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

Prepared for:

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and

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Table of Contents

1. INTRODUCTION

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

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

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

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

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

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

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

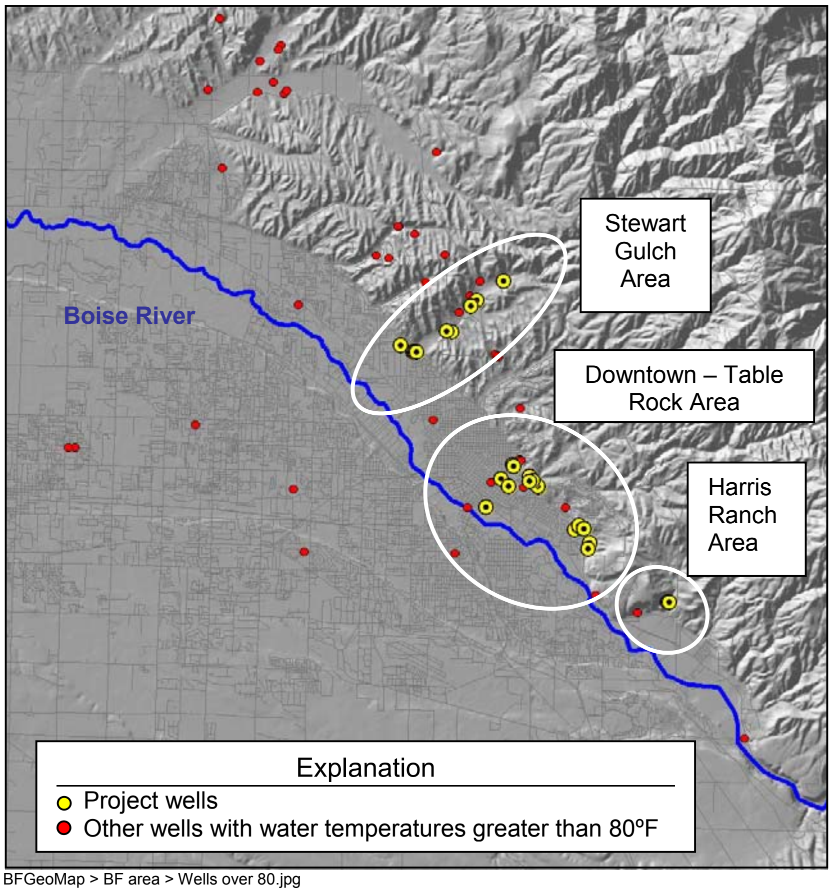

Figure 1: Map of the Boise Front area showing primary production areas.

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

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

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

2. Project Components

The project included the following tasks:

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

3. Overview

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

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

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

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

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

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

Simulations of the Boise area geothermal aquifer were conducted to determine if increased injection at the City of Boise injection well would affect the temperatures and/or water levels at other primary geothermal wells. The simulations were conducted using the FEHM computer code (Zyvoloski et al., 1997) and the PEST parameter estimation code (Doherty, 2000). The model area included the Harris Ranch, downtown – Table Rock, and Stewart Gulch areas. Recharge was simulated as upward flow in fault areas and lateral flow across the northeast boundary. Outflow included lateral flow across the southwest model boundary and discharge to wells. The model grid represented a 3-dimensional flow system, with the finest discretization in the downtown – Table Rock area. The model was calibrated to selected 1984 through 1992 water level and temperature data, and checked against 1984 through 2002 water level and temperature data.

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

4. Conclusions

The primary conclusions from this study are that:

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

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

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

3. Water levels in the Boise area stabilized somewhat beginning in the late 1980s, based on observations in the BLM well. The stabilization of water levels presumably was, at least in part, in response to stabilization of net production following the production increase of 1984.
4. Water levels in the downtown – Table Rock area have been recovering since 1999, based on observed water level increases in the BLM, VA, BWSWD, Kanta wells. The recovery appears to be in response to the City's re-injection of a portion of its withdrawals since 1999.
5. Water temperatures in the CM #2 well declined from approximately 1983 – 1990, which may reflect the time to reach temperature equilibrium in the Capitol Mall couplet.
6. Water levels in the Edwards well also decreased beginning in approximately 1984, but at least part of the decrease appears to have been caused by the start of production from Quail Hollow (Golf Course) Upper well.
7. Several Stewart Gulch wells (e.g., Edwards, Quail Hollow Lower, Terteling Windsock, Terteling Pool, and Terteling Motorcycle) experienced water level increases in the mid to late 1990s. These increases began between approximately 1992 through 1996. Water levels in the Quail Hollow Lower, Terteling Windsock, Terteling Pool, and Terteling Motorcycle began to stabilize (or drop slightly) beginning in about 1999 (although August 2002 levels were slightly higher than in previous years). Water levels in the Flora Silkey and Flora Tiegs wells decreased between 1994 and 1998, and increased between about 1998 and 2002.
8. Faulting that connects the Harris Ranch, downtown – Table Rock, and Stewart Gulch areas provides the basis for hydraulic connection between these areas. There appears to be some evidence for hydraulic connection between the downtown – Table Rock, and the Harris Ranch areas. Thermal water in the downtown – Table Rock, and Stewart Gulch areas appears to share a common source, although there are clear differences in water chemistry, residence times, and temperature. The current water level/pressure and production data are insufficient to describe the degree of hydraulic connection between the downtown – Table Rock area and Stewart Gulch areas.
9. It appears from the simulations that the hydraulic connection between the City production and injection wells is sufficient for the proposed amount of increased water production and re-injection.
10. The simulation results suggest that the average head in the downtown – Table Rock production area will be increasing for the near future, even if the City increases production and re-injection as proposed. This is because the net production has decreased in recent years, and the increased

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

11. The City injection well is far enough removed from other users in the downtown area that the simulated thermal perturbation caused by the injected water does not appear to propagate to the other wells in the downtown – Table Rock area. However, the increased injection may produce local hydraulic changes that in turn could change the temperature mix entering individual wells.
12. Two alternative conceptual models were implemented in the numerical model: partial hydraulic connection and no hydraulic connection. Neither model accurately reproduced measured hydrographs at the Edwards well. It is unclear whether this result is because of conceptual model errors or the paucity of production data in the Stewart Gulch area. It is unlikely that modeling or data analysis can be used to definitively determine the influence (or lack thereof) of withdrawals in the downtown – Table Rock area on wells in the Stewart Gulch area (or vice versa) given the current level of hydrologic and production data.

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

5. RECOMMENDATIONS

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

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

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

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

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

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