Research Technical Completion Report

BASE LINE DATA ANALYSIS OF A DEVELOPING GEOTHERMAL SYSTEM, BOISE, IDAHO

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Washington, D.C. 20242

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We wish to thank Mr. Robert Griffiths, Boise Warm Springs Water District Water Engineer, for enthusiastically supplying data and background information on the BWSWD pumping system. To Will Burnham we owe a debt of gratitude for guidance, and for sharing some of his considerable knowledge of the system, its characteristics and history.

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ABSTRACT

Calculated aquifer transmissivities in the Boise Warm Springs Water District portion of the geothermal system range from 3500-25,000 gals/day/ft. Withdrawals during the 1984-1985 heating season stabilized drawdown at the pumpbowls and water levels approached stability in observation wells as distant as 1675 ft (507.6m). In this near steady-state condition, recharge, and water from storage beyond the observation wells provided a maximum Q of 840 gpm.

INTRODUCTION

Hot water (150-172°F) is produced from deep wells in northeast Boise for heating office buildings and residences (Figure 1). The Boise Warm Springs Water District (BWSWD) has produced water from two adjacent wells since 1892. In the 1980's Boise Geothermal Ltd. (BGL), and the State of Idaho Capital Mall project (CM) began major withdrawals from the system. In 1986 the U.S. Veterans Administration Hospital facility (VA) will begin withdrawal from the system. The spent warm water from the BWSWD and BGL distribution system are disposed of in the Boise River. The spent water from the CM is reinjected into a 2100 ft deep well, and the VA system will also reinject its spent water when the project is completed.

The natural hot-water system is now understood to consist of aquifers of fractured and faulted rhyolite of the Idavada Group (Wood and Burnham, 1983). The present hypothesis is that deeply circulating geothermal waters rise by mass-convection through fractured conduits associated with zones of normal faults along the boundary of the Idaho Batholith and the Snake River Plain. These waters then spread laterally--and mostly southwestward--in the fractured rhyolite and interbedded arkosic sandstone and conglomerate. Basalt layers do not appear to be favorable aquifers. Basaltic tuff, basalt, and lacustrine claystone overlie the rhyolite sequence and act as aquitards sealing the geothermal water systems (Figure 2). We are clearly dealing with a confined, or semiconfined aquifer system.

It is well known that mismanaged confined aquifer systems can be rapidly depleted with a host of ensuing problems (loss of water supply,

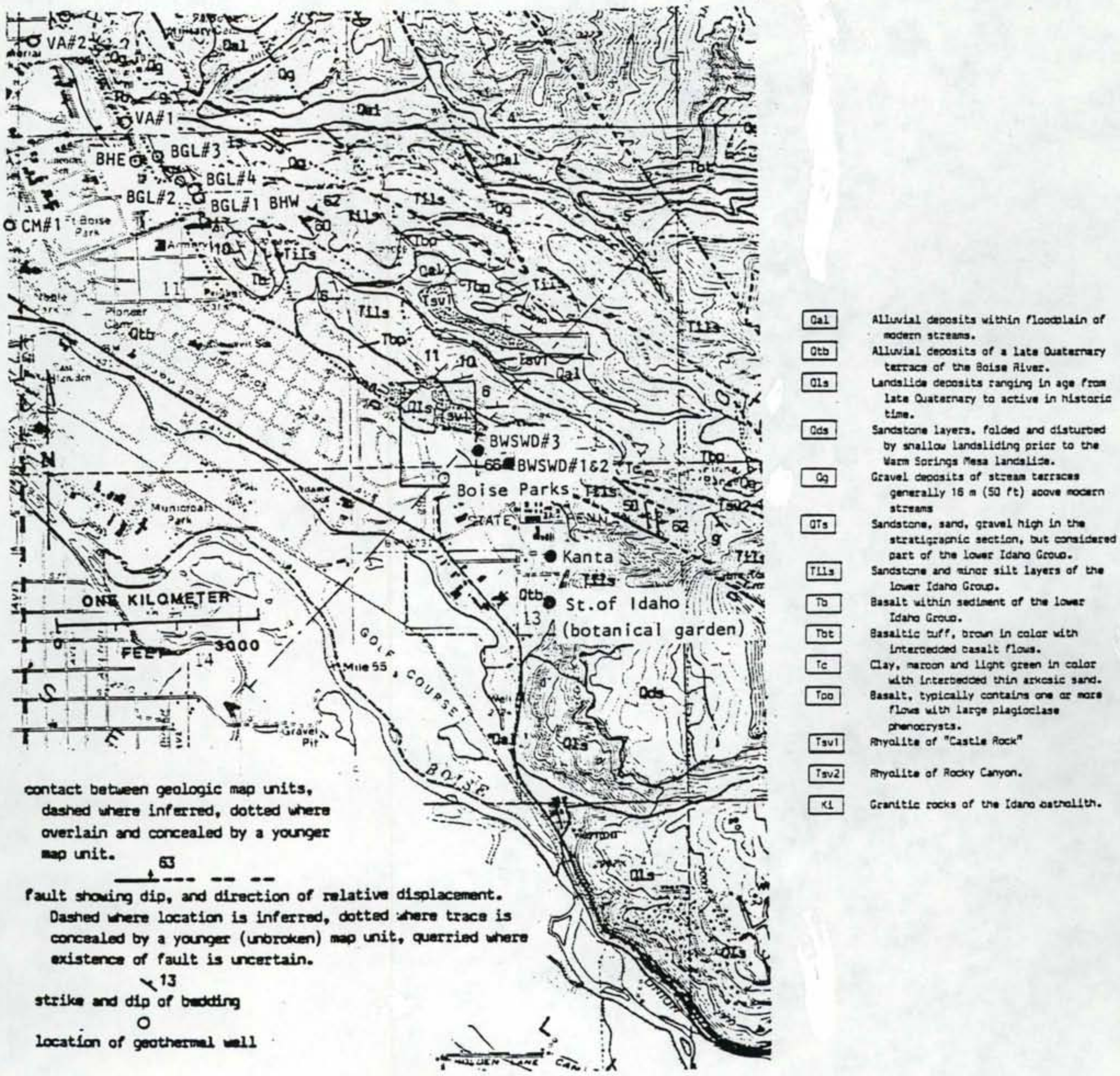

Figure 1. Location of geothermal wells in northeast Boise and geology after Burnham and Wood (1985). BWSWD # 1 & 2 are producing wells. BWSWD #3 and Kanta Wells are used as observation wells in this study. State of Idaho (botanical gardens) and Boise Parks are irrigation wells using geothermal water. BGL #2, 3 & 4 are producing wells. BGL #1, VA #1 & 2, BHE, & BHW are not producing at the present time. CM #1 is a reinjection well for the Capital Mall system.

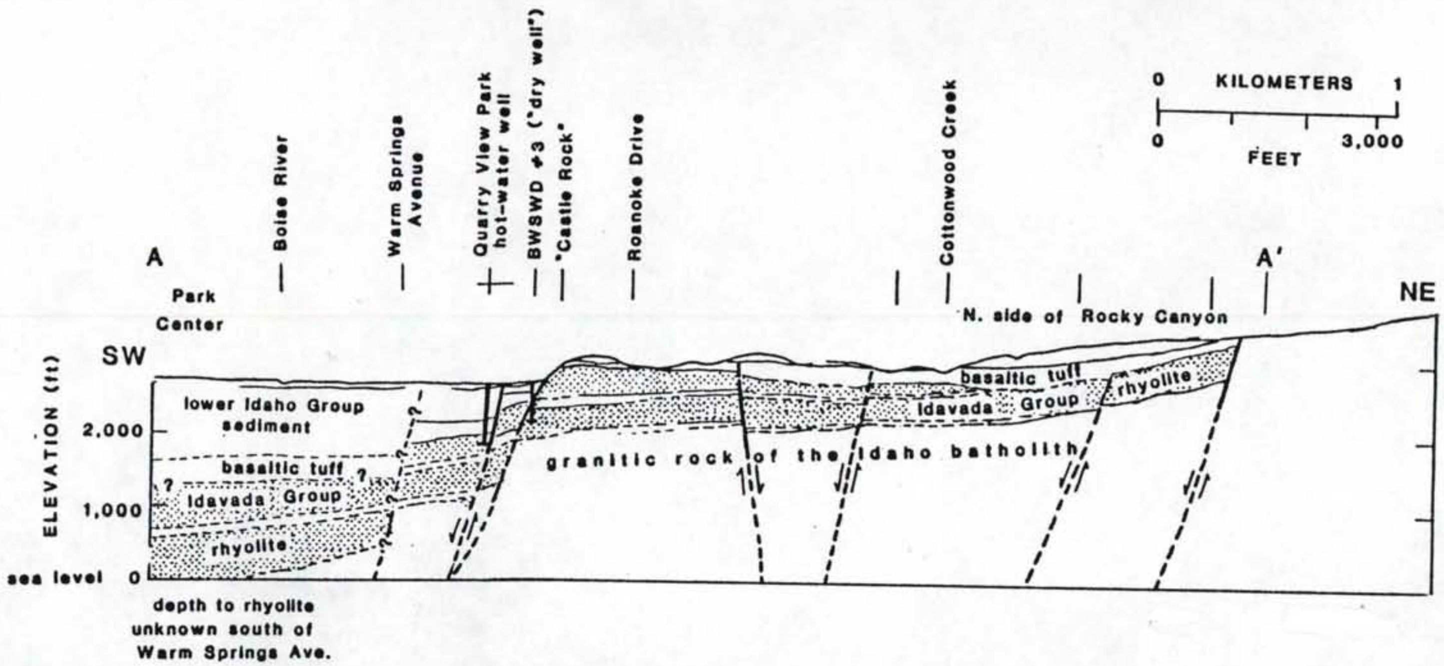

Figure 2. Geologic cros-section through the BWSWD Well No. 3 (observation well). Principal production for the BWSWD system comes from the fault zone between Well No. 3 and Quarry View Park Well. Location of section is shown as line AA' in Figure 1.

water-rights litigation, and subsidence and surface fracturing). This study initiates our efforts to monitor geothermal water withdrawals and aquifer pressure in the system. Present funding limited the study to the northeast part of the system near the Boise Warm Springs Water District Wells. We installed water-level recorders on several wells, and maintained a system of record collection now entered in computer format for rapid access and for analysis. In order to better understand aquifer parameters and begin our efforts to model the system, we have also incorporated the seasonal production data to simulate well tests.

HYDROLOGIC SETTING AND DATA GATHERING

In lieu of pump tests we have taken advantage of the seasonal pumping cycle to simulate aquifer testing of the geothermal groundwater system. Values of transmissivity were determined using drawdowns within the system created by the effects of prolonged pumping in the Boise Warm Springs Water District Wells Nos. 1 and 2. Such an approach does not ideally meet the assumptions of the mathematical models for determination of aquifer performance developed by Theim, Theis and Jacob (Ferris, et al, 1962). In spite of the caveats which must accompany our methods, we believe the transmissivity values obtained are meaningful, and that we have advanced our understanding of the system significantly.

Boise Warm Springs Water District (BWSWD) Wells Nos. 1 and 2, pumping wells, and 2 observation wells, BSWSD No. 3 and the Kanta Well, are shown in Figure 1. BWSWD Wells 1 and 2 are 30 feet apart and are both drilled into a fracture zone which strikes approximately N70°W, dips steeply southeast and is downthrown to the southeast. BWSWD Well No. 2 is the principal pumping well for the district. Usually No. 1 is pumped only when No. 2 cannot supply the demand on the system. Figure 3 shows the drawdown versus time in wells 1 and 2, and total pumpage from both wells for the period September 20, 1984 to August 30, 1985. September was selected to begin the plots because the system is at or near its maximum recovery at that time. The data were provided by the Boise Warm Springs Water District Engineer, Mr Robert Griffiths. Water level measurements were made using an airline in each well. Flow-rate measurements were determined from a Sparling cumulative flow meter

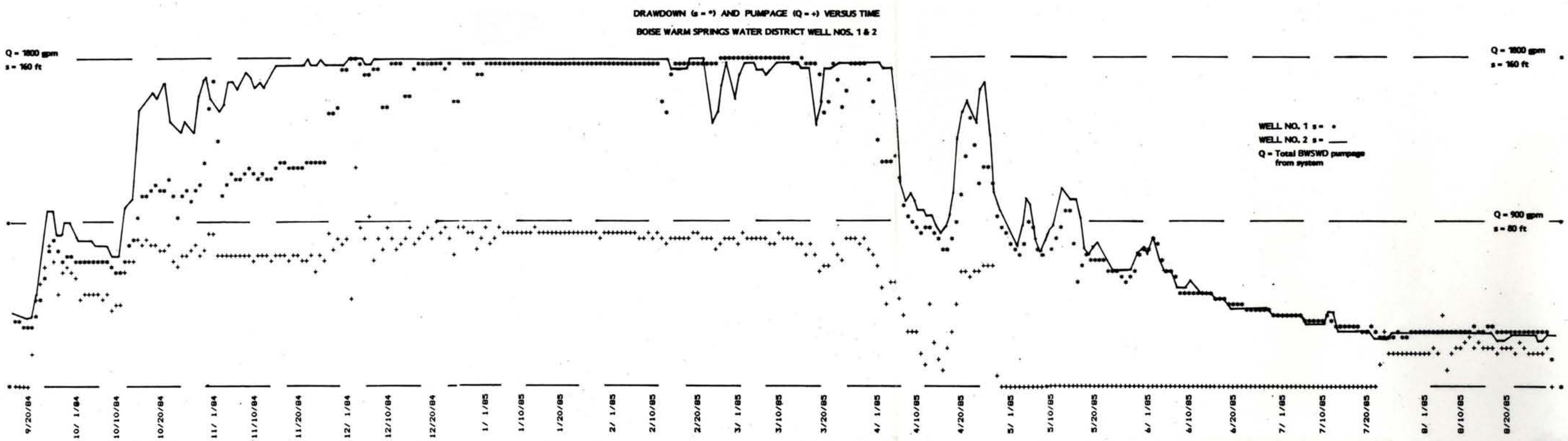

Figure 3. Drawdown and Pumpage Versus Time for Warm Springs Water District Wells Nos. 1 and 2.

installed in a common pipe served by both wells. Water levels and the meter are read once per day, usually in the morning between 8 A.M. and 10 A.M. and occasionally in late morning or afternoon. The readings reflect the water level only at the time of reading and are somewhat skewed toward levels at a time of day when domestic demand is high. However, during the peak heating season, even random readings reflect a maximum drawdown. Sparling meter readings are averaged over the period since the previous reading was taken to determine the pumpage in gallons per minute; thus, they reflect an average flow rate for the period.

The pump bowls in both wells are set approximately 160 ft (48.5m) below the surface elevation, 2764.9 ft (837.9m), of the pump house floor at 2605.9 ft (789.4m). During most years drawdown reaches the level of the pumps. The duration of the period during which drawdown is at a maximum and the date when maximum drawdown first occurs varies from year to year.

Several observation wells were also monitored during this study. Vandalism was unfortunately a serious problem, especially at the beginning of the project, and some records were lost. Cyclone-style fence-enclosures were placed around two of the observation wells which has resulted in a decrease in damage to recorders and to the loss of records. Water level measurements were recorded using Type F and Type A Stevens recorders, and checked frequently using a tape measure.

Figure 4 is a semilogarithmic plot of drawdown versus time data obtained from one of the observation wells, the BWSWD Well No. 3 Well No. 3 is 645 ft (195.5m) northwest of pumping wells 1 and 2 and is drilled into the same fracture zone. Apparently the hole was drilled

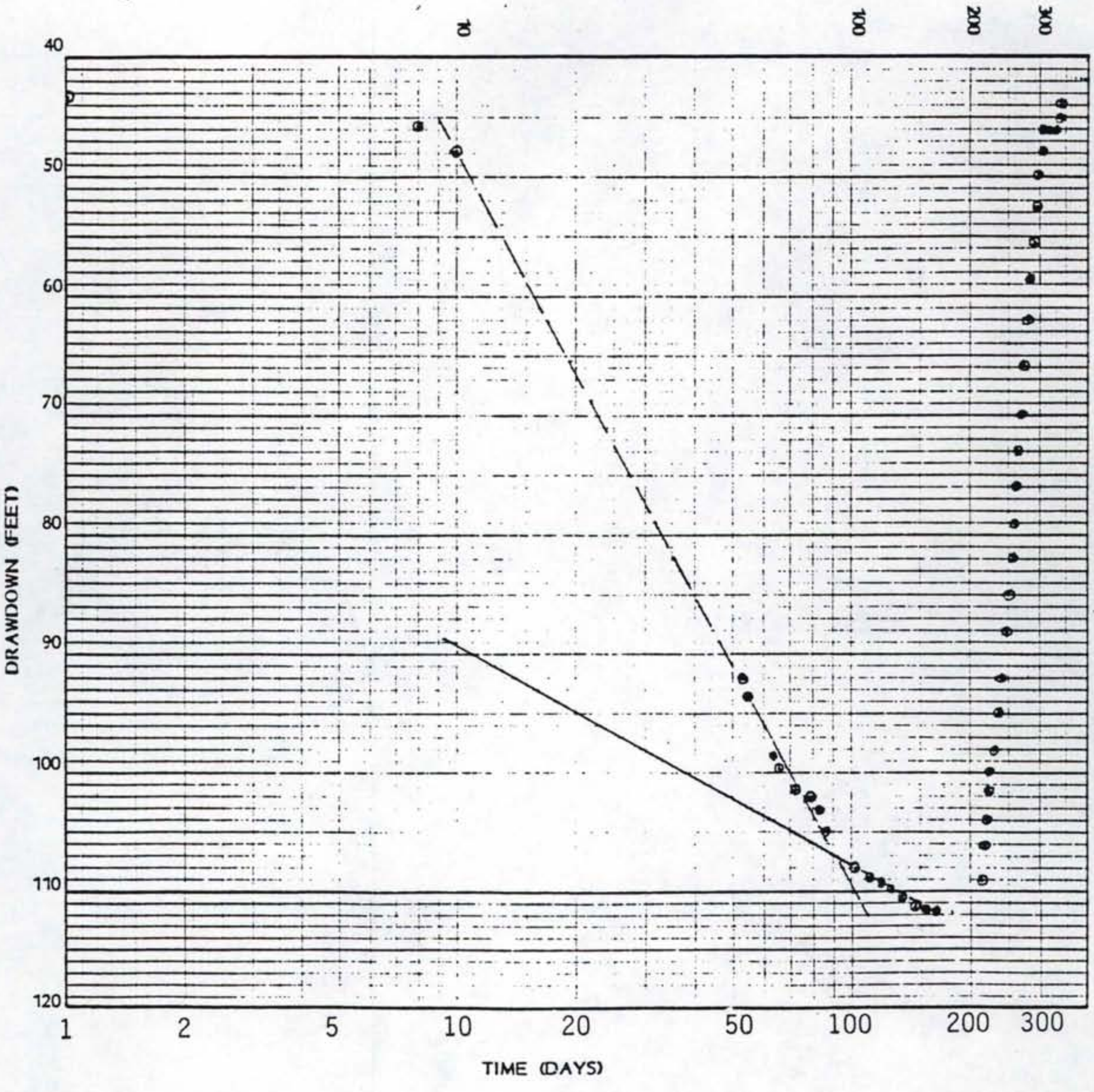

Figure 4. Time - Drawdown for BWSWD Well No. 3

through the fracture zone into the footwall, and was terminated in rhyolite at 600 ft (181.8m). The well did not yield significant amounts of water during a pump test, but serves well as an observation well.

The most complete observation well data were obtained from the Kanta Well which is approximately 1675 ft (507.6m) south 10° east of BWSWD pumping wells (Figure 1). It is outside the fracture zone into which Nos. 1, 2 and 3 are located and is drilled into the downthrown block. The well was drilled from a surface elevation of 2782 ft (843m) to a total depth of 1015 ft (307.6m).

A third observation well, the State of Idaho Penitentiary Well, was monitored during the early portion of this study. This well is approximately 2350 ft (712m) S13°E of No. 2 pumping well and was drilled to a total depth of 872 ft (264.2m). The well casing is perforated from 220 to 872 ft and allows mixing of the geothermal and non-geothermal waters. The well was monitored from September 1 until November 6, at which time the recorder was removed. Unfortunately, the State of Idaho entered an agreement with the Idaho Botanical Garden Society which allows the society to pump the well for irrigation water for their botanical gardens.

ANALYSIS

Drawdown and Flow Rates

Figure 3 shows some interesting conditions and relationships which existed within the system from September 1984 through August 1985. It is evident that for the period shown, large rapid drawdowns occurred within the principal pumping well, BWSWD Well No. 2. In the fall of 1984 drawdown reached its maximum value of 159 ft (48.2m) (level of the pump bowls) on November 26, 1984. The water level remained at that depth until February 12, 1985, a period of 78 days. In bringing well No. 2 to its maximum drawdown by November 26, 1984, approximately 64.2 million gallons were pumped at an average rate of approximately 665 gpm during the 67 day period September 20 to November 26. The most precipitous decline, however, was created in mid-October by pumping rates averaging 800 gpm.

Between November 26 and January 1, 1985 pumpage from the system fluctuated over a fairly narrow range, but increased to an average of 820 gpm. To obtain this additional water, Well No. 1 had to be pumped intermittantly to augment production. However, by January 5, demand on the system was so great that Well No. 1 had to be pumped nearly continuously along with No. 2. The water level in No. 1 receded to a depth of 158 ft (47.9m) and remained at that level until February 12. Production from well Nos. 1 and 2 during the period from January 5 to February 12 was essentially constant during the entire period and averaged 840 gpm. According to Mr. Robert Griffiths, the District Water Engineer, the drawdowns in both wells were so severe that pump suction was broken frequently during the period.

The period January 5 to February 12, 1985, is of special interest because both pumping wells were at their maximum drawdown for 38 days; thus, stabilizing the maximum depth of the drawdown "cone". Although the depth of the "cone" was continuing to grow outward from the pumping wells, the water levels were declining at slower rates near the pumping wells than at larger radii. During that same period declines in observation well No. 3 at a distance of 645 ft (195.5m) averged .71 inches (1.8cm) per day; whereas, further out at the radius of 1643 ft (498m) the Kanta Well water level was declining at the rate of 1.1 inches (2.8cm) per day. After February 12, and until April 1, 1985, the water-level decline-rate in the Kanta Well slowed even more to .32 inches (1.2cm) per day and the "cone" was essentially stabilized at that distance from the pumping wells. It should also be noted, however, that from February 22 until April 1 the average pumping rate decreased approximately 5 percent from 845 gpm to 800 gpm. Certainly this reduction affected the drawdown rate, but the near stabilizaiton of the drawdown in both pumping wells and the observation wells during this period indicates that the system was approaching equilibrium or a steady state.

Judging from the 1984-85 data collected the following general interpretations and conclusions about the system seem reasonable. (1) The October 11 pumping surge of approximately 800 gpm by Well No. 2 caused a rapid drawdown within the pumping well and in wells 1 and 3. This rapid decline reflects water being removed from storage in the fracture zone in the vicinity of the wells. The October 11 surge in pumping was also felt in the Kanta Well causing an increased drawdown rate and indicating a response to the pumping outside what seems to be the main fracture set. (2) The behavior of the drawdown "cone" and its apparent near stabilization indicates that the system was approaching equilibrium or a steady-state. (3) Under the near equilibrium conditions, essentially all of the water in the vicinity of the pumping and observation wells had been removed from storage and the system was acting as a pipeline whose primary function was to conduct water from greater radii to the pumping wells. (4) Under the current conditions within the system the maximum flow which the "pipeline" can conduct is between 800 gpm and 840 gpm.

DETERMINATION OF TRANSMISSIVITY

Recognizing that this study deals with an aquifer in fractured media rather than porous media, and that limiting assumptions for strict use of the mathematical models of Theim, Theis, and Jacob cannot be complied with, it is nevertheless useful to make a few qualified estimates of transmissivity using some of those models.

During the period from January 5 to February 12, 1985, when the water levels in the pumping wells were static and production was essentially constant at 840 gpm (Figure 3), the water level in observation well No. 3 was declining slowly at an average .71 inches/day (1.8cm) A plot of the water level readings from this period is shown in Figure 4. The data plot on a straight line indicating that the drawdown was occurring logarithmically with time. Using Jacobs modified non-equilibrium equation for Transmissivity (T),

$$T = \frac{264Q}{s}$$ where:

$$Q = 840 \text{ gpm}$$

$$T = 13{,}000 \text{ gals/day/ft}$$

For the intermediate period October 27 to December 2, drawdown was occurring more rapidly and pumpage was generally more erratic. However, for a portion of that period between November 16 and November 22 pumpage was nearly constant at 715 gpm. Projecting the slope across one log cycle on this portion of the drawdown curve s = 62 ft. Using a Q = 715 gpm and the modified non-equilibrium equation a value of transmissivity of 3500 gal/ft/day is obtained.

Judging from the plots, it appears that the rapid drawdown and the low transmissivity value of the intermediate pumping period suggests that water is being removed from storage in the main fracture system in which the three wells are drilled. Although the higher transmissivity value of 13000 gals/day/ft seems low, it reflects increased supply available with increased drawdown. Perhaps a more pervasively fractured portion of the system comes within the influence of the pumping wells as the potentiometric surface declines at a greater radius from the pumping well.

To check the transmissivity value obtained using the Jacob equation, a drawdown-distance graph was also plotted using the No. 3 observation well and the No. 2 pumping well (Figure 5). Although using a pumping well introduces potential errors because of head loss due to well losses, such an estimate should reflect a minimum transmissivity applicable to the late phase pumpage from the system. As noted earlier, when the drawdown at the pumping well was at its maximum and water levels in the observation well were declining at a slow rate, the system was approaching equilibrium and the drawdown "cone" had migrated sufficiently far afield that recharge to the system was nearly equal to extractions. At that time, pumpage from the system was steady at an average of 840 gpm and conditions were conducive to yielding a reasonably accurate but conservative determination of transmissivity. Using the maximum Q value of 840 gpm and the maximum drawdown in Wells 2 and 3 projected across one logarithmic cycle (26.5 ft, 8m), a transmissivity of 16,700 gals/day/ft was obtained. In spite of the assumption of no well losses in the pumping well, this method yields

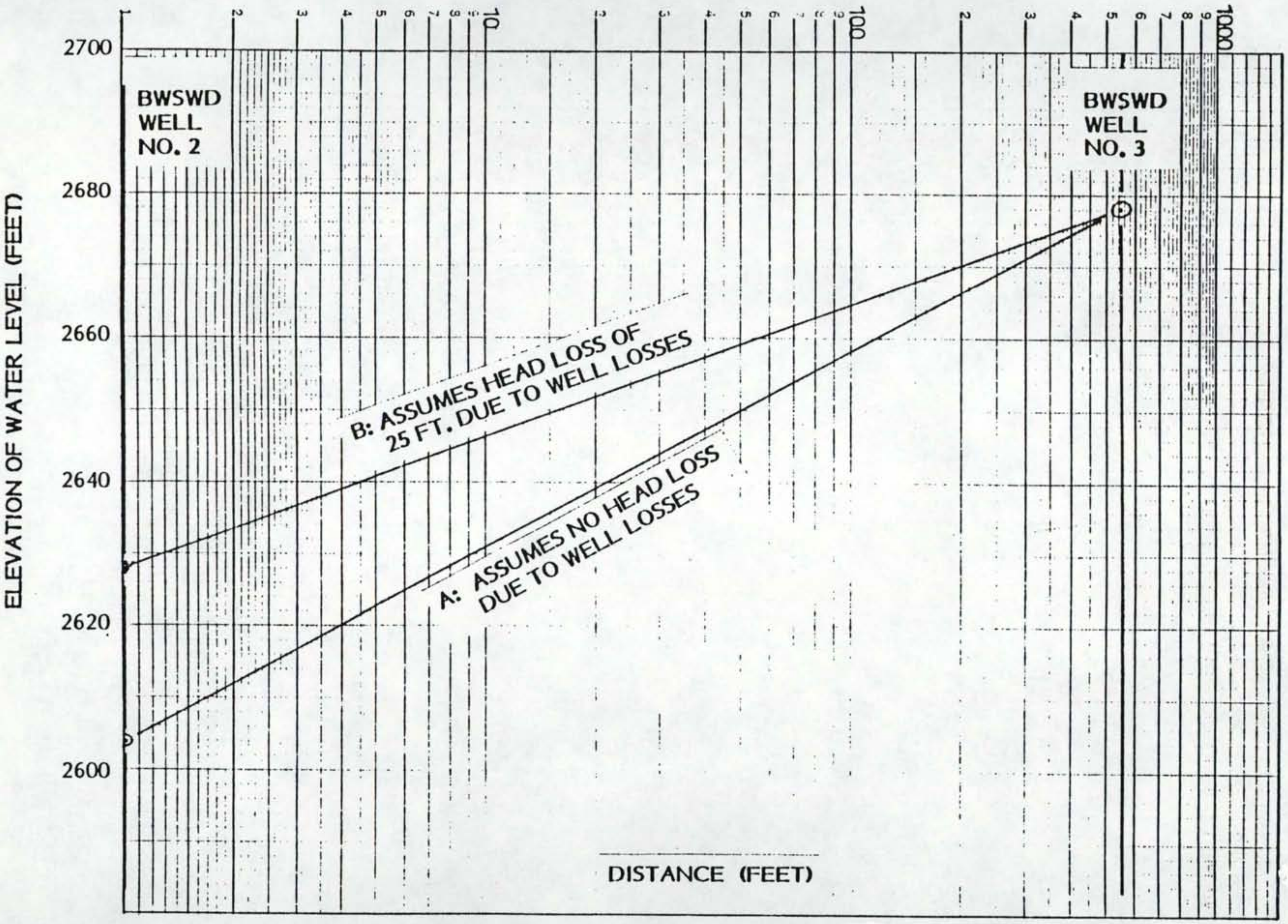

Figure 5. BWSWD Well No. 3 Distance-Drawdown Graph

a higher transmissivity than using only drawdown data from Well No. 3. Perhaps a part of the explanation for the lower transmissivity when using only data from the No. 3 Well lies in the fact that the well is drilled in a tighter part of the fault zone and the 13,000 gals/day/ft value partly reflects the lower transmissivity of that portion of the aquifer. It should be recalled that No. 3 yielded very little water during attempted pump tests. The drawdown-distance plot places more weight upon the higher permeability within the main fracture zone.

If one assumes that some reasonable increment of the drawdown in Well No. 2 is due to well losses, a higher transmissivity is obtained. For example, if one assumes 25 ft (7.6m) of the drawdown in No. 2 is due to well losses, a transmissivity of approximately 25,000 gals/day/ft is obtained.

The fact that well losses due to pumping in Well No. 2 are large is shown in Figure 3. An estimate of those losses may be obtained from a comparison of the water level plots. The wells are approximately 30 ft (9m) apart in the same fracture zone. Pumping of No. 1 did not begin until about November 24, 1984. Until that time its water-level graph is a somewhat subdued, but nearly exact replica of the water-level graph of No. 2 as it fluctuated due to pumpage. The striking similarity of the curves also indicates that there is good interconnection between the wells. It is interesting that the difference in the amount of drawdown in the two wells increased to a maximum of 50 ft (15.2m) as the pumpage rates in Well No. 2 rose to 715 gpm and the water level in Well No. 2 declined to 159 ft (48.2m) below the surface. Certainly a large portion of the 50 ft (15.2m) difference must reflect large well losses in the pumping well, especially since the wells are so close together. In view of these observations and interpretations, perhaps, assigning a 25 ft (7.6m) head loss to well losses is reasonable, even conservative. Therefore, the transmissivity of the fracture systems northwest of the pumping wells in the late stage of drawdown is in the order of 25,000 gals/day/ft.

Figure 6 is a semilogarithmic plot of the measured water-level fluctuations in the Kanta Well for the period September 20, 1984, through September 15, 1985. Peak recovery in 1984 occurred in September. The sharp decline in the water level near the 70th day reflects a response to increased demand on the system and the beginning of pumping in Well No. 1 on November 29. Projecting a best-fit straight line through the water-level data from November 29 to February 7, 1985, yields an average drawdown across one logarithmic cycle of 32.75 ft (9.9m). Using Jacob's modified non-equilibrium equation for transmissivity, where Q = 840 gpm, and s = 32.75 ft, the transmissivity has a value of approximately 6800 gals/day/ft. This transmissivity is from one-half to one-third of those values determined using data from the BWSWD No. 3 and the pumping wells. Our interpretation of this difference is that this value, 6800 gals/day/ft, mainly reflects the transmissivity of the downthrown block in which the Kanta Well is drilled as opposed to the fracture zone into which Wells 1 and 2 are drilled.

Pumping prior to November 29 was erratic and estimating the transmissivity from the earlier portion of the drawdown graph is somewhat tenuous. However, there is some encouragement from the data which fit a straight line. Pumpage from the No. 2 Well during the period October 10 to November 29 averaged approximately 715 gpm. Using

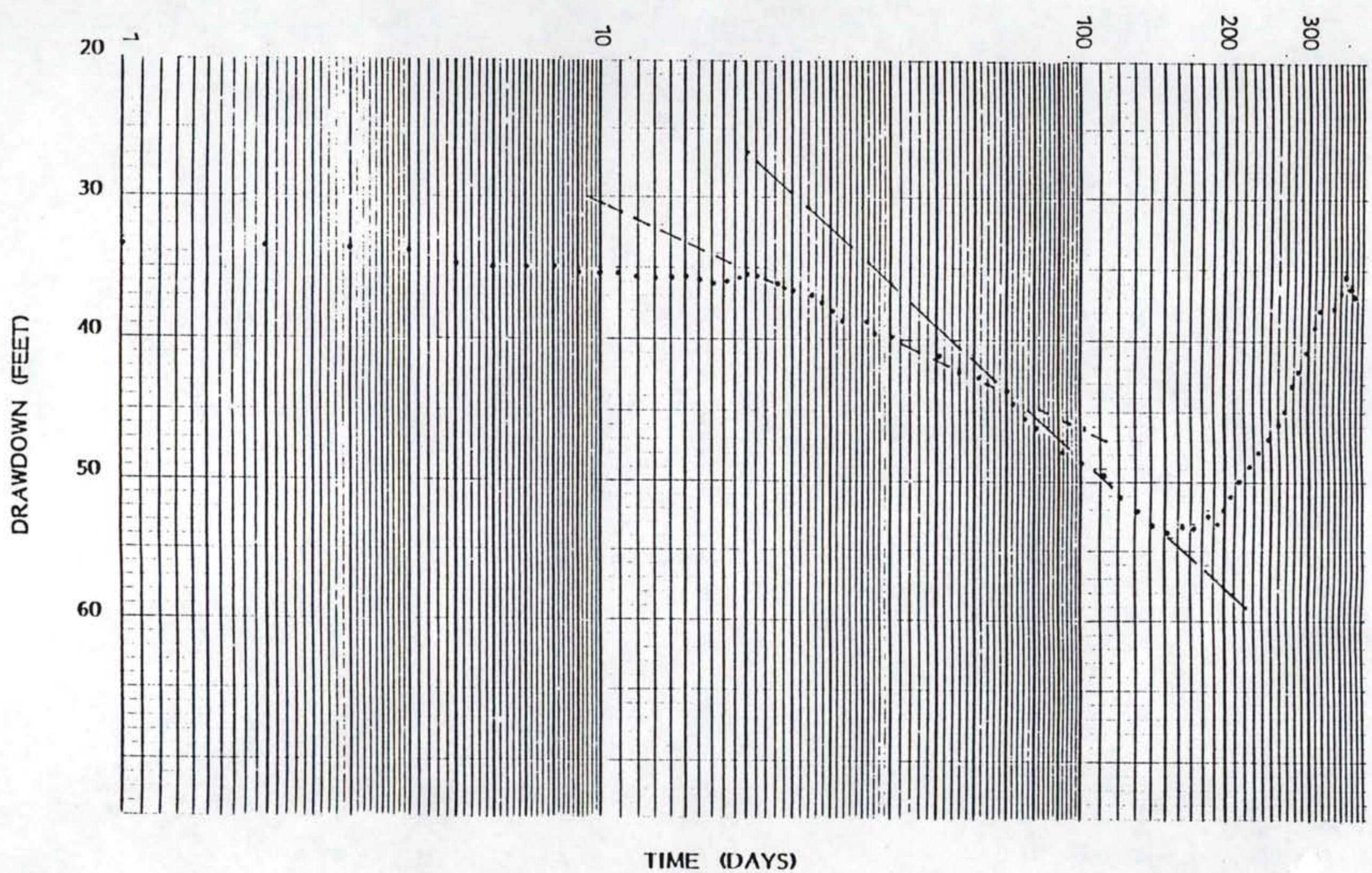

Figure 6. Drawdown-Time Graph for Kanta Observation Well

the drawdown for that period projected across one logarithmic cycle yields a drawdown of 15.75 ft (4.8m). Again using Jacob's modified non-equilibrium equation, a transmissivity of 12,000 gals/day/ft is obtained. Although this value is suspect, because of erratic pumping, it probably is a reasonable number for the transmissivity of the main fracture zone southeastward from the pumping well and in the direction of the Kanta Well.

Figure 7 is a distance-drawdown graph of the water-levels in the BWSWD Well No. 1 and Kanta Well on November 20. Well No. 1 did not begin pumping until November 25 and serves here as an observation well. Projecting drawdown across one logarithmic cycle yields a difference of 26.5 ft (8.0m). The pumpage from Well No. 2 was essentially constant at an average of 715 gpm from November 17 through November 24. Using these values of Q and s, the Theim equation yields a transmissivity of 14,300 gals/day/ft. The similarity of this value, and that calculated above using the more gentle drawdown slope in the Kanta Well shown in Figure 6 suggests that these transmissivity estimates are probably in the correct range. This impression is further reinforced by Mr. Will L. Burnham who recollects that some early pump tests on the BWSWD wells yielded transmissivity values between 15,000 and 25,000 gals/day/ft (personal communication).

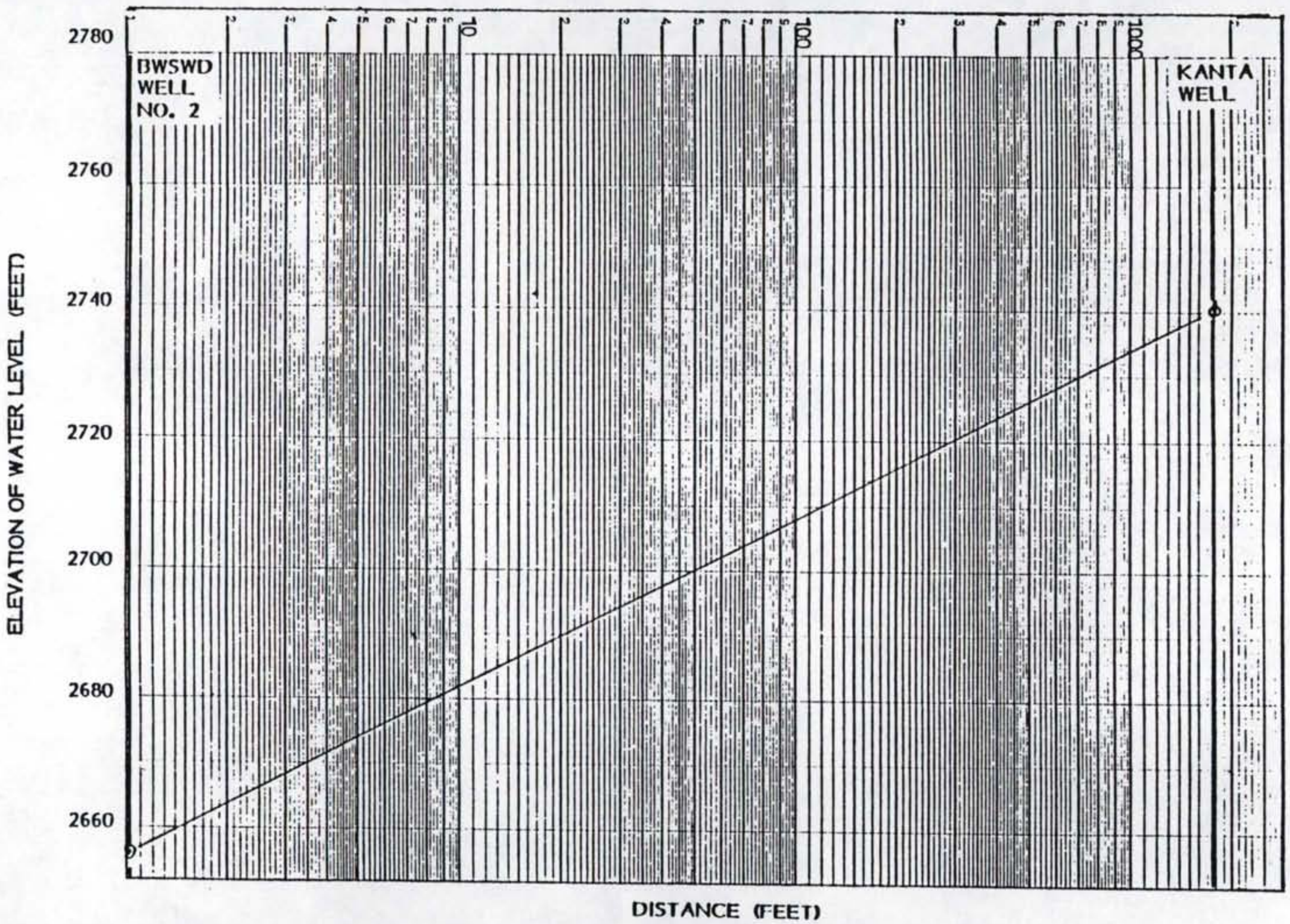

Figure 7. Drawdown-Distance Graph for Kanta Observation Well

SUMMARY AND OVERVIEW OF THE SYSTEM

The transmissivity values determined from the data in this study range from 3500 gals/day/ft to 25,000 gals/day/ft. In general the main fracture zone has the intermediate to higher transmissivities. The lower values are probably due to water being taken from storage in the vicinity of the BWSWD wells during early pumping, or to a comparatively low hydraulic conductivity in the downthrown block in which the Kanta Well is completed. Long term pumping within the system creates severe drawdown to the level of the pump bowls, and the drawdowns in the pumping wells and observation wells tend to stabilize. During 109 days of the 1984-85 heating season drawdown in the pumping wells were at or near their maximum. Drawdown in the Kanta Well reached its maximum by February 22 and essentially stabilized until April 1 when recovery began. This prolonged drawdown within the system apparently allowed the potentiometric "cone" to migrate sufficiently far afield to intercept sufficient recharge to bring the system to near steady-state conditions. From January 1, 1985, until February 7, Wells 1 and 2 were at their maximum drawdown and pumping was essentially constant at 840 gpm. During that time the aquifer system near the pumping and observation wells was essentially acting as a pipeline. The "pipeline" was a conduit to bring storage water from the outer portion of the system, and intercepted recharge to the pumping wells. The very slow water-level declines measured in the observation wells during the later to middle portion of the heavy pumping period yield the largest transmissivities because of this increased interception of recharge and storage.

Unfortunately we do not have a complete record of pumpage from the system during the period of this study. Between April 28 and July 23, 1985, the Sparling meter was broken. Fortunately this is not within the peak demand period and one can see from Figure 3 that the water levels in the pumping wells had recovered considerably. To estimate the flow during this period average flow rates were extrapolated from previous years in which the drawdown curves had similar levels and configurations. Using the Sparling meter records and this method to fill the gap, the cumulative flow for the period September 16, 1984, until August 30, 1985, was estimated to be approximately 265 million gallons. Assuming that this figure is a reasonably accurate total for the extractions from the system by the BWSWD pumping wells, an average annual recharge rate of approximately 500 gpm is required. This compares to a maximum sustainable withdrawal capacity of the current pump and aquifer system of approximately 840 gpm. Thus, even though the system at maximum drawdown intercepts additional recharge, it is not sufficient to supply pumpage in excess of the 840 gpm on a sustained basis. Currently during peak demand, 840 gpm is not sufficient to meet the BWSWD's delivery obligations.

According to BWSWD water level records, July-August 1983 was the last period in which maximum recovery brought the water level in the system to surface flow at the well house. In addition, the duration of the period of flow generally decreased from 1980 through 1983. In 1984 and 1985 the maximum water level recovery at the well house was only within 20 ft (6.06m) of the surface. In the Kanta Well the 1985 recovery was 2 ft (.6m) short of that in 1984. Furthermore, the recovery peak has also been delayed. In 1984 and 1985 the system did not peak until mid-September.

Unfortunately we do not know yet if these effects reflect less recharge to the BWSWD aquifer system, greater extractions from the system by the Warm Springs District, new extractions creating interference of capturing previous recharge, or natural cycles within the system. This study has been a good beginning. It has initiated a computer format for treatment of data, contributed to our understanding of the aquifer network and its response to pumpage and recharge, and suggested transmissivity values characteristic of the complex aquifer system. But, it is just that--a beginning. Without a continuing effort to monitor this and other portions of the Boise Geothermal System on an integrated scale, and to analyze the past records of the BWSWD and other users, we will come no closer to understanding how to manage this important resource.

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