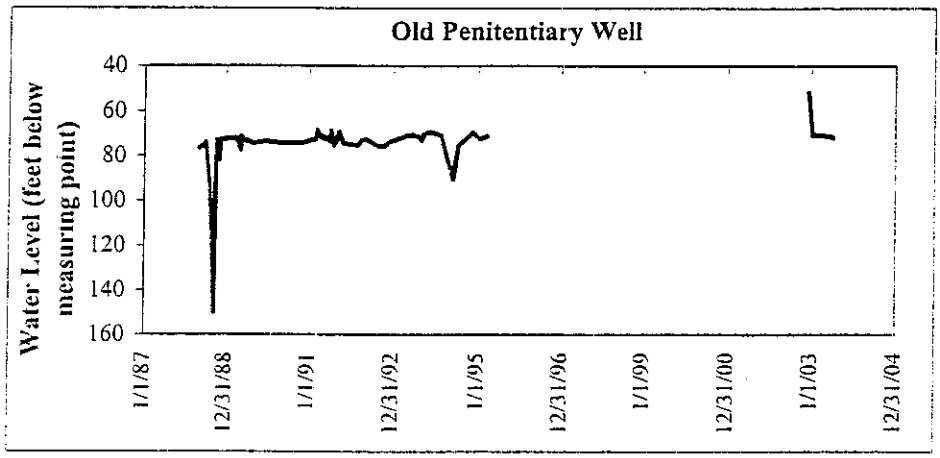



**Figure 7.** Water levels in the Old Penitentiary well.

1.3 6. Harris Ranch, West and East Wells

Water level and temperature data for the two Harris Ranch wells were submitted in an Excel® file by Steven Hannula (ERO Resources). Water levels and water temperatures were captured at four-hour intervals by a data logger for the West well. Manual water level measurements were recorded for both the East and West wells on a weekly basis (Figure 8)

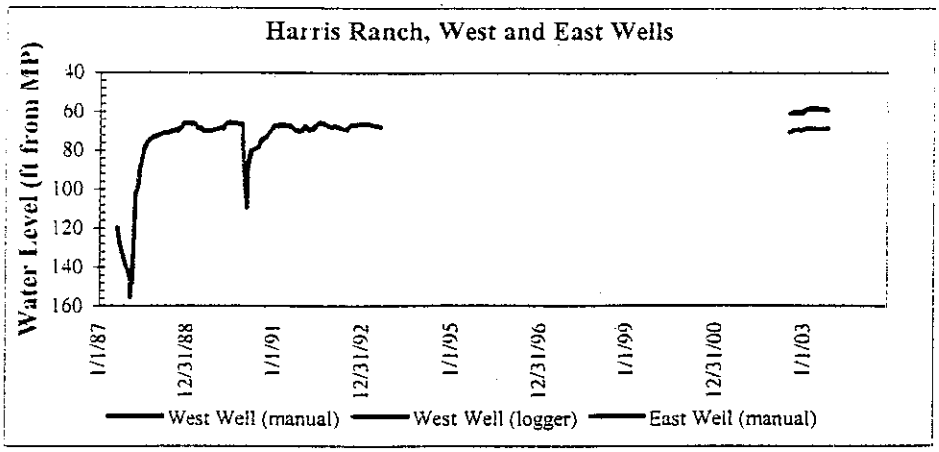



**Figure 8.** Water levels in the Harris Ranch West and East wells.

# 2. STEWART GULCH GROUND WATER DISTRICT 63-S

## 2.1. Production

Table 2 shows production totals for the Stewart Gulch Water District 63-S wells for the first six months of 2003.

**Table 2.** Production from Stewart Gulch Water District 63-S geothermal wells in the first six months of 2003.

| Well | Production (gallons) |
|---|---|
| Flora Company Tiegs (Triangle) | 0 |
| Flora Company Silkey (Shed) | 21,927,916 |
| Flora Company House (Office) | 2,041,427 |
| Edwards Greenhouse | 48,417,000 |
| Terteling Ranch Windsock | 49,129,223 |
| Terteling Ranch Pool | 11,782,209 |
| Terteling Ranch Motorcycle Club | 0 |
| Quail Hollow Upper | 2,508,525 |
| Quail Hollow Lower | 86,325 |
| **Total** | **135,892,625** |

## 2.2. Individual Data Summaries

### 2.2.1. Edwards Greenhouse

Monitoring data for the Edwards Greenhouse were submitted in hardcopy log sheets by Garnette Monnie. Data were collected at approximately once-a-week intervals. Shut-in pressures have declined slightly since the fall of 2001, but are still considerably higher than the readings in the early to mid 1990s (Figure 9). In addition to these data, the Water Master for Ground Water District 63-S began collecting monthly readings in June, 2003.

### 2.2.2. Flora Company Tiegs, Silkey, and House wells

Monitoring data for the Flora Company Tiegs, Silkey, and House wells were submitted in Excel® files by Ed Squires (HydroLogic, Inc.). Shut-in pressure data were recorded manually for all three wells on an approximately once-a-month frequency. Monitoring data were also collected using data loggers on the Tiegs and Silkey wells at a frequency of once every four hours for Tiegs and once every hour for Silkey. Shut-in pressures were slightly lower in the first half of 2003 than in 2002, and also lower than in 2001 for the Tiegs and House wells (Figure 10). In addition to these data, the Water Master for Water District 63-S began collecting monthly readings in June, 2003.

### 2.2.3. Terteling Ranch Windsock, Pool, Motorcycle Club wells

Monitoring data for the Terteling Ranch Windsock, Pool, and Motorcycle Club were submitted in Excel® files by Ed Squires (HydroLogic, Inc.). Manual measurements at the three wells were collected once a month. Data loggers recorded data at a frequency of one reading per hour. Water levels were lower in the Terteling wells from July 2002 to June 2003 than in preceding 12 months (Figure 11). In addition to these data, the

Water Master for Ground Water District 63-S began collecting monthly readings in June, 2003.

### 2.2.4. Quail Hollow

Monitoring data for January through April were submitted for the Quail Hollow Upper and Lower geothermal wells by Dave Hendrickson. Water level and totalizer measurements at the two wells were recorded monthly. In addition to these data, the Water Master for Water District 63-S began collecting monthly readings in June, 2003. Water levels in the first half of 2003 were lower than in 2002, which had usually high water levels for both the Upper and Lower wells, but were higher than the water levels in 2001 (Figure 12).

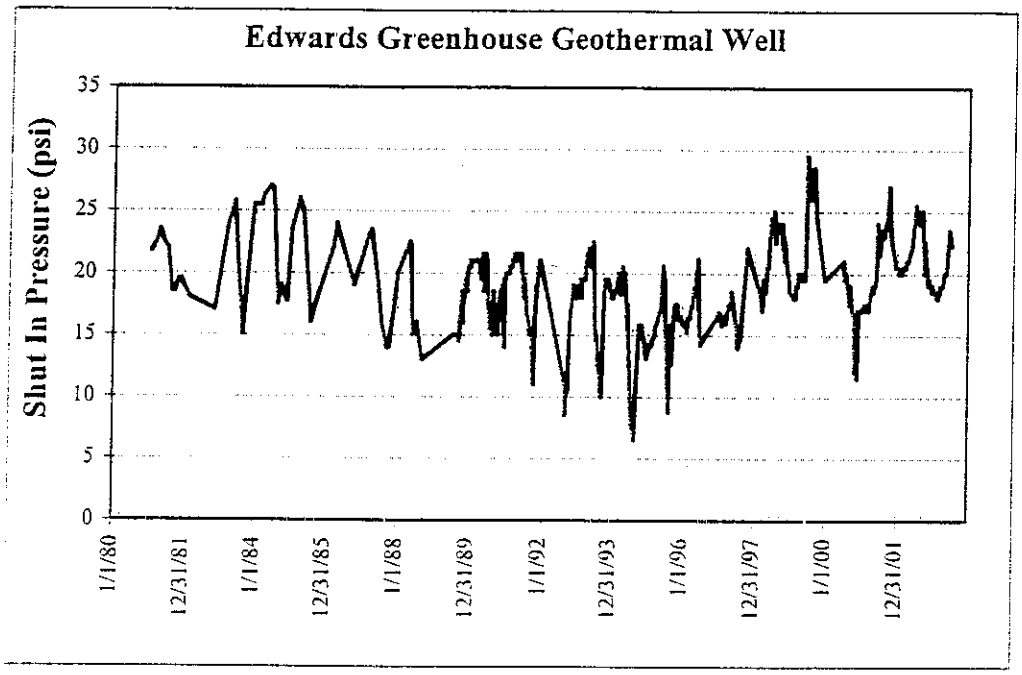



**Figure 9.** Shut-in pressures in the Edwards Greenhouse well.

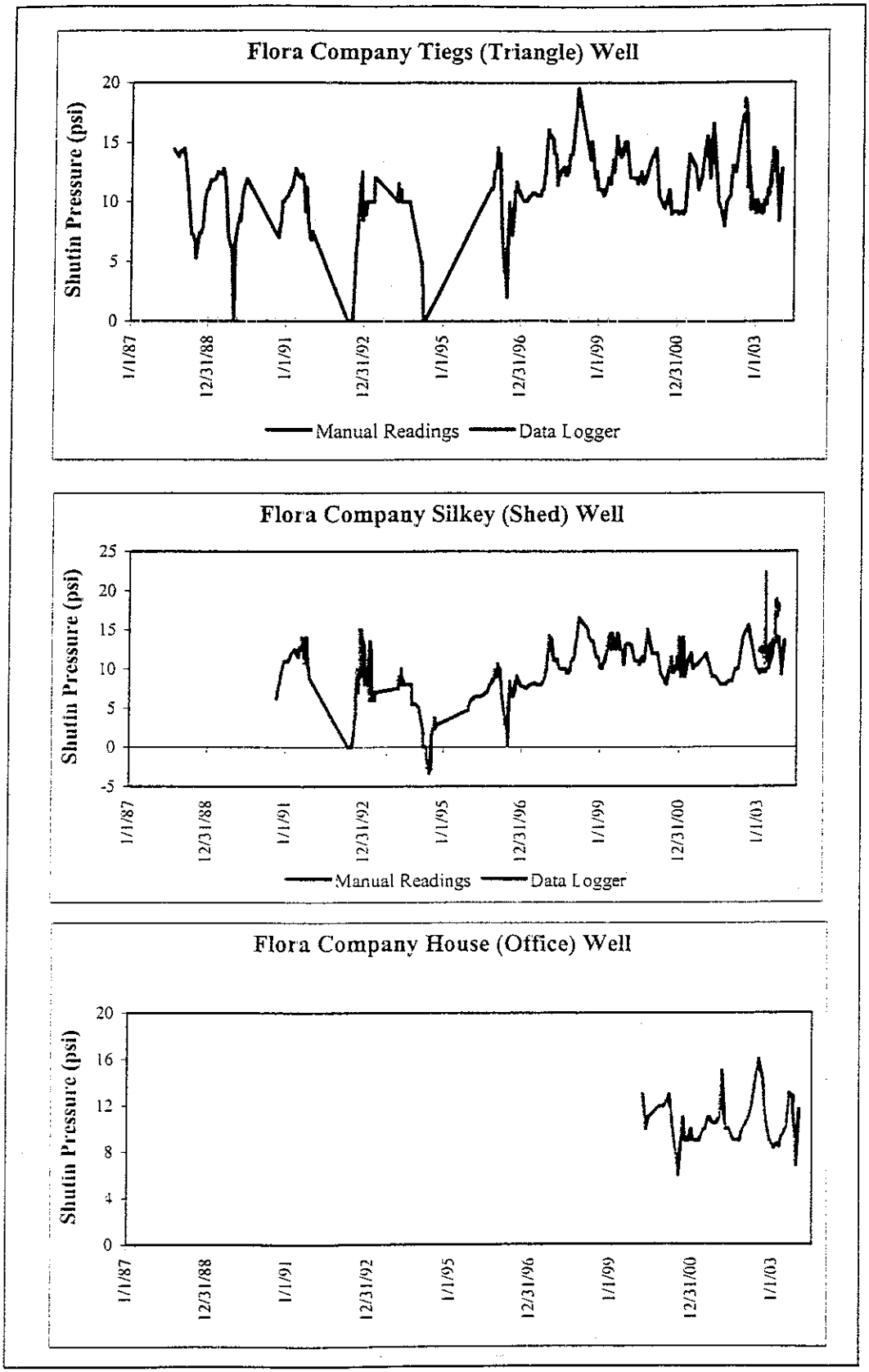



**Figure 10.** Shut-in pressures in the Flora Company Tiegs, Silkey, and House wells.

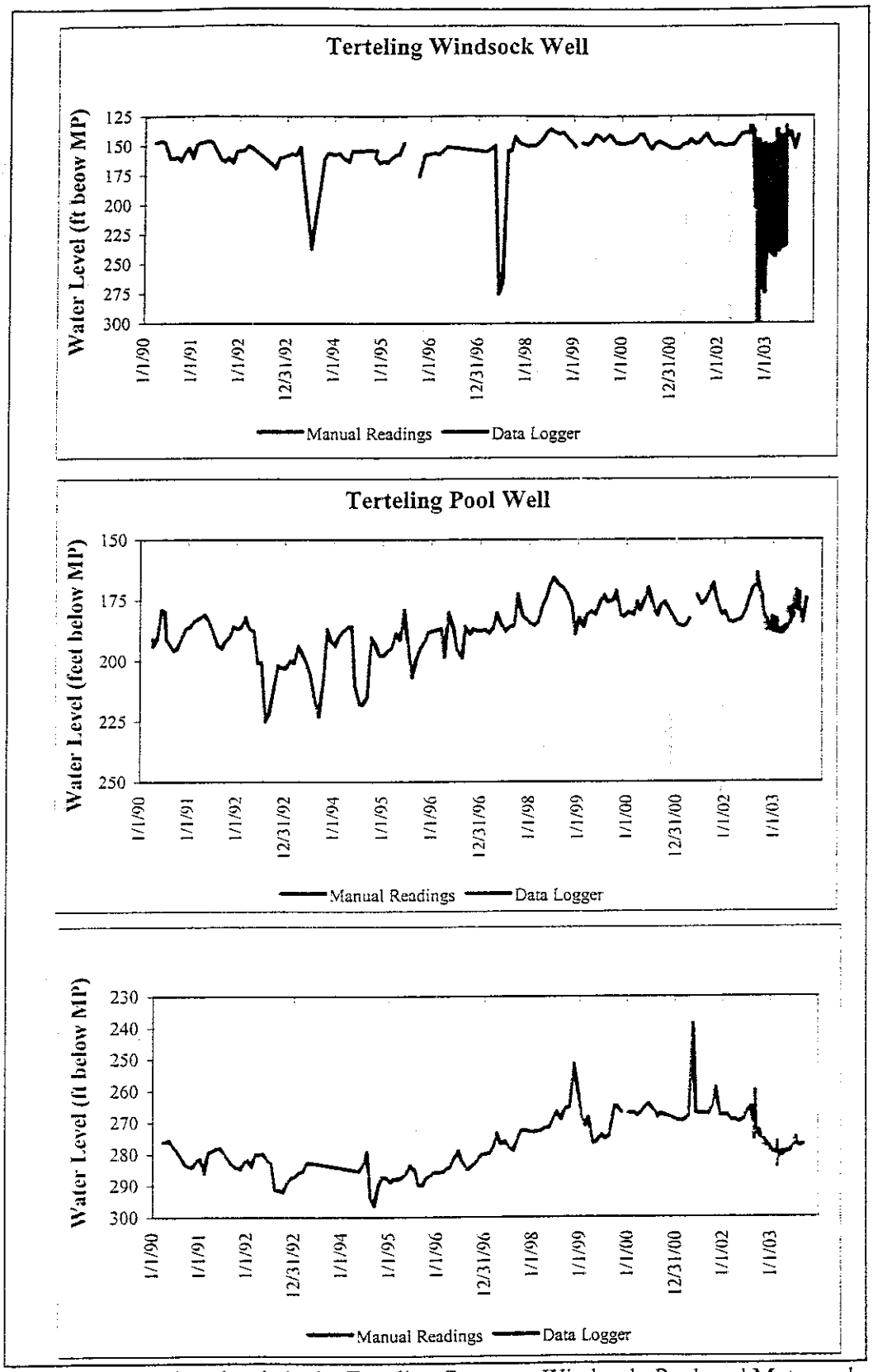



**Figure 11.** Water levels in the Terteling Company Windsock, Pool, and Motorcycle Club geothermal wells.

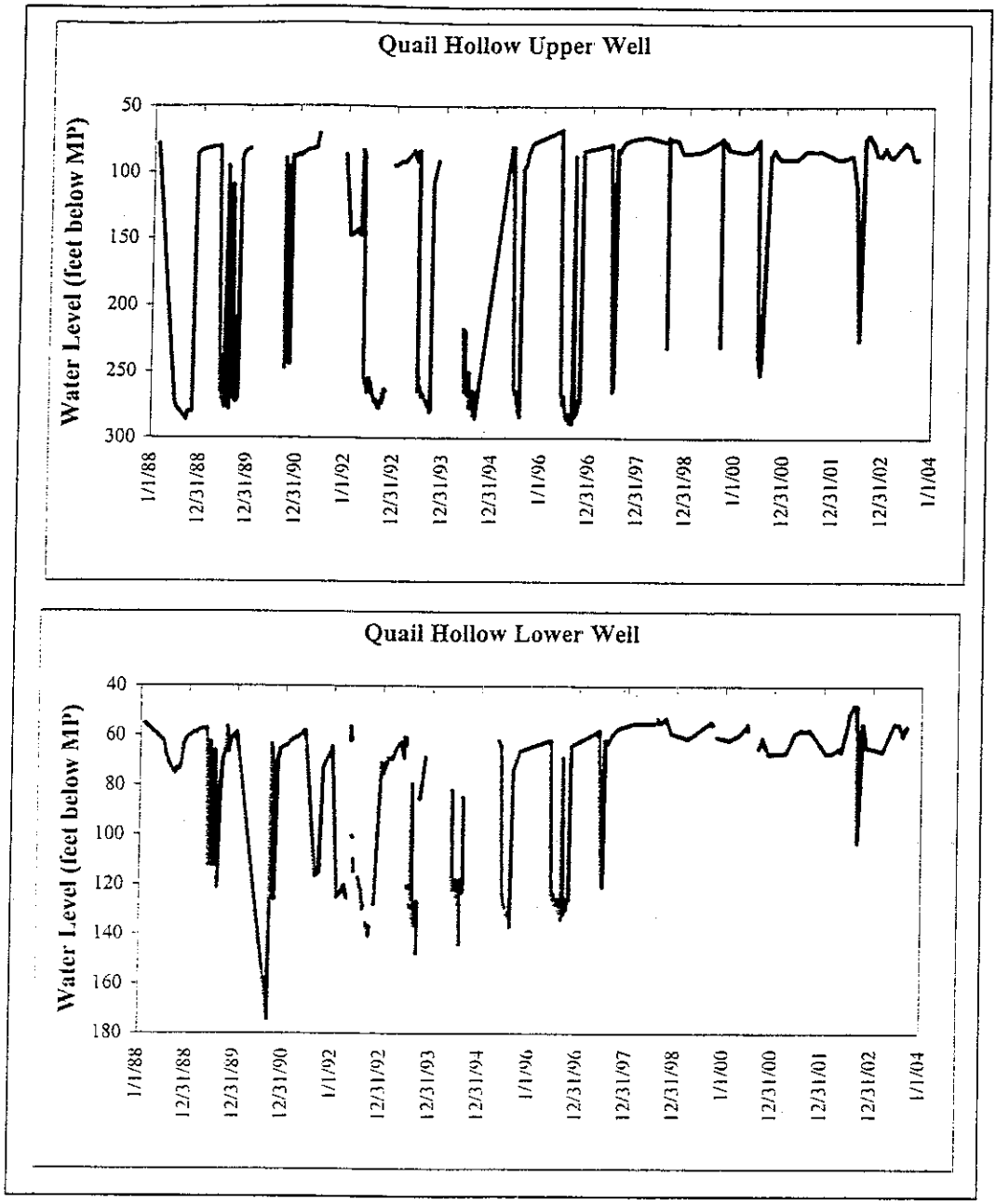



**Figure 12.** Water levels in the Quail Hollow Lower and Upper geothermal wells.

# 3. RECOMMENDATIONS

Monitoring requirements for the geothermal users in the Boise Front system are complex. Users find themselves needing to adhere to one or more of the following legal proceedings:

1. Boise Front Low Temperature Geothermal Resources Ground Water Management Area (GWMA) (June, 1987).
2. Orders requiring monitoring and record keeping for four of the geothermal users in the Boise Front Low Temperature Geothermal Resources GWMA (July, 1987).
3. Order establishing a moratorium in the Boise Front Low Temperature Geothermal Resources GWMA (June, 1988, with five-year extension orders signed in 1993 and 1998).
4. Order establishing Water District 63-S, Stewart Gulch (December, 1989).
5. Order giving the Water Master of Water District 63-S the authority to administer ground water in the district under the terms of the Silky v. Tiegs decree, and to fill senior water rights if artesian pressure is not sufficient (September 1990).
6. Stipulated Agreement in the matter of petition for order authorizing additional use for the City of Boise (July, 2002).
7. Order accepting settlement in the matter of petition for order authorizing additional use for the City of Boise (September, 2002).

Numbers 2, 4, and 6 contain language regarding geothermal monitoring.

- In Number 2, the Boise Warm Springs Water District, City of Boise, State of Idaho Capitol Mall, and Veterans Administration were required to collect: 1) continuous withdrawal rate and withdrawal amounts, 2) continuous casing pressure and/or drawdown measurements on production and injection wells, and 3) temperatures of withdrawn and injected fluids on a daily basis.

- In Number 4, the owners of wells in Water District 63-S were required to "install flow measuring devices and the rate of flow and volume of pressure measuring equipment acceptable to the Department for the measurement of the rate of flow and volume of water diverted from the respective wells". There was no language in the Order regarding the reporting of the data to IDWR.

- In Number 6, each party to the agreement is to "comply with the Monitoring and Reporting Plan attached hereto as Exhibit 1 . . ." Parties to the agreement include: Perkins Coie LLP (representing the City of Boise), Moore Smith Buxton & Turke Chartered (representing the Boise Warm Springs Water District), Hofstetter Law Office (representing the Edwards Family LLC), State of Idaho Department of Administration, State of Idaho Department of Lands, and Ringert Clark (representing the Terteling Company, Inc.). Tables 1-3 provide the details for monitoring the wells owned by the above parties. Table 4 lists Non-Party wells which includes the following owners: USGS, VA, Quail Hollow, and Harris Ranch.

Based on my interpretations of the orders, the following recommendations are made for the collection and reporting of monitoring data:

1. **Boise Warm Springs Water District.**
    a. Data are being recorded on a daily basis on log sheets. Data loggers would allow data to be collected in a more "continuous" fashion as required by the order of 1987.
    b. Check the East Well Signet and Sparling flowmeters for accuracy.
    c. Was West Well Signet checked for accuracy when it was installed in 2002? If not, can it be checked?
    d. It would be helpful to have the daily data entered into a spreadsheet and submitted electronically. The entries that I would like to have included in a spreadsheet are: Date, Time, Water Level, Rate, Totalizer Reading, and Temperature. IDWR could provide a spreadsheet template.
2. **Capitol Mall System.**
    a. Check the temperature sensor that measures supply temperatures for accuracy.
3. **City of Boise.**
    a. Re-establish data logger monitoring at the Kanta well.
    b. Collect monitoring data weekly at the BGL #2, #3, and #4 during the two time intervals designated in Table 2 of Exhibit 1.
    c. Check temperature sensor that measures return temperature at the injection well for accuracy.
4. **Veterans Administration** (Non-Party).
    a. Data are being recorded on an average of about 10 readings per month on log sheets. Data loggers would allow more "continuous" collection of monitoring data as required by the order of 1987.
    b. Determine if the air line on the production well is working properly for collecting water level data. Perhaps the well can be shut down for a short time, and static water levels can be taken by using a steel tape and an electric tape, and with the airline procedure that is currently used.
    c. Collect water levels in the injection and test injection wells on a weekly basis
    d. It would be helpful to have the log sheet data entered into a spreadsheet and submitted electronically IDWR could provide a spreadsheet template.
5. **Flora Company.**
    a. Determine the reason that the manual readings and the data logger readings on the Shed well are not in agreement.
6. **Edwards Greenhouse**
    a. Can the daily log data be entered into a spreadsheet and submitted electronically? IDWR could provide a spreadsheet template.
7. **Terteling Ranch.**
    a. Record water temperature at the Pool and Windsock wells.
8. **Quail Hollow** (Non-Party).
    a. Since the two wells are "Non-Party" according to Table 4 of Exhibit 1, Mr. Hendrickson believes that Quail Hollow is not required to submit monitoring data. A discussion of the matter with John Homan (attorney at IDWR) and a review of the order for the Ground Water District 63-S monitoring requirements leads me to agree with Mr. Hendrickson's conclusions. As such, all monitoring data (i.e., water levels, instantaneous flows, and totalizer readings) will be collected on a monthly basis by the

Water Master of Water District 63-S, as per the plan adopted by the District. Weekly data collections for the two six-week time periods in Table 4 of Exhibit 1 will not be collected since that frequency is beyond the duties defined for the Water Master of Water District 63-S.

9. According to the Stipulated Agreement of July 2002, IDWR is to visit each well listed in Tables 1-4 of Exhibit 1 annually, with the goal of checking the accuracy of monitoring gages and performing calibrations. The goal is to accomplish this task in October or November, 2003.

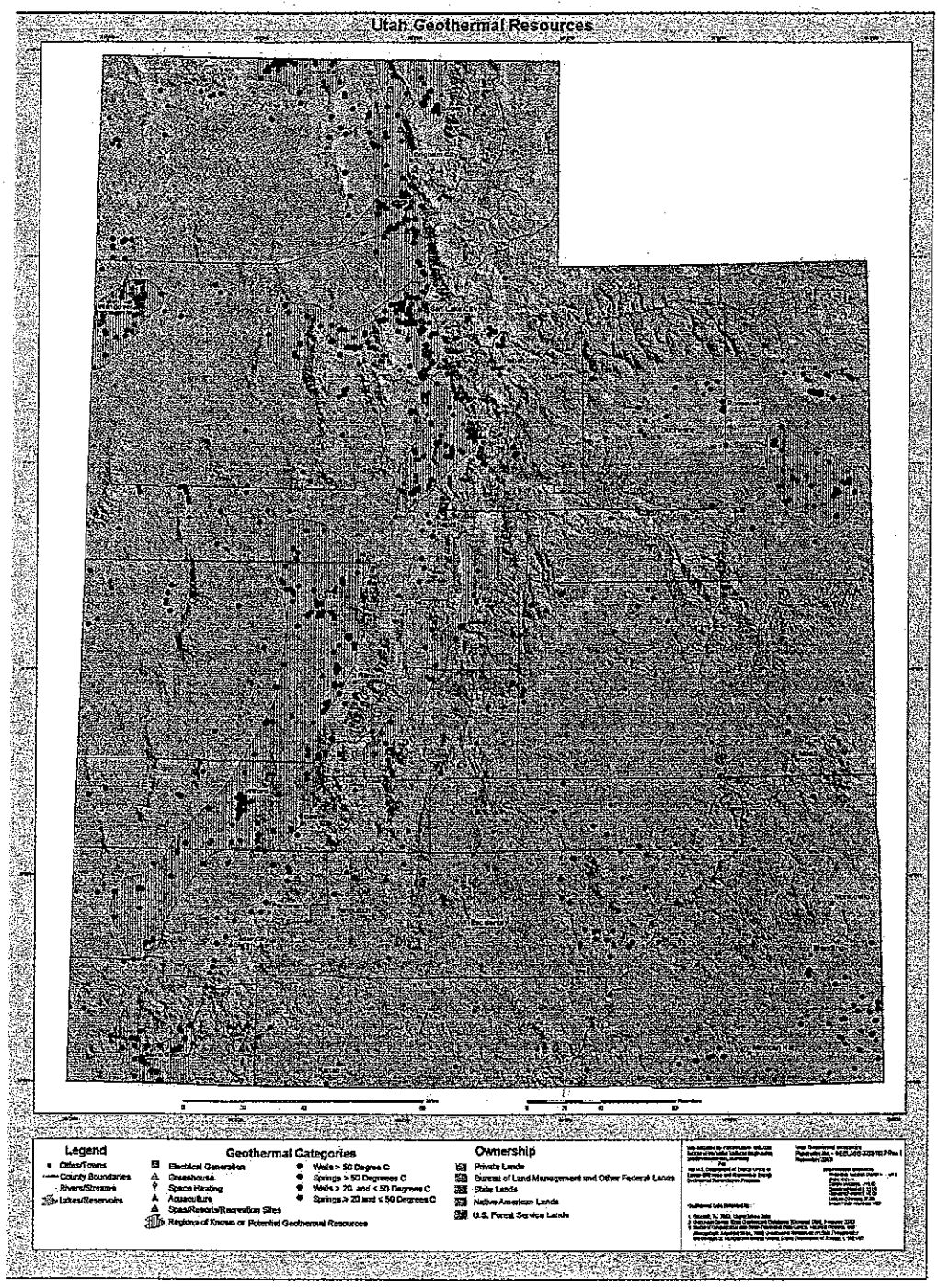
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# UTAH GEOTHERMAL RESOURCES & UTILIZATION

# GEOTHERMAL RESOURCES OF UTAH
# - AN OVERVIEW -

## PHYSIOGRAPHIC REGIONS

Utah comprises parts of three major physiographic provinces (Fenneman, 1931), each with characteristic landforms and geology (Figure 1). These include the Basin and Range Province, the Middle Rocky Mountains Province, and the Colorado Plateau Province. An overlapping of two of these provinces essentially forms a fourth distinctive physiographic region. The Basin and Range-Colorado Plateau Transition Zone extends through central and southwestern Utah, and contains physiographic and geologic features similar to both the Basin and Range and Colorado Plateau Provinces. The physiographic regions of Utah are also shown in Figure 2.

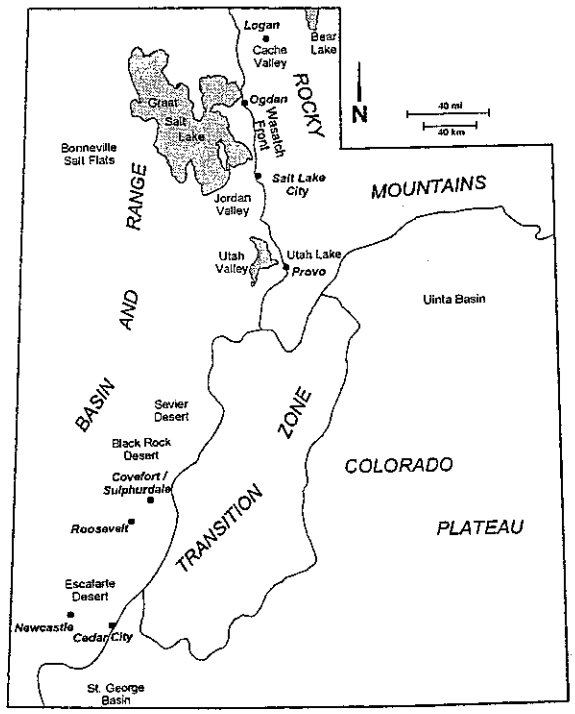



*Figure 1.* ***Physiographic provinces of Utah (Utah Geological Survey, Open File Report 311, 1994).***

The Middle Rocky Mountains Province in northeastern Utah consists of mountainous terrain, stream valleys, and alluvial basins. It includes the north-south trending Wasatch Range, comprising mainly pre-Cenozoic sedimentary and Cenozoic silicic plutonic rocks, and the east-west trending Uinta Mountains, comprising mainly Precambrian sedimentary and metamorphic rocks.

The Colorado Plateau is a broad area of regional uplift in southeastern and south-central Utah characterized by essentially flat-lying, Mesozoic and Paleozoic sedimentary rocks. Scattered Tertiary and Quaternary volcanic rocks are present on the western margin of the Colorado Plateau in south-central Utah, and some Tertiary intrusive bodies are present in southeastern Utah. Plateaus, buttes, mesas, and deeply incised canyons exposing flat-lying or gently warped strata distinguish the Colorado Plateau of southeastern Utah. Bedrock units are spectacularly exposed, while surficial deposits are sparse.

The Basin and Range Province is noted for numerous north-south oriented, fault-tilted mountain ranges separated by intervening, broad, sediment filled basins. The mountain ranges are typically 20 to 50 km (12 to 31 mi) apart, 45 to 80 km (28 to 50 mi) long and are bounded on one, or sometimes two sides by high-angle, often listric, normal faults. Typical ranges are asymmetric in cross section, having a steep slope on one side and a gentle slope on the other. The steep slope reflects an erosion-modified fault scarp and the range is a tilted fault block (Hintze, 1988). Rocks within the Basin and Range vary widely in age and composition. Older rocks consist mostly of a variety of Mesozoic and Paleozoic sedimentary units and their metamorphic equivalents. Proterozoic-age rocks have limited exposures in the region. Cenozoic volcanic rocks and valley-fill units generally overlie the sedimentary and metamorphic rocks. Valley-fill deposits consist mostly of late Cenozoic lakebeds and alluvium as much as 3,000 m (10,000 ft) thick.

The Transition Zone is a broad region in central Utah containing structural and stratigraphic characteristics of both the Basin and Range Province to the west and the Colorado Plateau Province to the east. The boundaries of the Zone are the subject of some disagreement, resulting in various interpretations using different criteria (Stokes, 1988). Essentially, extensional tectonics of the Basin and Range has been superimposed upon the adjacent coeval uplifted blocks of the Colorado Plateau and Middle Rocky Mountains. The result is that block faulting, the principal feature of the Basin and Range, extends tens of kilometers into the adjacent provinces forming a 100-km- (62-mi-) wide zone of transitional tectonics, structure, and physiography (Hecker, 1993; Black, et al., 2003).

## LATE CENOZOIC TECTONICS IN UTAH

Comprising essentially the western half of Utah, the Basin and Range Province is separated from the Middle Rocky Mountains by the Wasatch Fault Zone in northern Utah, and from the Colorado Plateau by the Transition Zone in central and southern Utah (Figure 2). Within the Basin and Range and the Transition Zone, east-west structural extension is thought to have taken place over the past 17 million years (Hintze, 1988) creating numerous north-south-oriented, fault-bounded blocks. Prior to Basin and Range extension (during

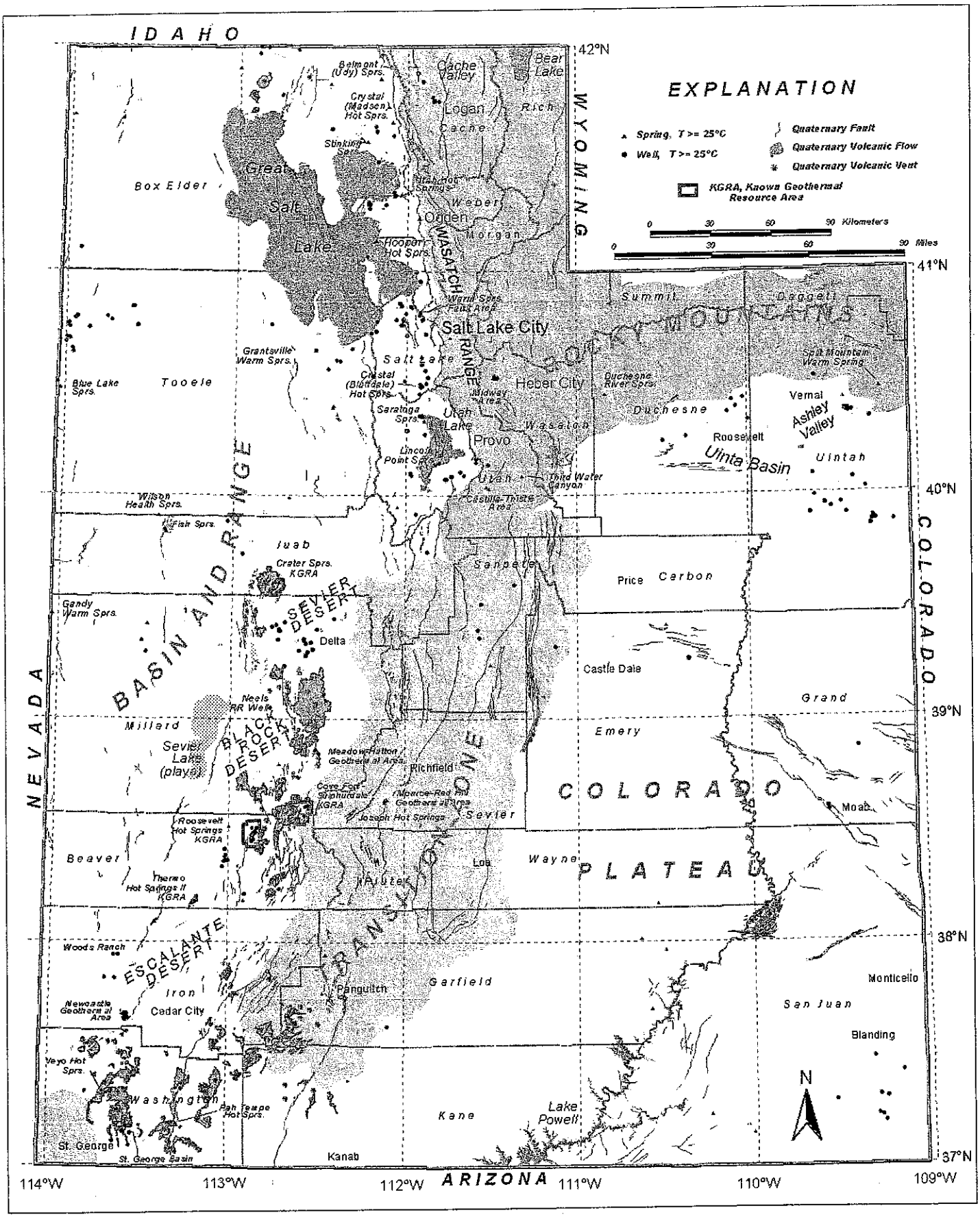



*Figure 2.* *Geothermal resources of Utah showing thermal wells and springs. Quaternary tectonic and volcanic features, and major physiographic regions.*

mid-Cenozoic time), voluminous silicic volcanism with associated hydrothermal activity took place within several east-west trending belts (Stewart, et al., 1977) Patterns of volcanism changed during the latter stages of the Basin and Range development to less-voluminous basalt and rhyolite (bimodal assemblage), spatially controlled by north-south Basin and Range faults

**Quaternary Faults**

Tectonically active regions typically have abundant active geothermal systems as fault movement fractures bedrock, thereby opening potential fluid pathways. In areas of active tectonism, meteoric water has more opportunity to circulate deep and absorb thermal energy from the surrounding rocks. Hecker (1993) presents a detailed review of the Quaternary tectonic activity in Utah and describes the potential for earthquake-related hazards in the state. Utah is in a tectonically active region where the Intermountain Seismic Belt (ISB), a north-trending zone of historical seismicity, bisects the state. The ISB coincides with the broad transitional eastern margin (including the Transition Zone) of the Basin and Range Province, extending from southern Nevada, through Utah, southeastern Idaho, western Wyoming, and into central Montana. It includes the major active faults of Utah, such as the Wasatch fault system in northern Utah, and the Hurricane and Sevier faults in southern Utah and northern Arizona (Figure 2).

**Quaternary Volcanic Rocks**

Recent igneous activity may provide local, high-level, heat sources for geothermal systems. As a result, the distribution and timing of volcanic events is important for assessing the geothermal potential of a region. Hecker (1993) summarizes previous work (Best,et al., 1980; Hoover, 1974; Clark, 1977; Lipman, et al., 1978; Nash, 1986; Anderson, 1988; and Anderson and Christenson, 1989) to describe the distribution and timing of Quaternary volcanic rocks in Utah.

Clusters of young volcanic rocks (generally less than 2 Ma) extend from northwestern Arizona through southwestern and west-central Utah. These units consist of a bimodal assemblage of mainly basaltic rocks and less voluminous rhyolitic rocks. In southwestern Utah, several clusters of mostly basaltic rocks are oriented northeast-southwest, subparallel to the Basin and Range-Transition Zone margin. This package of volcanic rocks consists of series of basaltic flows and vents that do not seem to coincide with mapped faults. Rather, some vents lie adjacent to major faults, such as the Hurricane and Sevier faults, localized on the footwall or hanging-wall block, but not appearing to have used the fault as a conduit for magma Cinder cones and mounds, which generally form alignments parallel to the faults, appear to have formed along steep joints.

In west-central Utah, another cluster of young basaltic rocks, with lesser quantities of rhyolite form a narrow belt generally aligned with the eastern margin of the Basin and Range. This volcanic assemblage formed in an intra-graben area between the Pavant and Tushar Mountains on the east, and the Mineral and Cricket Mountains to the west. The region is referred to as (from south to north) the northern part of the Escalante Desert, the Black Rock Desert, and the southern part of the Sevier Desert. Volcanism here appears to have been concurrent with east-west extension across numerous, small-scale intra-basin faults. Vents and cinder cones mostly lie along high-angle normal faults, suggesting that the faults provided the conduits for movement of magma. Basaltic eruptions began in this region about 2 Ma and have continued intermittently since then.

A small volcanic field of Pleistocene age is located just north of Great Salt Lake in the southern Curlew Valley in Box Elder County. Basaltic rocks comprise the field and have been dated between about 0.7 and 1 15 Ma. Although the field is aligned generally parallel to Basin and Range faults, it does not appear to be spatially associated with any mapped Quaternary faults.

## GEOTHERMAL RESOURCES IN UTAH

**Previous Workers**

The earliest implied reference to geothermal systems in Utah is by Gilbert (1890), who described Fumarole Butte and the nearby Crater (Abraham) Hot Springs. Stearns and others (1937) and Waring (1965) summarized data for about 60 known thermal occurrences. Mundorff (1970) prepared a comprehensive report on the thermal springs of Utah that included data on individual springs. Swanberg (1974) made estimates of subsurface temperatures using chemical analyses of water samples and employing geothermometry. Goode (1978) and Rush (1983) both produced summaries of geothermal occurrences in Utah. Various workers from the University of Utah Department of Geology and Geophysics, Utah Geological Survey, Utah Energy Office, and the University of Utah Energy and Geoscience Institute have published details on geothermal systems and geothermal applications in Utah.

Budding and Bugden (1986) compiled a bibliography of this early work up through the mid-1980s. Since then, several authors (Blackett, 1994; Blackett and Moore, 1994; Blackett and Ross, 1992;) have published more recent compilations and research on geothermal systems in Utah. Mabey and Budding (1987, 1994) compiled detailed geological, geochemical, and geophysical information, including previously unpublished data on seven individual systems within the "Sevier thermal area," an area of central and southwestern Utah containing all of Utah's known high-temperature geothermal systems Budding and Sommer (1986) gathered field data and published a study of low-temperature geothermal resources in the St George area of southwestern Utah Wright and others (1990) summarized geothermal resources and developments in Utah up through the 1980s, and discussed how factors such as regional low energy costs resulted in relative low growth of geothermal energy in the state. Blackett and Ross (1992) published the results of geochemical and geophysical studies for geothermal systems within the Escalante Desert of southwestern Utah.

## Geothermal Occurrences in Utah

With few exceptions, the higher temperature geothermal areas in Utah occur either in the Basin and Range Province or within the Transition Zone (Figure 2). In central and western Utah, most thermal areas are located in valleys near the margins of mountain blocks, and are probably controlled by active Basin and Range faults. Other geothermal systems occur in hydrologic discharge zones at the bottoms of valleys. A few thermal areas are situated in mountainous regions.

The most significant known occurrence of geothermal water in eastern Utah is from oil wells of the Ashley Valley oil field, which yield large volumes of nearly fresh water at temperatures between 43°C and 55°C (109°F and 131°F) as a byproduct of oil production. In 1981, the Ashley Valley field yielded 5.42 million $m^3$ (26.1 million barrels) of water (Goode, 1985).

Using geothermometry and other information, Rush (1983) suggested that six areas in Utah are probably high-temperature geothermal systems with reservoir temperatures above 150°C (302°F). He also suggested that ten other areas could be classified as moderate-temperature geothermal systems with reservoir temperatures between 100°C and 150°C (212°F and 302°F). Known high-temperature systems include the Roosevelt Hot Springs and Cove Fort - Sulphurdale Known Geothermal Resource Areas (KGRA). Other potential moderate- to high-temperature systems are Thermo Hot Springs, Joseph Hot Springs, the Newcastle area, and the Monroe-Red Hill area.

## Geothermal Use in Utah

Presently, electric power is generated at the Roosevelt Hot Springs and the Cove Fort - Sulphurdale KGRAs. Commercial greenhouses, that use thermal water for space heating, operate at Newcastle in Iron County, at Crystal Hot Springs near Bluffdale in Salt Lake County, and at Utah Hot Springs near Pleasant View in Weber County. Ten resorts use geothermal water for the heating of swimming pools, small space-heating applications, and therapeutic baths. Three of the newer direct-use geothermal developments consist of commercial SCUBA-diving and aquaculture facilities near Grantsville in Tooele County, near Plymouth in Box Elder County, and at Midway in Wasatch County.

### Power Plants

Utah Power, a PacifiCorp company that merged with Scottish Power in 1999, has operated the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area near Milford in Beaver County since 1984. Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from wells that tap a geothermal resource in fractured, crystalline rock. The resource depths range generally between 640 and 1,830 m (2,100 and 6,000 ft). Resource temperatures are typically between 271 and 316°C (520 and 600°F). Wellhead separators are used to "flash" the geothermal fluid into liquid and vapor phases. The liquid phase, or geothermal brine, is channeled back into the reservoir through gravity-fed injection wells. The vapor phase, or steam fraction, is collected from the production wells and directed into the power plant at temperatures between 177 and 204°C (350 and 400°F) with steam pressure approaching 7.66 kilograms per square centimeter (109 psi). The plant produces 26 $MW_e$ gross (23 $MW_e$ net).

At Sulphurdale in Beaver County in 1985, Mother Earth Industries, in cooperation with the city of Provo, installed a geothermal binary-cycle power system and a steam-turbine generator. In 1990, Provo City and the Utah Municipal Power Agency (UMPA) dedicated the Bonnett geothermal power plant, becoming the third geothermal power unit to go on-line at Sulphurdale to provide electricity for Provo City. The estimated net output capacity from the power units is about 10 $MW_e$. Because hydrogen sulfide ($H_2S$) gas is produced, the plant includes a sulfur abatement system designed to extract up to 1.36 metric tons (1.5 short tons) per day of sulfur. In 2003, Recurrent Resources acquired the Sulphurdale geothermal properties and facilities of Provo City/UMPA. Recurrent has presently shut down the operation and plans to reconstruct the facility, eventually building a 30 to 40 megawatt binary power plant. Production wells primarily tap a shallow, vapor-dominated part of the geothermal system at depths between 335 and 366 m (1,100 and 1,200 ft). A deeper well (~ 730 m [2,400 ft]), however, reportedly taps the liquid-dominated part of the system.

### Commercial Greenhouses

Various research organizations and energy companies became interested in the Newcastle area of Iron County in the 1970s after farmers accidentally discovered a relatively shallow hydrothermal system while drilling a irrigation well. The well had encountered a hot-water aquifer with a maximum temperature of 108°C (226°F) between depths of 75 and 94 m (245 and 310 ft). Subsequent studies by the Utah Geologic Survey (UGS) suggest a model of hot water rising along a range-bounding fault and discharging into an aquifer in unconsolidated Quaternary sediments, forming a broad outflow plume. Temperatures within the outflow plume generally range between 82° and 104°C (180° and 220°F). Several commercial greenhouses, covering about 100,000 $m^2$ (25 acres), use the geothermal fluid from shallow production wells (152 m [~ 500 ft] deep) to produce high-quality flowers, vegetables, and ornamental plants year-round.

Crystal (Bluffdale) Hot Springs is located at the southern end of the Salt Lake Valley where Bluffdale Flower Growers (formerly Utah Roses) operates a geothermal-heated greenhouse complex. The facility covers about 11,700 $m^2$ (2.9 acres), and produces cut roses as its primary product. Hi-Tech Fisheries, Inc. located at the nearby Utah State Prison uses thermal water cascaded from the prison geothermal production well for raising tropical fish commercially. Surface spring temperatures are about 62°C (144°F). Subsurface temperatures of 88°C (190°F) have been reported in one of two 122-m (400-ft) deep production wells. The springs normally issue from valley alluvium into several ponds. When production wells are in operation, the surface springs and ponds reportedly dry up.

Therapeutic Baths, Resorts, and Aquaculture

Bonneville SeaBase is a SCUBA-diving facility developed at Grantsville Warm Springs located about 66 km (40 mi) west of Salt Lake City along Interstate Highway 80 in Tooele County. SeaBase consists of several dive pools fed by warm springs and stocked with tropical marine fish. The facility is associated with Neptune Divers of Salt Lake City, a business devoted to SCUBA diving and related-product sales.

At Belmont (Udy) Hot Springs in northeastern Box Elder County, about 50 hot springs and seeps issue along the Malad River at about 52°C (125°F). In addition to a golf course and camping facilities, the resort has therapeutic hot tubs, a swimming pool, and a SCUBA diving pool. The resort also operated a commercial aquaculture facility, raising lobsters and crayfish for distribution out of the local area, which is now closed.

Crystal (Madsen) Hot Springs Resort, near Honeyville along Interstate Highway15 in Box Elder County, uses cold springs and hot springs at the same facility. The springs are situated along the northern extension of the Wasatch fault, which traverses along the western side of the Wellsville Mountains. A cold spring (11°C [52°F]) is used to help fill a 1.1-million liter (300,000-gallon) pool, while hot springs 60°C (140°F) fill therapeutic hot tubs, mineral pools, and also flow into the swimming pool. Pool temperatures range from 29° to 44°C (85° to 112°F)

Thermal springs in and around the community of Midway in Wasatch County issue from several widespread, coalescing travertine mounds covering an area of several square kilometers. Temperatures in the springs generally range from 35° to 46°C (95 to 115°F). Thermal water at Midway probably originates from deep circulation of meteoric water from recharge zones located to the north near Park City. The Mountain Spa Resort uses thermal water for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 35°C (95°F) thermal pool inside "the old hot pot," a large travertine mound.

The Monroe-Red Hill Hot Spring area is 16 km (10 mi) south of Richfield in Sevier County. The proprietors have named the resort "Mystic Hot Springs" and offer a geothermal-heated swimming pool, therapeutic baths, camping facilities, and tropical fish ponds. The Monroe and Red Hill Hot Springs issue at about 77°C (170°F) near the surface trace of the Sevier fault adjacent to the Sevier Plateau. The area was the focus of U.S. Department of Energy-sponsored geothermal studies in the late 1970s.

Veyo and Pah Tempe Hot Springs resorts in southwestern Utah offer swimming and therapeutic baths. At Veyo Hot Springs Resort, located southeast of the town of Veyo along the Santa Clara River canyon, spring flows are channeled to a swimming pool at a temperature of about 32°C (89°F). At the Pah Tempe Hot Springs Resort springs flow from a number of vents along the Virgin River at about 42°C (108°F) near where the river crosses the Hurricane fault between the towns of Hurricane and La Verkin. The thermal water is channeled into a swimming pool and therapeutic baths.

## SUMMARY OF GEOTHERMAL ENERGY USES IN UTAH

Two separate electric power plants using geothermal energy have been installed in the southern part of the state, at Cove Fort/Sulphurdale (Bonnett) and near Roosevelt (Blundell) (Table 1). The Bonnett plant is presently shut down and probably will be replaced with a 30-to 40-MWe plant. These two plants are described in more detail in subsequent articles in this issue.

Direct-use is more extensive in the state, where geothermal energy is used at 21 sites located along the entire central arc of geothermal resources in the state (Figure 2)(Table 2). Greenhouse heating is the largest use, followed by swimming pools. Many of the resorts and spas have closed throughout the state as detailed in an article by Susan Lutz in this issue. The direct-use amounts to a savings of about 162,000 barrels of oil (assuming 35% efficiency from electricity), and eliminating 21,700 tons of carbon and 42,000 of carbon dioxide.

## ACKNOWLEDGMENTS

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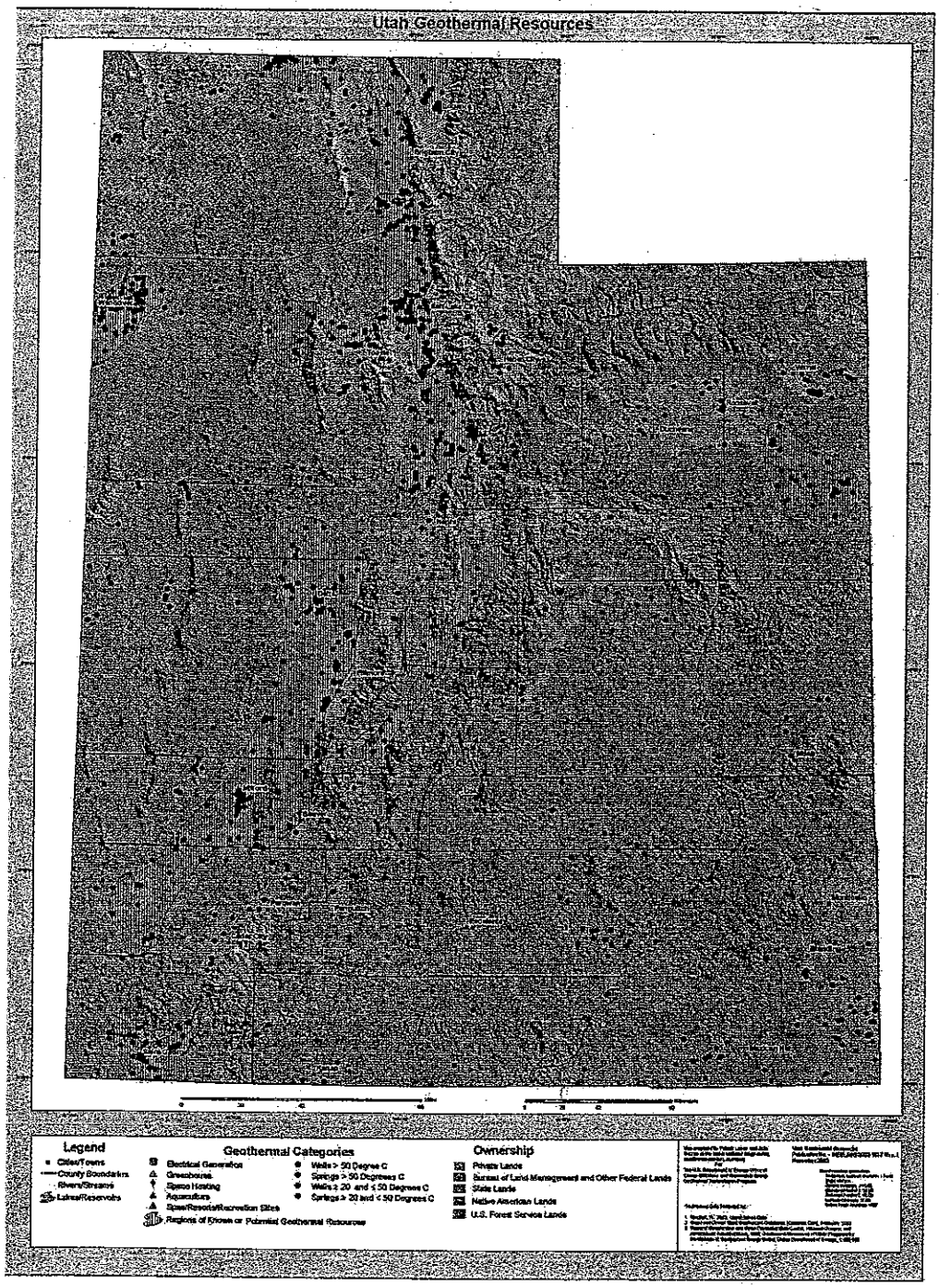
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# UTAH GEOTHERMAL RESOURCES & UTILIZATION

# CRYSTAL HOT SPRINGS - SALT LAKE COUNTY

**Jon Allred**
**Utah Energy Office**
**Salt Lake City, UT**

## INTRODUCTION

For more than 100 years, Crystal Hot Springs has provided geothermal water to a wide variety of community uses. At present, these uses include building heat for dormitories at the Utah State Correctional Facility, a commercial greenhouse next door to the prison and a fish farm nearby. Well known from pioneer times, this collection of geothermal springs and ponds are located 15 miles (24 km) south of Salt Lake City and should not be confused with Madsen's Crystal Hot Springs, another geothermal resource located about 70 miles north in Box Elder County. Unlike Madsen, which is highly saline, the Draper resource produces salts and sulfur mild enough for watering cattle, and meets state standard as a secondary drinking water source. However, dissolved oxygen and other water chemistry still require careful management to prevent pipe corrosion and mineralization. Current regional drought conditions have reduced geothermal flow. Still, with careful management, Crystal Hot Springs can support new commercial uses in addition to those in place.

## GEOTHERMAL RESOURCES

Located adjacent to Interstate 15, Crystal Hot Springs is an artesian geothermal flow that fills a number of ponds and a small lake that scuba divers have measured at more than 50 ft (15 m) deep. In 2003, temperatures were reported at 195°F (91°C) in a 400-ft (122 m-) deep production well, consistent with other reports and investigations done over the years. Occasional well pump testing over the last 30 years consistently reports artesian flow at 600 to 1,000 gallons per minute (38 - 63 L/s). Pumping of geothermal well water causes a corresponding immediate decline in artesian flow. Elsewhere in Salt Lake Valley, groundwater measurements since about 1930 show a steady decline in water table of 15 to 40 ft (5 - 12 m)(Haradan, 2003) The primary cause of this decline is believed to be well pumping, although periods of apparent recharge coincide with high levels of annual precipitation.

Northern Utah is characterized as cold desert, with total annual precipitation seldom exceeding 15 inches (38 cm). Crystal Hot Springs is located at the south end of the Salt Lake Valley at about 4,550 ft (1,387 m) elevation above sea level. As such, winter low temperatures may reach 0°F (-18°C); while, summer high temperatures commonly reach 100°F (38°C) Windy conditions are frequent, because mountains to the east and west form a funnel in whose path the springs lie, and there is little micro terrain or vegetation to block air flow. The area experiences about 270 sunny days per year, although conditions around nearby Traverse Ridge are known for storminess. Atmospheric humidity can descend to as little as 20 percent, relative Soils are typically alkaline

Crystal Hot Springs is within the municipal boundary of Draper City, a 400-square mile (1,037-km$^2$) geographic basin underlain by groundwater in unconsolidated deposits Salt Lake Valley is bounded by the Wasatch Mountains on the east and the Oquirrh Mountains on the west. The Crystal Hot Springs geothermal system rises from the northern base of an east-west ridge known as the Traverse Range (Murphy and Gwynn, 1979). This feature is intermediate in elevation between the Wasatch Range to the east and the valley grabens to the north and south. A series of northeast striking normal faults, with a combined displacement of at least 3,000 feet (914 m) separate the Traverse Range from the Jordan Valley graben to the north. The spring system is located between two closely spaced range-front faults that are intersected by a north-northeast striking fault

The Wasatch Mountain fault system exhibits predominately vertical movement, and represents the longest and most tectonically active geologic structure in Utah, with abundant evidence of surface rupturing events The Wasatch fault is crosscut by numerous underlying, older faults and folds that complicate understanding of geothermal resources found on both slopes of the range The entire region is also part of the Intermountain Seismic Belt and, as such, produces terrestrial heat flow averaging about 107 milliwatts per square meter (mW/m$^2$). In contrast, the adjacent Colorado Plateau region to the east exhibits average terrestrial heat flow of about 57mW/m$^2$.

The geothermal system is fed by mountain rain and snowfall that descend through fractured bedrock before returning to the surface by convection and artesian flow into overlying unconsolidated alluvium (Blackett and Wakefield, 2003) The Crystal Hot Springs resource is considered to be fault-controlled, with geothermal energy rising from normal heat flow of the Basin and Range province, rather than by cooling of igneous rock at depth (Murphy and Gwynn, 1979).

The surface expression of Crystal Hot Springs consists of several springs found within a 70-acre (28-ha) area that lies mostly within state prison property (Murphy and Gwynn, 1979) Some of the springs feed small ponds located at the eastern edge of the geothermal zone, while others are present at the bottom of Crystal Pond, a small lake at the western edge of the geothermal resource.

Chemistry tests in 1979 reveal silica, calcium, magnesium, sodium, and related minerals in concentrations below 230 parts per million (ppm). Chlorine was found to be higher, at 590 ppm. Total dissolved solids (TDS) registered 1,462 ppm in 1979, which is slightly lower than tests done more recently that found TDS at about 1,750 ppm. In contrast, pH was measured at 5.9 in 1979, somewhat more acidic than recent test results that ranged from 6.0 to 6.5. One

test indicated pH at 7.6, total suspended solids (TSS) at 14 mg/L and TDS at 1,810 mg/L (Murphy and Gwynn, 1979). Well pumping tests in 1979 proved steady flow at 650 to 1,000 gpm (41-63 L/s) (Murphy and Gwynn, 1979). Water quality testing done for discharge permit approval indicated levels of arsenic, managanese, radium, potassium, various chlorides and radium slightly higher than found in Jordan River receiving waters. In 2003, a nearby well tested to a maximum flow of 1,100 gpm (69 L/s). However, neither of these tests examined the cone of depression, nor projected rates of recovery. Temperature gradient testing found an elliptical area 200 hundred yards (183 m) wide in which soil temperatures exceeded 190°F. A roughly concentric area 600 yards (550 m) wide tested to at least 90°F (32°C) at a depth of 200 ft (61 m). It is believed, but not verified, that the Crystal Hot Springs resource is a limestone reservoir, resulting in production of $CO_2$ that may supply some corrosive effect in spite of best efforts to keep oxygen and other gases from entering at points in the mechanical system above ground

## GEOTHERMAL USES

Crystal Hot Springs has been commercially exploited since the late 1800s, supporting a brewery, stock watering, log floating, a recreational resort that burned down in the 1920s, beaver raising and a country inn. At present, geothermal water is used for production of fish for commercial sale, greenhouse production of cut flowers, and building heat at the prison. As such, Crystal Hot Springs may be one of the better examples of multiple-use development of geothermal energy in the region.

### Prison Building Heat

In 1983, the Utah Department of Corrections installed a geothermal well and heat exchange equipment to supply space heat to Oquirrh 4, a minimum-security dormitory facility that also included a gymnasium, offices and a cafeteria. That equipment met winter season building heat requirements and year-round hot water needs for Oquirrh 4 until sometime during 1985, when corrosion resulted in severe pitting of stainless steel pipes. Mineral build-up also caused pump shaft failure. Both wells were abandoned in place, along with the original heat exchanger and related equipment. Since then, the discharge permit for one well has expired and its location has been lost to memory. Prison officials and Johnson Controls plan to eventually search for the missing well, determine if it can be rehabilitated, and verify whether or not lapsed water rights and state permits for pumping and discharge can be renewed.

In 2003, the State of Utah Department of Corrections contracted with Johnson Controls, a world-wide energy service company (ESCO) to re-establish a geothermal building heat and culinary water system in two phases. This new geothermal facility is part of a larger contract awarded to Johnson Controls for improved facilities management at the Draper prison, the largest correctional facility in the region. The overall contract improvements for energy, water and waste management services is worth $5.7 million. Energy control measures (ECMs) include the installation of more efficient lighting and motors, use of digital building climate controls and the two-phase geothermal system.

The Johnson Controls performance guarantee calls for annual savings of about $228,000 on energy improvements, and $175,000 in annual savings for improvements in water, sewer and solid waste handling. For performance comparison purposes, base year energy consumption at the prison complex totals 19.5 million kWh and 1.85 million therms (195 kJ) of natural gas for about 1.1 million square feet (102,000 $m^2$) of buildings (Johnson Controls, 2003).

Phase I of the geothermal portion of the project calls for supplying culinary hot water and building heat for the Oquirrh 4 complex. Built in 1987, each of the four units at Oquirrh 4 contains 9,714 square feet (902 $m^2$) of floor area. All units are constructed of hollow concrete masonry, built-up roof and single pane windows. These units were originally heated by ducted forced air coils supplied with steam from a campus distribution system fired by natural gas. That mechanical system is still in place, and can be supplied interchangeably by either campus steam or hot water from the geothermal-plate-and frame heat exchanger (Figure 1).

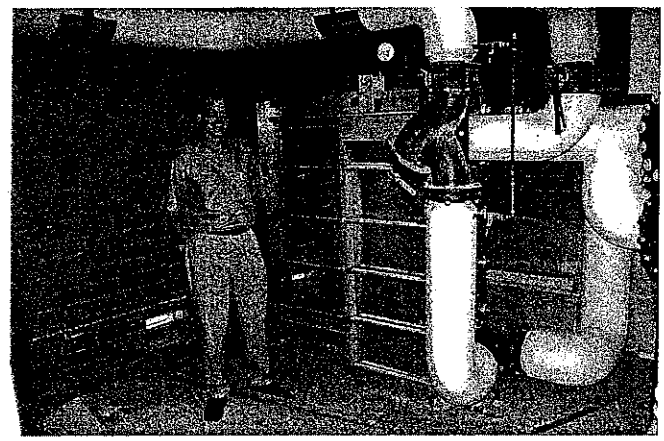


*Figure 1. Plate-and-frame heat exchanger (Bruce Munson, Johnson Controls).*

Phase I geothermal improvements refurbished one of the old geothermal wells, installed a line-shaft constant speed pump on the geothermal side, new heat exchange equipment, and variable speed drive for heat control on the building side (Figure 2). Among other things, the holding tank from the 1983 system was removed as part of effort to prevent air intrusion that is believed to contribute to corrosion and mineral deposition. The constant speed pump installed in Phase I is set at 240 gpm (15 L/s) on maximum capacity of 300 gpm (19 L/s). Entering water temperature is about 185°F (85°C). The system uses the existing coil and fan equipment from the original steam system. A variable-speed drive on the clean side governs the rate of heat exchange, with a 40°F (22°C) drop in geothermal temperature being an efficiency goal. Actual discharge water temperature is about 160°F (71°C). Constant-speed pump pressure is applied to the geothermal side in order to prevent precipitation of minerals that might otherwise occur during periods of slack demand.

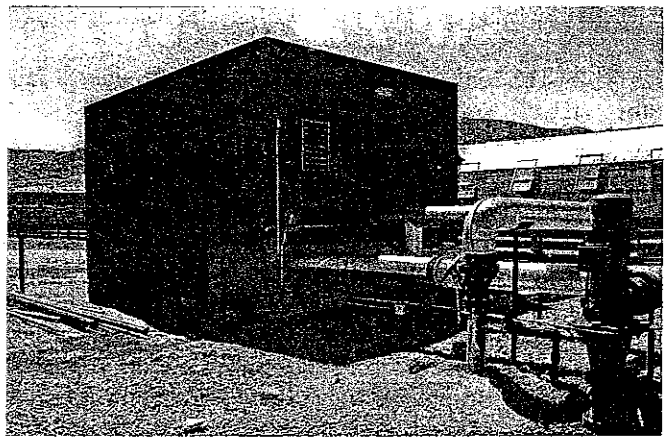


*Figure 2.* ***Heat exchange building with wellhead and pump in foreground.***

Johnson Controls avoided installing probes for flow measurement piping in order to reduce the number of potential places where air intrusion could occur. Instead, a sensor to measure geothermal heat is in place to calculate energy passing through the heat exchanger. Strainers that would normally be in place have also been omitted in order to reduce points of potential corrosion. Piping on the geothermal side is made of fiberglass-reinforced plastic, considered a good general alternative to stainless steel for chemical and temperature conditions at Crystal Hot Springs. The vertical turbine pump is located seven feet (2 m) down a 1,000-ft (305-m) deep well, and is a Bell and Gossett enclosed lineshaft, 12-in. (30-cm) conductor casing to 40 ft (12 m), 4-in. (10-cm) pump column, 6-in. (15-cm) Schedule 40 liner to 1,000 ft (305 m), slotted bull nose entry below pump bowls and impellers.

At the time Johnson evaluated the existing heating system at Oquirrh 4 (Figure 3), the heat recovery system was in poor condition, and variable air volume vanes were fixed in place and inoperable. Meanwhile, to meet air quality needs, 100 percent outside air is still used for both ventilation and winter heating. As such, there is no return air circuit, resulting in substantial heating system inefficiency. Thus, Johnson Controls estimates that use of geothermal heat probably saves more in natural gas for the Oquirrh 4 facility than its proportionate share of square footage served by the overall prison gas-fired steam facility. As is common with large institutional uses, general lack of sub-metering at the correctional facility prevents the accumulation of itemized data on cost savings.

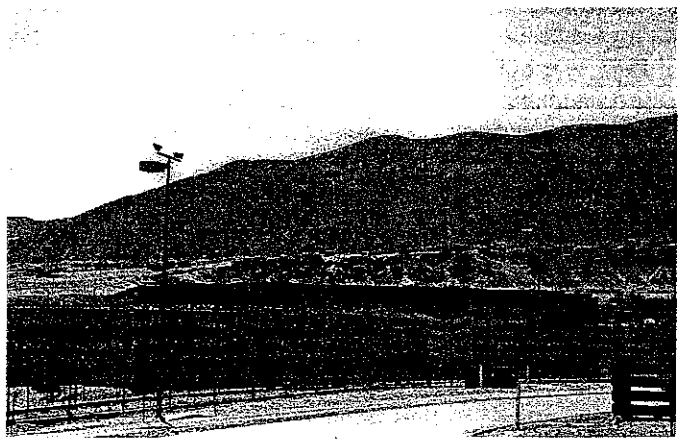


*Figure 3.* ***Oquirrh 4 Complex.***

Thermostatic controls are set higher on the campus steam side to prevent heat from that system entering the Oquirrh 4 loop unless geothermal flow fails. During the first six months of geothermal system operation, natural gas-fired steam has been needed only once, when the geothermal pump failed due to ingestion of well debris left from the 1983 geothermal system. As expected, system controls made a smooth switch to campus steam heat when the geothermal pump failed.

Phase II geothermal development, planned for late 2004, calls for replacement of the fixed speed 10-horsepower (hp) (7 kW) geothermal well pump by a 25-hp (19-kW) variable-speed drive that can potentially deliver up to the full water right of 750 gpm (47 L/s). The practical expectation is for a base load of about 600 gpm (25 L/s). A second heat exchanger will also be added. This larger geothermal flow will continue to supply space heat for the Oquirrh 4 cell block, and will also supply the prison furniture shop, sewing shop, and Special Service Dormitory (SSD). Altogether, geothermal heat will eventually supply space heat and culinary hot water for a total of 252,350 square feet (23,440 $m^2$) of building area.

Under Phase II, geothermal input temperature is expected to reach 185°F (85°C) or higher, dropping to 165°F (74°C) at discharge during warm weather and 135°F (57°C) in winter. A variety of other improvements will be needed to ensure system performance, including fan/coil unit heaters in the prison industry buildings, upgraded insulation and thermostats in individual sections. Phase II improvements will continue to send the usual 200 gpm (13 L/s) discharge flow to prison fish ponds. However, discharge by buried pipe to the cooling pond will rise from about 40 to 400 gpm (2.5 to 25 L/s) or more. After Phase II geothermal improvements are operational, the existing back-up boiler will be considered for retrofit to better fit with the geothermal system.

Phase I of the geothermal performance contract calls for capital expenditures of $519,000 intended to produce guaranteed annual energy savings of $68,944 in deferred natural gas cost. Those savings are tempered by an expected base increase of $1,068 in additional annual electricity charges for pumping geothermal fluid and electronic controls. Geothermal improvements are projected to have a payback period of 7.6 years, and a predicted equipment life of 17 years. In contrast, the overall performance contract has a combined estimated payback period of 15 years. Phase II geothermal improvements are expected to cost a total $1,523,611, and should produce annual natural gas savings of $123,813, offset by an increase in electricity cost of $69,145 for pumping geothermal water. Phase I became operational in January of 2004, providing initial monthly savings of $17,000 in deferred natural gas costs.

**Bluffdale Flowers**

In 1981, Utah Roses established a commercial greenhouse using 450 gpm (28 L/s) of geothermal water

pumped from a 1,000-ft (305-m) deep well on property located immediately adjacent to the prison. That facility was sold and renamed Bluffdale Flowers in 1998. In the interim, some 250,000 sq ft (2.3 ha) of greenhouse space was constructed for raising roses and other ornamental flowers (Figure 4)



*Figure 4. Interior of Bluffdale Flowers greenhouse with finned-tube heating system.*

In 1983, at about the same time the prison was developing its first attempt at geothermal building heat in 1983, Utah Roses used U.S. Department of Energy funding to install a geothermal production well at a commercial greenhouse located in Sandy City, about five miles north of Crystal Hot Springs. Well depth eventually reached 5,000 ft (1,524 m), but produced only about 200 gpm (13 L/s) of water at 120°F (49°C) and was therefore abandoned. Eventually, the entire greenhouse operation in Sandy was also abandoned and operations were consolidated at the Crystal Hot Springs site.

At present, Bluffdale Flowers uses a 40-hp (30-kW) lineshaft pump running at constant speed to supply geothermal water from a well depth of about 200 ft (61 m) (Figure 5). Space heat is provided through plate-and-frame heat exchangers showing an intake temperature of about 190°F (88°C) and discharge temperature of 140°F (60°C) (Figure 6). There is no back-up heat system, and indoor greenhouse temperatures on winter nights may descend to near freezing. A brief experiment with by-passing the heat exchanger caused rapid mineral fouling of capillary piping. Discharge water travels by 8-in. (20-cm) pipe to Crystal pond where it cools to about 80°F (27°C) before traveling about 1,000 ft (305 m) by open ditch to a Hi-Tech Fisheries, a downstream user of geothermal water (described below).

For several years, attempts were made to re-inject spent geothermal water for aquifer recharge. However, artesian effect and slow permeability resulted in surface leakage and pump failure. After deliberation, the State of Utah Division of Water Rights was persuaded to grant a permit for surface discharge of spent fluid. As such, even though greenhouse use of heat-exchanged water is a "non-contact" use of the geothermal resource, surface disposal exposes the fluid to chemical alteration. Geothermal pumping is limited to the cool months of September to May each year during the hours of 4:00 p.m. to 8:00 a.m.



*Figure 5. Lineshaft pump at Bluffdale Flowers (Jack Kaleel).*

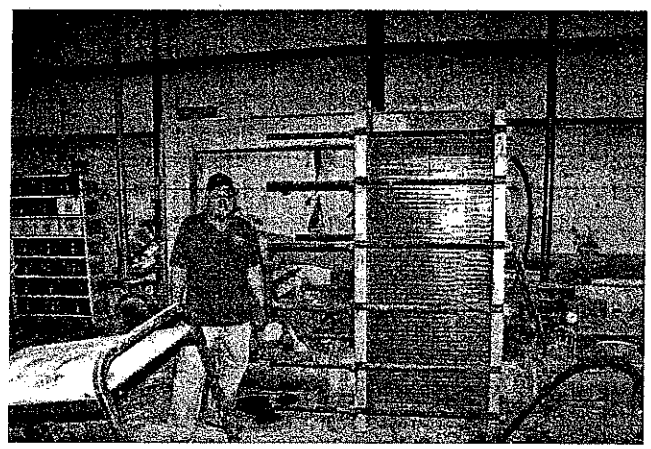


*Figure 6. Plate-and-frame heat exchanger (Stan Goldberg).*

The state-issued discharge permit requires semi-annual water tests for metals, including cadmium, copper, lead, mercury, radium and others. Some concern has been raised regarding tests of discharge water that show TDS at 1,700 ppm, close to the state maximum limit of 2,000 ppm, and pH readings as low as 5.9.

Bluffdale Flowers is in the process of expanding greenhouse space from 250,000 to 500,000 sq ft (2.3-4.6 ha). To provide winter space heat, discharge water at about 140°F(60°C) will be re-heated using natural gas boilers to about 180°F (82°C) and circulated through that additional space before discharging en-route to Hi-Tech Fisheries further downstream.

Water rights total about 1.95 cubic feet per second (55 L/s), which would allow Bluffdale Flowers to augment geothermal flow by running the idled re-injection pump in reverse, resulting in a potential doubling of geothermal flow to about 900 gpm (57 L/s).

Bluffdale Flowers managers note that artesian flow is substantially lower in 2004, compared to recent years, as evidenced by the fact that natural ponds are nearly empty during early summer. Ordinarily, these ponds would actually deepen as summer progresses, due to cessation of greenhouse and prison use of geothermal water during previous cool months. Informal discussion among various parties in the area suggest that persistent regional drought conditions account for a large fraction of diminished geothermal spring flow. More recently, discussion has focused on the possible role of prison geothermal pumping as a cause of spring flow reduction for other geothermal users. These concerns add interest to the widespread belief that water rights have been over-appropriated by the State Engineer. As noted above, regular groundwater monitoring in Salt Lake indicates that wells have caused a steady decline in water table across several decades (Haradan, 2003)

**Other Commercial Geothermal Uses**

In the past, a number of aquaculture operations have used discharge water from either the prison, Bluffdale Flowers or directly from Crystal Pond, the largest of several ponds fed by Crystal Hot Springs. The most successful of these downstream geothermal users is Hi-Tech Fisheries, a 25-year old commercial producer of tropical fish based around Crystal Pond. Hi-Tech is a contract operator on behalf of Utah Corrections Industries, an enterprise of the state prison system. As such, the land, water rights and facilities are largely state-owned. Labor is provided by prison inmates.

Crystal Pond varies widely in size, up to about 3.0 acres (1.2 ha), but currently covers only about 1.0 acre (0.4 ha) in surface area due to persistent regional drought conditions. The pond was once host to a large variety of fish but is presently occupied only by a few hardy species of low-value fish that help control mosquitoes. Hi-Tech Fisheries uses discharge water from Bluffdale Flowers and from the prison geothermal facility to feed Crystal Pond, which is also supplied by artesian springs. Discharge water from Bluffdale Flowers leaves that facility at about 140°F (60°C), and travels through a succession of 8-in. (20-cm) piping, open ditches and intermittent ponds before arriving at Hi-Tech at an acceptable temperature of about 80°F (27°C). Discharge water from the prison geothermal facility travels entirely by pipe to Hi-Tech. Together, this flow moves successively through covered greenhouse space totaling about 4,500 sq ft (418 $m^2$), occupied by some 80 fish propagation tanks that vary in size from 200 to 1,000 gallons (760-3,786 liters) (Figure 7). Many of the fish originate from Africa's Lake Malawi, where water conditions are similar to those produced at Crystal Hot Springs. At times, this facility has also produced a variety of vegetables for commercial sale, including corn, tomatoes, squash and peppers. Propagation of aquarium plants for retail sale was also tried for a time, but proved unsuccessful.

During cold weather, geothermal water may arrive at fish tanks at temperatures as low as 60°F (16°C), only marginally viable for fish propagation. In the past year, Hi-Tech also reports that combined inflow to Crystal Pond is down by about 50 percent from average years, resulting in the pond's lowest water level in 30 years. As a result, Hi-Tech currently re-circulates its own outfall water back into Crystal Pond in order to maintain adequate supply to the fish tanks. Concern has been raised by Hi-Tech that declining water supply may also be due, in part, to recent re-establishment of prison geothermal use, and recommends that consideration be given to circulating additional prison geothermal discharge water through Hi-Tech before final outfall to wetlands or the Jordan River.

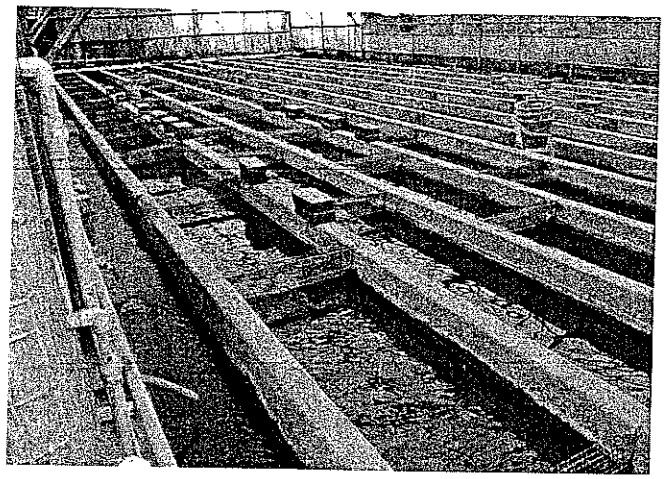


*Figure 7. Fish propagation tanks (Hi-Tech Fisheries).*

At present, about 200 gpm (13 L/s) of geothermal outflow from the prison goes directly to Hi-Tech. The remaining 40 gpm (2.5 L/s) is sent to a cooling pond that is planned for eventually serving new wetland development. About 450 gpm (28 L/s) of geothermal discharge flows toward Hi-Tech from Bluffdale Flowers, although an unknown amount is lost to evaporation and seepage along that path. Hi-Tech does not directly measure the combined total of inflow to Crystal Pond from these various sources. Discharge water from Hi-Tech Fisheries ordinarily travels about 800 ft (244 m) in a ditch to a collector canal running through farm fields before either percolating fully into soil or reaching the Jordan River.

Original plans called for discharge of geothermal water from the prison to percolate into the soil through open ditches, with no significant surface flow off-site. However, the need for mosquito abatement resulted in re-direction of geothermal water through a buried 14-in. (36-cm) concrete pipe running about 1.5 miles (2.4 km) before entering a cooling pond. The pond is designed to overflow into the Jordan River through a culvert running under the Bangerter Highway, reaching the river at a temperature close to ambient

**UDOT Wetland Development**

The Utah Department of Transportation (UDOT) plans to take geothermal discharge water, in combination with other surface flow, to create a new wetland in the area below the lowest pond at Crystal Hot Springs. This end-use of geothermal water helps fulfill UDOT need for wetland creation to offset loss of wetland caused by highway development elsewhere. As such, geothermal water is

expected to reach ambient temperature before entering the river, having dissipated heat through a combination of at least three different beneficial uses and passing through thousands of feet of ditches and piping before disposal.

### Crystal Springs Fisheries

A second aquaculture facility is also using geothermal waters in the area–Crystal Springs Fisheries, located just outside the Correctional Facility. Spring water at 80°F (27°C) feed 12,000 ft$^2$ (1,115 m$^2$) of indoor fiberglass tanks and raceways under three greenhouses covering a little less than an acre (0.4 ha). These consist of 200 tanks at 150 gal (568 liters), 350 at 250 gal (946 liters) and 14 raceways. Between 667 and 833 gpm (42 and 53 L/s) are used on the average with approximately double this during peak periods. Approximately half a million cichlids (tropical fish from Africa) are raise annually.

## SUMMARY

Crystal Hot Springs will continue to provide water and energy for community uses into the foreseeable future. Further study of resource hydrogeology could assist with long term planning for further economic development and help prevent conflicts between users and their respective water rights. There is ample supply of geothermal water for development of additional uses of Crystal Hot Springs, particularly with more careful delivery of outfall water from one use to the next.

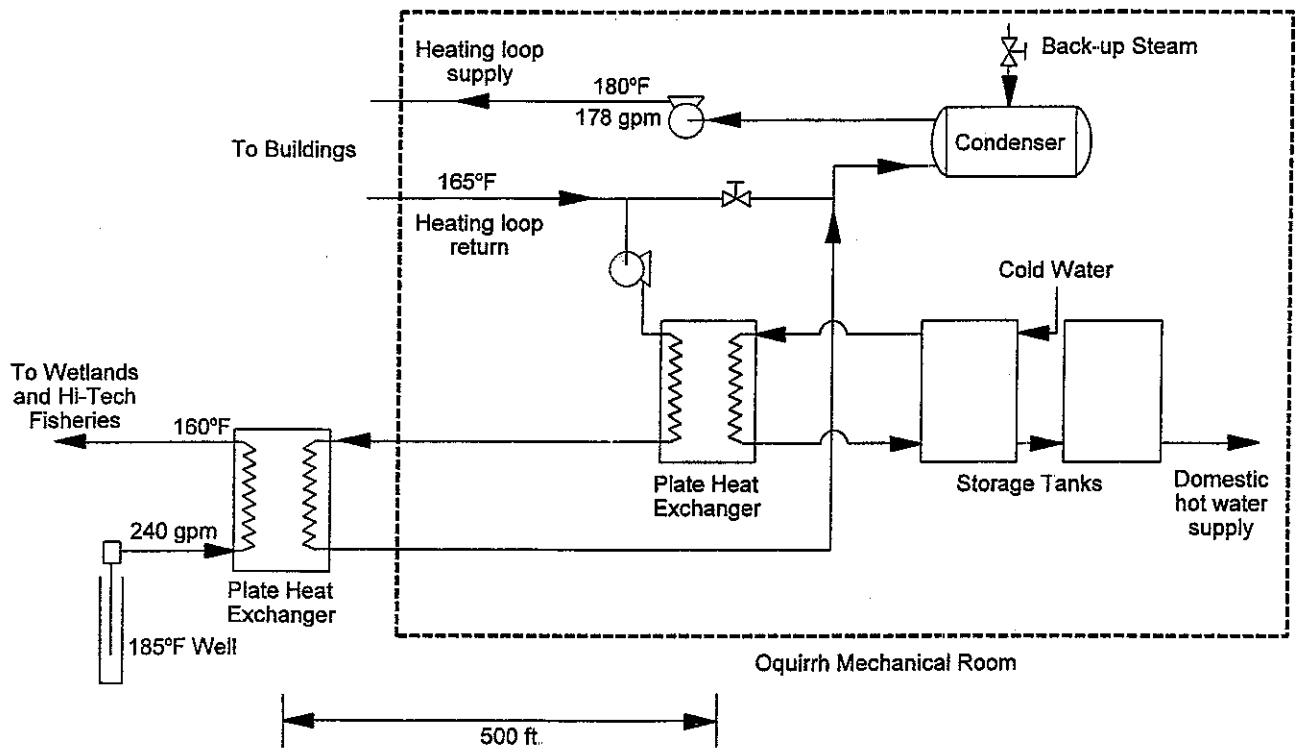
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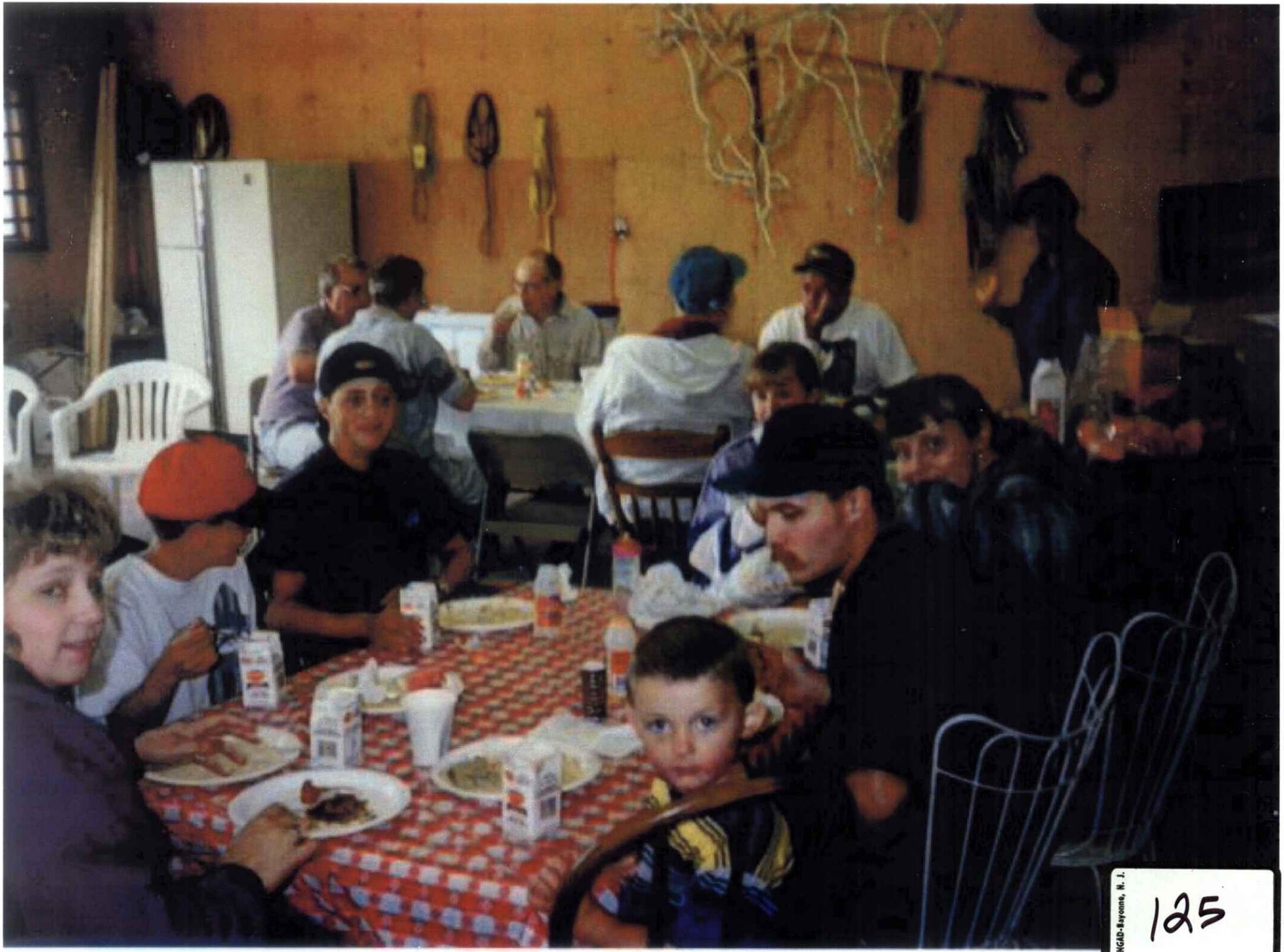
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*Schematic of the Utah Department of Corrections heat supply system to the Oquirrh building complex.*

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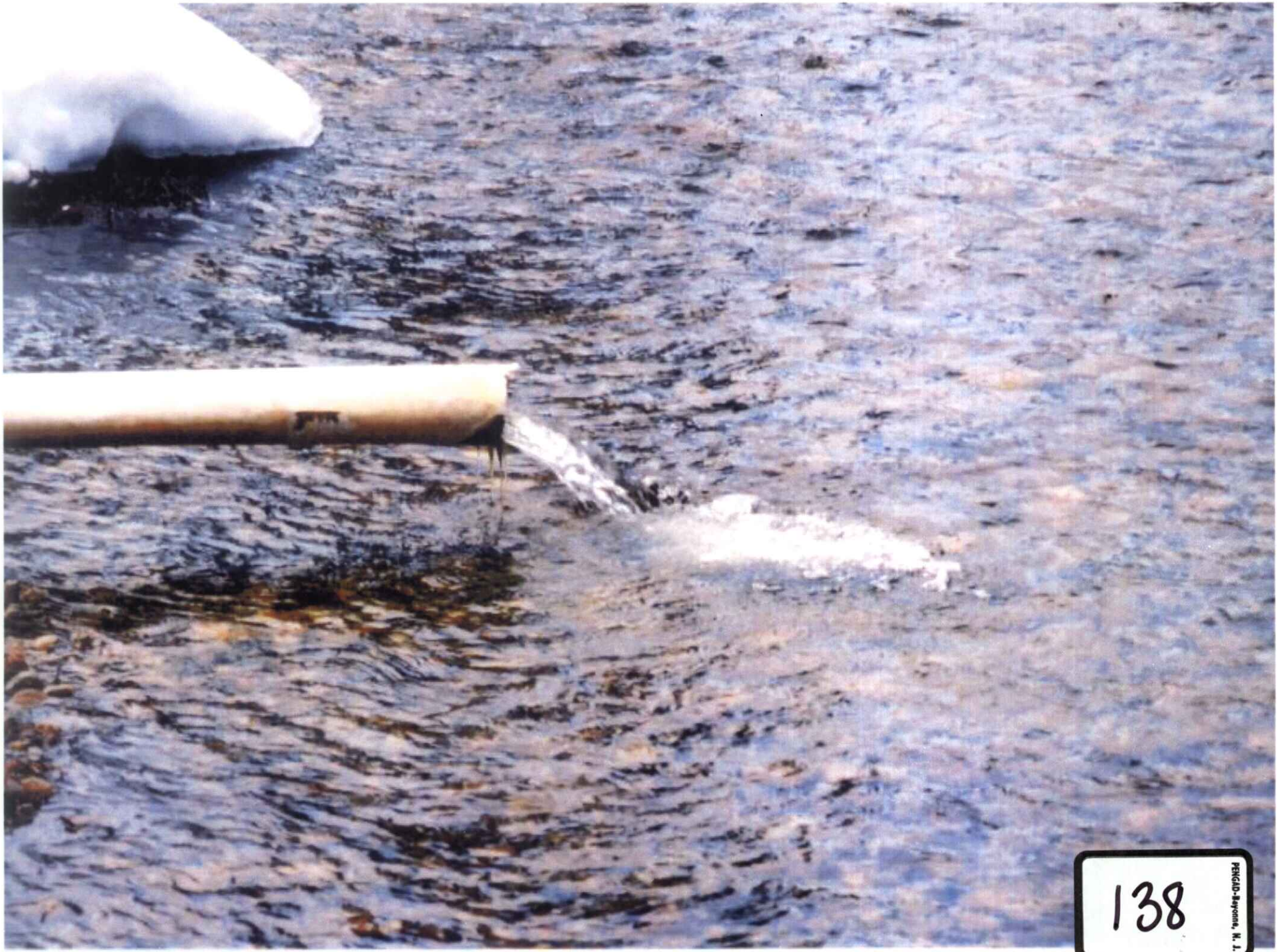
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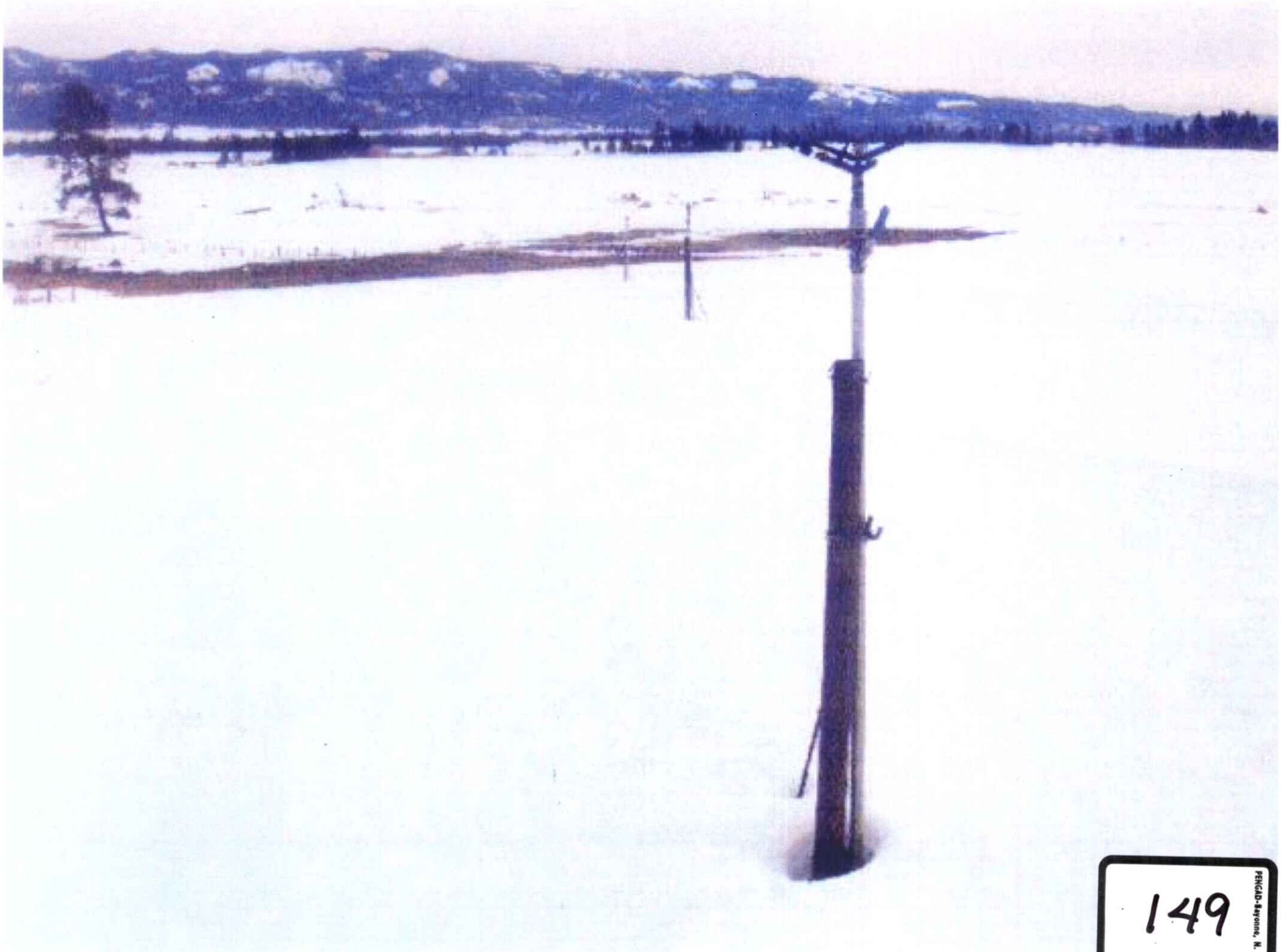
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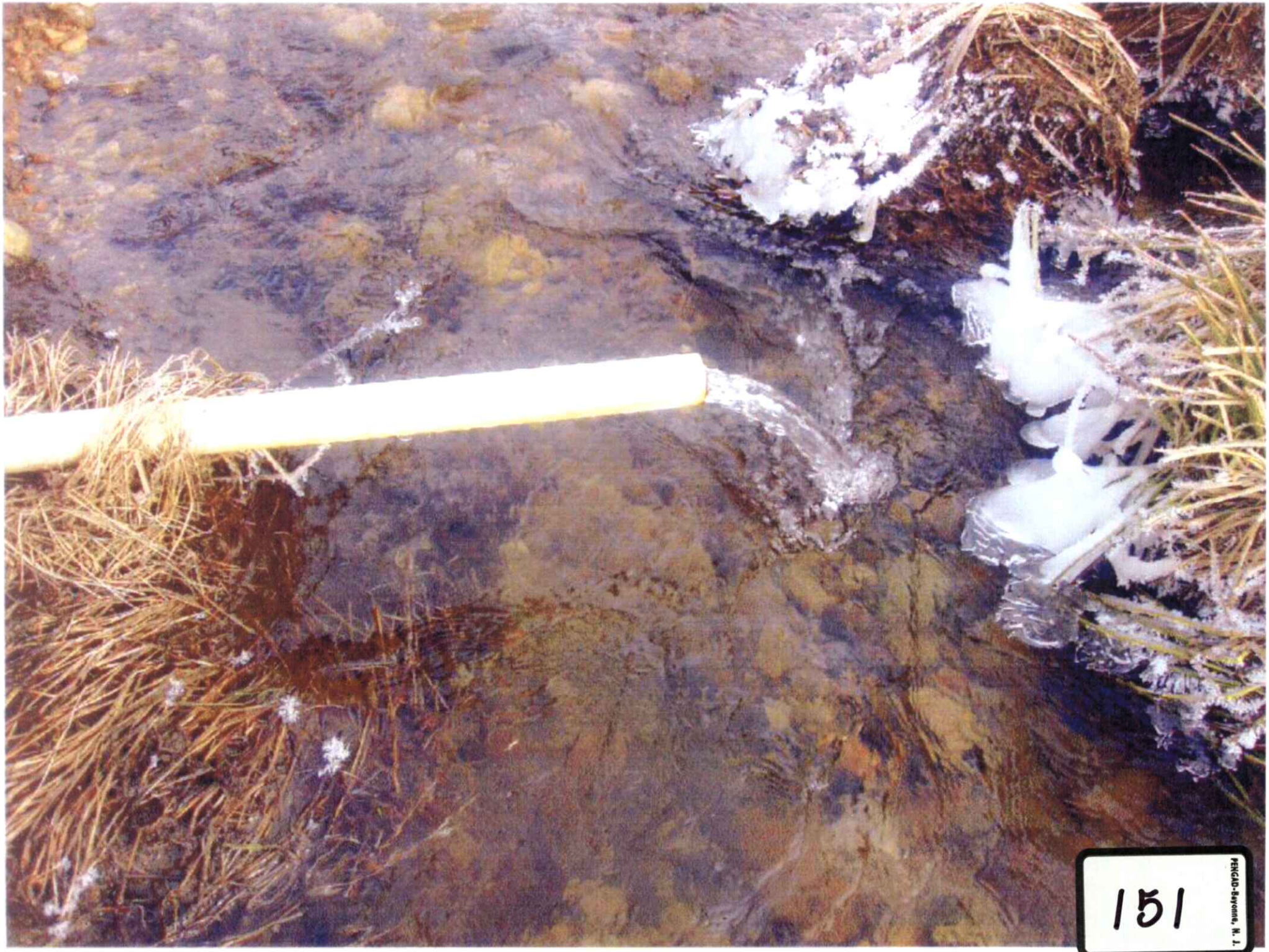
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