HYDROGEOLOGIC CONDITIONS IN THE BOISE FRONT GEOTHERMAL AQUIFER

Prepared for:

City of Boise, ID

and

National Renewable Energy Laboratory, Golden, CO

Prepared by

Christian R. Petrich
Idaho Water Resources Research Institute
University of Idaho – Boise

Idaho Water Resources Research Institute
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ABSTRACT

An extensive low-temperature geothermal aquifer system underlies the Boise area along the Boise Foothills. The aquifer system lies within the Boise Front Ground Water Management Area. Proposed increases in thermal water use have led to concerns about potential long-term impacts to the geothermal aquifer system, and the ability of current aquifer monitoring to detect possible changes.

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 (1) conducting a mass measurement (i.e., "simultaneous" measurement of numerous wells over a short period of time) of water levels and/or pressures in geothermal wells, (2) developing a relational database using existing data, (3) reviewing hydrologic conditions in the aquifer, and (4) constructing a numerical model to simulate aquifer production. The primary areas of interest for this study included the Harris Ranch, downtown Boise – Table Rock, and Stewart Gulch areas.

This report provides a summary of hydrogeologic conditions in the geothermal aquifer system. A description of numerical model construction and simulation results are presented in a separate volume (Zyvoloski et al., 2003).

The Boise Front geothermal aquifers reside in a complex series of igneous rocks and interbedded sediments. Geothermal water appears to be associated with fractures along a northwest trending fault zone along the Boise Foothills. Thermal water in the downtown Boise – Table Rock area is drawn from granitic rocks of the Idaho Batholith, Tertiary-aged rhyolite and associated sediments, and/or Tertiary basalt. Water temperatures in geothermal wells used for heating range from 135° to 175°F. Geothermal water in the Harris Ranch area appears to reside primarily in fractured granite. Two Tertiary basalt layers appear to be the primary source of 90° to 125°F thermal water in the Stewart Gulch wells. Potentiometric surface maps, based on the 2002 simultaneous water level measurements, indicate westerly or southwesterly horizontal hydraulic gradients in all three of these areas.

The downtown Boise – 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 there has not been a water level response in the Stewart Gulch area from 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.

Acknowledgements

This work was made possible by a grant from the National Renewable Energy Laboratory (NREL) and the City of Boise, Idaho. Terry Scanlan (Scanlan Engineering) provided data, a chronology of geothermal development, and hydrogeologic descriptions of aquifer characteristics. Ed Squires (Hydro Logic, Inc.) provided data and a description of hydrogeologic characteristics of the Stewart Gulch area. In addition, substantial in-kind support and data have been provided by Ken Neely, Bruce Tuttle, Linda Davis, and Dayna Ball of the Idaho Department of Water Resources (IDWR). The Boise Warm Springs Water District (BWSWD), the City of Boise, The Terteling Company, the Flora Company, Quail Hollow Golf Course, Harris Ranch, Edwards Greenhouses, Veteran's Administration Hospital (VA), the Idaho Department of Administration, and the U.S. Geologic Survey provided data, access to wells, and logistical support. Last, but not least, this project would not have been possible without the research efforts over the last 25 years by Will Burnham, Jack Kelly, Spencer Wood, E. G. Crosthwaite, Charles Waag, and many others.

Project Technical Committee

This project has been guided by, and this report has been reviewed by, a project technical committee. The committee agrees that the report represents a general consensus understanding of the committee regarding hydrologic conditions in the Boise Front Geothermal Aquifer system, based on currently-available data. 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)

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1. INTRODUCTION

1.1. Description of Project Area

An extensive geothermal aquifer system underlies the Boise area along the Boise Foothills – an area known as the Boise Front. Wells in this area with water temperatures ranging from about 80ºF to 170ºF are shown in Figure 1-1. The lateral extent of the aquifer along the northwest-southeast orientation of the Boise Front is unclear, 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 Boise – Table Rock[1], and Stewart Gulch (Figure 1-1). Thermal water from these wells is withdrawn for space heating, irrigation, and domestic purposes by a variety of private, commercial, and governmental users.

The motivation for this study arose from a request by the City of Boise to expand current levels of production (and subsequent 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 geothermal water 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 primary focus of this study is on three areas: Harris Ranch, downtown – Table Rock, and Stewart Gulch (Figure 1-1). Wells in these areas generally represent the warmest wells in the Boise Front geothermal system, generally share a common use (space heating), and have more available data than 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.

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[1] Hereafter referred to as the “downtown – Table Rock” area.

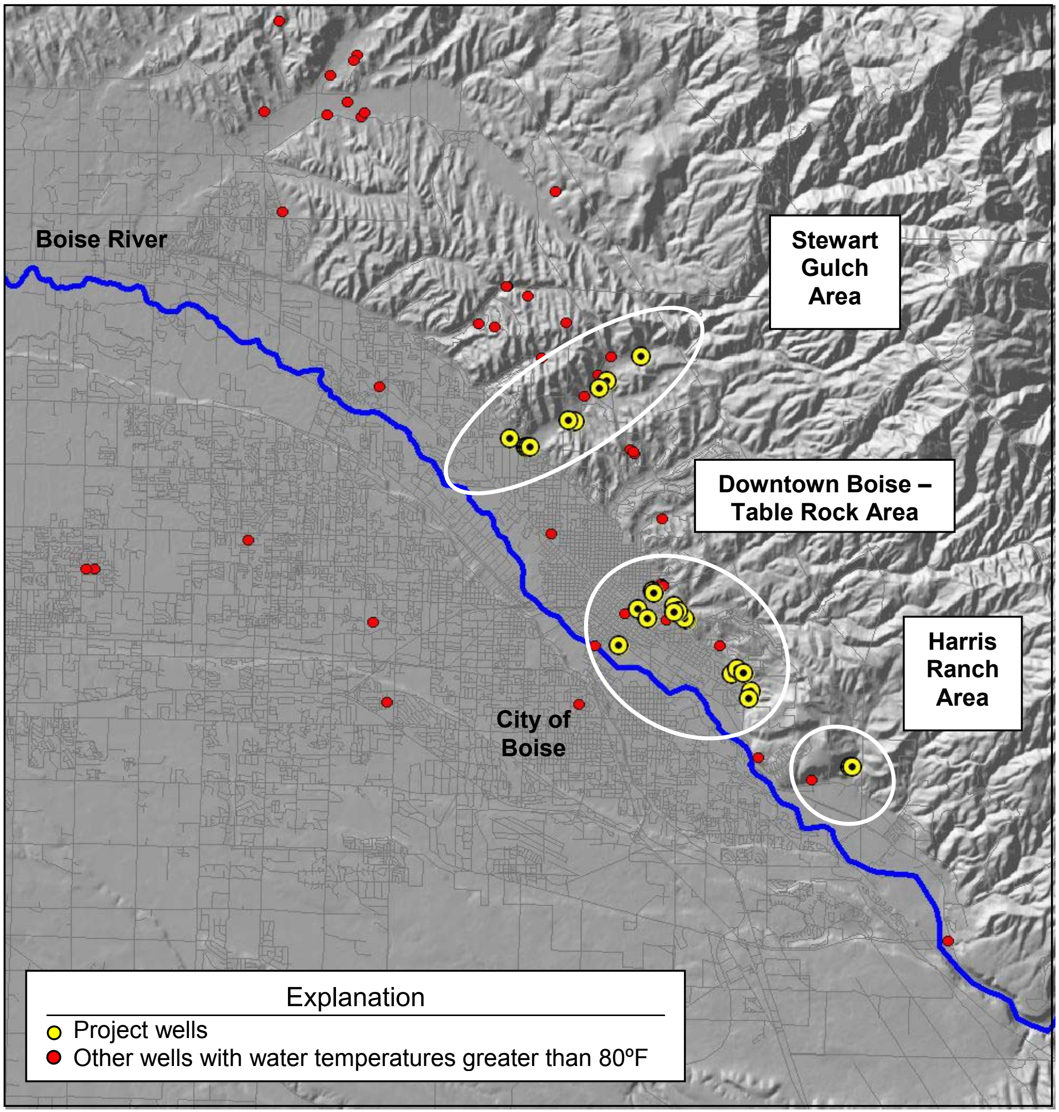

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Figure 1-1: Project area.

1.2. Purpose and Objectives

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 geothermal aquifer.
2. Consolidate existing hydrogeologic and production data into a single database.

3. Conduct a mass measurement[2] 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, Harris Ranch, and Stewart Gulch areas.

1.3. Report Organization

This report consists of a (1) general description of the Boise Front geothermal aquifer system, (2) detailed description of geothermal development and hydrogeologic conditions in four sub-areas, (3) summary of the August 2002 measurement of water levels in geothermal wells, and (4) discussion of a conceptual model of ground water flow in the Boise Front geothermal aquifer system. A companion volume contains a description of model construction, calibration, and simulation results (Zyvoloski et al., 2003). A final summary provides conclusions and recommendations based on the hydrogeologic assessment and simulation results (Petrich, 2003).

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[2] 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. DESCRIPTION OF DATA

2.1. Previous Studies

Numerous published and unpublished studies over the past 25 years have focused on the Boise Front geothermal aquifer system (Anderson and Kelly, 1981a; Anderson and Kelly, 1981b; Anderson and Kelly, 1982a; Anderson and Kelly, 1982b; Anderson and Kelly, 1983; Anderson, 1981; Burnham and Wood, 1992; Clemens, 1993; Higginson and Barnett, 1987; IDWR, 1947; IDWR, 1988; James M. Montgomery Consulting Engineers, 1987; Liberty, 1996a; Liberty, 1996b; MacGregor, 1999; Mariner et al., 1989; Mayo et al., 1984; Mink and Graham, 1977; Montgomery-Watson, 1994a; Montgomery-Watson, 1994b; Montgomery-Watson, 1998; Morgan, 1988; Neely, 1995; Neely, 1996; Neely, 1998; Russell, 1902; Russell, 1903; Squires et al., 1993; Squires et al., 1992; Waag and Wood, 1987; Wells, 1971; Wood, 1997; Wood and Burnham, 1987; Wood and Clemens, *in press*). These studies were conducted to develop a better understanding of system hydrogeology, drill production and injection wells, and simulate system behavior. This study builds on these reports and associated data.

2.2. Data Overview

Data used in this study were obtained from the Idaho Department of Water Resources (IDWR), U.S. Geological Survey, individual users, and private consultants. Many production and water level data obtained from IDWR were collected by geothermal water users, private consultants, faculty and students from the Boise State University (BSU) Geosciences Department, and others. Spatial data (obtained from IDWR) include political boundaries, hydrography, major roads, digital elevation data, and registered air-photo images. Well information was taken from Montgomery-Watson reports (1994a) and augmented with information collected from driller's reports and other sources (E. Squires, T. Scanlan).

Well elevations of selected wells (primarily geothermal wells in the Stewart Gulch, downtown – Table Rock, and Harris Ranch areas) were surveyed by the City of Boise with a survey-grade Global Positioning System device. Measurement point and ground surface locations are provided in Appendix H (under separate cover). Elevations were surveyed using the NAVD88 datum. However, most of the IDWR elevation data are in the NAVD29 datum. In the Boise Front area, the NAVD29 datum is 3.14 feet less than the NAVD88 datum. Data presented in this report, unless otherwise noted, are presented using the NAVD29 datum.

Water level data were obtained from IDWR records. The sources of most of these data were geothermal users or their representatives. The IDWR data included water level data collected as part of a 1994 study (Montgomery-Watson, 1994a; Montgomery-Watson, 1994b). Measuring point elevations generally were given for these existing data, but the basis for the elevations was not always clear, nor was the precise location of the well measuring point. Hydrographs were plotted using the elevations given for the time during which the data were collected.

Production and re-injection data were obtained from IDWR files. The City of Boise (Kent Johnson) supplied post-1999 projection and re-injection data for the city system. The original sources of IDWR production data were geothermal water users.

Borehole geophysical logs have been recorded in a number of geothermal wells. These logs have been kept by geothermal users, their consultants, and/or the BSU Department of Geosciences. Available geophysical logs were scanned and stored as images as part of this study. Wells from which geophysical logs were scanned are listed in Appendix G.

2.3. Data Quality

The quality of existing data obtained from hand measurements, installed transducers, pressure gauges, etc., is highly variable. Installed measuring equipment in geothermal production wells is prone to malfunction over time, which may result in inaccurate data. Measurements of maximum drawdown levels taken in operating production and injection wells may reflect atypical hydrologic conditions. Measurements in production and injection wells taken after extended recovery periods (e.g., late summer for wells used for seasonal heating) should reflect local aquifer conditions. Pressure gauges and transducers for measurements conducted as part of this project (Section 5) were new; double pressure gauges were used to verify readings. During project measurements several installed system gauges were observed as being inaccurate and/or inoperative. Similarly, some totalizer readings used for estimating production data were suspect – and one totalizer was switched off during the mass measurement in August 2002. Thus, the pre-2002 data vary in accuracy; some pre-2002 water level and temperature data are suspect. Some of the hydrographs in Section 4 include exceptionally high or low data points that may reflect erroneous measurements or data entry. Data that were clearly in error (when identified) were removed from the database. Despite precautions, some of the remaining historical data reported in this report may be in error.

2.4. Database Description

Existing well information and water level and production data, and new data collected as part of this study, were integrated into a Microsoft Access database. The database contains information on 33 geothermal wells in the Boise Front area. Database fields and relationships are shown in Figure 2-1. Explanations for fields are included in database tables.

This database was designed to be linked to an IDWR database of statewide well information. The statewide database contains location, water use, temperature, and basic well construction information for over 2,600 wells. Approximately 1,200 of these well records can be linked to USGS information containing more detailed well construction data, water level data, or other information.

The spatial data projection for map components is IDaho Transverse Mercator (IDTM). Spatial data are stored in metric units. The IDTM projection was used for consistency with other spatial data used by IDWR. Well elevations are included in both U.S. and metric units (see Section 2.2 for datum explanation).

Several well names and/or well identifiers have been used for geothermal data over the years. The current identifier is the “GeoWellID”, which is consistent with other Idaho geothermal well data. Previous identifiers were included for reference (such as “IDWRWellID”, USGS station name, or common name). The “GeoWellID” should be used for linking all future tables and data.

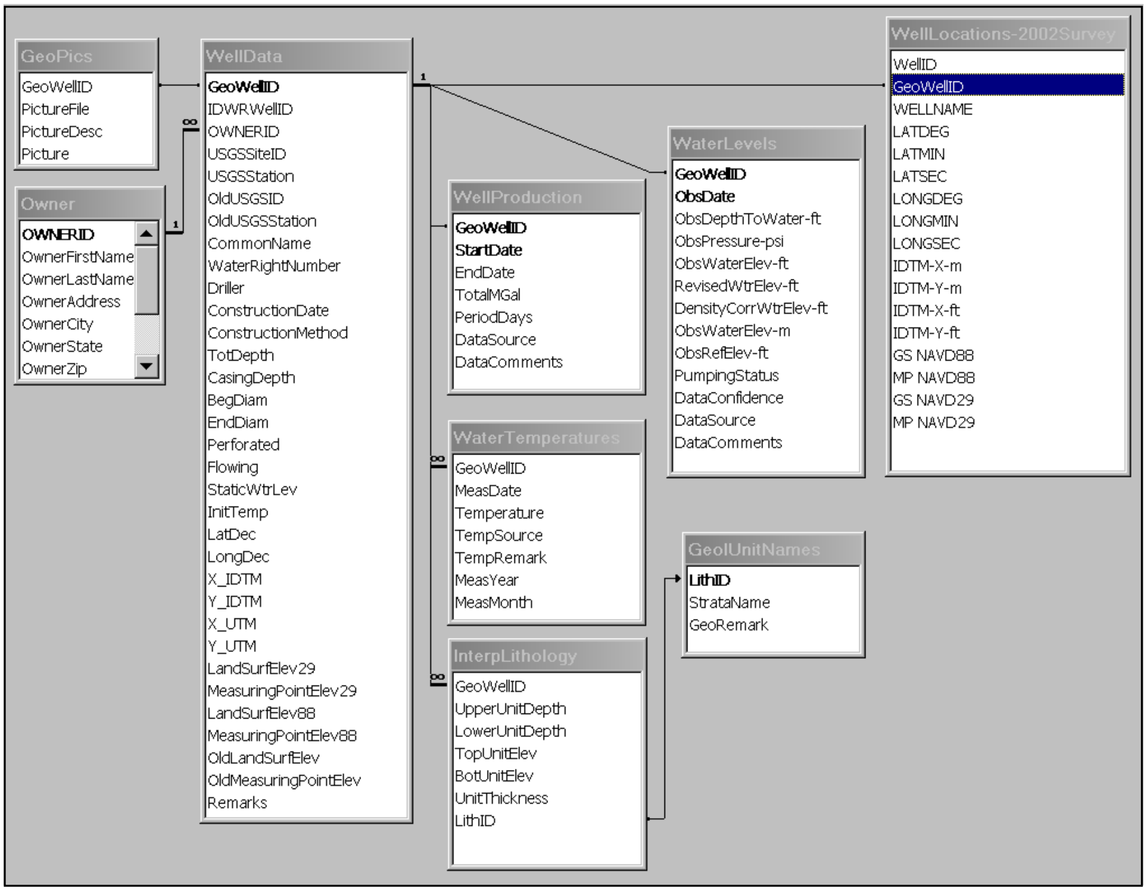


Figure 2-1: Database components and relationships.

3. BOISE FRONT GEOTHERMAL AQUIFER CHARACTERISTICS

3.1. Introduction

This section consists of a general description of the Boise Front geothermal aquifer system, including geologic setting, general hydrogeologic characteristics, structural influences, water chemistry, and general origin of the geothermal water. A more detailed description of aquifer characteristics in the downtown – Table Rock, Stewart Gulch, and Harris Ranch sub-areas is provided in subsequent sections.

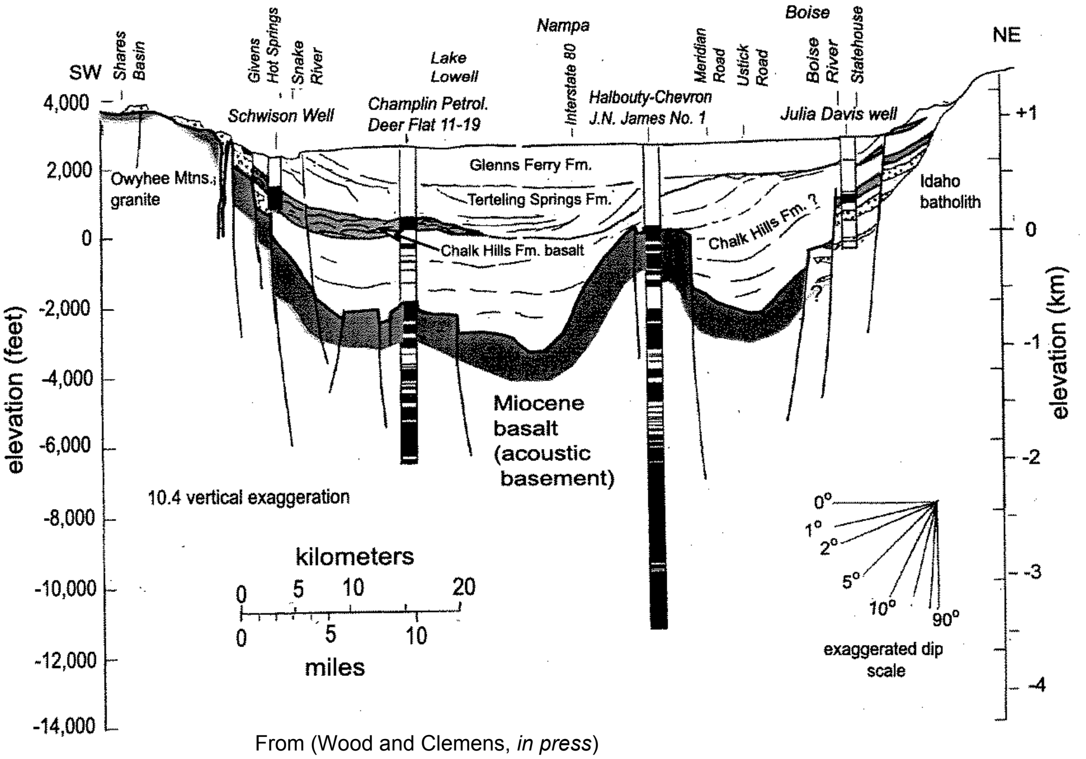
3.2. Regional Hydrogeologic Setting

The lower Boise River sub-basin (Treasure Valley) is located along the northern margin of the northwest-trending topographic depression known as the Western Snake River Plain. The Western Snake River Plain is a Neogene-aged continental rift basin (Wood and Clemens, *in press*) separating Cretaceous-age granitic mountains of west-central Idaho from the granitic/volcanic Owhyee mountains in southwestern Idaho. The Western Snake River Plain has the appearance of a northwest trending graben associated with continental rifting (Mabey, 1982; Wood and Anderson, 1981). The Western Snake River Plain extends from about Twin Falls, Idaho northwestward to Vale, Oregon. The Snake River Plain is about 30 miles wide in the section containing the lower Boise River.

The Western Snake River Plain is believed to have been formed by crustal extension (Malde, 1991) that began forming about 11 million years ago, with major faulting that occurred between 11 and 9 million years ago (Wood and Clemens, *in press*). Miocene-aged rhyolite flows and domes are present along the margins of the western plain. Rhyolite is present in the Boise Foothills near Boise, but not in deep basinward wells (e.g., the 14,100 foot-deep J.N. James well near Meridian did not encounter rhyolite). For this reason Wood and Clemens (*in press*) hypothesize that much of the plain may have been an upland during Miocene silicic volcanism.

The basin dropped relative to surrounding highlands by isostatic compensation (Malde, 1991) because of thick emplacements of volcanics (Figure 3-1) associated with rifting and overlying sediments (Mabey, 1982). Wood and Clemens (*in press*) describe sediment deposition in a large lake ("Lake Idaho") that extended from Glenns Ferry to Hells Canyon. Initial sediments, consisting of interbedded arkose, mudstone, and volcanic ash, are associated with the Chalk Hills formation. A transgressive sequence followed, with Lake Idaho levels reaching approximately 3,600 feet in elevation. Most of the exposed sediments in the Boise Foothills appear to have been deposited during this transgressive sequence. These sediments, mapped as the Terteling Springs

Formation, include shoreline sand deposits (including some oolitic sands), small deltaic deposits, and thick accumulations of lake muds basinward. Wood and Clemens (*in press*) hypothesize that Lake Idaho began to recede about 4 million years ago, with the outlet downcutting at a rate of approximately 400 feet per million years. Sediments from the basin margins filled the receding lake, forming interbedded sand and mud sequences and extensive lacustrine deltaic deposits. The Glenns Ferry Formation includes most of the sediments associated with the slowly lowering lake level, and are represented in the Boise Foothills by a 200-foot thick coarse sand unit with Gilbert-type foreset bedding (Pierce Gulch sand). Basinward, Pierce Gulch sands – reworked Terteling Springs sands (E. Squires, *written communication*) – are thought to form one or more primary "cold water" aquifer sections of the Treasure Valley.



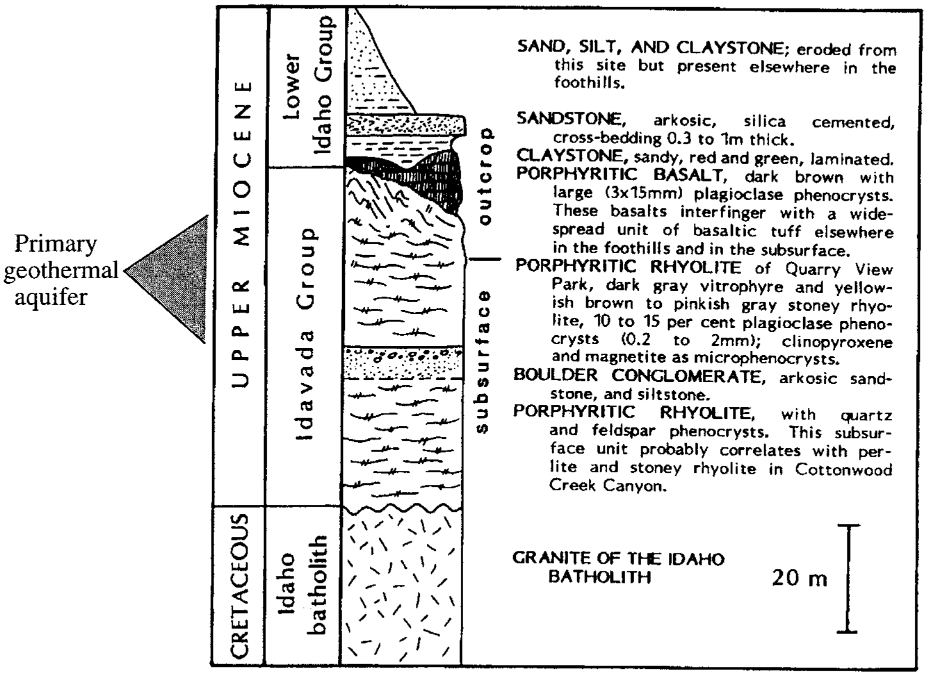
From (Wood and Clemens, *in press*)

Figure 3-1: Cross-section of the Western Snake River Plain

Volcanic activity returned to the Western Snake River plain during the late stages of Lake Idaho, erupting from a line of vents referred to as the Kuna-Mountain Home volcanic rift (Wood and Clemens, *in press*). These Quaternary basalt flows, assigned to the upper Snake River Group (Malde, 1991, p.266; Malde and Powers, 1962), flowed across portions of the ancestral Snake River Valley in an area that is now south of the Boise River (Malde, 1991, p.266). The Snake River then changed course, incising at its present location along the southern margin of the basalt flows. More recent eruptions (from Kuna Butte and other local sources) spilled lava into the canyon south of Melba. The Snake River has since incised this basalt (Malde, 1991, p.267).

3.3. General Aquifer Description

The Boise Front geothermal aquifers reside in a seemingly complex series of igneous rocks and interbedded sediments underlying the "cold water" sedimentary aquifers. Depending on location, geothermal water is found in Cretaceous-aged granite of the Idaho Batholith, Tertiary rhyolite and associated sediments, and/or Tertiary basalt and basaltic tuffs (Figure 3-2).



Based on an "outcrop above Quarry View City Park and subsurface geologic units known from drilling beneath the park." (Wood and Burnham, 1987).

Figure 3-2: Stratigraphic section from rocks related to the geothermal system (Wood and Burnham, 1987)

Geothermal water is thought to be associated with fractures along a northwest trending fault zone that marks the northeastern boundary of the Snake River Plain (Figure 3-3). Faults, fractures, and joint systems within the volcanic units serve as conduits for horizontal and vertical ground water movement. Individual range-front faults have apparent offsets of 200 to 800 feet, based on seismic evidence. The deeper geologic strata appear to dip between four to seven degrees to the southwest on the downthrown side of the primary foothills fault system. Additional minor faults are present on both sides of the main fault system. Because of sedimentary cover, the faults southwest of the main fault zone are known or inferred primarily from seismic imaging. Most of current successful geothermal production wells in the system are concentrated along the downthrown side of the main fault system.

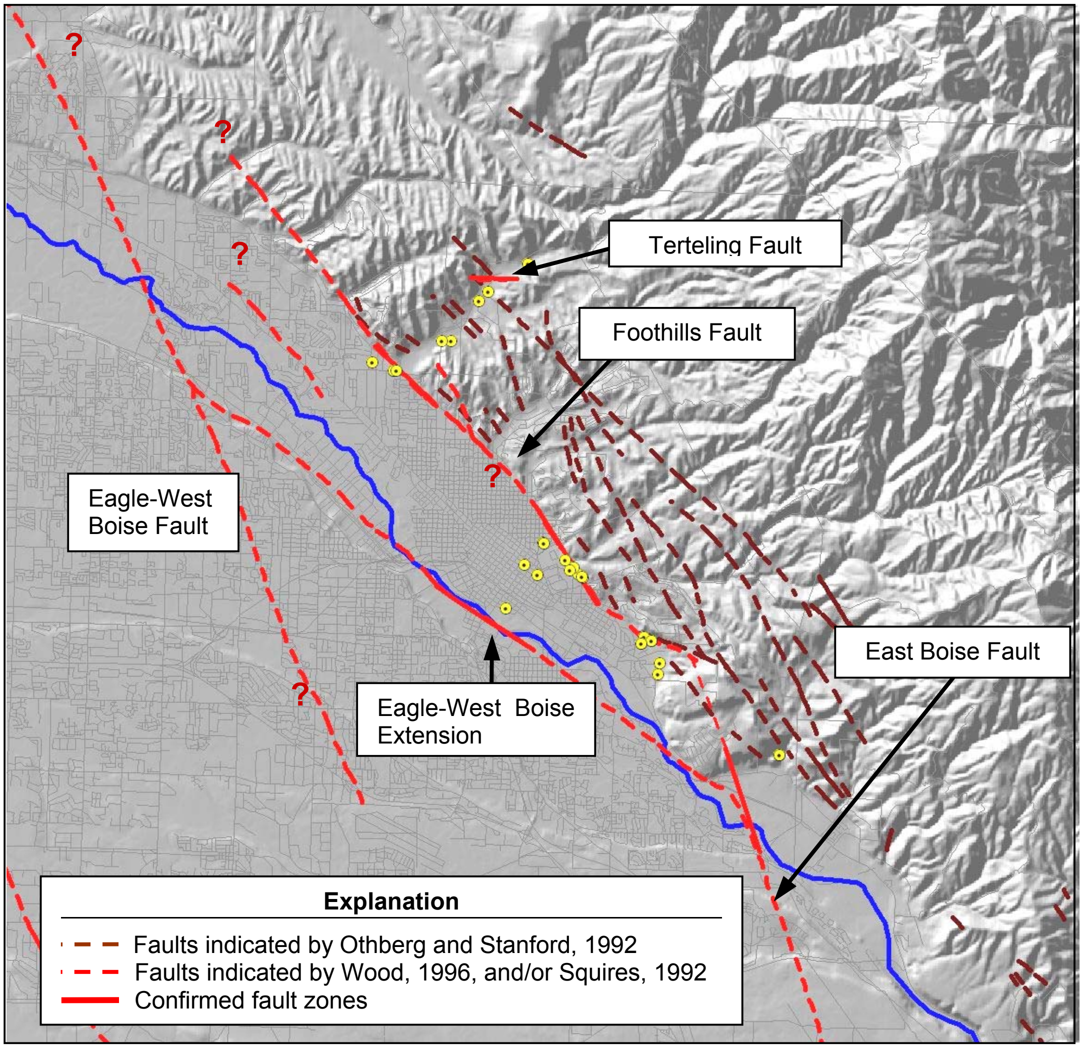


Figure 3-3: Faults in vicinity of Boise Front geothermal aquifer system.

Tertiary Basalt, including fractured and unfractured basalt and basaltic tuffs, extends throughout most of the project area. Geothermal wells in the Stewart Gulch area produce geothermal water from this basalt zone (no wells except the Terteling Motorcycle well penetrate through the basalt). Approximate elevations for the upper surface of the Tertiary basalts are shown in Figure 3-4. Tertiary rhyolite and associated sediments are considered the primary geothermal production aquifers in the downtown

Boise area (Figure 3-2). The extent of the rhyolite aquifer into the valley is unknown, but no wells in the central portion of the valley have encountered rhyolite. Rhyolite flows and domes are thought to have erupted near valley margins (Wood and Clemens, *in press*). Because of their viscous character, these flows may be highly non-uniform and not laterally extensive in the Boise Front area (E. Squires, 2002, personal communication). Two differentiable rhyolite flows are present in the downtown Boise area, separated by a boulder conglomerate, sandstone, or siltstone (Wood and Burnham, 1987).

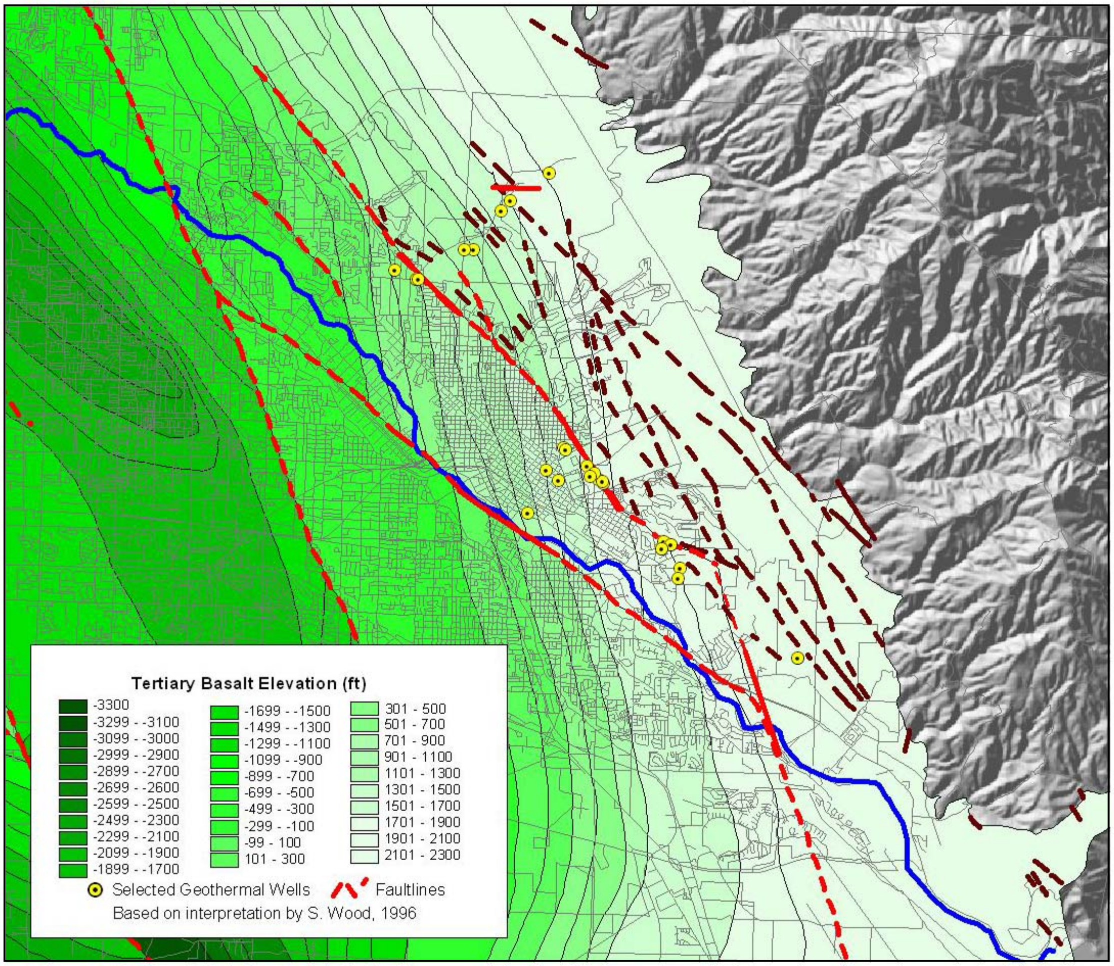


Figure 3-4: Approximate elevations of the upper surface of Tertiary basalt.

There is consensus that the geothermal flow system is largely dominated by the basin margin fault-fracture zone. Effective permeabilities within the faults (especially in portions of the Foothills Fault) are likely larger than the conductivity transverse to the faults. However, there are insufficient data to quantify the longitudinal or transverse effective hydraulic conductivity tensors or even to determine relative hydraulic conductivities. Development of successful wells located away from exposed faults along the front (e.g., Capitol Mall wells, City Injection, Veteran's, and BLM), and documented hydraulic connection between these wells, demonstrates that the aquifer is continuous to the southwest (transverse to the main faults) for some distance (miles).

3.4. Geothermal Water Chemistry

Ground water in the geothermal system is chemically different from water in overlying "cold water" aquifers in the Idaho Group strata. Geothermal water from the volcanic geothermal aquifers generally contain greater concentrations of sodium, bicarbonate, sulfate, chloride, fluoride, silica, arsenic, boron, and lithium than the overlying non-geothermal systems (Wood and Low, 1988). Upper aquifers, even if containing warm water, generally have lower concentrations of calcium and magnesium than the geothermal system. Squires and Wood (1989) note that ground water taken from Ten Mile Ridge wells exhibits warm temperatures (70° to over 90° F), but does not contain the elevated fluoride content associated with geothermal water on the north side of the Boise Valley.

Mayo et al. (1984) presented evidence that fault zones are the primary avenue of upward migration of geothermal ground water. They noted that the thermal waters typically are depleted in calcium and enriched in sodium and fluoride, possibly through ionic exchange during contact with zeolites in the Idavada Volcanics. More recent sampling indicates high sodium and low calcium in several wells in the southeast Boise area, although fluoride is not enriched. This suggests some influence of geothermal water in deeper wells (e.g., wells at depths below approximately 1,000 feet) of the east Boise area.

Mariner et al. (1989), based on data in Young et al. (1988), further described geochemical characteristics based on water analyses from 37 thermal-water wells and three nonthermal springs in the Boise area. The thermal waters are dilute, slightly alkaline, and a sodium bicarbonate type, which makes them identical to thermal water in the Idaho Batholith east of the Boise Front. Fluoride concentrations in the thermal water samples taken from the Boise area ranged from 12 to 19 milligrams per liter (mg/l), and those from the Stewart Gulch area ranged from 9.8 to 10 mg/l. Chloride concentrations ranged from 7.2 to 8.6 mg/l in thermal water samples taken from the Boise area, and from 3.6 to 4.3 mg/l in samples taken from Stewart Gulch thermal wells.

Thermal water in the Stewart Gulch area differs from thermal water in the downtown area also on the basis of geochemical radioisotope data (Mariner et al., 1989). Thermal waters in the Stewart Gulch area were estimated to range between 15,000 and 20,000 years, compared to between 20,000 to 30,000 years in the downtown Boise area (Mariner et al., 1989). Based on stable isotope (deuterium) and chloride data the authors maintain that the thermal waters of Stewart Gulch cannot be related to the Boise thermal waters by mixing. Thus, the Stewart Gulch thermal water is of a similar origin to the Boise thermal water, but based on the USGS study (Mariner et al., 1989; Young et al., 1988), water in the Stewart Gulch has experienced little if any mixing with thermal water in the Boise area. The downtown thermal wells generally are deeper than the Stewart Gulch wells.

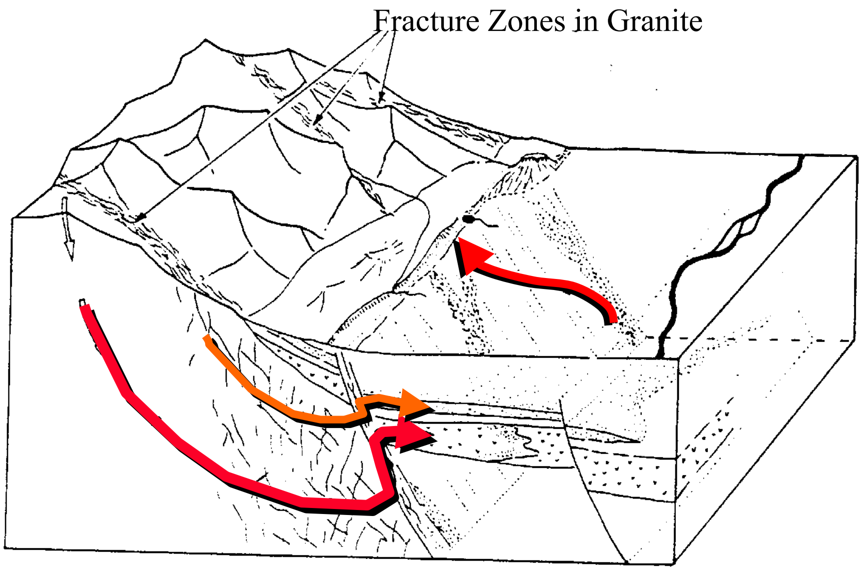
3.5. Origin of the Geothermal Water

Both the Idaho Batholith and the Snake River Plain are situated in a region of high geologic heat flow. A geothermal “belt” marked by hot springs and warm water wells is found along the northern margin of the Snake River Plain from Weiser to the northwest to beyond Bliss to the southeast. The concentration of heat flow and hot springs along the margin of the plain could be caused both by convective heat transfer from upward-moving hot water along fault zones and by the refraction of heat flow that diffuses at the interface of the granite mass with the layered sediments and volcanics (Wood and Burnham, 1987).

The origin of these thermal waters is not fully understood. Mayo et al. (1984) indicated that at the time “most researchers agree that radiogenic decay in the granitic rocks of the Idaho Batholith is the principal source of heat” in the geothermal system. The source of water is thought to be recharge from precipitation in the mountains to the north that follows a deep path of circulation through the batholith and rises along the frontal fault system. A conceptual geothermal water circulation loop (Figure 3-5) has been proposed (Wood and Burnham, 1987, p.121; Wood and Low, 1988, p.32-33), in which meteoric water from surrounding highlands circulates to a depth of about one mile over a horizontal distance of about six miles, through deep fractures in the Idaho batholith. This concept of a long path of circulation appears consistent with the age dating based on carbon-14 and dissolved helium concentrations (see section 3.4).

Smith (1981) also recognized that geothermal heat probably is originating with radioactive minerals within the underlying and surrounding granitic batholith. Smith notes that regional heat flow is refracted away from poorly conductive sediments (e.g., Idaho and Snake River Group sediments) and towards more thermally conductive silicic rocks (e.g., granitics of the Idaho Batholith).

Thermal waters in the Stewart Gulch and the downtown – Table Rock areas appear to have originated from a similar source (Idaho Batholith granitics), but generally exhibit different deuterium and chloride concentrations, temperatures, and residence times (see Section 3.4). The difference in residence times and chemistry may reflect shorter (or faster) flowpaths for the Stewart Gulch thermal water compared to the downtown – Table Rock thermal water.



From Wood and Burnham (1987)

Figure 3-5: Conceptual model of ground water circulation through fractured granite into rhyolite aquifers along the foothills fault beneath the northeastern part of Boise.

3.6. Hydraulic Connection with Overlying Aquifers

In most parts of the lower Boise River Basin there appears to be limited hydraulic interaction between the geothermal, fractured volcanic rock aquifers and the overlying sedimentary, non-geothermal aquifers. This is attributed to low permeabilities of the materials separating the aquifer zones. Miocene basalt and tuffaceous sediments overlying the rhyolite geothermal aquifer have low permeability because of clay alteration and minerals filling the fractures (Squires and Wood, 1989). Low permeability mudstone (which may be more than several hundred feet thick) at the base of the Idaho Group sediments further restricts the vertical permeability and hydraulic connection. However, elevated fluoride and temperature (see next section) in some non-geothermal aquifers along the Boise Front and in an area southwest of Nampa, or elevated sodium and low calcium (such as in the southeast Boise area), suggest that some upwelling does occur, leading to mixing of geothermal and overlying “cold” aquifers.

3.7. Thermal Properties

Smith (1981) estimated the thermal properties of rocks along the Boise Front. A summary of his results is listed in Table 3-1.

Parameter	Basalt	Granite	Silicic volcanics	Sand and clay	Clay
Calculated mean and standard deviation of “in situ” bulk thermal conductivity (cm/sec °C)	3.62 ± 0.38	6.01 ± 0.50	4.54 ± 0.24	3.49 ± 0.90	2.79 ± 0.51
Number of samples	61	33	25	153	61
From Smith (1981), based on samples analyzed by Brott et al. (1976) and Smith (1981).					

Table 3-1: Calculated thermal properties of Boise Front aquifer materials.

4. LOCAL GEOTHERMAL SYSTEM CHARACTERISTICS

This chapter outlines geothermal water use and hydrogeologic characteristics for three areas: (1) downtown – Table Rock, (2) Stewart Gulch, and (3) Harris Ranch (Figure 1-1). These areas are grouped together for this discussion because of hydrologic and water use similarities within these areas.

4.1. Downtown Boise – Table Rock Area

4.1.1. Description of Use and History of Development

Geothermal water from the primary geothermal wells in the downtown – Table Rock area ranges in temperature from 134° to 175°F, and is used for space heating by the (1) Boise Warm Springs Water District (BWSWD), (2) City of Boise (City), (3) State of Idaho Capitol Mall system (CM), and (4) U.S. Division of Veteran's Services (VA). Primary geothermal wells in this area are listed in Table 4-1, and are shown in Figure 4-1. There are other wells in or near this area (Figure 1-1) that produce warm water (with temperatures greater than 85°F), although most of these wells are not considered primary geothermal wells.

Geothermal resources in the Boise area were noted at the end of the 19th century. Russell (1903) mentions warm water wells and at least one "tepid" spring located in the Military Reserve area, presumably in the Cottonwood Creek area. These occurrences are also described by Lindgren in 1898 (Russell, 1903). Substantial development of geothermal resources in the Boise area began in 1891 (Table 4-2), when the first geothermal well in this area was drilled at, or near, the site of the present Boise Warm Springs Water District well house. This well first struck warm water beginning at 80 feet, with the water becoming progressively hotter and the flow increasing with depth. A flow of 150 gallons per minute (gpm) of 154˚F degree water was encountered at a depth of 308 feet. However, it was at 400 feet that "a tremendous flow of water" was encountered (Waag and Wood, 1987, quoting the Idaho Statesman, 1/30/1891). A second well was then drilled 50 feet from the first, with similar results. In combination, the two wells reportedly produced an artesian flow in excess of 800,000 gallons per day (555 gpm) of 170˚F water (Wells, 1971). A third well was drilled in 1895 in order to maintain production. Lindgren reported that the artesian pressure was sufficient for the water level to rise approximately 50 feet above ground surface in 1896 or early 1897 (Waag and Wood, 1987). Development of the geothermal resource for heating, domestic, and bathing use commenced soon afterward.

Well	Alternate Name	Entity	Current Use
BWSWD-East	BWSWD#2	BWSWD	Primary pumping
BWSWD-West	BWSWD#1	BWSWD	Secondary pumping
BWSWD#3		BWSWD	Monitoring well
BGL#1	Boise Geothermal Ltd #1	City of Boise	Monitoring well
BGL#2	Boise Geothermal Ltd #2	City of Boise	Secondary pumping
BGL#3	Boise Geothermal Ltd #3	City of Boise	Secondary pumping
BGL#4	Boise Geothermal Ltd #4	City of Boise	Primary pumping
Beard	BHW-1	City of Boise	Non-producing test well (adjacent to BGL#4)
Boise City Injection		City of Boise	Injection
Capitol Mall 1	CM-1	State of Idaho	Injection
Capitol Mall 2	CM-2	State of Idaho	Production
VA Test injection	VA Test	Veteran's Administration	Monitoring
VA injection	VA-2	Veteran's Administration	Injection
VA Production	VA-1	Veteran's Administration	Production
BLM	BEH-1	Bureau of Land Management	Monitoring
Kanta		Idaho Department of Lands	Monitoring
Old Pen	Old Pen #1	Idaho Department of Lands	Monitoring
Quarry View Park		City of Boise	Monitoring

Table 4-1: List of primary geothermal wells in the downtown – Table Rock area.

Air-lift pumps were installed in about 1909 to maintain or increase production in these wells. The use of air-lift pumps was short-lived because the aerated water was highly corrosive and caused the distribution pipes to fail within four years. At that time (approximately 1913), a new well, 16 inches in diameter, was drilled and one of the existing wells was enlarged to 16 inches. Both of these wells were equipped with line-shaft turbine pumps. These wells are probably the two wells that are in use today by the Boise Warm Springs Water District (BWSWD). The fate of the other two original wells is unknown.

The BWSWD system was the only major user of thermal water in the downtown – Table Rock area from the early 1900s until the mid 1980s. Production records are scarce or non-existent, but it is assumed that the annual production from the BWSWD wells was approximately 250 to 300 million gallons per year (750 to 900 acre-feet per year, or af/yr). Some additional production also occurred from smaller warm water wells at the Idaho State Penitentiary, and from private wells (Koch, Behrman, etc.) No estimates of production are available from these wells.

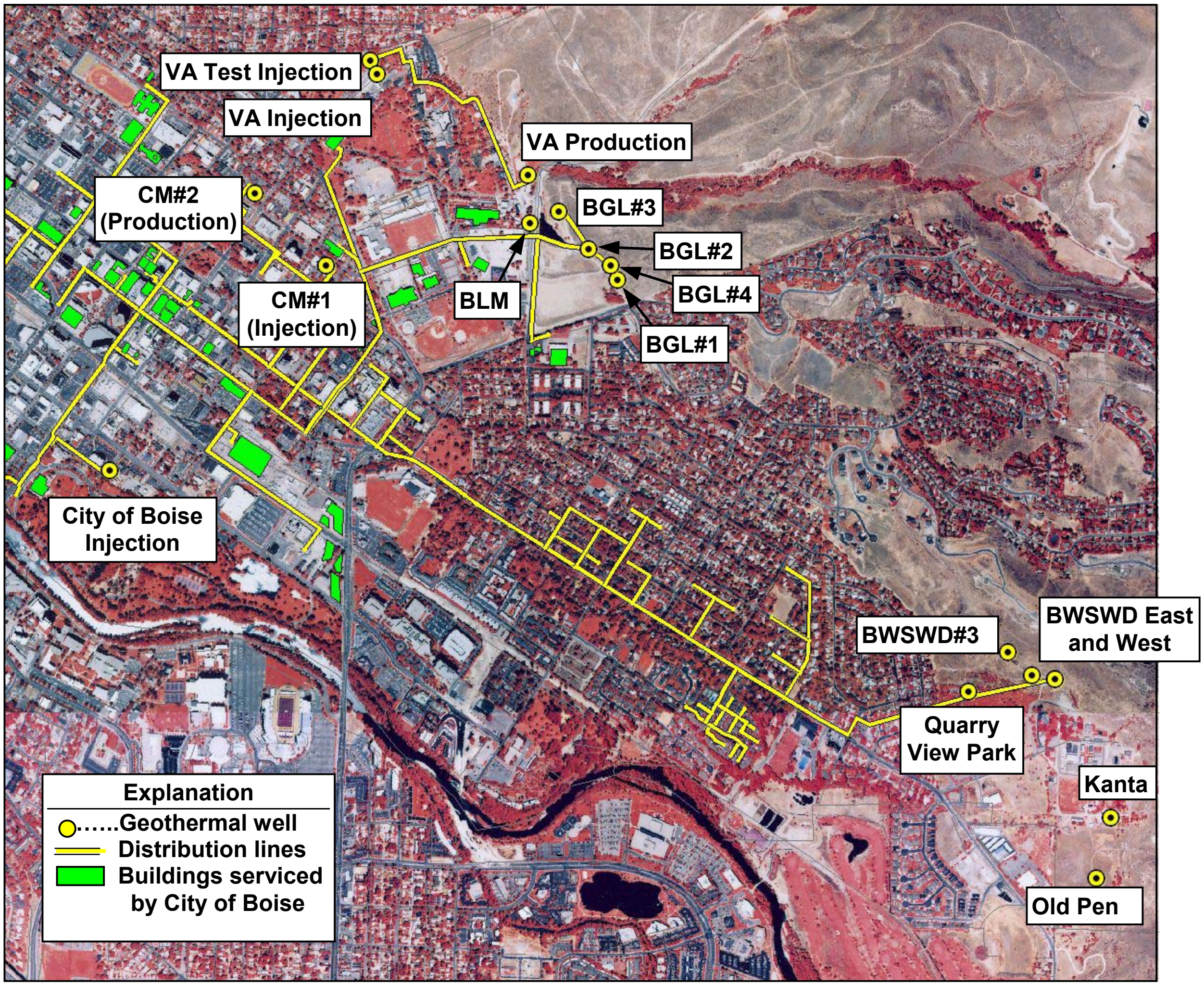


Figure 4-1: Locations of selected geothermal wells in the downtown – Table Rock area.

The BWSWD currently distributes geothermal water for space heating and domestic use in the eastern part of Boise (Figure 4-1). Spent geothermal water does not return to the geothermal aquifer, but (1) drains into shallow injection wells at points of use; (2) discharges to surface channels draining to the Boise River; or (3) discharges to the Boise River via the municipal sewer system. The primary distribution line along Warm Springs Avenue is connected to the City's geothermal distribution system (although under ordinary circumstances a valve between the two systems remains closed). Production data from the BWSWD system are available beginning in 1978. Net production has decreased from a high of 312 million gallons in the 1979 water year to an average of 214 million gallons per water year between 1994 and 2002 (Table 4-3, Figure 4-2). Production slowed between 1986 and 1988 (Figure 4-2), apparently because decreasing water levels caused pumps to break suction; the pumps were lowered and increased pumping resumed in 1989 (T. Scanlan, C. Brockway, *personal communication*).

Time	Event	Source
1890	Warm springs and wells in Military Reserve area; Kelly Hot Springs operating	Russell (1903) citing Lindgren (1898), Wells (1971)
1891	Two BWSWD wells completed, 0.8 mgd	Wells (1971)
1895	Third BWSWD well drilled	Hand written notes from BWSWD (1909) - attached to 1909 Tariff Rules
1896-7	Three BWSWD wells in operation; 550 gpm; 50 foot shut-in pressure	Russell (1903) citing Lindgren (1898), also Waag and Wood (1987) citing Lindgren (1898)
1908	Air pumps installed on two BWSWD wells	Hand written notes from BWSWD (attached to 1909 Tariff Rules)
1913 +/-	New 16-inch well drilled and one existing well enlarged to 16 inches; turbine pumps installed in both wells at the BWSWD	Wells (1971) (citing 1918 Tariff Rules); four years after installation of air pumps
1917 +/-	Kelly Hot Springs dried up	MacGregor (1999, pg 81)
8/6/1965	Old Pen Irrigation well drilled	Drillers report
1976	BLM and Beard wells drilled	Berkeley Group (1990, pg 45)
3/21/1977	Harris well 1 constructed	Driller's report; Water right (63-8627)
12/1980	Capitol Mall well # 1 completed/tested	Anderson and Kelly (1981a)
6/1981	BWSWD # 3 completed	Anderson and Kelly (1981b)
9/1981	Capitol Mall well # 2 tested	Anderson and Kelly (1981a)
4/1982	BGL wells # 2 and # 4 tested	Anderson and Kelly (1982b)
11/1982	Capitol Mall wells operating; assume 160-205 Mgal/yr (500 af/yr)	Berkeley Group (1990, pg 21); Neely (1995, pg 17)
2/1983	Kanta well drilled	IDWR driller's report (E. G. Crosswaithe reported on this well, according to E. Squires)
9/1983	VA Production well completed	Anderson and Kelly (1983)
10/1983	BGL wells operating; 121-189 Mgal/yr (400 af/yr)	Berkeley Group (1990, pg 33); Neely (2001)
1984	Quarry View well on	Scanlan (*written communication*)
1986	Harris East well completed	Waag & Wood (Waag and Wood, 1987)
1/1987	VA Injection well completed	James M. Montgomery Consulting Engineers (1987)
11/1988	VA wells operational; 118-204 Mgal/y (500 af/yr)	Berkeley Group, pg. 33; Neely 8/28/01
2/1988	Quarry View well off; pump removed	Scanlan (*written communication*)
1998 +/-	Old Pen well off	Scanlan (*written communication*)
4/1998	City Injection well drilled & tested	Montgomery Watson (1998)
2/1999	City Injection well operational	City of Boise

Table 4-2: Chronology of geothermal development and/or responses in the downtown – Table Rock area.

Year	BWSWD	Capitol Mall	Boise City			VA	Summary	
	Production	Production & Injection	Production	Injection	Net With-drawals	Production & Injection	Total Use	Net With-drawals
1978	256.1						256.1	256.1
1979	312.2						312.2	312.2
1980	308.1						308.1	308.1
1981	239.4						239.4	239.4
1982	276.0						276.0	276.0
1983	283.5	12.8					296.3	283.5
1984	300.2	164.6	166.7		166.7		631.5	466.9
1985	281.2	175.4	121.4		121.4		578.0	402.6
1986	253.1	192.0	176.8		176.8		622.0	429.9
1987	183.1	169.1	188.9		188.9		541.1	372.0
1988	199.4	138.8	123.8		123.8		462.1	323.2
1989	278.0	154.4	158.0		158.0	28.48	618.9	436.0
1990	244.6	130.5	122.3		122.3	118.21	615.7	366.9
1991	245.7	182.7	121.3		121.3	129.08	678.8	367.0
1992	243.3	139.0	123.3		123.3	116.69	622.3	366.6
1993	259.2	217.9	156.0		156.0	137.01	770.2	415.2
1994	220.8	174.5	122.5		122.5	137.42	655.2	343.3
1995	221.2	154.3	127.9		127.9	166.715	670.1	349.1
1996	226.6	118.7	132.1		132.1	186.22	663.7	358.8
1997	212.8	98.6	130.7		130.7	203.61	645.7	343.5
1998	184.2	111.6	131.2		131.2	195.95	623.0	315.4
1999	204.0	125.5	164.9	53.6	111.3	191.64	686.1	315.3
2000	210.5	117.9	188.0	145.8	42.2	186.95	703.3	252.6
2001	218.7	144.8	172.0	145.6	26.4	172.96	708.5	245.1
2002	230.1	123.3	170.7	139.8	30.9	163.1	687.1	261.0

Units: millions of gallons per water year (October 1 through September 31); all data supplied by users

Table 4-3: Production and injection of geothermal water in the downtown – Table Rock area, 1978-2002.

The Idaho State Penitentiary drilled a warm-water (97˚F discharge, 134˚F bottom hole temperature) well for irrigation in 1965 (Old Pen well). The well was used for irrigating approximately 20 acres (80 af/yr +/-) until the early 1970s. This well was later used for irrigating the Idaho Botanical Garden property from the mid 1980s through the late 1990s, with diversion volumes progressively increasing from 2 to 25 acre-feet annually over that period. Another irrigation well in the Penitentiary area, the Quarry View Park well, was operated for irrigation from 1984 through 1987, producing approximately 25 acre-feet annually of 134˚F water. The Kanta-Yanke well was completed in 1983, but was never equipped with a pump for production. It produced 161˚F water during test pumping (IDWR driller's report).

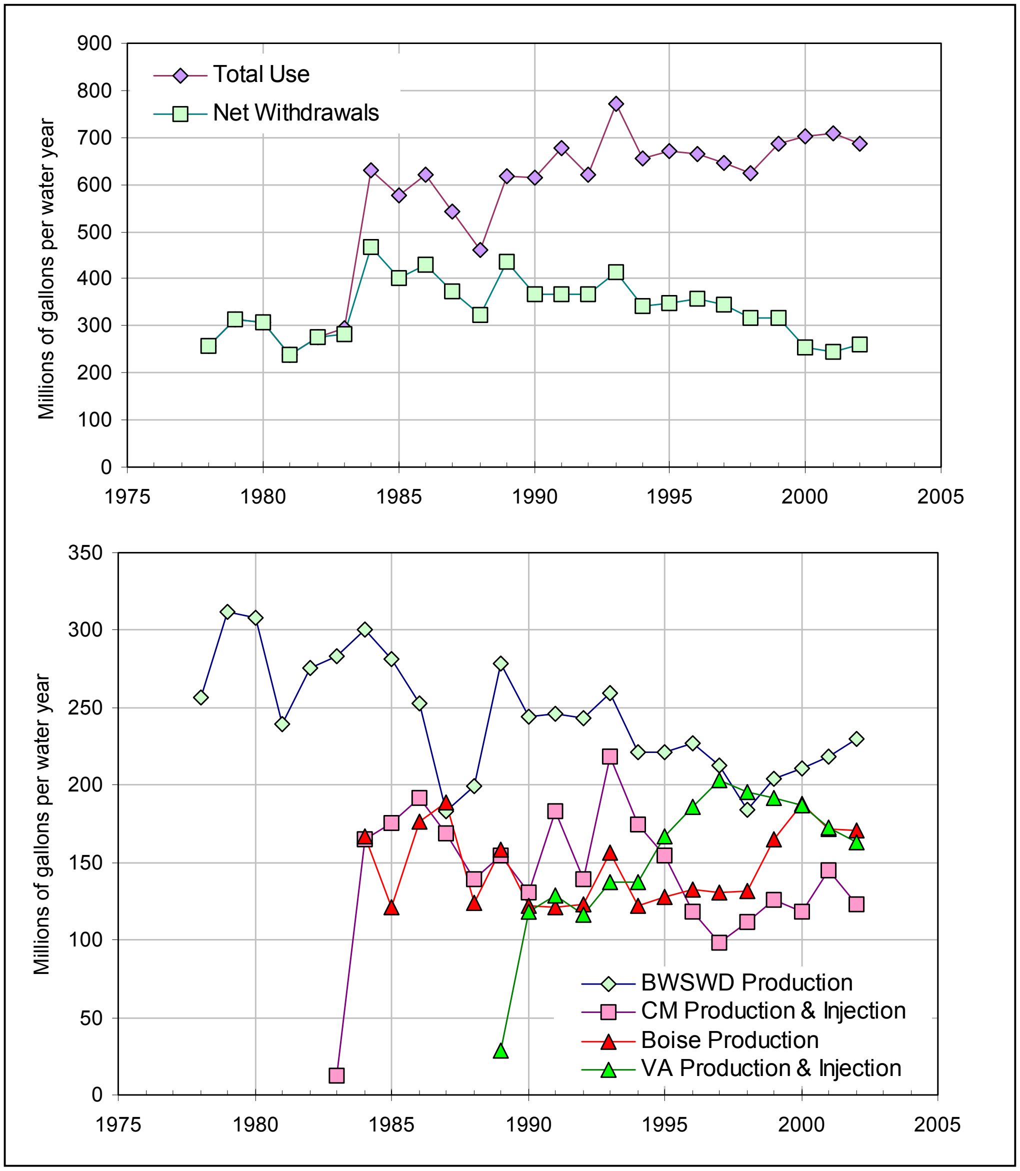


Figure 4-2: Estimated annual geothermal production in the downtown – Table Rock area.

Three new geothermal systems were developed in the downtown Boise area during the 1980s based on results from geothermal exploration during the late 1970s. First, the State of Idaho began heating the State Capitol building and surrounding office buildings with geothermal heat. The State Capitol Mall (CM) system began operation in the fall of 1982, and has withdrawn approximately 150 million gallons per year since that time. Production in the State of Idaho system spiked in 1993, although the reason for the production spike is unclear. All of the effluent is re-injected into the geothermal aquifer through the CM#1 well (Figure 4-1).

Next, the City of Boise (City) system began operation in the fall of 1983. The City system provides water for space heating to a number of downtown government and commercial buildings (Figure 4-1). Production in the first years of operation ranged from 121 to 189 million gallons per water year, and averaged 140 million gallons per year between 1984 and 1998 (Table 4-3). In 1998, the City of Boise drilled an injection well at Julia Davis Park (Figure 4-1). Injection of spent geothermal water began in February 1999, although a portion of the City's production continues to be discharged to the Boise River (Table 4-3). Annual City production increased between 1999 and 2001 (Figure 4-2), but net production (total production minus injection) decreased by approximately 100 million gallons per year during that period (Table 4-3 and Figure 4-2).

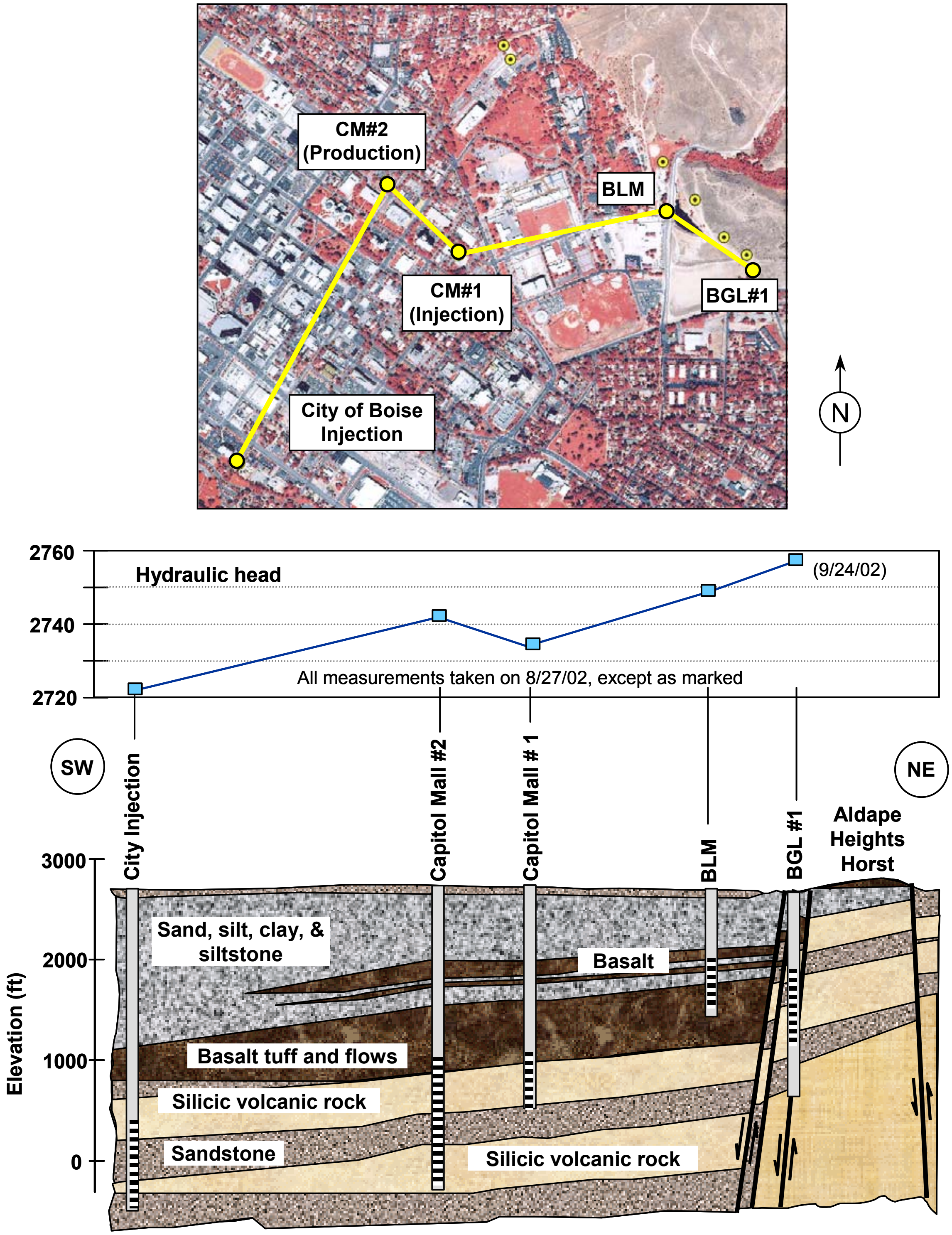
The Veterans Administration (VA) system began operation in the fall of 1988. The VA uses geothermal water primarily for space heating at its campus north of downtown Boise. The VA system has withdrawn an average of approximately 142 million gallons per year (Table 4-3 and Figure 4-1). All of the spent thermal water is re-injected into the geothermal aquifer via the VA injection well.

The Quarry View well was reconstructed in 2001 into a two-piezometer monitoring well (Scanlan, 2001). One piezometer was completed between 600 and 700 feet below ground surface; the second piezometer was completed between 813 and 848 feet below ground surface. In 1984 Anderson & Kelly (Castelin, 1984) found temperatures between 131° and 134°F between 620 and 660 feet, and 158°F at about 825 feet. These temperatures were not as hot as the 172°F temperatures in the BWSWD wells, and therefore, despite proximity to the BWSWD wells, probably are not drawing water from the same aquifer zones.

In summary, the net withdrawals from the downtown – Table Rock area (total production minus the amount re-injected) were highest in the mid-1980s, peaking at approximately 467 million gallons in the 1984 water year (Table 4-3 and Figure 4-2). Net withdrawals have decreased since then, averaging 354 million gallons per water year between 1990 and 1999. Net withdrawals between 2000 and 2002 were approximately 253 million gallons, reflecting, in part, the commencement of injection by the City of Boise in 1999.

4.1.2. Hydrogeology

Wood and Burnham (1987) developed a general stratigraphic sequence for the downtown Boise area (Figure 4-3). Uppermost sediments may include shallow alluvium (in the vicinity of the Boise River) or coarse-grained Pleistocene sediments of the Snake River Group. These shallow sediments overlie Tertiary-aged sands, silts, and clays. These sediments are remnants of transgressive episodes during the filling of Lake Idaho, and regressive facies as Lake Idaho slowly drained.



Cross section adapted from Wood and Burnham (1987). Approximate vertical scale.

Figure 4-3: Stratigraphy and hydraulic gradient of the Boise Front geothermal aquifer in the downtown Boise area.

Geothermal flow in this area is thought to be dominated by a zone of faulting parallel to the Boise Front (Figure 3-3). In addition, a seismic reflection survey (Liberty, 1996a) from the vicinity of the City geothermal production wells to BSU and from BSU to Ann Morrison Park provided evidence of a major fault offset of approximately 600 feet in the vicinity of 9th Street and Royal Boulevard. Based on offset, location, and inferred orientation, this fault has been interpreted (Wood, 1996a; Wood, 1996b; Wood, 1996c) as an extension of the Eagle-West Boise fault (Figure 3-3). The magnitude of offset suggests that this fault might function as a geothermal system boundary, with either reduced or enhanced flow characteristics.

The East Boise Fault (Figure 3-3), a north-northwest trending fault, extends south-southeast to the vicinity of the Old State Penitentiary and beyond to Barber Dam on the Boise River (Squires et al., 1992). In addition, a northeast trending fault is discernible near Warm Springs Creek, from southeast of Table Rock to just west of the Harris well.

In general, the geologic section on the downthrown side of the main frontal fault system along the Boise Front (in the downtown – Table Rock area) consists of the following (top to bottom) sequence (Burnham and Wood, 1983).

1. Recent-age alluvium of the Boise River floodplain and tributary fan deposits extend from ground surface to typical depths of 30 to 80 feet. These deposits are associated with the Snake River Group, and generally consist of coarse-grained sediments with large cobbles. An unconfined cold-water aquifer in these deposits is tapped by irrigation, municipal, commercial, industrial, and domestic wells.

2. Sand, silt, clay and siltstone sediments of the lower Idaho Group underlie the recent-age alluvium. The lower Idaho Group sediments are lake-margin sediments that grade to finer-grained units laterally away from the granitic source in the Idaho Batholith. The base of the Idaho Group sediments extend to depths of a few hundred feet in close proximity to the Front, and to depths of more than 1500 feet at the City of Boise Injection well. The upper 600 to 1000 feet of these sediments generally contain cold-water aquifers tapped by domestic, municipal, and irrigation wells in the Boise area.

   Silica cemented sandstones of the Idaho Group occur in the eastern foothills in the vicinity of Table Rock. These sandstones were cemented by precipitation of dissolved silica contained in geothermal water.

   One or two Tertiary basalt flows are found near the bottom of the lower Idaho Group. These basalt flows range in thickness from 10 to 150 feet.

3. Basaltic tuffs and flows, with beds of arkosic and tuffaceous sediments, underly the lower Idaho Group. This unit's thickness is highly variable, but is up to about 600 feet thick. The basalt tuff probably functions as a confining unit above the main geothermal aquifer, separating geothermal aquifers from overlying non-thermal aquifers. Where competent and fractured, the basalt unit may yield warm water to wells – some wells (e.g., BLM) completed in basalt are hydraulically connected to underlying geothermal zones.

4. Two Tertiary-aged rhyolite flows, separated by coarse-grained sediments, form the main geothermal aquifer in most of the wells. This sequence of volcanic rock and sediment is part of the Idavada Group.

   The upper rhyolite is multicolored, generally varying from black to yellowish brown, often with bluish or green colors. Where dark colored, the rock is commonly mistaken for basalt or andesite. This rhyolite is approximately 400 feet thick at the Capitol Mall #2 well and perhaps somewhat thicker at the City of Boise injection well. The upper rhyolite is reported to be the main geothermal reservoir rock, based on the current wells penetrating this zone.

   Below the upper rhyolite is coarse-grained sandstone and conglomerate, with interbedded silicic tuff. These sediments are approximately 300 feet thick at the Capitol Mall #2 well and 400 feet thick at the City of Boise injection well. The coarse nature of these sediments suggests that, if not cemented, they may have relatively high conductivities and porosities.

   The lower rhyolite is approximately 300 feet thick. It generally consists of light gray to dark greenish gray rock with quartz and feldspar phenocrysts. The lower rhyolite is generally believed to be less permeable than the upper rhyolite. In the City of Boise injection well and in BGL No. 1, the lower rhyolite is underlain by at least 200 feet of coarse-grained sediments.

5. Granitic rock of the Idaho Batholith (Cretaceous-aged biotite granodiorite and granite) is generally believed to underlie the volcanic rocks associated with the geothermal aquifer. The granite has been penetrated only in wells drilled into upthrown fault blocks along the frontal fault system, such as BGL #1. Granite of the Idaho Batholith was also penetrated in the lower portion of both of the Harris wells. The water-bearing characteristics of unfractured granitic rock are generally poor, and therefore the granite, where unfractured, may function as the bottom of the geothermal aquifer. However, recharge to the Boise geothermal aquifer is thought to travel as deep circulation through open fractures in the granite from upland areas to the north and east. Locally,

the granite may have sufficient fracture permeability along the faults to yield water to wells.

4.1.3. Water Levels

Periodic water level measurements or pressure readings have been taken in a number of geothermal wells since the early 1980s. Most of these water level measurements were conducted by geothermal users and well owners, and were obtained from IDWR files. Numerous measurements were conducted and reported by consultants and/or the BSU Department of Geosciences. In some cases, the data sources are unknown. Measurements conducted on August 27, 2002 were taken by T. Scanlan, E. Squires, K. Johnson, and C. Petrich. Hydrographs based on these measurements for wells in the downtown – Table Rock area are provided on pages 30 through 32.

Water levels in the downtown area have reflected the impacts of geothermal production rates:

1. Prior to development, the static water levels in the geothermal system were at least 50 feet above ground surface at the BWSWD, based on Lindgren's report from 1896 or 1897. Since the BWSWD wells had been flowing for several years at that time, actual pre-development static water level may have been more than 50 feet[3].

2. From the early 1900s until 1982, the system is assumed to have been in equilibrium, with an average annual discharge of approximately 275 to 300 million gallons (840 to 920 acre-feet annually). Water levels peaked each August or September at elevations of 2,760 to 2,765 feet, as measured at the BLM well[4] (Figure 4-4). Artesian flow occurred for several days each summer during this time period at the BWSWD wells (Figure 4-5 and Figure 4-6).

3. BWSWD East and West well hydrographs indicate relatively low summer peaks in 1977 and 1978. However, pump house logs for those years indicate that the "East Well flowing" in 1978 and 1979 (Scanlan, 2003), with no mention of whether this occurred in 1977. The water level data shown for these wells (Figure 4-5 and Figure 4-6) between 1977 and 1979 may be suspect.

4. The CM system began pumping in November of 1982 (Table 4-1). The total CM production volume was not recorded for 1982-83, but is

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[3] Water level estimates (or assumptions) made for wells under flowing artesian conditions without the use of accurate pressure gauges may be in error – hydraulic head values could be feet or tens of feet above the well casing for wells flowing under artesian conditions.

[4] The BLM well, which has been monitored by the USGS and Boise State University, has one of the longest, better-quality records of water levels in the geothermal aquifer in the Boise area.

assumed to have been similar to that of later years, i.e., approximately 160± million gallons per year (Table 4-3). All spent water was re-injected into the geothermal aquifer. The peak 1983 summer water levels in the BLM well appear to fall in the range of prior years (Figure 4-4), but there are insufficient data from the BLM well between November 1982 and summer of 1983 to identify possible impact from the CM production/injection. There is a very slight decrease in summer peak water levels in the BWSWD wells (Figure 4-5 and Figure 4-6) between 1982 and 1983, although the change appears to be well in the range of normal year-to-year fluctuations. In general, it appears that the CM system did not have a net impact on local geothermal water levels during this period.

5. The City of Boise (i.e., BGL) wells began operating in October of 1983 (Table 4-1). Net geothermal production from the aquifer increased by approximately 180 million gallons between the 1983 and 1984 water years (Table 4-3). Water level data for City of Boise wells were not available from this time. However, the BLM well, which is completed in the basalt overlying the rhyolite aquifers, is thought to be a good indicator of geothermal water levels in the Boise area. Water levels in the BLM well (Figure 4-4) began declining in the winter of 1983 (compared to water levels from 1976 through the summer of 1983), declining a total of approximately 30 feet between 1983 and 1988. Water levels in the BWSWD East (Figure 4-5) and West (Figure 4-6) wells also declined during this period, as did the VA production (Figure 4-9) and Kanta (Figure 4-11) wells. Water levels also appear to have declined during this period in the BWSWD #3 (Figure 4-7) and Old Pen (Figure 4-10) wells, but the data for these wells are incomplete during this period. The declines appear to have been caused by the increased production from the BGL wells. Artesian flow has not occurred at the BWSWD wells since the City system began operation in 1983.

6. The VA system (Figure 4-9) began operating in the fall of 1988. The total VA production volume was not recorded for the 1988-89 season, but is assumed to have been similar to later years (100 to 200 million gallons, 300 to 600 acre-feet). All production was re-injected. No change in summertime BLM or BWSWD water levels occurred in the fall of 1989 or later years. This suggests that the VA system did not have a net impact on geothermal water levels.

   The VA hydrographs appear to show some spurious water level readings. For instance, a measurement taken by the VA by air line on 7/29/02 shows a water level of 2,682 feet (approximately 75 feet below ground surface), yet two measurements taken by the author on 8/27/02 and 9/24/02 indicated water levels at approximately 2760.6 feet (at ground surface). Flowing artesian conditions were observed at the second measurement, taken while the pump was temporarily removed from the well. Artesian conditions were assumed to reflect City of Boise injection (which began in February 1999).

7. Summertime peak water levels in the BLM well (Figure 4-4) were relatively stable at approximately 2735 feet from 1987 through 1998. Water levels began to rise beginning in the fall of 1999, apparently in response to City injection activities since 1999. Since 1998, water levels at the BLM well have recovered approximately 20 feet, probably in response to a 100 Mgal/yr net production decrease. Water levels from the August 2002 indicate that the BWSWD wells have also risen by over 20 feet since the mid-1990s.

8. There were three known water level measurements taken in the Old Pen well prior to 1988. A static depth-to-water of 73.5 feet was reported when the well was drilled in the summer of 1965. Two water level measurements in 1983 (Figure 4-10) indicated a depth-to-water of approximately 50 feet, and a 2002 measurement indicated a depth to water of approximately 50 feet. Subsequent measurements (not shown), however, indicated depths to water of about 70 feet (Neely, 2003). A series of measurements between 1988 and 1996 indicate water levels approximately 70 feet below ground surface. If the 1983 measurements are accurate, then water levels in the Old Pen well appear to have decreased in the 1980s to a depth-to-water level of 70-75 feet below ground surface (Figure 4-10), but have risen to a depth of approximately 52 feet below ground surface between 1987 and 2002. However, two subsequent measurements (Neely, 2003) suggest that water levels have not risen since the 1980s.

9. Water level measurements in the Kanta well (Figure 4-11) indicate a water level decline during the mid 1980s. A resumption of monitoring in the Kanta well beginning in August 2002 shows increased water levels consistent in magnitude with water level increases observed in other downtown – Table Rock wells. The historical data in this well are reported as reliable measurements obtained using a continuous float and cable water level chart recorder (E. Squires, *personal communication*, 2003).

10. Recent data from the Quarry View well (Figure 4-12) indicate similar (Neely, 2003)water levels in both Quarry View piezometers over time, which suggests hydraulic connection between the zones in which the Quarry View piezometers are completed. A general decrease in water levels during the summer suggests possible local irrigation influences.

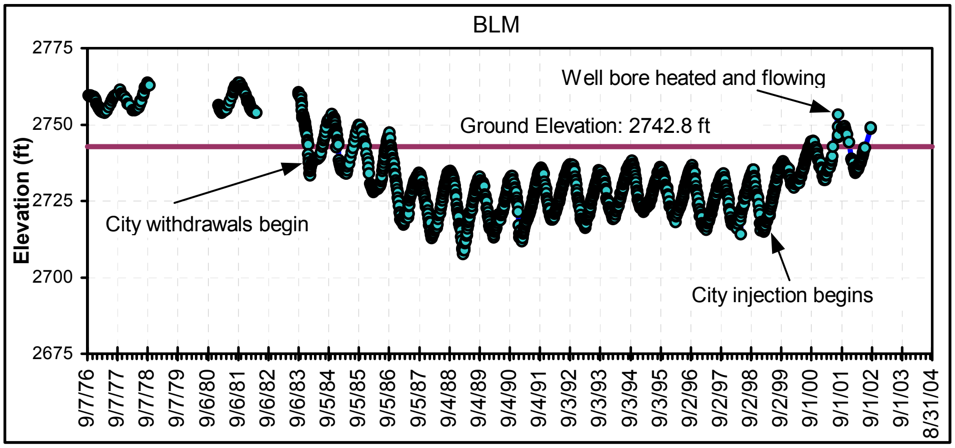

Figure 4-4: Hydrograph for the BLM well.

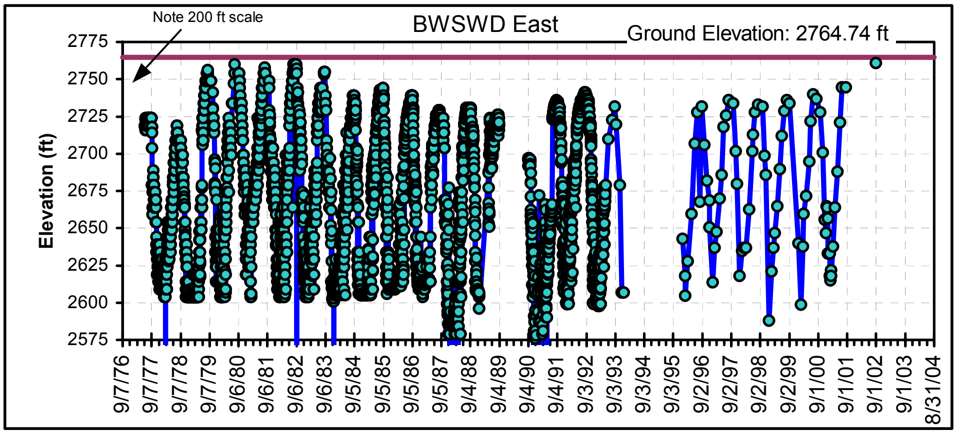

Figure 4-5: Hydrograph for BWSWD East well.

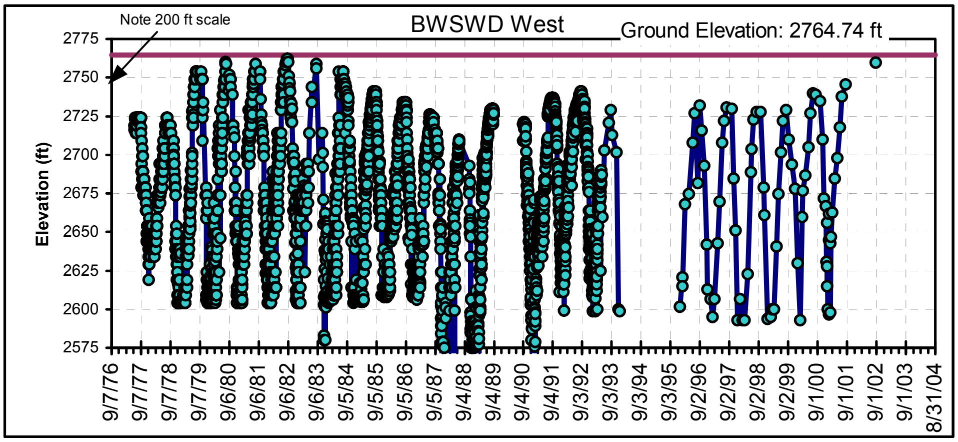

Figure 4-6: Hydrograph for the BWSWD West well.

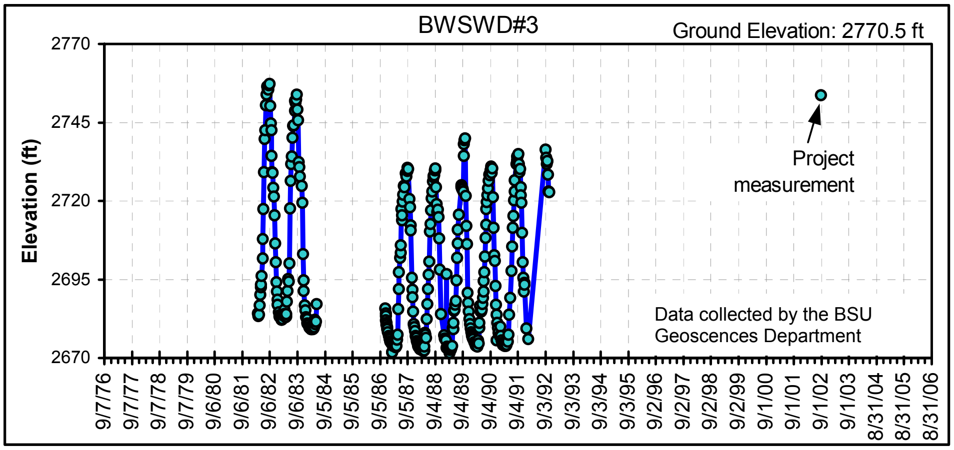

Figure 4-7: Hydrograph for the BWSWD #3 well.

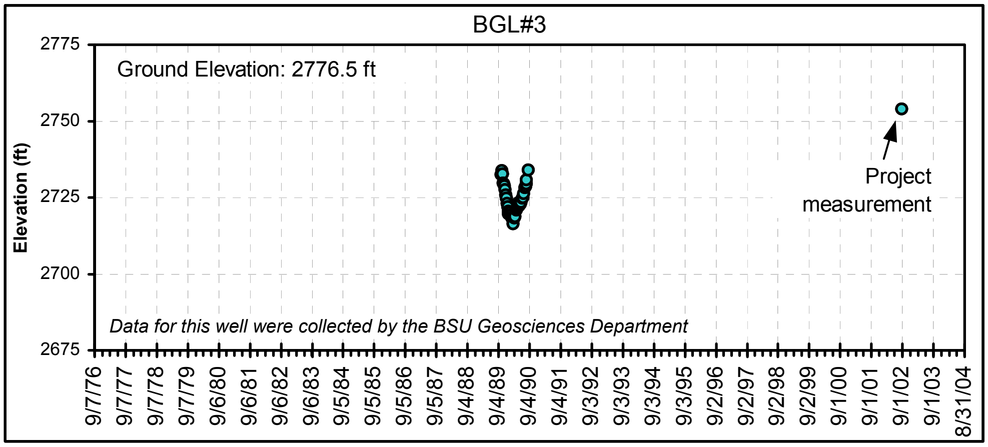

Figure 4-8: Hydrograph for the BGL #3 well.

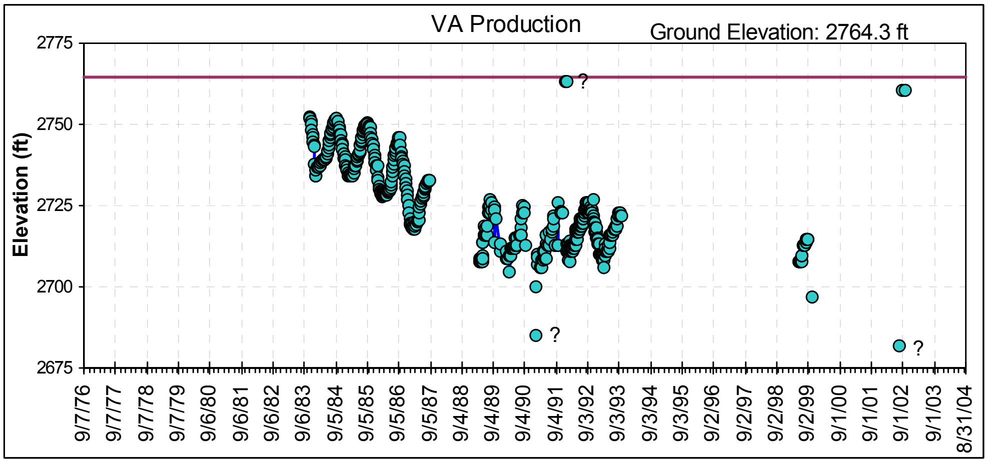

Figure 4-9: Hydrograph for the VA Production well.

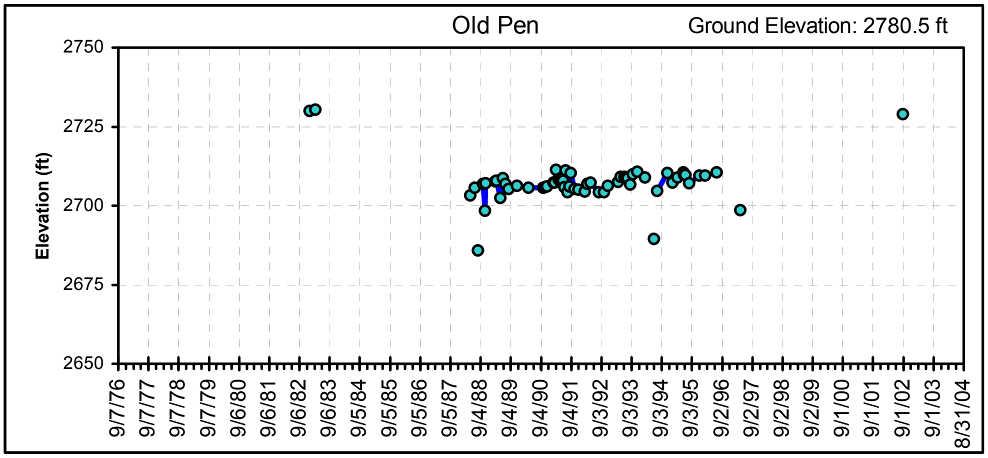

Figure 4-10: Hydrograph for the Old Pen well.

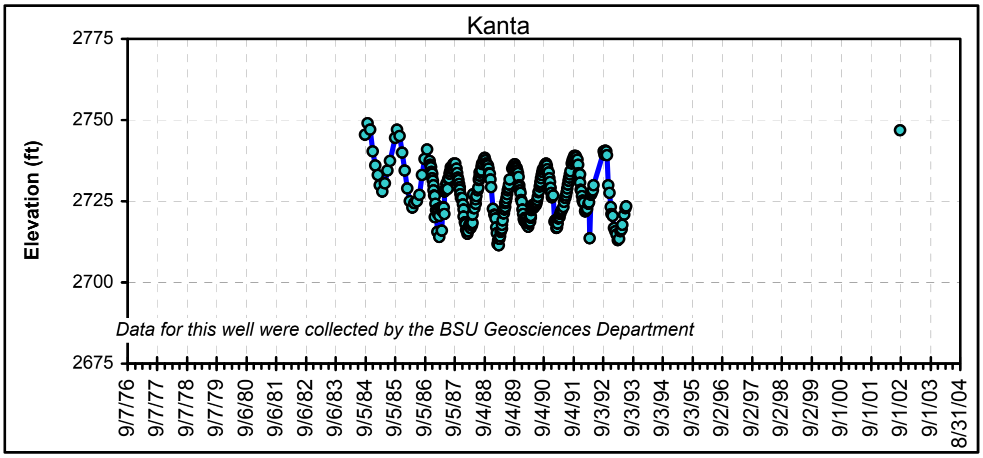

Figure 4-11: Hydrograph for the Kanta well.

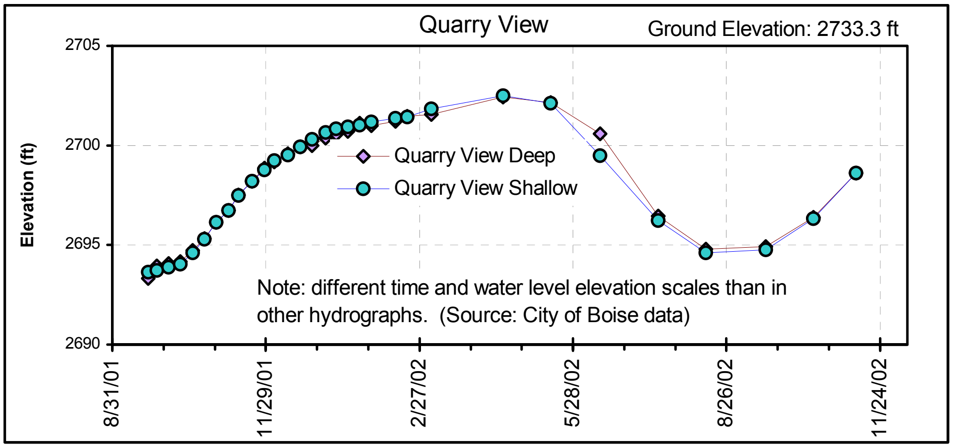

Figure 4-12: Hydrographs for Quarry View wells.

4.1.4. Temperature Data

Few current temperature data are available for downtown – Table Rock area wells. One of the only complete long-term records is for water temperatures in the CM #2 well (Figure 4-13). Low recorded temperatures during summer months probably reflect the well bore cooling during times of little or no flow.

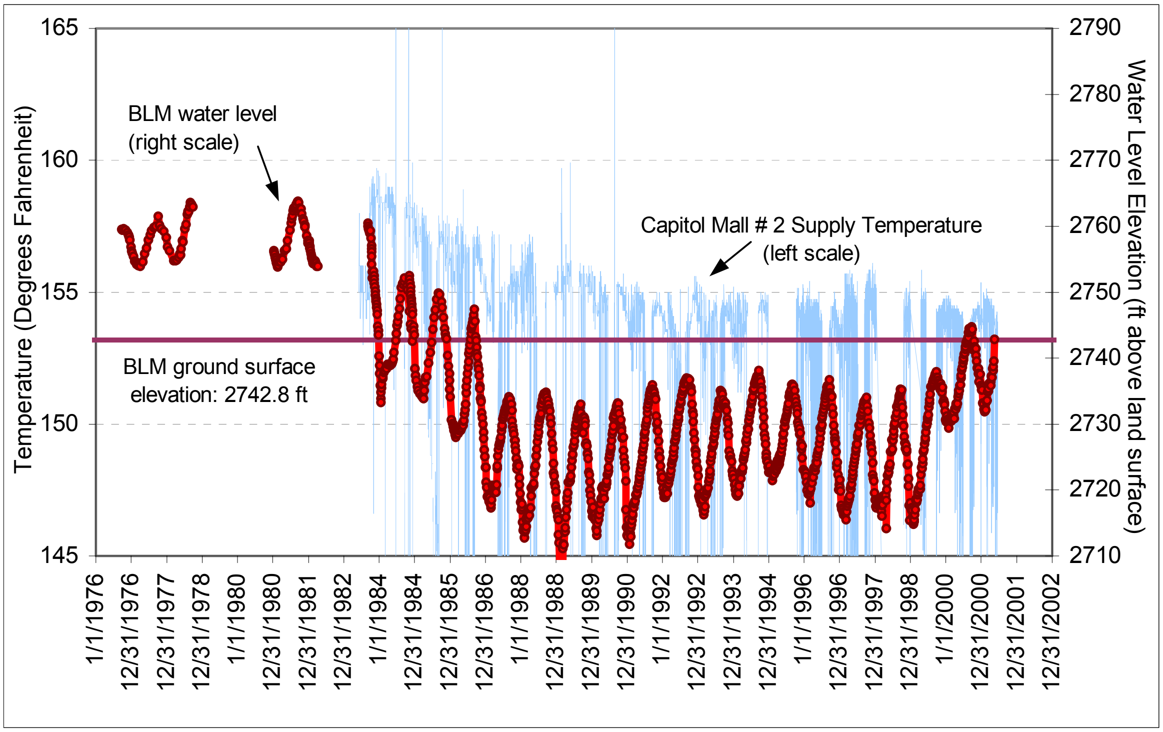

Figure 4-13: CM #2 discharge temperatures and BLM water levels.

There appears to be a downward temperature trend from about 1983-1990 (Figure 4-13). Several alternative explanations could be considered for the temperature decline. First, the temperature decline might reflect a decreased large-scale geothermal reservoir temperature decrease, but decreased temperatures were not reported by other major geothermal users. Second, the temperature decline in the CM#2 well might have been caused by the change in local hydraulic heads associated with City withdrawals beginning in 1983-84. This may have occurred if the change in hydraulic heads caused by City withdrawals led to mixing of water with slightly different temperatures. However, if this were the case, one would expect a reversal of the temperature trend as hydraulic heads began to rise in response to City injection, which does not seem to have occurred. Third, the temperature decrease may reflect conditions during the time that it took for the circulation loop (i.e., warm water withdrawals, and cooler water injection) between the two Capitol Mall wells to reach temperature equilibrium. Similarly, local changes in hydraulic head associated with the Capitol Mall production/injection loop may have induced water of slightly different temperatures reaching the production well, causing the temperature variations in the water flowing into the production well. Given the amount of available information, it seems most likely that local conditions in the Capitol Mall couplet are primarily responsible for the temperature decline from 1983 to 1990. However, temperatures in Capitol Mall and other systems should be monitored and reported most closely.

Temperatures since 1990 appear to have remained relatively steady. Temperatures do not appear to have risen after 1999 when the City began re-injecting water[5], and when water levels began to recover. Temperatures in the 1999 and 2000 water years are slightly less than earlier measurements, but it is not clear whether this represents a downward trend. Temperatures in 2002 (not shown) appear slightly less than previous years (Ken Neely, personal communication) – this may reflect a slight decrease or an aging temperature sensor (the temperature sensor in this well should be checked).

Temperatures in the City wells have remained relatively stable since City production began (Kent Johnson, *personal communication*), as have temperatures in the BWSWD wells (Dick Clark, *personal communication*). Of the BWSWD wells, Griffiths (1990) wrote that the "geothermal water comes from the wells at a temperature of approximately 172° F and has shown no change during the last thirty years of personal experience."

4.1.5. Aquifer Test Data

A summary of the various well and aquifer tests evaluated for this study is provided in Table 4-4. Also included are transmissivity values used in previous modeling efforts. The range of calculated transmissivities reflects the varied nature of the tests and the heterogeneity of the aquifer. The 7-day test of BGL #2 in 1982, which included observations in all of the BGL wells, the BLM well, and both CM wells, indicated that hydraulic boundaries or significant lateral changes in permeability are present within the aquifer.

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[5] Based on recorded CM #2 temperatures and anecdotal user information.

4.2. Stewart Gulch Area

4.2.1. Description of Use and Development

The Stewart Gulch area is located approximately two to three miles northeast of the downtown Boise area (Figure 4-14). Primary thermal water users in this area include Terteling Ranch, the Flora Company, Quail Hollow Golf Course, Edwards Greenhouses, and residential homes. Wells in this area include the Terteling Motorcycle, Terteling Pool, Terteling Windsock, Quail Hollow Upper, Quail Hollow Lower, Tiegs, Flora Office, Silkey (Flora shed), and Edwards wells (Figure 4-14). Geothermal water in the Stewart Gulch area is used primarily for space heating with some irrigation (Table 4-5). Production in the Stewart Gulch area is currently estimated at approximately 250 million gallons of water per year from wells ranging in temperature from approximately 90º to 125ºF.

Pumping Well	Test Rate (gpm)	Date	Reported Transmissivity (gpd/ft)
Beard	100-380	1976-78	Beard: 6,000 to 8,000 BLM: 69,000 to 90,000
BLM	90-120	1977-78	BLM =600 to 20,500 Beard =100,000
BWSWD#1 (West Well)	250-1,300	1979	BWSWD#1: 15,000-50,000
BWSWD#2 (East Well)	350-1,600	1979	BWSWD#2: 15,000-30,000
CM-1	350-800	1980	CM-1: 5,000
CM-2	300-1,450	1981	50,000-100,000 @ CM-1, BLM, BGL
BGL-2	400-1,000	1982	125,000-825,000 @ CM, BLM, BGL
BGL-4	20-160	1982	112,000-820,000 @ CM, BLM, BGL
VA Prod	400-1,245	1983	200,000 from specific capacity
BWS/Kanta		1985	3500-25,000 – (Waag and Wood)
VA Injection	180-580	1987	Not calculated from short-term data
Aquifer System		1989	Berkeley Group analytical modeling indicated average T=5750 gpd/ft
Aquifer System		1994	Montgomery Watson numerical modeling indicated 100,000 to 1,000,000 gpd/ft for downtown-Warm Springs area, 5,000 to 50,000 for outlying areas
City Injection	400-1,800	1998	185,000 near well, 25,000-30,000 long-term

Table 4-4: Summary of aquifer transmissivities, downtown – Table Rock area.

Geothermal development at the mouth of Stewart Gulch began in the early 1920s with the drilling of the two Silkey wells in 1921 and 1922 (Table 4-6) at the present Flora

Company Greenhouse site. These wells reportedly flowed 42 miners inches (378 gpm) in 1924 and 1925. No shut-in pressure measurements are available for this period.

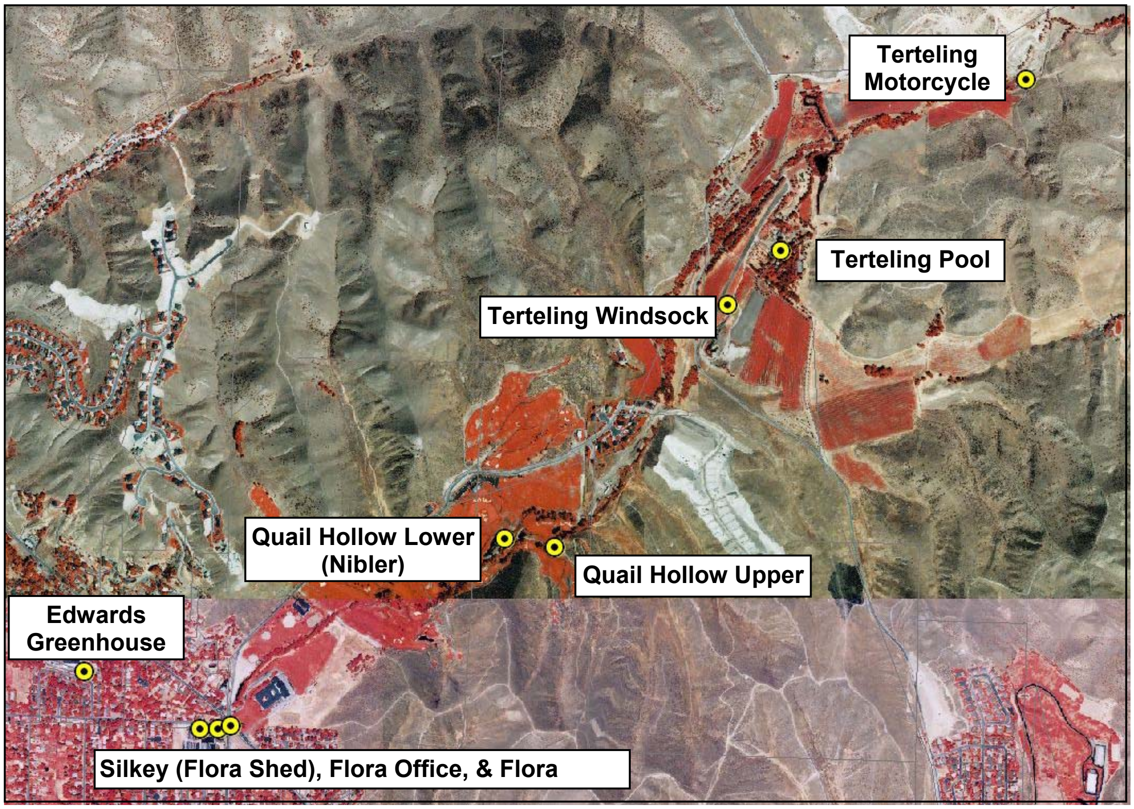

Figure 4-14: Locations of selected geothermal wells in the Stewart Gulch area.

The Edwards well was drilled in approximately 1926, followed by the Tiegs well in about 1927. A well was also drilled for Ryan in 1927. Alleged interference effects between these wells and water level declines in the aquifer apparently prompted legal action. The resultant Silkey v. Tiegs decree restricted diversions by Edwards, and prohibited diversions by Tiegs and Ryan. The apparent intent of the decree was to protect artesian pressure in the Silkey wells.

Artesian pressure was measured at 31 pounds per square inch (psi) in one of the Silkey wells on August 21, 1930. More than seventeen years later (October 23, 1947), the USGS measured a similar shut-in pressure (30.8 psi), and a combined flow from the Silkey and Tiegs wells of 37.4 miners inches (337 gpm). This flow from the two Silkey wells and the larger Tiegs well was less than the flow reported for the two Silkey wells alone in 1924 and 1925. This may suggest that the original shut-in pressure for the Silkey wells was somewhat higher than 31 psi. Alternatively, it may indicate measurement error or loss of well efficiency between 1924 and 1947.

Well	Alternate Name	Entity	Current Use
Terteling Motorcycle[6]		Terteling Ranch	Commercial (currently used only for monitoring)
Terteling Windsock		Terteling Ranch	Commercial (space heating)
Terteling Pool		Terteling Ranch	Space heating and recreation
Quail Hollow Upper	Tee Ltd.	Quail Hollow Golf Course	Irrigation
Quail Hollow Lower	Nibler	Quail Hollow Golf Course	Irrigation
Edwards		Edwards Greenhouse	Commercial (space heating)
Flora Office	Old Flora Office	The Terteling Company (formerly Flora Co.)	Commercial (space heating)
Silkey	Flora Shed	The Terteling Company (formerly Flora Co.)	Commercial (space heating)
Tiegs	Flora Triangle	The Terteling Company (formerly Flora Co.)	Commercial (currently used only for monitoring)

Table 4-5: Primary thermal wells in the Stewart Gulch area.

Shut-in pressures at the Silkey and Tiegs wells have been recorded since 1988. Pressure at the Tiegs well has ranged from 19.5 psi (June 11, 1998) to zero psi (August-September 1992 and June-July 1994). Pressure at the Silkey Shed well has ranged from 16.5 psi (38 feet above ground surface) on June 11, 1998 to 3.35 feet below ground surface on August 18, 1994.

Shut-in pressures at the Edwards well have been recorded since 1981, and have ranged from 29.5 psi (June 11, 1999) to 6.5 psi (August 20, 1994). Bob Griffiths (notes dated 1/19/81) was told by Paul Edwards that the maximum observed shut-in pressure prior to 1981 was 38 psi, but no date was given for this measurement. Pressures at the Edwards well appeared to be approximately 10 psi greater than at the Silkey and Tiegs wells. Elevation difference would account for 7 or 8 psi of difference. Inaccuracies associated with poorly functioning gauges also account for some of the difference (E. Squires, *personal communication*).

Diversion from the Silkey and Tiegs wells in past years was estimated at between 320 and 380 af/yr (Squires, 2002). Recorded discharge from the Edwards well from 1990 to 2000 ranged from 152 to 234 af/yr (Scanlan, personal data files). In combination, the average production from the Edwards and Flora (Silkey-Tiegs) sites probably totals about 500 af/yr.

Development of the geothermal aquifer in central Stewart Gulch apparently began with drilling of the Terteling Ranch wells in the 1940s and the Nibler well (Quail Hollow Lower) at the present site of Quail Hollow Golf Course. A water right permit was not

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[6] All references to the Terteling Motorcycle well in this report refer to a geothermal well; a cold-water well also is present at the same location.

obtained at the time, but a statutory water right claim (63-4037) was filed for 0.67 cfs and a priority date of October 1931. The extent of use of the well from 1931 through the early 1980s has not been determined.

Time	Event	Source
1922	First Silkey well drilled	Claim 63-12
1921	Second Silkey well drilled	Claim 63-13
1924-25	Silkey wells discharge 42 inches	Notes of R.L. Nace (data from District Court records)
11/22/1926	Edwards well drilled	Claim 63-14
3/23/1927	Tiegs well drilled	Claim 63-15
8/21/1930	George Carter measurement of Silkey at 31 lbs	Notes of R.L. Nace (data from District Court records)
10/1/1931	Nibler well drilled	Claim 63-4037
11/1/1940	Terteling Springs well drilled	Claim 63-31054; 0.055 cfs
10/23/1947	USGS measurement Silkey/Tiegs; 337 gpm; 30.8 psi	Notes of R.L. Nace, USGS in IDWR files
4/24/1948	Terteling Pool well drilled	Claim 63-31052; 0.12 cfs
4/26/1967	Terteling hot water irrigation begins	License 63-3603 priority date
1968	Terteling Windsock drilled	IDWR driller’s report
3/7/1973	Terteling hot water irrigation expanding	License 63-7595 priority date
1978	Terteling Motorcycle Hot well drilled	IDWR driller’s report
1981	Tee Limited well drilled (deepened in 1982)	IDWR driller’s report and IDWR file notes
5/23/1984	Begin Quail Hollow Upper pumping	Permit 63-9758 approved
Sep-88	Windsock well not used "for years"; Motorcycle well provides all irrigation*	IDWR Terteling inspection notes
1997	Terteling cold water irrigation well constructed	IDWR driller’s report
1998	Water District 63-S covering the Stewart Gulch area established	IDWR files
1998	Quail Hollow cold water well constructed	IDWR license file
2002	Transfer of water rights from the Flora Company to The Terteling Company	IDWR files

* See text.

Table 4-6: Partial chronology of geothermal development and/or responses in the Stewart Gulch area.

Irrigation of the Quail Hollow Golf Course began sometime in the early 1980s using the Nibler well and Tee Ltd well. The Tee Ltd well (Quail Hollow Upper well) was drilled to 710 feet in 1981, but was deepened and completed sometime in 1982. The water right permit for the Quail Hollow Upper well was approved in May 1984. Therefore, irrigation of the golf course may have begun in 1984. The golf course is assumed to cover approximately 100 acres, and therefore requires approximately 350 af/yr (3.5 af per acre) for irrigation. A portion of this supply may have been derived from surface flow in Stewart Gulch. Therefore, an estimate of 250 af/yr of geothermal water pumping seems reasonable. However, the 250 af/yr estimate is far greater than the volumes reported by Quail Hollow. For instance, Quail Hollow reported a total production of 17.5 million in 1995. Assuming that Quail Hollow is reporting in gallons (rather than cubic feet), the 1995 production would be only 54 acre-feet. This volume is adequate for irrigating only about 15 acres.

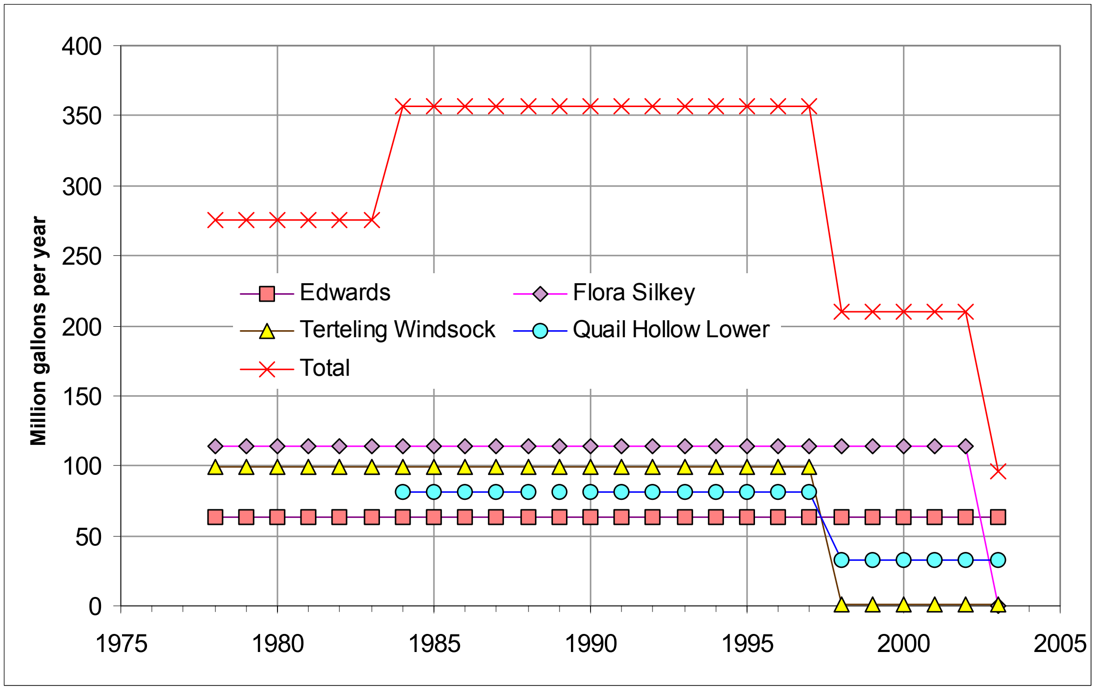
A cold-temperature ground water source (shallow water well) for Quail Hollow was developed south of Hill Road in 1998. The water is piped to the golf course for irrigation. Average production from this well in 2000 and 2001 was approximately 166 af/acre (K. Neely, *personal communication*, 2003).

Geothermal development in Stewart Gulch on the Terteling Ranch may have begun with drilling of a small artesian well at Terteling Springs in 1940 (claim 63-31054, 0.055 cfs and 17 af/yr), followed by drilling of the Terteling Pool well in 1948 (claim 63-31052, 0.12 cfs and 3 af/yr). Significant development for irrigation then occurred with drilling of the Windsock well in 1968 and the Motorcycle Hot well in 1978. In combination, the two wells were licensed for irrigating 178 acres. Information in IDWR files (Castelin, 1988) indicates that the "lower well" (assumed to be the Windsock well) is "infrequently used," and that nearly all of the irrigation pumping in the 1980s occurred from the Motorcycle well. However, E. Squires indicated that (at least in the last 10 years) nearly all of the pumping from these wells occurred in the Windsock well (because of lower pumping lifts), and that the Motorcycle well was used as a backup to the Windsock well (Squires, 2003). If a portion of the irrigation demand was derived from surface water and cold ground water sources, and that approximately 150 acres were irrigated, the geothermal water demand was probably on the order of 300 af/yr. This demand occurred until about 1997 when an additional cold ground water source (Champagne well) was developed.

There are very few reliable Stewart Gulch geothermal production rates prior to recent years. Nonetheless, possible production rates were estimated for primary geothermal wells in the previous paragraphs (there is a high degree of uncertainty in some of the estimates). These estimated production rates are illustrated in Figure 4-15. Production in the Flora Silkey, Office, and Tiegs wells is shown as dropping to zero; however, production from these wells is being or will be transferred to the Terteling greenhouses.

4.2.2. Hydrogeology[7]

Two Tertiary basalt layers appear to be the primary source of thermal water in the Stewart Gulch wells. In contrast to wells in the Boise downtown area, no rhyolite has been confirmed in the Stewart Gulch wells (Stewart Gulch wells have not penetrated through the basalt). Water-bearing zones within the basalt layers appear to be at discrete intervals. For instance, water had to be added to the Quail Hollow well during drilling (with cable-tool) to suspend cuttings while drilling basalt prior to reaching the bottom of the well once the present well yield was encountered. Down-hole camera footage of the Terteling wells shows many basalt fractures to be filled with calcium carbonate precipitates.



This figure does not include production from the Terteling Windsock well that is now being used to heat the Terteling greenhouses (using water rights formerly held by the Flora Company), nor does it include remaining production at the Flora facility.

Figure 4-15: Estimated geothermal production in Stewart Gulch, 1978 to present.

A thick mudstone section of the Terteling Springs Formation overlies the thermal basalt aquifers. Over 1,100 feet of this low-permeability unit overlies the basalt aquifer at the old Flora Greenhouses, based on drilling logs from nearby wells and interpretation of natural gamma-ray geophysical logs from these wells. Midway up the

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[7] Most of the text in Section 4.2.2 was provided by Ed Squires, Hydro Logic, Inc., with permission from the Terteling family.

gulch, at Quail Hollow and lower Terteling Ranch, the mudstone is continuous from land surface to the top of the basalt aquifer at 750 feet. At the upper Terteling Ranch, the basalt aquifer is overlain by sandstone of the sandy facies of the Terteling Springs Formation. At the lower gulch area, Pleistocene floodplain gravels of the Snake River Formation along the Boise River overlie the mudstone. The upper portion of the gulch has a sandy facies associated with the Terteling Springs Formation exposed at ground surface. There appears to be no measurable hydraulic connection between cold and geothermal wells in the Stewart Gulch.

Conspicuous light-colored volcanic ash layers are interbedded within the volcanic geologic section and may serve as marker beds. Their tendency to spall into open boreholes is characteristic and problematic to open bore wells (Silkey, Tiegs, Terteling Motorcycle, and Tom Terteling geothermal wells).

Several shallow faults are observed in the Stewart Gulch area (Othberg and Stanford, 1992); several deeper faults are inferred and/or observed (Wood, 1996b). An east-west trending normal fault appears to exist within the volcanic section between Terteling Motorcycle and Terteling Pool wells. This fault was indicated by the Chevron IB-2 deep seismic line and is exposed along Cartwright Road (E. Squires, *personal communication,* 2002). This fault was confirmed by two shallow seismic surveys conducted by Boise State University (Liberty, 1996b) for the Terteling family.

The wells in the central gulch (Terteling Pool, Terteling Windsock, Quail Hollow Upper, Quail Hollow Lower) and those in the lower gulch (Silkey and Edwards Greenhouse) are in direct hydraulic connection, based on several pumping tests[8] (E. Squires, *personal communication*, 2002). The pumping tests failed to show a direct hydraulic connection between the Terteling Motorcycle geothermal well in upper Stewart Gulch and the other Stewart Gulch wells. The extent of hydraulic connection between the Motorcycle well and other Stewart Gulch wells is not currently known.

Geothermal aquifer water temperatures range from approximately 110º to 125˚F in the lower to mid Stewart Gulch area. Water temperatures in the Stewart Gulch fault block(s) containing the Terteling Motorcycle well range between 80° and 95˚F.

4.2.3. Water Levels

Periodic water level measurements or pressure readings have been taken in various Stewart Gulch wells. Hydrographs based on these measurements are provided on pages 44 through 45. Hydrograph data were provided by IDWR from measurements provided by water users (including Edwards Greenhouses and the Terteling family).

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[8] Conducted for the Terteling family.

Aquifer water levels in Stewart Gulch have fluctuated with changes in geothermal water use. Annual production volumes have not been well documented, and season of use has varied depending on whether users are irrigating or heating with the water. Therefore, relating changes in water levels to specific stress events is not uniformly possible, but some general observations are provided below.

1. Pre-development shut-in pressures were possibly more than 30 psi at the Silkey, Tiegs, and Edwards wells.

2. Geothermal aquifer development in the 1920s may have reduced aquifer pressures to approximately 31 psi at the Silkey wells by 1930. Pressures remained in this range until at least 1947 (IDWR, 1947).

3. Pumping for irrigation from the Quail Hollow-Lower (Figure 4-18) and upper Stewart Gulch wells, i.e., Windsock (Figure 4-20) and Motorcycle (Figure 4-21) wells, likely reduced maximum annual aquifer pressures by perhaps an additional 10 psi between 1947 and 1980.

4. Increased irrigation pumping in the late 1980s associated with Quail Hollow Golf Course reduced maximum annual aquifer pressures by an additional 5 psi.

5. Reductions in the use of geothermal water for irrigation beginning in 1997 (Terteling) and 1998 (Quail Hollow) resulted in substantial recovery (8 psi) of peak annual water levels. However, slight declines in water levels during 2000 and 2001 (Figure 4-18) suggests a partial resumption of geothermal water use for irrigation purposes (although resumption did not occur in the Terteling wells – E. Squires, *personal communication, 2003*).

6. The 1981 through 1997 period of the Edwards well hydrograph (Figure 4-23) shows more water-level influence from irrigation pumping than from heating pumping[9]. The annual high appears to occur in May or June, and the annual low occurs in late summer. Water level fluctuations between 1998 and 2002 (with the exception of the year 2000) appear to correspond with heating season withdrawals only.

7. The Edwards well has the longest water levels records in Stewart Gulch. Water levels in the Edwards well (Figure 4-23) show a decline beginning from approximately 1984 through 1994. The decline beginning in 1984

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[9] Some have speculated that water levels in Stewart Gulch also may be influenced by warm-water wells used for irrigation in other areas in the Boise Front (Figure 1-1), such as the Simplot and Cartright wells, located near Bogus Basin Road (E. Squires, *personal communication*). These wells were not included in the study because the temperatures are generally less than most of the "geothermal" wells, they are generally used for irrigation in the summer (as opposed to space heating in the winter), lack of data availability, and the owners did not express concern about the City's plans for increased production/re-injection.

coincides with the decline beginning in the downtown Boise area when the City wells began operating. However, the Quail Hollow Upper well also began pumping in 1984 (Table 4-6), which probably is responsible for at least part of the water level decline in the Edwards well.

8. Water levels rose in the Edwards well (Figure 4-23) from approximately 1996 through the summer of 1999. The reason for the recovery is unclear, as production records from Stewart Gulch wells are unavailable for this time period. Decreases in withdrawals at the Quail Hollow (in 1996), Terteling (in 1997) and Silkey (Flora Shed), Office, and Tiegs wells may have contributed to the declines. Water levels in the Edwards well between 1998 and 2002 have been more variable than in previous years, and it is not clear that there has been a continued recovery of water levels during the 1998-2002 period.

9. Water levels also rose in the Terteling Windsock (Figure 4-20) and the Terteling Motorcycle (Figure 4-21) wells, beginning in about 1994. Water levels in the Terteling Pool well began rising in approximately 1992 (Figure 4-22). Withdrawals from the Terteling wells may have decreased during this time, and, if so, may have contributed to increases in water levels at the Edwards well. Water levels in these three wells generally stabilized beginning in about 1998.

10. Water level decreases (between approximately 10 to 30 feet) are apparent in the Silkey (Flora Shed) (Figure 4-16) and Flora Tiegs (Figure 4-17) wells in the period between 1994 and about 1998. Water level increases (smaller in magnitude than the decreases) are apparent in the same wells beginning in about 1998 or 1999. These increases seem consistent with increases observed in the Terteling Pool (Figure 4-22), Terteling Windsock (Figure 4-20), Terteling Motorcycle (Figure 4-21), and Edwards (Figure 4-23) wells, all of which began earlier than 1998.

11. Recent rises (in 2002) in the Flora-Silkey (Figure 4-16) and Flora Tiegs (Figure 4-17) wells appear to reflect a cessation of withdrawals from these wells.

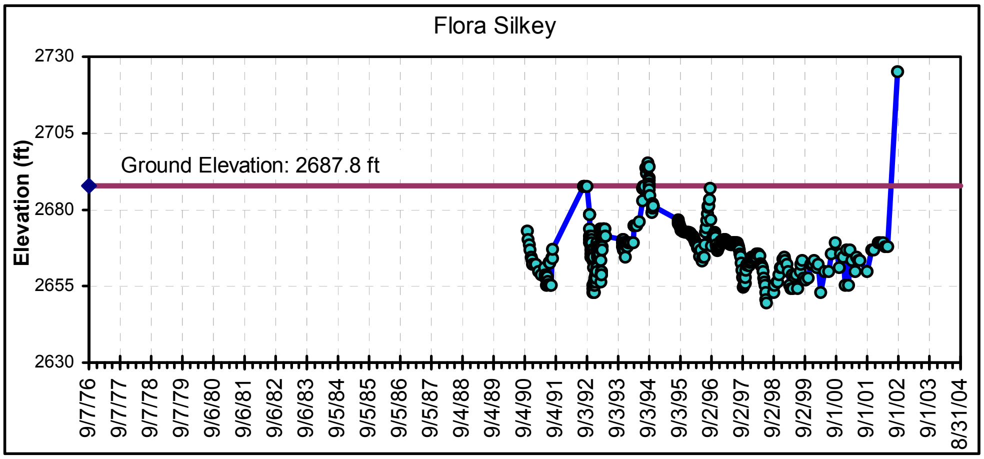


Figure 4-16: Hydrograph for the Silkey (Flora Shed) well.

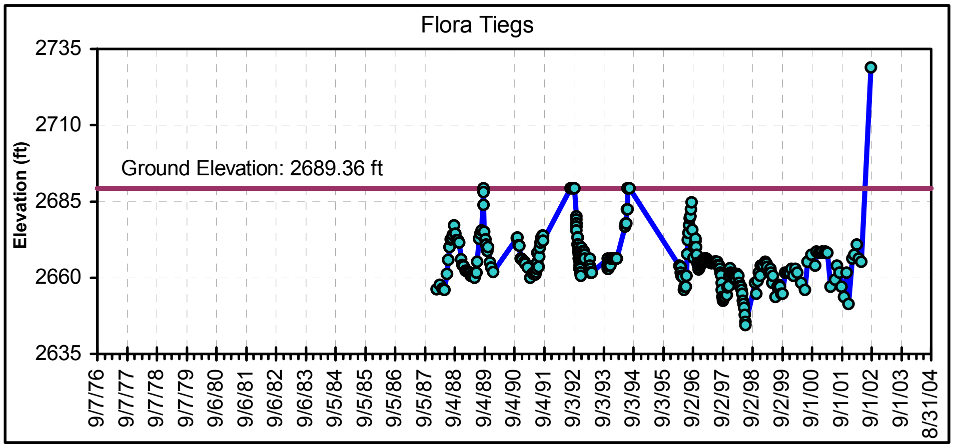


Figure 4-17: Hydrograph for the Flora Tiegs well.

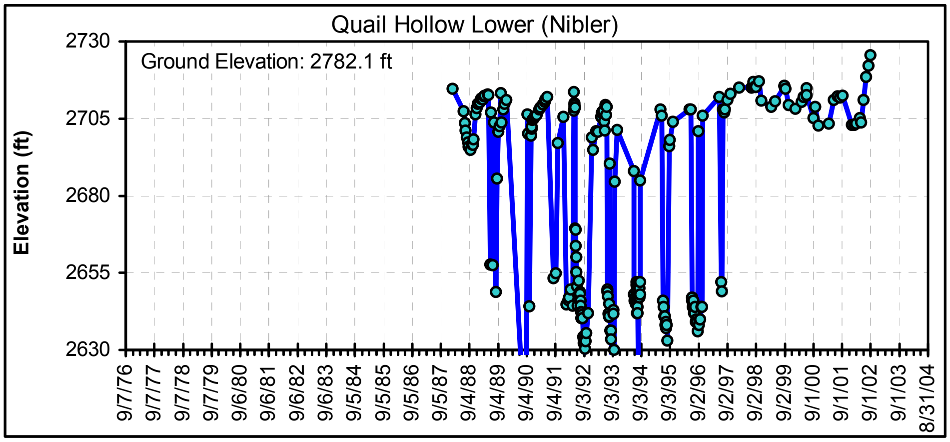


Figure 4-18: Hydrograph for the Quail Hollow Lower (Nibler) well.

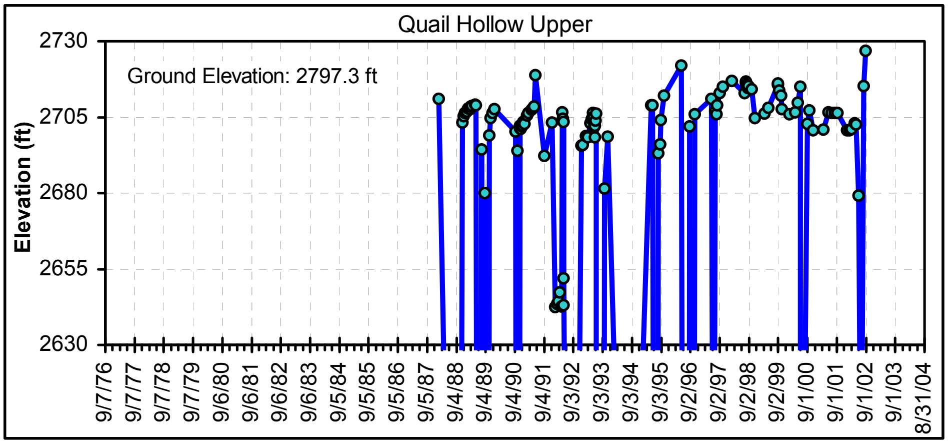


Figure 4-19: Hydrograph for the Quail Hollow Upper well.

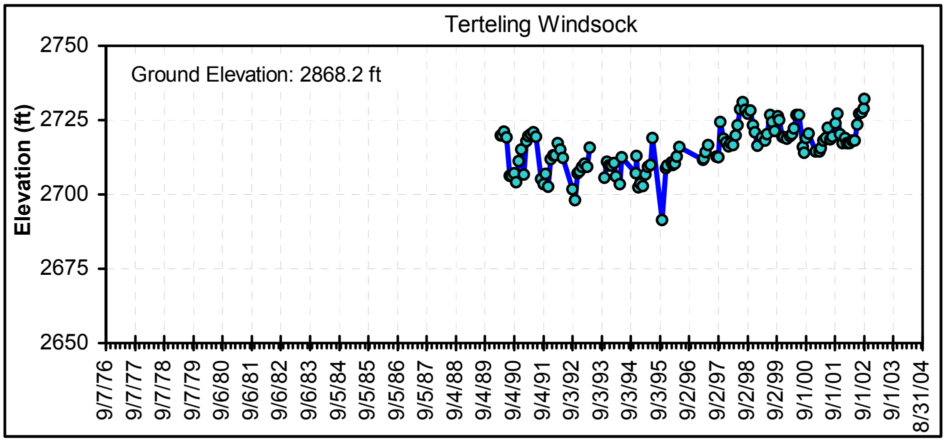


Figure 4-20: Hydrograph for the Terteling Windsock well.

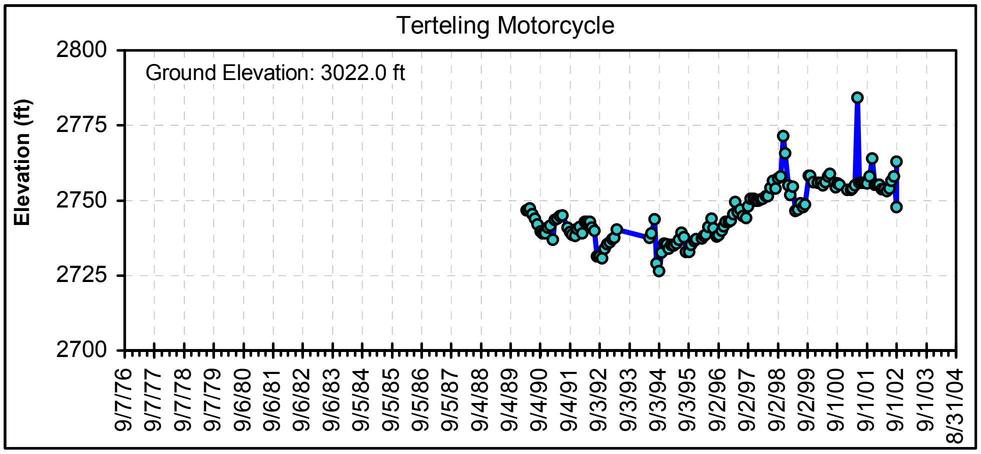


Figure 4-21: Hydrograph for the Terteling Motorcycle geothermal well.

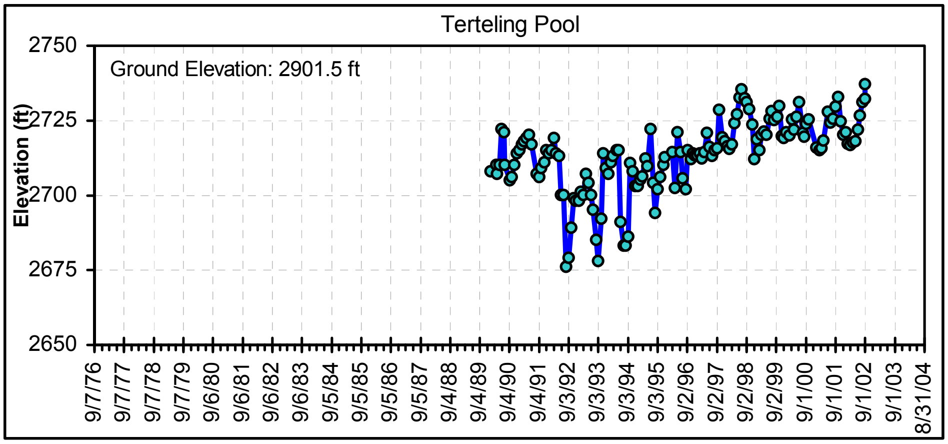


Figure 4-22: Hydrograph for the Terteling Pool well.

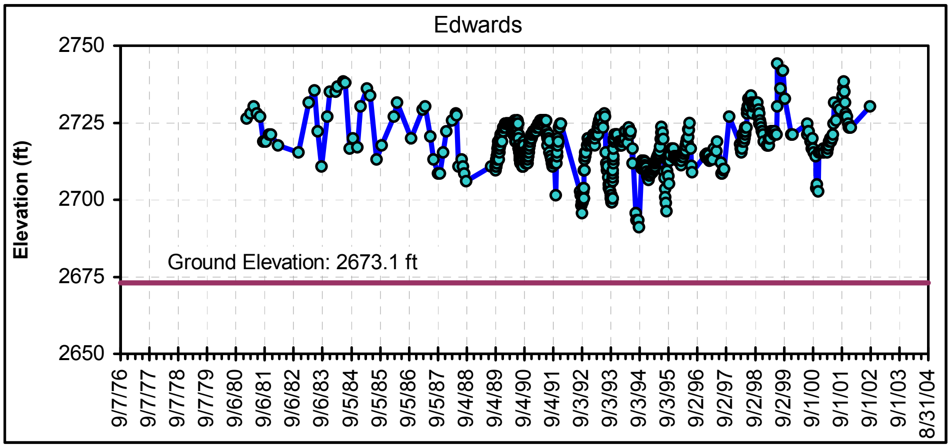


Figure 4-23: Hydrograph for the Edwards Greenhouse well.

4.2.4. Temperature Data

Long-term temperature data are not available for this area. Anecdotal information suggests that water temperatures have remained relatively stable. However, some changes may have occurred. Squires indicates that temperatures in the Terteling Motorcycle well have declined from 100°F to 90°F, although this may reflect long idle periods where cooler water enters the well (Squires, 2003).

4.2.5. Aquifer Test Data

Several pumping tests have been conducted in the Stewart Gulch area, but the data have not been analyzed for aquifer coefficients (Squires, 2003). Well interference patterns were noted in these data (Squires, 2003).

4.3. Harris Ranch

4.3.1. Description of Use and Development

The Harris Ranch area includes two geothermal wells, located at the base of Warm Springs Gulch (Figure 4-24). These wells are currently not in use, but apparently have been used for irrigation in the past. The water right for these wells currently is in the State Water Bank.

Geothermal development in Harris Ranch area has been limited to utilization of hot spring discharge prior to 1918, and reported irrigation withdrawals from the Harris Well in the 1980s and early 1990s. Withdrawal data were not available for this well.

The hot springs near the mouth of Warm Springs Creek were developed by early settlers of the Boise Valley as an outdoor “plunge” for bathing purposes. The plunge and bathhouses were purchased by Judge Milton Kelly in 1889, and subsequently became known as Kelly’s Hot Springs (MacGregor, 1999). The springs were described by Lindgren, but no estimate of flow volume was given (Waag and Wood, 1987). Russell (1903) notes that the springs varied in temperature from 125°F to near the boiling point. MacGregor (1999) indicates that the springs dried up by 1918.

No additional geothermal development occurred in this area until about 1977 when a well was drilled for Dallas Harris at a location within a few hundred feet to the south of the former hot springs. This well (“East” well) was deepened to 742 feet in 1986 (IDWR driller’s report). The initial water temperature was listed on the driller’s report as 180°F. There also is a second well at the site (the “West” well), but little is known about this well (it may be collapsed at some unknown depth). The West well has been used for monitoring and is not equipped with a pump. The East well is equipped with a turbine pump, and has been used for irrigation.

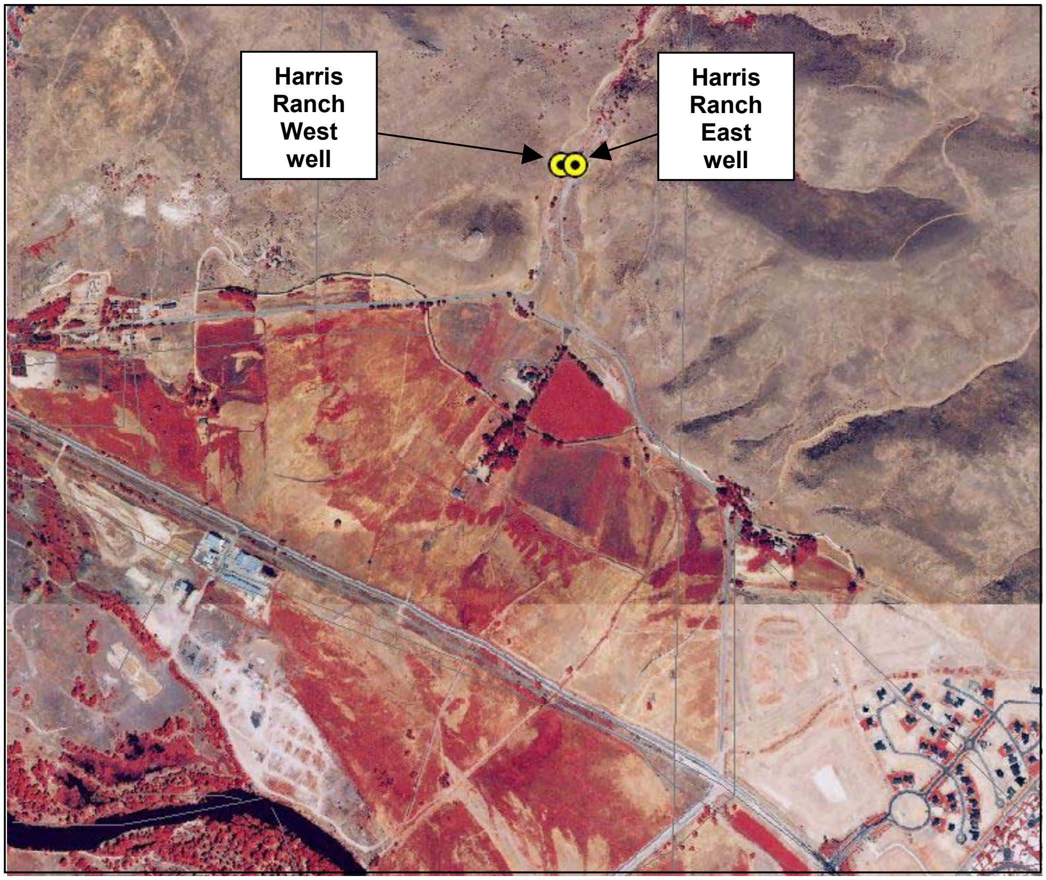


Figure 4-24: Geothermal wells in the Harris Ranch area.

4.3.2. Hydrogeology

The primary source of geothermal water to the Harris Ranch wells appears to be fractured Cretaceous granite (based on interpretation of 1977 and 1987 Driller's Reports for the Harris West well). No basalt or rhyolite was encountered in this or other nearby shallower wells. The East Boise Fault may bisect the area between East Boise and the Harris Ranch area (the BWSWD-East and BWSWD-West wells appear to be located near this fault).

4.3.3. Water Levels

Water-level monitoring at the Harris-West well was conducted from May 1987 through May 1993, and resumed in August 2002 (Figure 4-25). Water level monitoring in the Harris-East well began in August 2002. The water level data did not show any significant seasonal fluctuation (except in those years – 1987 and 1999 – when the East well was being pumped). The water level in late August 2002 (61 feet below top of casing) was approximately 8 feet higher than water levels in late August of 1988, 1991, and 1992. Water levels in the East well in August 2002 were 10 feet lower than in the West well.

The information above suggests the following:

1. The water level in the geothermal aquifer at the former Kelly's Hot Springs has likely declined by approximately 100 feet since 1891, coinciding with initiation of withdrawals in BWSWD wells. This estimate is based on (1) the 70-foot depth to water in the Harris East well and (2) an estimated 30 feet of surface elevation difference between the well and the former hot spring. Further investigation of Kelly's Hot Spring (elevation, history from 1890 to 1918, etc.) is warranted.

2. While the degree of hydraulic connection between the Harris West well and the geothermal aquifer in the downtown area can not be determined on the basis of current data, the apparent decline of Kelly Hot Springs represents evidence of at least some degree of hydraulic connection. On-going monitoring is needed to determine if heating season fluctuations associated with downtown – Table Rock withdrawals can be measured at the Harris East or Harris West wells.

3. Water levels appear to have risen by approximately 8 feet since the early 1990s (Figure 4-25).

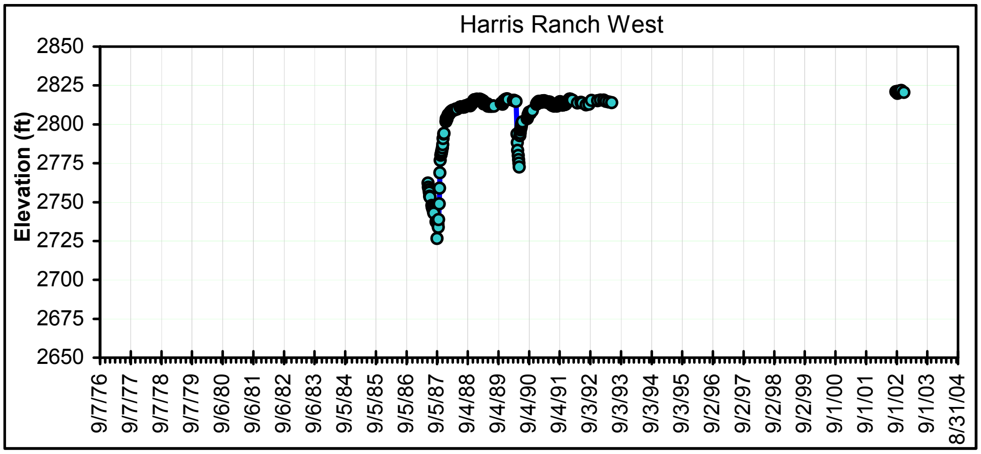


Figure 4-25: Hydrograph for the Harris Ranch West well.

4.3.4. Temperature Data

Long-term temperature data are not available for this area.

4.3.5. Aquifer Test Data

To the author's knowledge, there are no aquifer test data available for these wells.

5. MASS GROUND WATER LEVEL MEASUREMENT

5.1. Description

A mass measurement of water levels and/or pressure head was taken in 29 geothermal wells on August 27, 2002, with some repeat measurements taken in early September 2002. The measurements were taken by E. Squires, T. Scanlan, K. Johnson, and C. Petrich, with assistance from well owners/representatives. The measurements were taken with a steel tape, electronic sounder, and/or twin pressure gauges. Data from these measurements have been included in the project database (Section 2.4). Measurement data are included in Appendix F. Measurement locations for individual wells are described in Appendix H (provided under separate cover).

The timing of the mass measurement was intended to correspond with seasonal high water levels. The wells were turned off for a period of 4 to 24 hours prior to the measurement. Some wells are used for non-heating purposes during the summer (e.g., domestic hot water in the BWSWD, VA, and City systems) and could not be turned off completely for a longer period. Status of wells during the mass measurement are given in Appendix F. Water level elevations collected during the mass measurement are based on the new survey elevations (Section 2.2 and Appendix C).

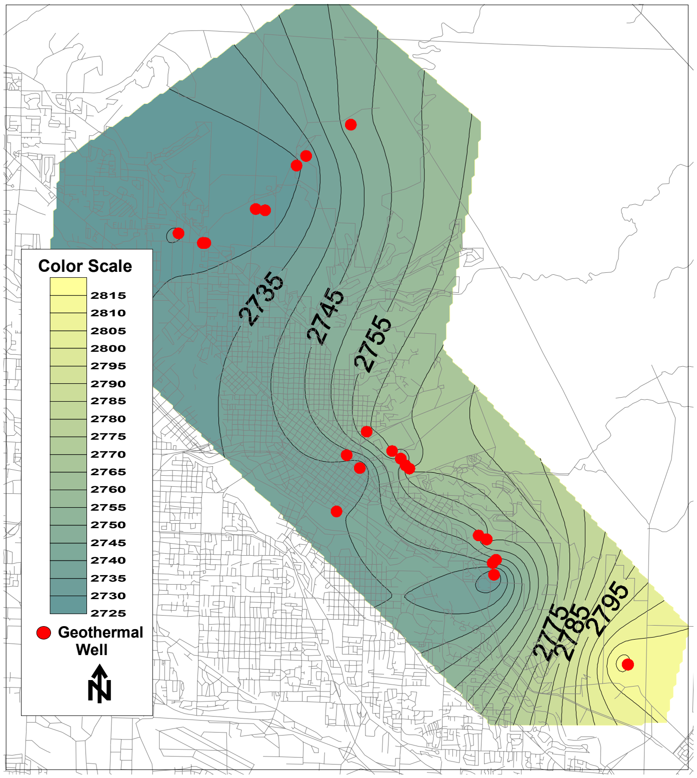
A complicating factor in defining hydraulic head in geothermal wells is that the density of water in the water columns may vary between wells at a given time, or temporally within individual wells. The temperature (and density) of a water column in a geothermal well depends on the (1) well depth, (2) temperature of the water entering the well, (3) flow rate of water entering the well, (4) distance from the screen to the top of the water column, (5) temperature of the formation surrounding the borehole, and/or (6) temperature of the top of the water column. Variations in water column density may introduce error into hydrograph and/or hydraulic gradient plots. Rough estimates suggest that the average error for water level elevations is probably less than about 7 feet, although larger errors may be possible in some individual wells.

Downhole-temperature logs are available for some wells, but the logs may not reflect current temperature conditions in the well, especially if the well is in use. Measurements of temperature profiles are difficult in most wells because installed pumps block access for downhole temperature probes. One way to reduce the error associated with density effects may be to allow wells to flow at a minimal rate until outflow water temperature stabilizes close to the local aquifer water temperature.

5.2. Interpreted Hydraulic Gradient

The hydraulic head data collected in the August 2002 mass measurement were used to estimate horizontal hydraulic gradients in the Boise Front geothermal aquifer system. Hydraulic gradients were illustrated using two forms of spatial interpolation: kriging (Figure 5-1) and minimum curvature (Figure 5-2).

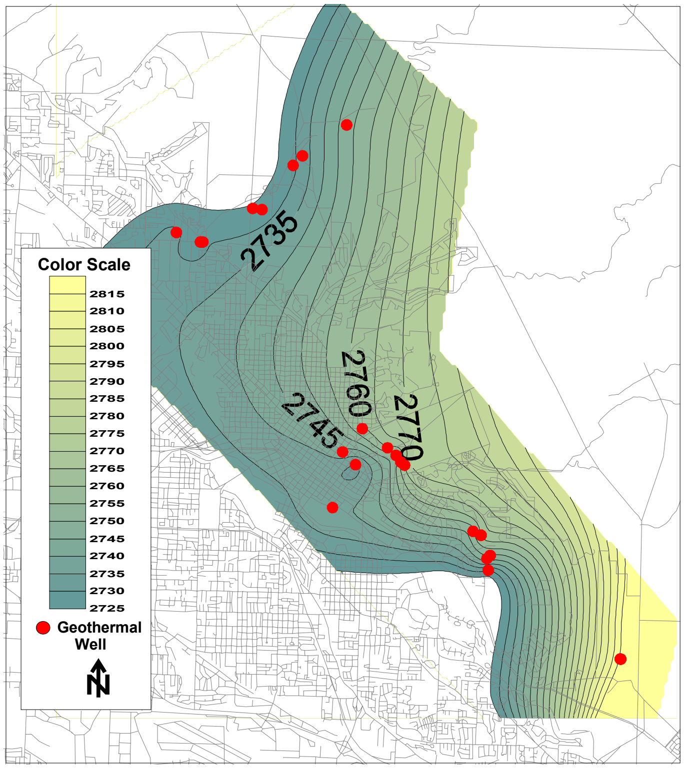
In general, the potentiometric surface in Figure 5-1 suggests westerly to southwesterly flow in the Stewart Gulch and downtown – Table Rock areas. There are not enough data points to estimate gradient directions within the Harris Ranch area. Based on these potentiometric surface maps, it appears that there is a hydraulic gradient from the Harris Ranch area toward the downtown – Table Rock area, which is consistent with the general westerly (or southwesterly) gradients observed in the downtown Boise and Stewart Gulch areas.



Units: elevation above mean sea level (feet).

Figure 5-1: Potentiometric surface (interpolated with "kriging", using a default linear variogram model).

The horizontal gradient maps may include error associated with (1) different well completion depths, (2) spatial interpolation error, and (3) water column density differences between wells. First, the mass measurement included wells that had been shut-in for a long time, wells that were flowing (at small rates), and wells that had recently been flowing. Nonetheless, there is general consistency in measurements within groups of wells, suggesting that the hydraulic gradient observations indicated are reasonable. Second, different wells are completed at different depths, so the horizontal gradients indicated may reflect both vertical and horizontal components. Finally, spatial interpolation error may have been introduced because of the relatively small number of points and the spatial distribution (clustering) of the points.



Units: elevation above mean sea level (feet).

Figure 5-2: Potentiometric surface (interpolated with "minimum curvature", using default interpolation values).

6. CONCEPTUAL MODEL OF GROUND WATER FLOW

This section describes a conceptual model of ground water flow in the Boise Front geothermal aquifer. The geologic basis for the conceptual model outlined in this section was developed largely by Wood and Burnham (1987), and subsequently described by Montgomery-Watson (1994b). The conceptual model forms the basis for numerical simulation of ground water flows in the geothermal system (Zyvoloski et al., 2003).

6.1. Geothermal Aquifer Description

The Boise Front Geothermal aquifer system consists of one or more aquifers or sub-aquifers present along the Boise Foothills underlying an area between Harris Ranch and Stewart Gulch. Geothermal water is found in (1) Tertiary-aged basalts, (2) two rhyolite zones and interbedded coarse-grained sediments belonging to the Idavada Group, and (3) Cretaceous-aged granitic rocks belonging to the Idaho Batholith in the Harris Ranch area. From seismic data, the Tertiary basalt and rhyolites tilt basinward at an angle of four to seven degrees in the downthrown side of the Foothills fault zone.

An exposed northwest-southeast trending fault-fracture zone is present along the entire length of the Boise Foothills in the vicinity of the Boise Front geothermal aquifer. This fault system is thought to represent a primary conduit for geothermal water entering the system. Geothermal springs were present along this fault zone in the late 1800s, and several current geothermal wells are located in or near this fault zone. The role of other faults in the vicinity (Eagle-West Boise, Eagle-West Boise Extension, and East Boise faults) is less clear. Based on aquifer testing in the Stewart Gulch area, the Motorcycle fault appears to inhibit geothermal flow in the Stewart Gulch areas (E. Squires, *personal communication*).

Temperatures of geothermal water are in the 134º to 175ºF range in the downtown – Table Rock area, and in the 90º to 125ºF range in the Stewart Gulch area. Hydraulic gradients are southwesterly to westerly in the Stewart Gulch area and downtown – Table Rock areas, and westerly (on the basis of one data point) in the Harris Ranch area.

6.2. Hydraulic Connection Along the Boise Front

One of the objectives of this study has been to evaluate the potential for hydraulic and/or thermal effects of increased production and re-injection by the City of Boise on wells in the Harris Ranch and Stewart Gulch areas. The degree of hydraulic connection between these areas influences the potential for hydraulic and/or thermal effects.

Faults and fracture zones clearly contribute to ground water flow in the geothermal system, and faulting extends along the Boise Front between the Stewart Gulch, downtown – Table Rock, and Harris Ranch areas. Some degree of hydraulic connection is therefore hypothesized between these areas. If present, hydraulic connection could manifest itself in the form of water level/pressure influences in one area in response to withdrawals and/or injection in another area.

There is some evidence for a direct hydraulic connection between the downtown Boise and Harris Ranch areas. Historical descriptions suggest that early pumping (in the early 1900s) in the BWSWD wells diminished flows in the Kelly Hot Springs, which had been near the current location of the Harris East and West wells. Hydraulic connection does not appear evident in the available hydrograph data.

Waters in the Stewart Gulch and downtown – Table Rock areas clearly have different chemical characteristics and different estimated ages, but similar origin (Mariner et al., 1989). These differences, however, may not preclude hydraulic interaction between these two areas if the amount and/or duration of hydraulic stress were of a sufficient magnitude.

One indication of hydraulic connection between the Stewart Gulch and downtown – Table Rock areas would be an observable impact on Stewart Gulch geothermal water levels from past withdrawals and/or injection in the downtown – Table Rock area, or vice versa. Some water level declines were observed in both areas in the 1980s, and increases were observed in both areas in the 1990s.

Water level declines in the Edwards well were observed beginning in about 1984 (Figure 4-23). The declines coincided with initiation of withdrawals by the City of Boise (and associated declines in the downtown area). However, withdrawals from the Quail Hollow Upper well began at about the same time, and hydraulic testing has shown hydraulic connection between wells in the Stewart Gulch area – see Section 4.2.2. It is therefore not possible to discern from these data the amount of impact that withdrawals from the downtown – Table Rock area had on Stewart Gulch water levels during this time, or vice versa.

Water levels in several Stewart Gulch wells experienced water level increases beginning in the mid 1990s. Water levels in the Edwards well rose from about 1996 through 1999 (Figure 4-23). Annual water level patterns between 2000 and 2002 have been more variable, and it is not clear whether the multi-year trend of increasing water levels has continued during this time. Water levels in the Terteling Windsock, Motorcycle, and Pool wells began to rise in about 1995, 1995, and 1992, respectively. Water levels in the Windsock well stabilized in about 1997; water levels in the

Motorcycle and Pool wells stabilized in about 1998, although August 2002 water levels in the Windsock and Pool well were slightly higher than previous years. Water levels in the downtown – Table Rock area also began to rise when the City of Boise began injection of spent thermal water in 1999. A post-1999 effect on Stewart Gulch water levels, if any, from City of Boise injection cannot be discerned from the Stewart Gulch water level data. A water level rise of about 20 feet in the downtown area would probably translate to a small effect (if any) in Stewart Gulch area, easily masked by local conditions in the Stewart Gulch area. Similarly, the beginning of water level rises in downtown wells occurred so closely to the initiation of injection that it appears unlikely that water level rises between 1992 and 1999 in the Stewart Gulch area led to ground water level rises in the downtown area beginning in 1999.

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). If present, these responses have been masked by changes associated with local hydrologic influences or from wells that were not included as part of this study. Conceptually, faulting along the Boise Front would provide a basis for hydraulic connection between these areas. 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.

6.3. Boundary Conditions

The lateral extent of the Boise Front geothermal aquifer is unknown. To the east, hot water is known to exist near Mayfield (approximately 20 miles southeast of the Harris Ranch wells), but information about geothermal zones between Harris Ranch and Mayfield is not available. In the Boise area, the practical extent of the geothermal aquifer to the north probably is the foothills fault zone, although geothermal water may be present in faults and/or granite fractures north of the fault zone (which probably is the source of geothermal water in the Harris Ranch area). Geothermal water extends further north in Stewart Gulch. The Terteling Motorcycle well is the northernmost geothermal well in the Stewart Gulch area. The extent of the geothermal aquifer to the west and south is unknown. Hot water is known to exist further west in the Dry Creek area and further south in areas near the Snake River. The rhyolitic rocks have not been penetrated by deep wells west of the Boise area, although the occurrence of warmer water (greater than 85˚F) has been documented in numerous locations in the Western Snake River Plain. Geothermal zones may be terminated, or substantially offset, by the Eagle-West Boise fault southwest of Boise. Several other major faults are present in the geothermal aquifer area (Figure 1-1). The influence that basin margin faults have on geothermal ground water movement is unknown, and is probably quite variable.

6.4. Inflows and Outflows

Thermal ground water originates in the fractured granitic rock of the Idaho Batholith. Primary recharge is thought to occur from the granitic rock through north-south and northeast trending lineaments in the batholith. The specific location and rate of recharge from the Idaho Batholith to the Boise Front geothermal aquifer system is not known. Northwest trending fault systems (which appear to include some perpendicular and east-west components) provide conduits for movement of geothermal waters upward to the surface or into subsurface permeable zones. Geothermal residence time data suggest either a slow rate of movement from recharge areas to existing wells or a long flow distance.

Known discharge from the geothermal aquifer system occurs in two forms: (1) discharge to wells, and (2) diffuse discharge to overlying aquifers or horizontally into the basin. The spatial distribution and flow rates of the diffuse discharge, and the extent to which the discharge occurs, is not known. Upward movement of geothermal water above the Tertiary basalt may be restricted by precipitates that have formed as geothermal water has encountered cooler conditions in overlying zones. However, chemical constituents (e.g., fluoride) associated with geothermal water are found in some cold-water aquifer wells.

6.5. Aquifer Properties

The geothermal aquifer system can be considered confined or semi-confined, a result of thick Idaho Group sediments and/or other aquitards overlying most of the geothermal system. Several aquifer tests have been conducted in the downtown – Table Rock area; transmissivities in this area have been estimated to range from less than 1,000 to over 800,000 gallons per day per foot (gpd/ft). The geothermal aquifers in the Stewart Gulch and Harris Ranch areas may have different transmissivity ranges because of different geologic materials.

7. CONCLUSIONS AND RECOMMENDATIONS

This report represents a summary of the current level of understanding of the Boise Front Geothermal Aquifer based on available geologic, geophysical, and hydrologic information. A companion report (Zyvoloski et al., 2003) presents the results and conclusions from simulating increased withdrawals (with associated re-injection) from the Boise Front geothermal aquifer system. Conclusions regarding the potential effects of the increased production and re-injection are presented in an Executive Summary (Petrich, 2003).

Two general conclusions based on this analysis of hydrologic conditions 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.

Specific conclusions 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.

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. The following is a list of related or additional recommendations that might be considered as part of the management of the Boise Front geothermal aquifer:

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.

5. Consider approaches to improving quantification of aquifer and/or fault characteristics through multi-well aquifer tests using existing wells.
6. Consider approaches to improving quantification of aquifer and/or fault characteristics through geophysical methods (e.g., seismic surveys).

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APPENDIX A: UNITS, ABBREVIATIONS, AND CONVERSIONS

Volume

1 cubic foot of water = 7.4805 gallons = 62.37 pounds of water
1 acre-foot (af) = enough water to cover 1 acre of land 1 foot deep
1 acre-foot (af) = 43,560 cubic feet
1 acre-foot (af) = 325,850 gallons
1 million gallons = 3.0689 acre-feet

Flow Rates

1 cubic foot per second (cfs) = 448.83 gallons per minute (gpm) = 26,930 gallons per hour
1 cubic foot per second (cfs) = 646,635 gallons per day = 1.935 acre-feet per day
1 cubic foot per second (cfs) for 30 days = 59.502 acre-feet
1 cubic foot per second (cfs) for 1 year = 723.94 acre-feet
1 cubic meter per second (cms) = 25.31 cubic feet per second
1 cubic meter per second (cms) = 15,850 gallons per minute
1 million gallons per day (mgd) = 1,120.147 acre-feet per year
1 miner's inch = 9 gallons per minute
1 miner's inch = 0.02 cubic feet per second

Hydraulic Conductivity

1 gallon per day per foot^2 (gal/day/ft^2) = 0.134 foot/day = 0.0408 meters/day

Economic

$0.10 per 1,000 gallons = $32.59 per acre-foot

APPENDIX B: SELECTED WELL INFORMATION

Well Name	Well-ID	IDTM-X (ft)	IDTM-Y(ft)	Ground Surface - NAVD29 (ft)	Measuring Point - NAVD29 (ft)
Edwards' Well	1704	1047884.25	939716.69	2673.09	2673.09
VA Test Injection Well	1674	1059887.55	927071.18	2718.23	2720.43
VA Injection Well	1675	1059964.08	926959.77	2716.81	2716.81
VA Production Well	1671	1061496.15	925788.99	2764.32	2761.77
Capitol Mall Well #2	1670	1058599.98	925464.38	2711.64	2714.57
Capitol Mall Well #1	1663	1059481.78	924748.24	2718.73	2713.89
BGL #2	1666	1062345.79	924855.04	2748.48	2749.77
BGL #1	1664	1062708.77	924553.79	2750.49	2751.47
BGL #4	1665	1062632.22	924665.19	2749.95	2750.03
BGL #3	1667	1062065.13	925263.52	2770.54	2769.17
Kanta	1646	1068142.18	918541.15	2782.11	2783.28
Dallas Harris	230	1076510.44	912126.47	2880.37	2881.87
Dallas Harris	229	1076510.44	912126.47	2879.85	2881.35
BWSWD#3	3322	1066998.03	920394.09	2786.49	2789.24
BWSWD#1	1652	1067521.92	920161.66	2764.74	2765.82
BWSWD#2	1653	1067521.92	920161.66	2764.74	2764.74
Old Pen Well	1645	1067964.32	917816.53	2780.49	2780.99
Silkey (Flora Shed)	1698	1049403.04	939092.30	2687.84	2691.22
Flora Office	1697	1049403.04	939092.30	2687.29	2690.83
Flora Tiegs	1696	1049561.78	939088.03	2689.36	2689.63
Terteling Motorcycle	296	1058869.84	946642.70	3022.00	3022.95
Terteling Pool	1714	1056038.45	944675.96	2901.48	2901.23
Terteling Windsock	1712	1055411.62	943999.85	2868.18	2868.18
Quail Hollow Upper	1693	1053431.10	941208.53	2797.25	2798.75
Quail Hollow Lower	1710	1052769.73	941226.23	2770.32	2773.32
BLM	1668	1061769.12	925089.00	2742.88	2746.55
Quarry View Shallow	3342	1066822.21	919912.96	2733.26	2729.19
Quarry View Deep	1651	1066822.21	919912.96	2733.26	2729.78
Boise City Injection	2670	1057287.14	922438.12	2688.34	2692.84

Table B-1: Survey locations for selected geothermal wells.

APPENDIX C: SURVEY DATA

The City of Boise conducted a survey of geothermal wells in September and October, 2002. The following table summarizes the survey results. Location data were converted to IDTM locations by the Idaho Department of Water Resources. Scanned images of the surveyor's results are included on the accompanying CD.

Well Name	Well-ID	IDTM-X (ft)	IDTM-Y(ft)	Ground Surface - NAVD29 (ft)	Measuring Point - NAVD29 (ft)
Edwards' Well	1704	1047884.25	939716.69	2673.09	2673.09
VA Test Injection Well	1674	1059887.55	927071.18	2718.23	2720.43
VA Injection Well	1675	1059964.08	926959.77	2716.81	2716.81
VA Production Well	1671	1061496.15	925788.99	2764.32	2761.77
Capitol Mall Well #2	1670	1058599.98	925464.38	2711.64	2714.57
Capitol Mall Well #1	1663	1059481.78	924748.24	2718.73	2713.89
Boise Geothermal #2	1666	1062345.79	924855.04	2748.48	2749.77
Boise Geothermal #1	1664	1062708.77	924553.79	2750.49	2751.47
Boise Geothermal #4	1665	1062632.22	924665.19	2749.95	2750.03
Boise Geothermal #3	1667	1062065.13	925263.52	2770.54	2769.17
Kanta	1646	1068142.18	918541.15	2782.11	2783.28
Dallas Harris	230	1076510.44	912126.47	2880.37	2881.87
Dallas Harris	229	1076510.44	912126.47	2879.85	2881.35
Boise Warm Springs #3	3322	1066998.03	920394.09	2786.49	2789.24
Boise Warm Springs #1	1652	1067521.92	920161.66	2764.74	2765.82
Boise Warm Springs #2	1653	1067521.92	920161.66	2764.74	2764.74
Botanical Gardens (Old Pen Well)	1645	1067964.32	917816.53	2780.49	2780.99
Flora Silkey (shed)	1698	1049403.04	939092.30	2687.84	2691.22
Flora Office	1697	1049403.04	939092.30	2687.29	2690.83
Flora Tiegs	1696	1049561.78	939088.03	2689.36	2689.63
Terteling Motorcycle	296	1058869.84	946642.70	3022.00	3022.95
Terteling Pool	1714	1056038.45	944675.96	2901.48	2901.23
Terteling Windsock	1712	1055411.62	943999.85	2868.18	2868.18
Quail Hollow Upper	1693	1053431.10	941208.53	2797.25	2798.75
Quail Hollow Lower	1710	1052769.73	941226.23	2770.32	2773.32
BLM	1668	1061769.12	925089.00	2742.88	2746.55
Quarry View Shallow	3342	1066822.21	919912.96	2733.26	2729.19
Quarry View Deep	1651	1066822.21	919912.96	2733.26	2729.78
Boise City Injection	2670	1057287.14	922438.12	2688.34	2692.84

APPENDIX E: PRODUCTION DATA

The following downtown – Table Rock production data are based on data provided to IDWR by primary geothermal users. The data are based on water years (October 1 – September 30). Production data for the Stewart Gulch and Harris Ranch areas are unavailable.

Year	BWSWD Production	CM Production & Injection	Boise Production	Boise Injection	Boise Net Withdrawals	VA Production & Injection	Total Use	Net Withdrawals
1978	256.1						256.1	256.1
1979	312.2						312.2	312.2
1980	308.1						308.1	308.1
1981	239.4						239.4	239.4
1982	276.0						276.0	276.0
1983	283.5	12.8					296.3	283.5
1984	300.2	164.6	166.7		166.7		631.5	466.9
1985	281.2	175.4	121.4		121.4		578.0	402.6
1986	253.1	192.0	176.8		176.8		622.0	429.9
1987	183.1	169.1	188.9		188.9		541.1	372.0
1988	199.4	138.8	123.8		123.8		462.1	323.2
1989	278.0	154.4	158.0		158.0	28.48	618.9	436.0
1990	244.6	130.5	122.3		122.3	118.21	615.7	366.9
1991	245.7	182.7	121.3		121.3	129.08	678.8	367.0
1992	243.3	139.0	123.3		123.3	116.69	622.3	366.6
1993	259.2	217.9	156.0		156.0	137.01	770.2	415.2
1994	220.8	174.5	122.5		122.5	137.42	655.2	343.3
1995	221.2	154.3	127.9		127.9	166.715	670.1	349.1
1996	226.6	118.7	132.1		132.1	186.22	663.7	358.8
1997	212.8	98.6	130.7		130.7	203.61	645.7	343.5
1998	184.2	111.6	131.2		131.2	195.95	623.0	315.4
1999	204.0	125.5	164.9	53.6	111.3	191.64	686.1	315.3
2000	210.5	117.9	188.0	145.8	42.2	186.95	703.3	252.6
2001	218.7	144.8	172.0	145.6	26.4	172.96	708.5	245.1
2002	230.1	123.3	170.7	139.8	30.9	163.1	687.1	261.0

APPENDIX F: MASS MEASUREMENT DATA, 8/27/03 TO 9/25/03

Mass Measurement, Boise Front Geothermal Aquifer System, 8/27/02

Well	Date	Time	Method	Depth to Water (ft)	Pressure (Gauge 2) (psi)	Pressure (Gauge 1) (psi)	Avg Pressure (psi)	Measurement Point	Status	Remarks
Old Pen #2 (Botanical Gardens)	8/27/2002	8:29	E-tape	51.55				Bottom of discharge shaft access window, approx 9" above concrete slab	Static; BWSWD East operating at approx 155 gpm	Turbine oil present on water
Quarry View (*tall piezo*)	8/27/2002	8:42	E-tape	38.51				Top of 2" casing; 0.75' above steel plate	Observation well	Piezometer completed from 813 to 848 feet
Quarry View (*lower piezo*)	8/27/2002	8:44	E-tape	38.14				Top of 2" casing; 0.16' above steel plate	Observation well	Piezometer completed from 600 to 700 feet
BWSWD East	8/27/2002	8:53	Steel Tape	10.58				Lowest point of 2" access tube	Q =approx 155 gpm	MP = 13" above pump house floor
BWSWD West	8/27/2002	8:56	Steel Tape	9.35				Floor level, bottom of blue pump base	Not pumping	Measure through casing
Kanta	8/27/2002	9:08	Steel Tape	36.56				Top of 8" casing, east side	Static	no turbine oil
BWSWD No. 3	8/27/2002	9:10	E-tape	36.32				Top of casing; 1.89' above concrete seal	Observation well	
BWSWD West	8/27/2002	9:26	E-tape	8.25				Floor level, bottom of blue pump base	Not pumping	2 minutes after shutdown of BWSWD East
Harris West	8/27/2002	9:44	E-tape	61.00				Top of casing	Observation well	Cascading water audible
Edwards	8/27/2002	9:45	two-60 psi gauges		25	24.5	24.8	Installed gauges	Off; recently flowing	
Harris East	8/27/2002	9:48	E-tape	70.32				Edge of discharge head cut out; 0.51 feet above floor slab	off	Depth to oil 70.32, depth to water 70.45, oil thickness 0.13'
Flora- Tiegs (Triangle)	8/27/2002	10:31	two-30 psi gauges		17	17.1	17.1	Gauge coupling (new location) 4.5' above pump vault floor	Well off	
Flora - Office (house)	8/27/2002	10:34	two-30 psi gauges		15.9	16	16.0	Gauge coupling	Recently flowing at a few gpm	Totalizer: 230783x100
Flora -Silkey (Shed)	8/27/2002	10:35	two-30 psi gauges		14.6	14.9	14.8	Gauge coupling (3.35' above steel plate on ground)	Not flowing	Totalizer: 084948x100

Mass Measurement, Boise Front Geothermal Aquifer System, 8/27/02 (cont)

Well	Date	Time	Method	Depth to Water (ft)	Pressure (Gauge 2) (psi)	Pressure (Gauge 1) (psi)	Avg Pressure (psi)	Measurement Point	Status	Remarks
BGL2	8/27/2002	10:40 +/-	two-15 psi gages + manometer	-7.14	2.9	3.1	3.0	Pressure gage port in center of 12x12x8 tee, 1.25 feet above floor	Pump off for months	49.5 C (121 F) well head temperature
BGL4	8/27/2002	10:50 +/-	two-15 psi gages		6.5	7.2	6.9	Pressure gage port in center of 12x12x8 tee	Pump on at 125 gpm +/-	176 degrees F; pressure fluctuating with pump rate
Quail Hollow Lower (Nibler)	8/27/2002	10:58	Steel Tape	47.83				Top of 8" casing	Not pumping cold pipes (off since 8/26 pm?)	Totalizer: 1068871x100
Quail Hollow Upper (Tee Ltd.)	8/27/2002	11:05	Steel Tape	71.89				Top of 14" casing	Not pumping - cold pipes (off since 8/26 pm?)	totalizer: 2332741x100
BLM	8/27/2002	11:11	water manometer	-4.15				Top of casing	Observation well	6.33 feet on tape on well house wall; well head temperature is 23 deg C
BGL 3	8/27/2002	11:35	E-tape	17.10				Lip of gate valve on access port	Pump off for years?	
Terteling Windsock	8/27/2002	11:40	Steel Tape	138.25				Pump base	Well off	Avg of 2 measurements; totalizer: 665408x100
Terteling Pool	8/27/2002	11:54	Steel Tape	168.87				Top of 1/2" riser, located above 0.25' above slab	Pump off/pipes cold (probably shut down since 8/26 pm)	Avg of 2 measurements; totalizer: 047029x10
City Injection Well	8/27/2002	12:12	gages and transducer		12.9	12.9	12.9	Gage level 5.0 feet above floor	Average injection rate is 120 gpm	102 deg F; flow varies 0-170 gpm, pressure varies 12.7-12.9 psi
Terteling Motorcycle Hot	8/27/2002	12:28	Steel Tape	275.22				Top of 1" PVC access port in 16" casing, located 0.2' above 16" casing	Static	Totalizer: 000000x100
VA Production	8/27/2002	13:11	E-tape	2.43				Lip of access tube, 1.75 feet above pit floor, 3.6 feet below top of grate & floor slab	Pump on at 160 gpm	162 degrees F

Mass Measurement, Boise Front Geothermal Aquifer System, 8/27/02 (cont)										
Well	Date	Time	Method	Depth to Water (ft)	Pressure (Gauge 2) (psi)	Pressure (Gauge 1) (psi)	Avg Pressure (psi)	Measurement Point	Status	Remarks
VA Production	8/27/2002	13:19	Steel Tape	0.1				Lip of access tube	Pump off	
UWID Cartwright (North)	8/27/2002	13:28	E-Tape	325.41				Top of well casing; 0.9' above pumphouse floor; 8.75' from pumphouse floor to top of concrete pump house roof	Static	No pump in well
VA Test Injection	8/27/2002	13:39	two-30 psi gauges				16.8	0.5' +/- above ball valve on well head	Observation well	22 deg C well head temperature
Capitol Mall 1	8/27/2002	13:55	two-30 psi gauges				9.2	Pressure gage port 5.0 feet below well house floor slab	Well off for summer	26 deg C well head temperature
Capitol Mall 2	8/27/2002	14:07	two-30 psi gauges				12.9	Pressure gage port 1.75 feet above floor slab	Well off for summer	26 deg C well head temperature

Selected measurements taken during afternoon of 8/27/03 after BWSWD shut-down (BWSWD-East shut down at 9:24 am)										
Well	**Date**	**Time**	**Method**	**Depth to Water (ft)**	**Pressure (Gauge 2) (psi)**	**Pressure (Gauge 1) (psi)**	**Avg Pressure (psi)**	**Measurement Point**	**Status**	**Remarks**
Old Pen #1(Botanical Gardens)	8/27/2002	14:20	E-tape	51.84				Bottom of discharge shaft access window, approx 9" above concrete slab	BWSWD East shut down at 9:24am	Turbine oil present on water column; incoming storm
Kanta	8/27/2002	14:28	E-tape	36.50				top of casing	Observation well	
BWSWD No. 3	8/27/2002	14:33	E-tape	35.55				top of casing; 1.89' above concrete seal	Observation well	
BWSWD-West	8/27/2002	14:47	E-tape	5.29				Bottom of pump base (floor level)	BWSWD East shut down at 9:24am	172-173 deg F incoming storm
BWSWD-East	8/27/2002	14:49	E-tape	4.99				Lowest point of 2" measuring tube (13" above floor)	BWSWD East shut down at 9:24am	172-173 deg F incoming storm; depth to top of oil

Selected measurements taken on 9/24/02										
Well	Date	Time	Method	Depth to Water (ft)	Pressure (Gauge 2) (psi)	Pressure (Gauge 1) (psi)	Avg Pressure (psi)	Measurement Point	Status	Remarks
Capitol Mall 1	9/24/2002	9:06	30 psi gauge		9.6	9.7	9.7	Gauge port	Well off for summer	Installed gauge: 5 psi on 100 psi gauge; city system temporarily off
Capitol Mall 2	9/24/2002	9:40	30 psi gauge		13.6	13.4	13.5	Gauge port	Well off for summer	Installed gauge reads 14 psig; city system temporarily off
BWSWD West	9/24/2002	10:15	TS E-tape	14.21				bLue pump base	Running	Well inadvertently shut down earlier; current east and west well combined flow approx 250 gpm
BWSWD East	9/24/2002	10:26	TS E-Tape	18.85				lowest elevation at top of measurement Tube	Running	Well inadvertently shut down earlier; current east and west well combined flow approx 250 gpm; DTW reading with steel tape is 18.65 ft, oil may be confounding electrical and/or steel tape reading
VA Production	9/24/2002	11:02								ARTESIAN flow through measurement tube (20 gpm?) beginning 2 minutes after pump shutdown
VA Test Injection	9/24/2002	11:14	30 psi gauges		18	18	18.0	Gauge height is 0.70 ft above survey point on top of casing	No pump	
BGL#1	9/24/2002	11:40	30 psi gauges		2.8	3	2.9	Gauge height is 3.68 ft below iron manhole rim	No pump	Top of ring is 0.48 ft above top of concrete manhole structure; installed city gauge reads 3.4 psi

Selected measurements taken on 9/24/02 (cont)										
Well	**Date**	**Time**	**Method**	**Depth to Water (ft)**	**Pressure (Gauge 2) (psi)**	**Pressure (Gauge 1) (psi)**	**Avg Pressure (psi)**	**Measurement Point**	**Status**	**Remarks**
BGL#4	9/24/2002	11:53							Pumping between approx 200 and 420 gpm	Temp reads 175 ° F; reading taken in BGL#2 pumphouse
BGL#2	9/24/2002	11:53	installed 15 psi gauges		3.1	3.3	3.2	Gauge height	Not pumping	
BGL#3	9/24/2002	11:57	Installed 100 psi gauge		5 (reading in error - reflects stuck gauge)			Gauge height	Not pumping	New measurement access port installed - see data sheets

Well	Date	Time	Method	Depth to Water (ft)	Pressure (Gauge 2) (psi)	Pressure (Gauge 1) (psi)	Avg Pressure (psi)	Measurement Point	Status	Remarks
VA Production	9/25/2002	13:04	E-tape	7.82				Top of open casing	Off since 7:00am; pump removed	Top of open casing is 7.58 ft above new measurement port valve; 4.05 ft above pumphouse floor. Temperature reading was taken by lowering thermometer; temperature at top of water column was approx 52 degrees C (126F), although there seemed to be cooling of the thermometer as it was being withdrawn from the well.
BWSWD East	9/25/2002	14:09	E-tape	18				Top of measurement tube	Running @ approx 220 gpm	Dick Clark's E-tape: 18.0 ft
BWSWD West	9/25/2002	14:14	E-tape	14.3				Base of pump housing	No pump	East well Q approx 220 gpm; Dick Clark's E-tape reads 14.3 ft DTW
BWSWD#3	9/25/2002	14:42	E-tape	40.15				Top of casing	No pump	East well Q approx 220 gpm; Dick Clark's E-tape reads 40.2 ft DTW
Kanta	9/25/2002	14:57	E-tape	35.72				Top of casing	No pump	

APPENDIX G: GEOPHYSICAL LOGS

Geophysical logs taken in geothermal wells were scanned and saved as digital images as part of this project. The logs were made available for scanning by Terry Scanlan (Scanlan Engineering), Spencer Wood (Department of Geosciences, Boise State University), and Ed Squires (Hydro Logic, Inc.). Wells with scanned geophysical logs (and approximate file sizes) are listed below. All of the files with the name "scan" were scanned at the Department of Water Resources. All of the other files were scanned by the Bonneville Blueprint Co. The digital files are available from the Idaho Department of Water Resources.

1. Barnes (1 scan, 2.7 MB)
2. Beard (4 scans, 21.1 MB)
3. BGL#1 (14 scans, 106 MB)
4. BGL#2 (30 scans, 244 MB)
5. BLM (3 scans, 14.7 MB)
6. Capitol Mall (26 scans, 269 MB)
7. Koch (2 scans, 4.03 MB)
8. Old Penitentiary (3 scans, 9.25 MB)
9. Silkey (1 scan, 302 MB)
10. Statehouse (2 scans, 5.45 MB)
11. Terteling (3 scans, 1.08 MB)
12. VA (6 scans, 15.5 MB)
13. Miscellaneous (1 scan, 6.83 MB)

APPENDIX H: MEASUREMENT POINT LOCATIONS FOR SELECTED BOISE FRONT GEOTHERMAL WELLS

(Under separate cover)