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ESTIMATION OF HYDRAULIC PROPERTIES AND DEVELOPMENT OF A LAYERED CONCEPTUAL MODEL FOR THE SNAKE RIVER PLAIN AQUIFER AT THE IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO

by

David B. Frederick
State of Idaho INEL Oversight Program

and

Gary S. Johnson
University of Idaho

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State of Idaho INEL Oversight Program
900 North Skyline Drive
Idaho Falls, Idaho 83402

Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho 83844-3011

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ABSTRACT

The Idaho INEL Oversight Program, in association with the University of Idaho, Idaho Geological Survey, Boise State University, and Idaho State University, developed a research program to determine the hydraulic properties of the Snake River Plain aquifer and characterize the vertical distribution of contaminants. A straddle-packer was deployed in four observation wells near the Idaho Chemical Processing Plant at the Idaho National Engineering Laboratory. Pressure transducers mounted in the straddle-packer assembly were used to monitor the response of the Snake River Plain aquifer to pumping at the ICPP production wells, located 2600 to 4200 feet from the observation wells. The time-drawdown data from these tests were used to evaluate various conceptual models of the aquifer.

Aquifer properties were estimated by matching time-drawdown data to type curves for partially penetrating wells in an unconfined aquifer. This approach assumes a homogeneous and isotropic aquifer. The hydraulic properties of the aquifer obtained from the type curve analyses were:

- Storativity = 3×10^{-5}
- Specific Yield = 0.01
- Transmissivity = 740 ft^2/min
- Anisotropy (Kv:Kh)= 1:360

Further evaluation of the time-drawdown data collected at various depth intervals in the aquifer indicated that drawdown generally increased with depth. Time-drawdown data were compared to the stratigraphy of the basalt flows and sedimentary interbeds at the Idaho National Engineering Laboratory developed by Anderson (1991). The greatest drawdown was observed in tested intervals below the top of Flow Group I.

To evaluate the implications of this observation, a radial flow model was used to simulate three conceptual models for the Snake River Plain aquifer near the Idaho Chemical Processing Plant:

1) One Layer System:

Single aquifer -	Flow Groups E-I (homogeneous and anisotropic)

2) Two Layer System:

Upper aquifer -	Flow Groups E-G (homogeneous and anisotropic)
Lower aquifer -	Flow Group I (homogeneous and anisotropic)

3) Three Layer System:

Upper aquifer -	Flow Groups E-G (homogeneous and anisotropic)
Confining unit -	sedimentary interbed at the top of Flow Group I (homogeneous and isotropic)
Lower aquifer -	Flow Group I (homogeneous and anisotropic)

The three-layer system, in which the upper 70 feet of the aquifer is unconfined, the sedimentary interbed at the top of Flow Group I is a leaky confining layer, and the basalt units in Flow Group I represent a leaky confined aquifer, provided the best match of simulated drawdown to observed drawdown. Estimates of the hydraulic properties of each layer were determined by trial and error model calibration. This optimization resulted in the following average estimates for the hydraulic properties of the composite, three-layer system:

- Storativity = 7×10^{-6}
- Specific Yield = 0.009
- Transmissivity = 430 ft^2/min
- Anisotropy (Kv:Kh)= 1:230

The estimated hydraulic properties for each of the three layers are as follows:

1) Upper aquifer (unconfined)
   Horizontal conductivity = 3.7 ft/min
   Vertical conductivity = 0.3 ft/min

2) Confining layer (leaky)
   Horizontal conductivity = 1.4×10^{-4} ft/min
   Vertical conductivity = 1.4×10^{-4} ft/min

3) Lower aquifer (leaky, confined)
   Horizontal conductivity = 0.6 ft/min
   Vertical conductivity = 0.4 ft/min

Calibration of the radial flow model and type curve analysis resulted in similar estimates of the hydraulic properties of the aquifer system, despite major differences in the conceptual models (i.e. one layer versus three layers).

For aquifer characterization studies with less quantitative objectives, such as an evaluation of an area's water supply potential, type-curve analysis may be adequate. However, for more complex needs, such as contaminant-transport modeling, it may be necessary to refine the conceptual model and corresponding estimates of the hydraulic properties.

ACKNOWLEDGEMENTS

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LIST OF ACRONYMS

b - saturated thickness of aquifer

ß - dimensionless parameter used to account for aquifer anisotropy in type curves developed by Neuman (1974)

$$\beta = (Kv/Kh)*(r^2/b^2)$$

bls - below land surface

DOE - U.S. Department of Energy

ft - feet

gpm - gallons per minute

ICPP - Idaho Chemical Processing Plant

INEL - Idaho National Engineering Laboratory

Kh - horizontal hydraulic conductivity

Kv - vertical hydraulic conductivity

min - minute

NA - not available

NM - not meaningful

Q - pumping rate

r - radial distance between pumping well and observation well

S - storativity

SRPA - Snake River Plain aquifer

Sy - specific yield

T - transmissivity

TDX - transducer

USGS - U.S. Geological Survey

WT - water table

CHAPTER 1:

INTRODUCTION

Background

The Idaho National Engineering Laboratory (INEL) is located in southeast Idaho and is operated by the U.S. Department of Energy (DOE). The INEL encompasses 890 square miles of the Snake River Plain about 40 miles west of Idaho Falls (Figure 1). Since it was established in 1949 as the National Reactor Testing Station, 52 nuclear reactors have been constructed and tested at the INEL.

There are several major facilities at the INEL which have served a range of uses associated with DOE operations, including nuclear-reactor research, waste disposal, and reprocessing of spent nuclear fuel. One of these facilities, the Idaho Chemical Processing Plant (ICPP), was constructed in the early 1950s to recover fissionable materials from spent nuclear fuel (Figure 2). Reprocessing of nuclear fuel began at the ICPP in 1952, and continued intermittently until 1994.

From 1953 to 1984, low-level radioactive, chemical, and sanitary waste water from the ICPP was discharged directly to the Snake River Plain aquifer (SRPA) via an injection well (CPP-03). At present, process waste water is discharged to two unlined infiltration ponds located south of the ICPP, and sewage effluent is routed to a infiltration pond east of the facility.

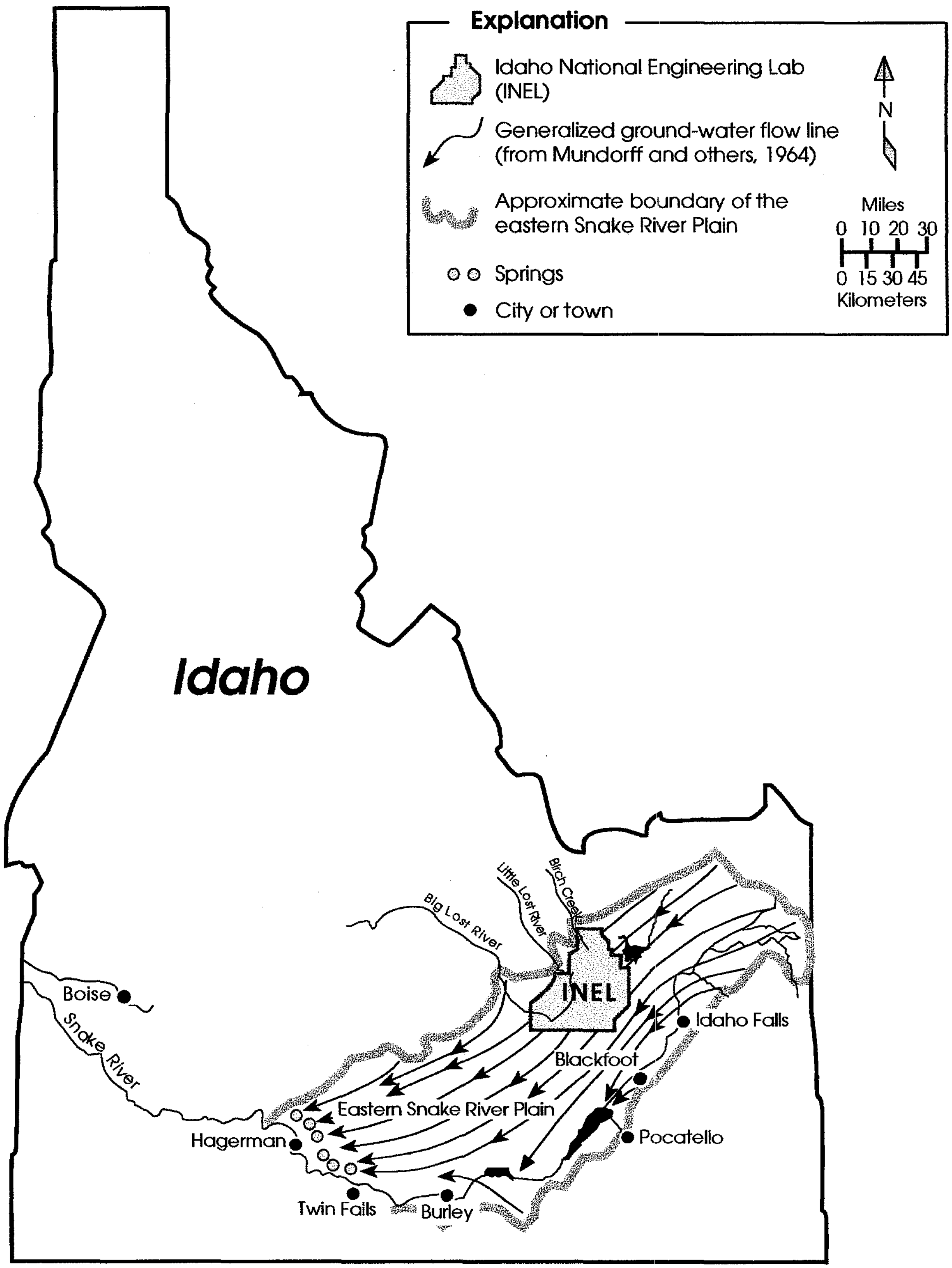

Figure 1. Map of Idaho showing the locations of the INEL, eastern Snake River Plain, and generalized ground-water flow lines of the Snake River Plain aquifer.

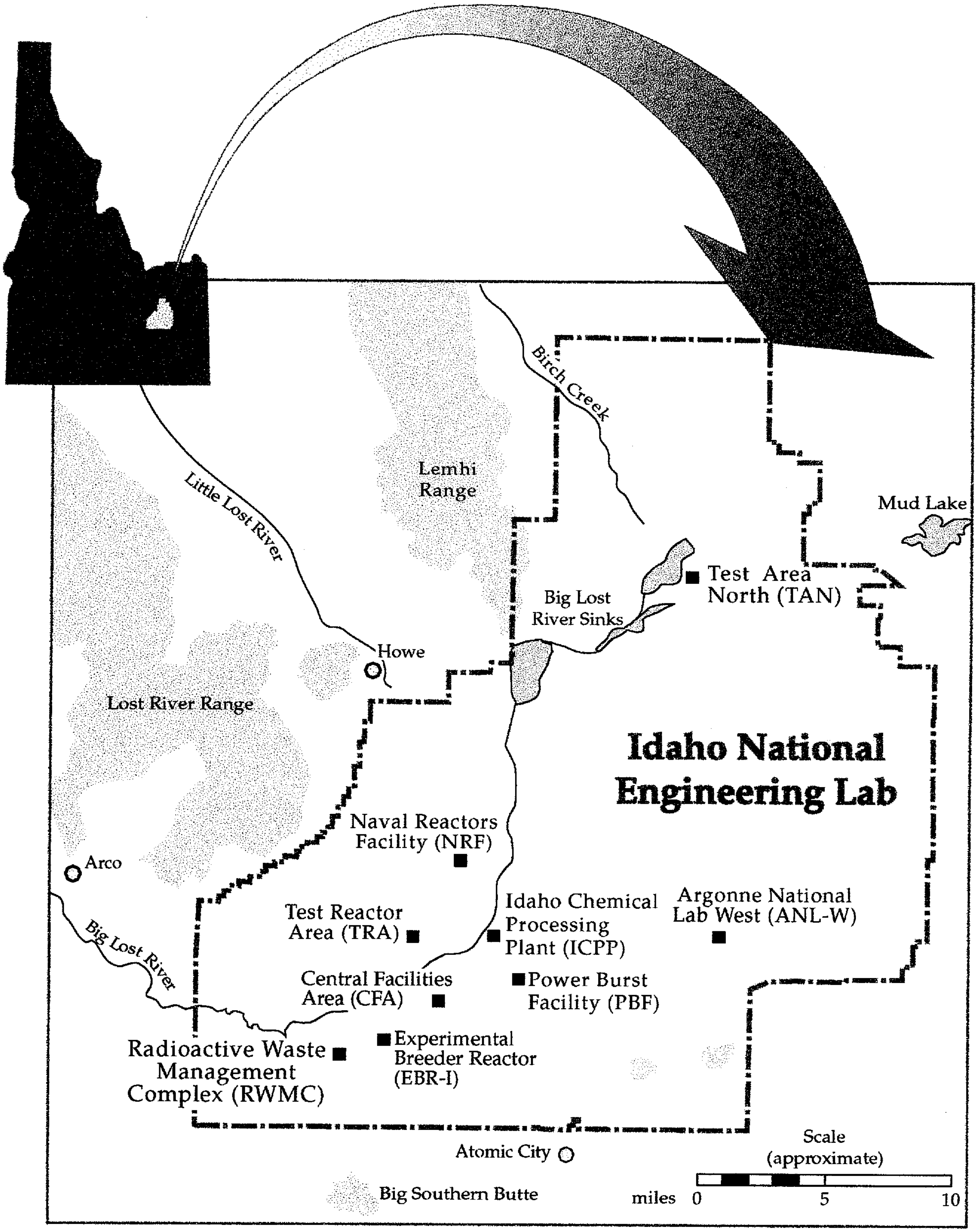

Figure 2. Location of the Idaho Chemical Processing Plant at the Idaho National Engineering Laboratory.

Disposal of waste water at the ICPP has resulted in the formation of contaminant plumes which extend several miles downgradient (Barraclough and Jensen, 1976; Barraclough and others, 1982; Mann and Cecil, 1990). Contaminants detected in the aquifer include tritium, strontium-90, iodine-129, nitrate, and chloride.

In 1989, the INEL Oversight Program was established by the legislature of the State of Idaho to provide an unbiased and independent source of information on the INEL's impact on the environment. In an effort to characterize the three-dimensional nature of the ICPP contaminant plumes, the INEL Oversight Program, in cooperation with the University of Idaho, Idaho State University, Boise State University, and the U.S. Geological Survey, conducted a series of straddle-packer tests in four observation wells (USGS-44, USGS-45, USGS-46, and USGS-59) located west and south of the ICPP (Figure 3). These wells were installed by the U.S. Geological Survey in the 1950s and 1960s to monitor the water quality of the aquifer.

A straddle-packer system was used to isolate specific intervals of the Snake River Plain aquifer and monitor water quality, vertical gradients, and the aquifer response to an applied hydraulic stress. Three types of aquifer tests were performed with the straddle-packer system:

1) **Single-well tests.** Water was pumped from a specific interval of the aquifer using a pump located between two packers.

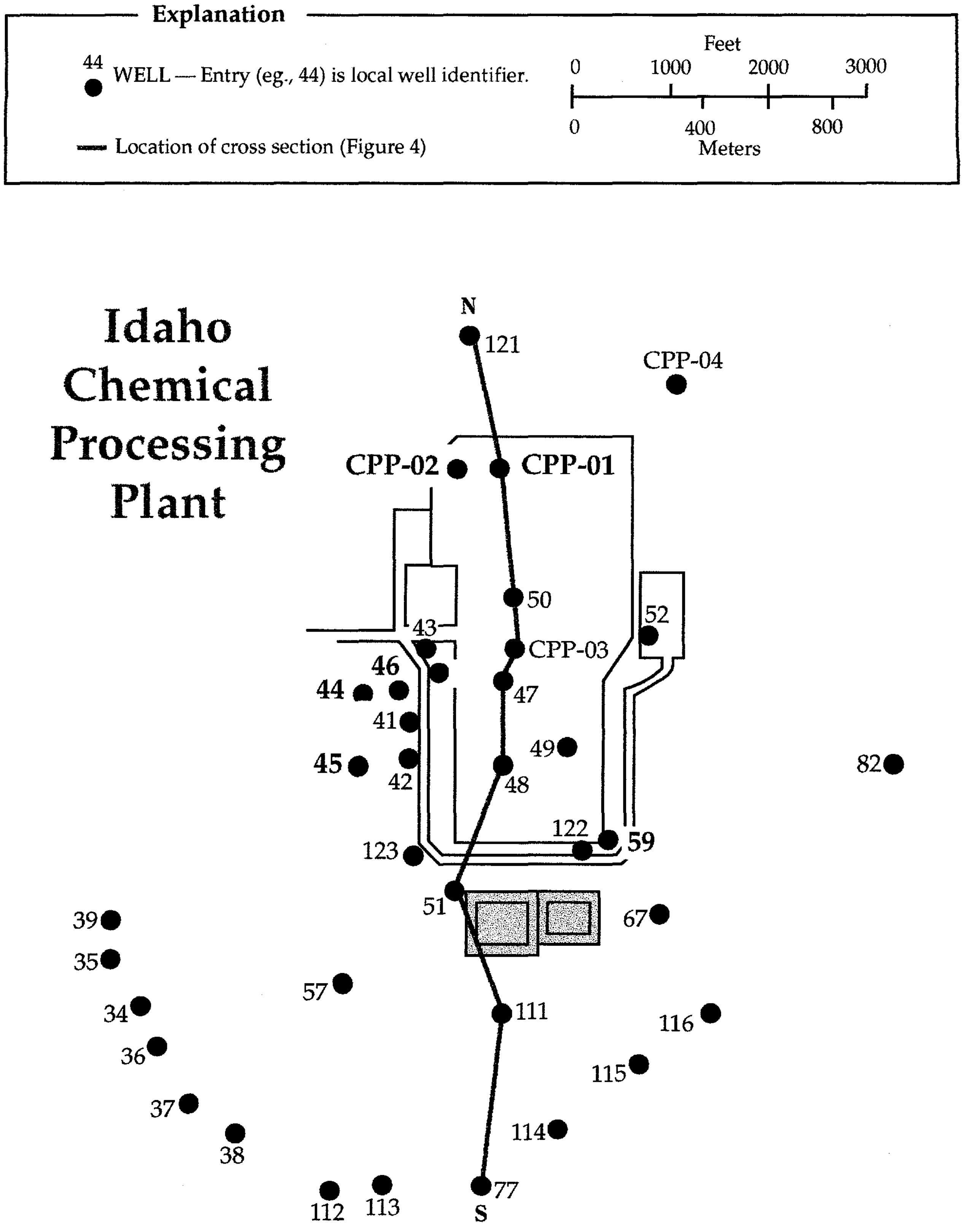

Figure 3. Locations of selected observation wells at the Idaho Chemical Processing Plant.

2) **Slug tests.** The riser pipe on the straddle-packer system was filled with water, which was instantaneously released into the interval of the aquifer between the two packers.

3) **Multiple-well tests.** The straddle-packer system was used in observation wells to measure the response of specific zones in the aquifer to pumping of the ICPP production wells.

This report discusses the results and interpretation of the multiple well tests.

Geology

The INEL is located in the central part of the eastern Snake River Plain, a large northeast-trending basin covering approximately 12,000 square miles (Figure 1). The basin has been filled by several thousand feet of Tertiary and Quaternary basalt and sediment. A more detailed discussion of the geology and geologic history of the Snake River Plain can be found in Robertson and others (1974), Bonnichsen and Breckenridge (1984), Hackett and others (1986), Whitehead (1986), and Lindholm (1993).

Anderson (1991) studied the stratigraphy of the vadose zone and upper portion of the Snake River Plain aquifer in the vicinity of the ICPP using geophysical logs coupled with paleomagnetic data and radiometric-age determinations from the basalt. Twenty three basalt-flow groups were identified and categorized into seven stratigraphic units based on source and age relations. Composite stratigraphic units generally consist of multiple basalt flows and sedimentary interbeds (Figure 4).

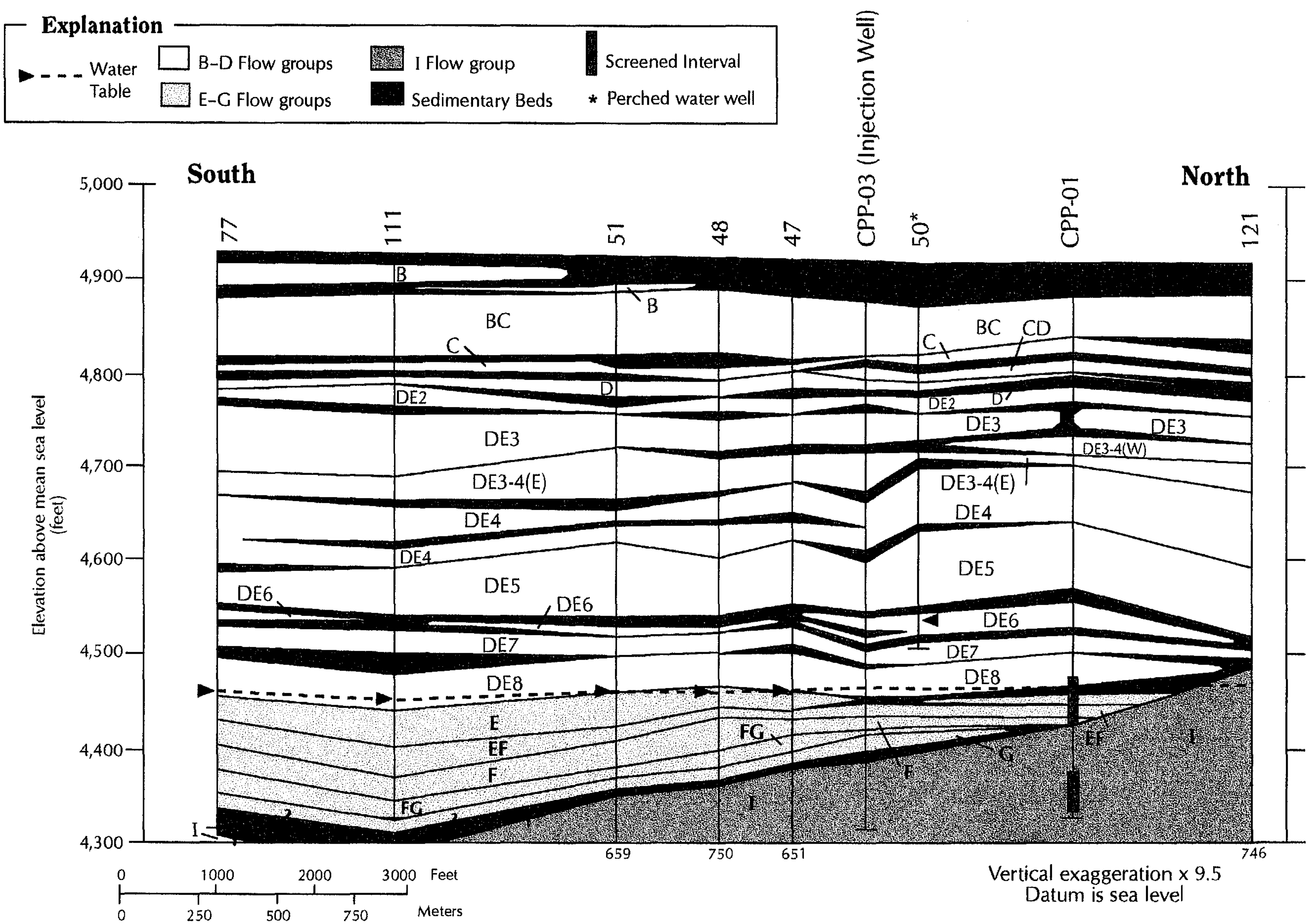

Figure 4. Geologic cross section at the Idaho Chemical Processing Plant (after Anderson, 1991). See figure 3 for location of cross section.

The location of the cross section in Figure 4 is shown on Figure 3.

The USGS wells tested by the INEL Oversight Program were ideally suited for performing packer testing in the Snake River Plain aquifer because they were drilled to a depth of about 650 feet below land surface (bls) and are open to the aquifer over an interval of approximately 200 feet. The wells, which were cased throughout the vadose zone, are completed in Flow Groups E-G and Flow Group I, as identified by Anderson (1991) and shown in Figure 4. The flow units dip to the southeast. Individual flows in Flow Groups E-G are 10-26 feet thick in wells USGS-44, -45, -46, and -59 (Steve Anderson, 1995, personal communication). The two basalt flows in Flow Group I which were identified in these wells are typically thicker, ranging from 19 ft to >90 ft. A sedimentary interbed, four to nine feet thick, is present at the top of Flow Group I in USGS-45, -46, and -59.

Hydrogeology

The Snake River Plain aquifer is present beneath nearly all of the eastern Snake River Plain. The aquifer primarily consists of a layered sequence of basaltic lava flows intercalated with sedimentary interbeds. Recharge to the aquifer is primarily from irrigation, underflow from basins north and northwest of the INEL, and precipitation on the plain. The primary discharge areas for the aquifer is the Thousand Springs region near Hagerman (Figure 1), and springs near American Falls Reservoir.

At the INEL, depth from land surface to the aquifer ranges from about 200 feet at the north end of the INEL to more than 600 feet at the south end.

Considerable debate exists over the thickness of the Snake River Plain aquifer. Robertson (1974) states that "Although the real aquifer system is probably more than 1,000 feet (300 meters) thick, a thickness of 250 feet (76 meters) is used in this study based on apparent layering effects in the aquifer." Based on the presence of low permeability sedimentary layers encountered in a well drilled approximately three miles north of the ICPP, Mann (1986) suggested that the Snake River Plain aquifer is 450-800 feet thick. Modeling studies performed by the U.S. Geological Survey represented the eastern Snake River Plain aquifer as a four-layer system, with the total thickness of the aquifer at the INEL ranging from 500 ft to over 3000 ft in thickness (Garabedian, 1989).

Most, if not all, of the aquifer tests at the INEL have been conducted in partially penetrating wells in an aquifer of unknown thickness. The thickness of the tested interval is a function of the construction characteristics of a given pumping well. Estimates of transmissivity from these tests do not represent the entire thickness of the aquifer.

Transmissivity estimates for the Snake River Plain aquifer range over several orders of magnitude. Walton (1958) analyzed aquifer test data for nineteen wells at the INEL, and determined that the transmissivity of the aquifer ranged from 2.8 to 1670

ft^2/min. Ackerman (1991) evaluated aquifer-test data from 94 wells at the INEL, and reported transmissivity estimates of the Snake River Plain aquifer ranging from 0.0008 to 530 ft^2/min. Table 1 summarizes the transmissivity determined for the ICPP production wells.

Table 1. Transmissivity estimates for the Snake River Plain aquifer determined from pumping tests of the ICPP production wells (Ackerman, 1991).

Well	Transmissivity (ft^2/min)
CPP-01	50
CPP-02	110

Wylie and others (1994) estimated the transmissivity of the aquifer to be about 695 ft^2/min based on a multiple-well pumping test conducted near the Radioactive Waste Management Complex (RWMC). Haskett and Hampton (1979) and Mundorff and others (1964) reported transmissivity values of 14 to 3472 ft^2/min from aquifer tests in the eastern Snake River Plain aquifer.

Previous studies have evaluated the Snake River Plain aquifer as a water-table aquifer (Garabedian, 1989; Wylie and others, 1994). Estimates of specific yield from aquifer tests in the eastern Snake River Plain aquifer range from 0.01 to 0.22 (Haskett and Hampton, 1979; Mundorff and others, 1964).

Objectives

The objectives of this study were to:

1) Collect and utilize drawdown and recovery data from routine pumping of the ICPP production wells.

2) Provide quantitative estimates of the storativity, specific yield, and horizontal and vertical hydraulic conductivities of the Snake River Plain aquifer near the Idaho Chemical Processing Plant.

This information will advance the conceptual and quantitative understanding of the three-dimensional characteristics of the Snake River Plain aquifer near the ICPP, and can be used to develop or refine ground-water models.

CHAPTER 2:

METHODOLOGY

From 1992 to 1994, aquifer tests were performed with the straddle-packer system in four wells (USGS-44, USGS-45, USGS-46, and USGS-59) near the Idaho Chemical Processing Plant. The investigations of the Snake River Plain aquifer performed in each well included monitoring the response of the aquifer to pumping at the ICPP production wells to evaluate properties of the Snake River Plain aquifer. This information was used to supplement the single-well pumping tests conducted with the straddle-packer. Well construction diagrams and the lithologic logs for the observation wells and production wells are in Appendix A. Sediments and other fine-grained material are readily "washed out" of the cuttings prior to reaching the surface. As a result, some discrepancies may exist between the driller's lithologic log and the lithology determined by Anderson (1991).

The results of the aquifer tests were first evaluated using type curves developed for wells which do not penetrate the entire thickness of the aquifer, assuming a homogeneous system (Neuman, 1974). As a result of the observed change in aquifer response which likely corresponds to the top of Flow Group I, the test data was also compared to numerical modeling results for a stratified (multi-layered) aquifer.

Straddle-Packer System

Intervals for packer testing were selected by viewing down-hole video logs of the basaltic rocks and identifying intervals of the wells where the basalt likely would provide a suitable seal for the packers. Ideally, a packer would be seated at a portion of the well where the borehole wall was smooth, and the basalt exhibited a minimal number of vesicles or fractures. The thickness of the straddled interval was adjusted by changing the configuration of pipe lengths between the packers; for this study, the straddle packer was used to isolate intervals of the aquifer which were 15-20 feet thick. After lowering the straddle-packer assembly to the desired depth, the packers, which are fabricated from Viton™[1] and rubber, were inflated with nitrogen gas. Hydraulic head was measured by three Paroscientific, Inc. "Digiquartz" depth sensors (transducers): one in the packed-off interval, and one each above and below the packed-off interval. This configuration provided measurements of the vertical gradients in the well. Figure 5 is a schematic diagram of the straddle-packer system.

The transducers have a pressure range of 0 to 400 pounds/in^2 (psi), and provide temperature and temperature-corrected pressure readings. The repeatability and hysteresis are listed at ± 0.005% of full scale, which is approximately ± 0.046 feet of head. The accuracy of the transducers for relative static head

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[1] The use of trade names in this document does not constitute an endorsement by the State of Idaho or its employees.

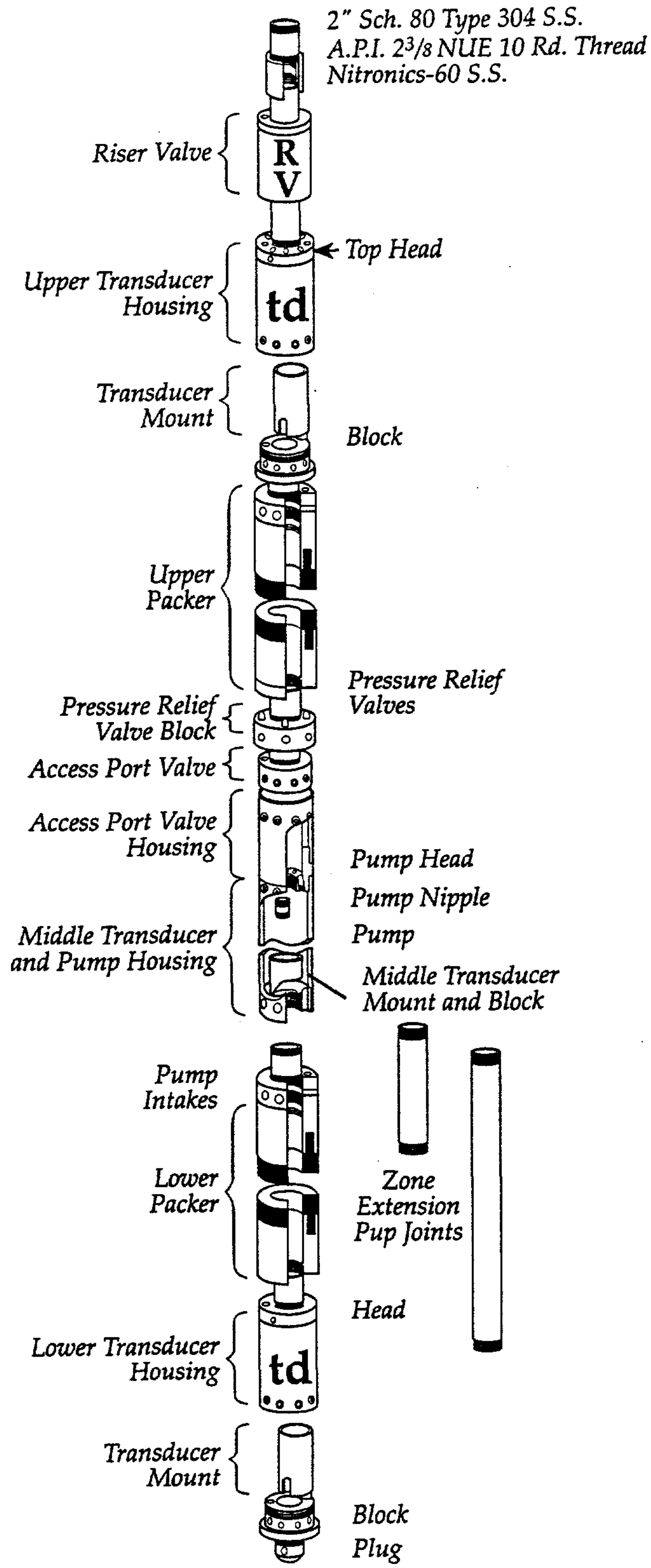


Figure 5. Schematic of the straddle packer system. (from Olsen, 1994; not to scale).

measurements is about $\pm$ 0.005 feet, due to background "noise". The transducers are linked in a serial loop, and data is recorded on a portable computer. The frequency at which the transducers measure and record pressure can be varied using a BASIC program.

Pressure data were collected at intervals ranging from one second to several minutes, depending on the design of the test. At time intervals greater than one minute, ten consecutive pressure readings are taken at one second intervals, and the BASIC program calculates an average, thus reducing the background "noise". Additional information on the straddle-packer assembly can be found in Olsen (1994).

Description of Production Wells

The Idaho Chemical Processing Plant has two production wells, CPP-01 (or CPP 670) and CPP-02 (or CPP 671) for supplying process water. These wells, which are located at the north end of the ICPP, were utilized as pumping wells for the aquifer tests discussed in this report (Figure 3). The pumping rate of the production wells was estimated to be 3000 gallons per minute (gpm) (Daryl Hall, ICPP Utilities Dept., personal communication, 1994).

The production wells were drilled in the early 1950s, and have a 16 inch diameter well screen. The depth to water in the wells is estimated to be 456 feet bls, based on measurements taken in nearby USGS wells in April 1994. CPP-01 is screened from 460-486 feet and 527-577 feet bls. CPP-02 is also screened over two intervals of the aquifer: 458-483 feet and 551-600 feet bls (Appendix A). Type curves for production wells screened in multiple intervals of the aquifer are not available. Therefore, for the type curve analyses, it was assumed that CPP-01 is screened from 460-577 feet bls, and CPP-02 is screened from 458-600 feet bls. Production wells screened in multiple intervals would result in vertical gradients between pumped zones near the production well. The radial distance between the production wells and the observation wells ranged from 2600 to 4200 feet (Table 2), therefore the error introduced into the type curve solution by assuming the production wells have a continuous interval open to the aquifer should be minimal. Furthermore, between the screened intervals in the production wells, gravel was placed in the annular space surrounding the casing (Appendix A). This gravel would facilitate a uniform vertical distribution of drawdown near the borehole.

The production wells are not equipped with a valve assembly to maintain the column of water in the riser pipe. Therefore, the discharge rate is higher when the pump is first turned on, and decreases as the pressure head increases due to increases in the height of the overlying water column in the pipe. Similarly, water in the riser pipe flows back into the aquifer when the pump is turned off. This imparts some degree of error in the estimation of aquifer storativity from early time data.

Table 2. Radial distance between observation wells tested with the straddle packer and the ICPP production wells.

	CPP-01	CPP-02
USGS-44	r = 2800 ft	r = 2600 ft
USGS-45	r = 3300 ft	r = 3100 ft
USGS-46	r = 2800 ft	r = 2700 ft
USGS-59	r = 4000 ft	r = 4200 ft

Data Collection

The time-drawdown data presented in Chapter 3 is frequently a combination of two data files which were collected for different purposes; "timed-response" and "static" tests. "Timed-response" data was collected by contacting the Utilities Department at the ICPP and requesting the production well be turned on or off, depending on the current cycle. In some instances, these tests were of relatively short duration (i.e. less than 10 minutes). The frequency of pressure readings collected during these tests ranged from one second (early-time), to several minutes (late-time).

The "timed-response" tests were supplemented with water level data collected during long-term tests, which were run for several hours. Drawdown from pumping at the ICPP production wells is readily recognizable in the long-term tests; however, the exact time that pumping began can only be estimated. The accuracy of the estimate is dependent on the frequency at which pressure readings were being collected by the transducers. For example, if the head data was being collected at five minute intervals, the production well may have been operational a few seconds or a few minutes before the pressure was measured. The time-drawdown data was plotted on logarithmic scale paper for the type curve analyses and comparisons to simulated drawdown from the radial flow model (for example, see Figures 7 and 18). As a result, the error in the estimates of aquifer properties associated with the uncertainty of the time at which pumping began is insignificant for the late-time data (i.e. greater than 30 minutes of pumping). This uncertainty will influence estimates of storativity, which are derived from the early-time data. To counter this ambiguity, the curve matching was weighted more heavily to the late-time data, and storativity estimates are listed as "not meaningful" if a timed response data file was not available. Table 3 contains a summary of the time-drawdown data collected with the straddle-packer assembly.

Previous studies have indicated that the water level in the Snake River Plain aquifer near the ICPP is affected by changes in barometric pressure (Johnson and others, 1994). The effect of barometric pressure changes on drawdown values should be minimal because 1) the pumping tests were less than five hours duration, and 2) data files from static tests were selected from time periods when fluctuations in barometric pressure were minimal.

Table 3. Summary of data files collected during the multiple-well aquifer tests.

Observation Well	Straddled Interval (feet below land surface)	Date of Test	Type of Data File	Type of Aquifer Test	Duration of Test	Frequency of Transducer Readings
USGS-44	461-482	8/13/92	Long-term	CPP-01 Pumping	165 minutes	5 minutes
	480-495	8/15/92	Long-term	CPP-01 Pumping	130 minutes	5 minutes
	500-515	11/12/92	Long-term	CPP-02 Pumping	130 minutes	5 minutes
	519-534	8/17/92	Long-term	CPP-01 Pumping	130 minutes	5 minutes
	580-600	7/29/92	Long-term	CPP-02 Pumping	130 minutes	5 minutes
	600-620	8/5/92	Long-term	CPP-01 Pumping	120 minutes	5 minutes
USGS-45	462-477	8/19/93	Long-term	CPP-01 Pumping	305 minutes	4.3 minutes
	480-495	8/18/93	Timed-response	CPP-01 Recovery	8.6 minutes	1-2 seconds
		8/16/93	Long-term	CPP-01 Pumping	140 minutes	5 minutes
	500-515	8/13/93	Long-term	CPP-01 Pumping	302 minutes	5 minutes
	519-534	8/4/93	Long-term	CPP-01 Pumping	260 minutes	8.5 minutes
	538-553	7/13/93	Long-term	CPP-02 Pumping	255 minutes	10 minutes
USGS-46	462-483	9/14/93	Timed-response	CPP-02 Recovery	9.3 minutes	1-2 seconds
	488-506	9/17/93	Timed-response	CPP-02 Recovery	44 minutes	3-5 seconds
		9/14/93	Long-term	CPP-02 Pumping	238 minutes	4.3 minutes
	507-525	9/28/93	Timed-response	CPP-02 Pumping	5.2 minutes	1-2 seconds
		9/23/93	Long-term	CPP-02 Pumping	234 minutes	6 minutes
	531-549	9/29/93	Timed-response	CPP-02 Recovery	8.8 minutes	1 sec to 1.1 min
		9/29/93	Long-term	CPP-02 Pumping	249 minutes	8 minutes
	553-571	9/30/93	Timed-response	CPP-02 Pumping	71 minutes	1 sec to 2.1 min
	575-593	9/23/93	Timed-response	CPP-02 Pumping	3.8 minutes	1-2 seconds
		9/22/93	Long-term	CPP-02 Pumping	251 minutes	8.3 minutes
	594-612	10/13/93	Timed-response	CPP-01 Pumping	60.5 minutes	1-33 seconds
		10/13/93	Long-term	CPP-01 Pumping	262 minutes	3 minutes
	611-629	10/23/93	Timed-response	CPP-01 Pumping	5.2 minutes	1-2 seconds
		10/23/93	Long-term	CPP-01 Pumping	256 minutes	5 minutes
USGS-59	462-480	6/28/94	Timed-response	CPP-01 Recovery	7.5 minutes	2 sec to 1.1 min
		6/28/94	Long-term	CPP-01 Pumping	240 minutes	5 minutes
	484-502	7/5/94	Timed-response	CPP-02 Pumping	187.4 minutes	2-3 seconds (edited)
		7/6/94	Long-term	CPP-02 Pumping	245 minutes	5 minutes
	517-535	8/2/94	Timed-response	CPP-01 Pumping	105 minutes	2 sec to 2.1 min
		8/2/94	Long-term	CPP-01 Pumping	253 minutes	4.2 min
	538-556	8/9/94	Timed-response	CPP-01 Pumping	65.5 minutes	2 sec to 4.3 min
		8/11/94	Long-term	CPP-01 Pumping	247 minutes	5 minutes

CHAPTER 3:

TYPE CURVE ANALYSIS

Introduction

When plotted on log-log paper, the time-drawdown data for the ICPP production wells often exhibits an "S"-shape, suggesting that the aquifer may be responding as either 1) an unconfined system (Neuman, 1974), or 2) a double-porosity media (Gringarten, 1987). The time-drawdown data collected by the three transducers in the straddle-packer system show an increase in drawdown with increasing depth in the observation wells, which is expected with a partially penetrating pumping well in an unconfined system (see Chapter 4). In addition, previous studies have concluded that the eastern Snake River Plain aquifer is an unconfined system (Garabedian, 1989; Wylie and others, 1994). Therefore, the time-drawdown data were evaluated using the type curves developed for an unconfined aquifer with partially penetrating wells (Neuman, 1974). The type curves developed by Neuman assume the aquifer is vertically and laterally homogenous, and can be used for isotropic or anisotropic aquifers.

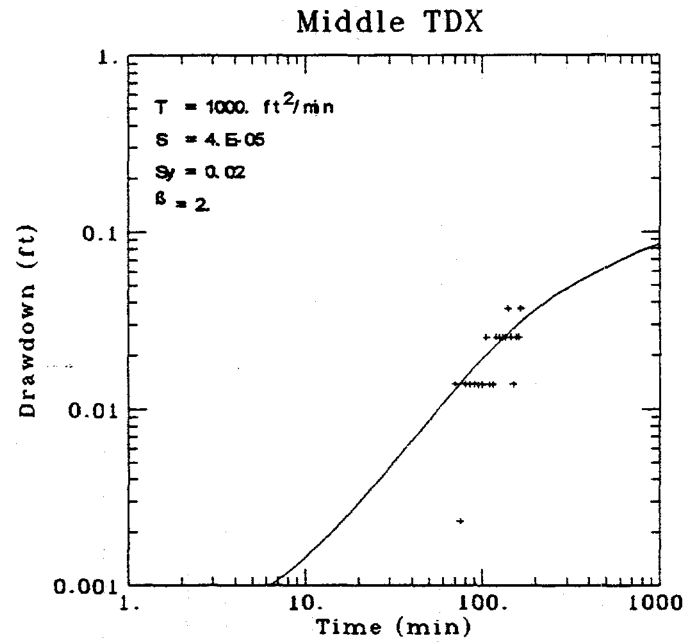
The time-drawdown data from the pumping tests were evaluated using computer-generated type curves from a commercial software package (Duffield and Rumbaugh, 1991). For the type-curve analyses, the screened interval of the observation well was defined as the interval over which the borehole was open to the aquifer. For example, the time-drawdown data from the upper transducer was matched to the type curve for an observation well with a screen extending from the water table to a depth corresponding to the center of the upper packer. Similarly, the middle transducer was matched to type curves for a well with a screened interval equal to the depth of the interval between the centers of the upper and lower packers, and the lower transducer was matched to the type curve for a partially-penetrating well screened from the center of the lower packer to the bottom of the borehole. In several tests conducted in USGS-45 and one interval in USGS-59 (484-502 feet bls) the time-drawdown data from the middle transducer suggests leakage of ground water around the packers, and a resulting error in the type curve solutions. Table 3 summarizes the intervals tested in each well. The time-drawdown data and type curves for intervals not discussed in the text are in Appendix B.

The aquifer was assumed to have an effective thickness of 250 feet based on the work of Robertson (1974). Because the effective thickness of the aquifer is poorly defined, and may in fact be variable due to heterogeneity, the effect of aquifer thickness on the estimation of aquifer properties was evaluated with a sensitivity analysis, which is presented at the end of this chapter.

USGS-44

USGS-44 is located west of the Idaho Chemical Processing Plant, approximately 2800 feet from CPP-01 and 2600 feet from CPP-02. The aquifer response to pumping at the ICPP production wells was measured in six intervals in USGS-44 in 1992. Time-drawdown data was taken from long-term tests. The duration of pumping ranged from 120 to 165 minutes (Table 3). During the testing periods, the depth to water in USGS-44 was about 461 feet below land surface.

There is considerable scatter in the drawdown data due, at least in part, to a small integration time, which decreased the resolution of the pressure transducers (Figure 6). This was corrected in later tests. The estimated transmissivity for the Snake River Plain aquifer, as determined from evaluation with the Neuman type curves for partially penetrating wells, was 250-2000 ft^2/min, with an average of 850 ft^2/min (Table 4). In general, the transmissivity appears to decrease with depth. The specific yield ranged from 0.006 to 0.02, with an average of 0.016. Early-time data were not collected, so the storativity of the aquifer could not be evaluated with the data sets for USGS-44. The ratio of vertical conductivity to horizontal conductivity (Kv:Kh) ranged from 1:60 to 1:540. The average Kv:Kh is 1:240 (Table 4).



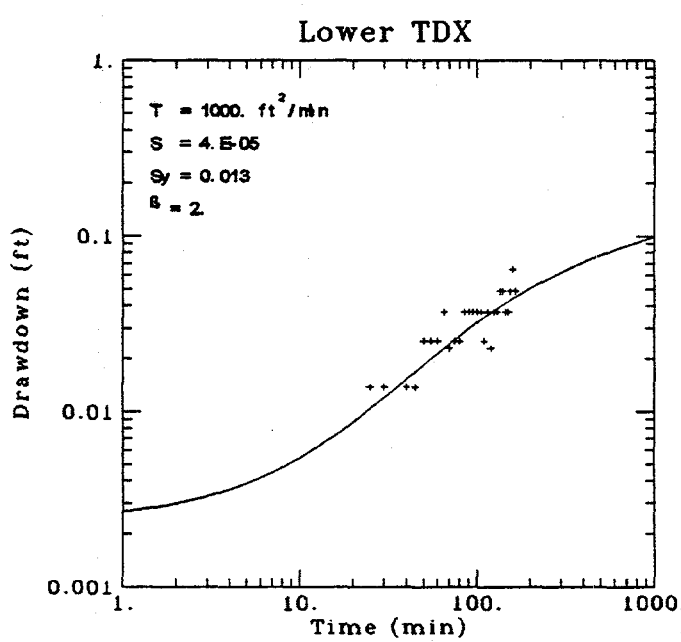


Figure 6. Time-drawdown data and estimated hydraulic properties from Neuman type curves for USGS-44, 461-482 ft bls.

Table 4. Estimated hydraulic properties of the Snake River Plain aquifer derived from matching the time-drawdown data from USGS-44 to type curves developed for partially-penetrating wells.

Straddled Interval (feet below land surface)	TDX	Transmissivity (ft^2/min)	Storativity	Specific Yield	Beta	Screened Interval (feet below water table)	Pumping Well	Kv:Kh
461-482	M	1000	NM	0.02	2	0-21 ft	CPP-01	1:60
	L	1000	NM	0.013	2	21-188 ft		1:60
480-495	U	NA	NA	NA	NA	0-19 ft	CPP-01	NA
	M	1000	NM	0.015	2	19-34 ft		1:60
	L	800	NM	0.008	2	34-188 ft		1:60
500-515	U	2000	NM	0.08	3	0-39 ft	CPP-02	1:40
	M	1000	NM	0.02	3	39-54 ft		1:40
	L	850	NM	0.006	0.2	54-188 ft		1:540
519-534	U	1000	NM	0.02	3	0-58 ft	CPP-01	1:40
	M	500	NM	0.01	0.2	58-73 ft		1:630
	L	900	NM	0.009	0.2	73-188 ft		1:630
580-600	U	1000	NM	0.01	0.5	0-119 ft	CPP-02	1:220
	M	450	NM	0.01	0.5	119-139 ft		1:220
	L	500	NM	0.01	0.5	139-188 ft		1:220
600-620	U	1700	NM	0.012	0.2	0-139 ft	CPP-01	1:630
	M	300	NM	0.009	0.5	139-159 ft		1:250
	L	250	NM	0.008	0.8	159-188 ft		1:160
Average		850		0.014	1.1			1:240

NA = Not available
NM = Not meaningful
TDX = Transducer (Upper, Middle, Lower)

USGS-45

Five intervals were tested with the straddle packer in USGS-45. This observation well is located 3280 feet southwest of CPP-01, and 3100 feet southwest of CPP-02 (Figure 3). The straddle packer could not be maneuvered deeper than 553 feet bls due to irregularities in the borehole, consequently deeper intervals could not be tested. The depth to water in this well is about 464 feet bls, and the well is cased to 461 feet bls. The total depth of the well is about 651 feet bls, which is 187 feet below the water table.

The duration of the tests ranged from 8.6 minutes to 305 minutes (Table 3). The estimated transmissivity ranged from 180 to 2000 ft^2/min, with an average of 890 ft^2/min (Table 5). Storativity estimates ranged from 2×10^{-5} to 4×10^{-5}; however, the type curves did not match the early-time data well for the lower transducer (Figure 7). This may be the result of the greater pumping rate when the production wells are first turned on, because the riser pipe is empty and there is no head on the system (see page 16). The average specific yield is estimated at 0.009, and the average Kv:Kh was 1:600 (Table 5).

USGS-46

The aquifer response to pumping at the ICPP production wells was measured in eight intervals in USGS-46 (Table 6). The depth to water in USGS-46 is about 462 feet bls, and the well is cased to a depth of 460 feet. This well has open-hole construction to

Table 5. Estimated hydraulic properties of the Snake River Plain aquifer derived from matching time-drawdown data from USGS-45 to type curves developed for partially-penetrating wells.

Straddled Interval (feet below land surface)	TDX	Transmissivity (ft^2/min)	Storativity	Specific Yield	Beta	Screened Interval (feet below water table)	Pumping Well	Kv:Kh
462-477	M	180	0.00004	0.011	0.1	0-13 ft	CPP-01	1:1700
	L	500	0.00004	0.01	0.3	13-187 ft		1:575
480-495	U	2000	NM	0.005	0.8	0-16 ft	CPP-01	1:215
	M	1200	NM	0.008	0.1	16-31 ft		1:1700
	L	250	0.00002	0.01	1	31-187 ft		1:170
500-515	U	500	NM	0.009	1.5	0-36 ft	CPP-01	1:115
	M	600	NM	0.009	1.5	36-51 ft		1:115
	L	400	NM	0.007	0.4	51-187 ft		1:430
519-534	U	2000	NM	0.016	0.2	0-55 ft	CPP-01	1:860
	M	700	NM	0.02	1	55-70 ft		1:170
	L	1100	NM	0.004	0.2	70-187 ft		1:860
538-553	U	900	NM	0.013	1	0-74 ft	CPP-02	1:150
	M	1200	NM	0.004	0.2	74-89 ft		1:770
	L	900	NM	0.005	0.3	89-187 ft		1:510
Average		890	0.00003	0.009	0.6			1:600

NA = Not available
NM = Not meaningful
TDX = Transducer (Upper, Middle, Lower)

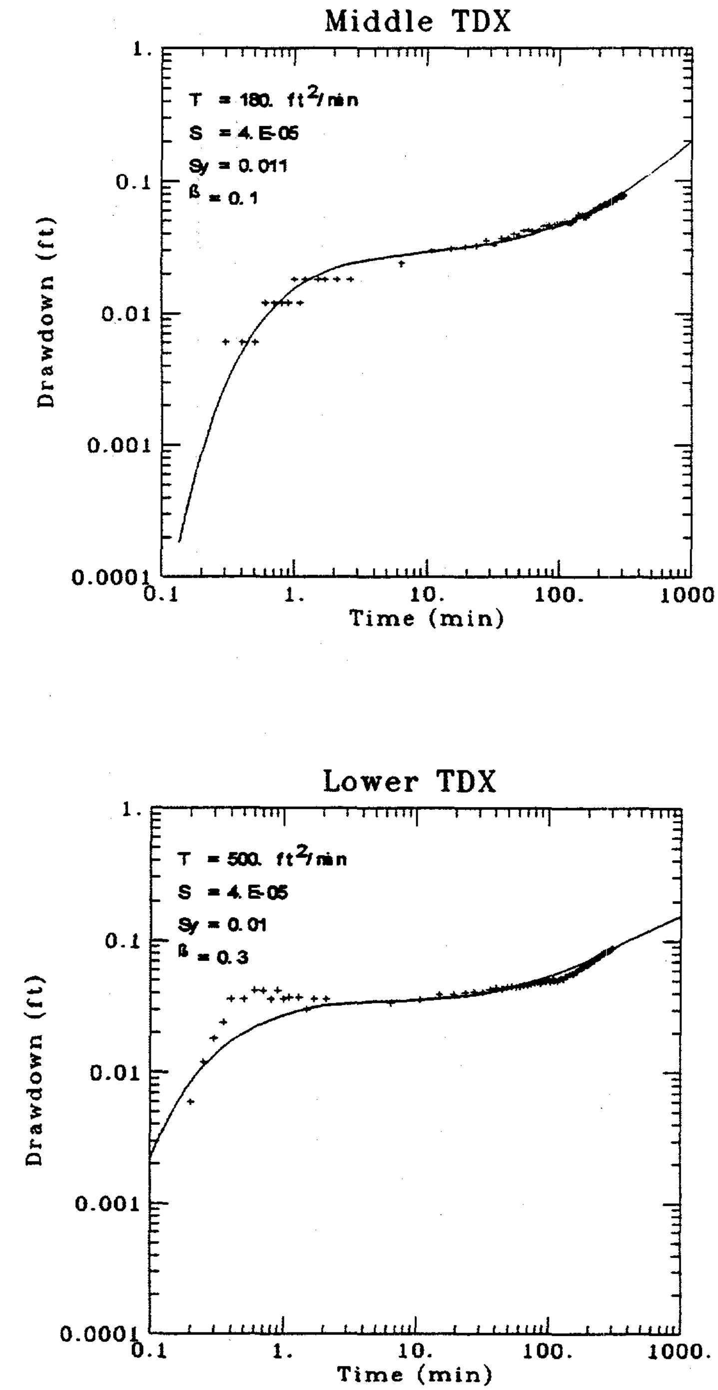


Figure 7. Time-drawdown data and estimated hydraulic properties from Neuman type curves for USGS-45, 462-477 ft bls.

Table 6. **Estimated hydraulic properties of the Snake River Plain aquifer derived from matching time-drawdown data from USGS-46 to type curves developed for partially-penetrating wells.**

Straddled Interval (feet below land surface)	TDX	Transmissivity (ft^2/min)	Storativity	Specific Yield	Beta	Screened Interval (feet below water table)	Pumping Well	Kv:Kh
462-483	U	NA	NA	NA	NA	None	CPP-02	NA
	M	NA	NA	NA	NA	0-21		NA
	L	NA	NA	NA	NA	21-189 ft		NA
488-506	U	800	0.00001	0.01	3	0-26 ft	CPP-02	1:40
	M	1000	NM	0.009	1	26-44 ft		1:120
	L	800	0.00005	0.01	1	44-189 ft		1:120
507-525	U	600	NM	0.017	1	0-45 ft	CPP-02	1:120
	M	800	NM	0.015	1	45-63 ft		1:120
	L	500	0.000013	0.01	0.5	63-189 ft		1:230
531-549	U	800	NM	0.014	0.5	0-69 ft	CPP-02	1:230
	M	500	NM	0.02	1.1	69-87 ft		1:100
	L	450	0.00004	0.013	0.5	87-189 ft		1:230
553-571	U	600	NM	0.013	1.1	0-91 ft	CPP-02	1:100
	M	430	0.00003	0.008	0.5	91-109 ft		1:230
	L	530	0.00004	0.007	0.5	109-189 ft		1:230
575-593	U	NM	NM	NM	NM	0-113 ft	CPP-02	NM
	M	520	0.00003	0.01	0.5	113-131 ft		1:230
	L	550	0.00003	0.01	0.5	131-189 ft		1:230
594-612	U	480	0.00002	0.009	0.5	0-132 ft	CPP-01	1:250
	M	350	0.00001	0.007	0.5	132-150 ft		1:250
	L	400	0.00003	0.008	0.5	150-189 ft		1:250
611-629	U	440	0.00003	0.007	0.5	0-149 ft	CPP-01	1:250
	M	450	0.00004	0.006	0.5	149-167 ft		1:250
	L	400	0.00004	0.006	0.5	167-189 ft		1:250
Average		570	0.00003	0.01	0.6			1:190

NA = Not available
NM = Not meaningful
TDX = Transducer (Upper, Middle, Lower)

a depth of 651 feet, which is 189 feet below the water table. USGS-46 is located approximately 2800 feet from CPP-01 and 2680 feet from CPP-02.

Oscillations in drawdown were observed in the upper transducer at two intervals: 488-506 feet bls, and 575-593 feet bls (Figures 8 and B-13). The cause of the fluctuations in drawdown is unknown. It does not appear to be related to a changing pumping rate, as the drawdown measured in the middle and lower transducers did not change. Pumping from CPP-04, a potable water supply well at ICPP (pumping rate of 400 gpm), can probably be eliminated as a possible cause because similar results were observed during two other long-term tests conducted at 575-593 feet bls. Due to oscillations in the drawdown data from the middle transducer during the static test at 488-506 feet bls on Sept. 14, the 44-minute recovery test was used to evaluate time-drawdown data from this transducer (Figure 8).

The estimates of transmissivity ranged from 350-1000 ft^2/min, with an average of 565 ft^2/min (Table 6). The transmissivity appears to decrease with depth, similar to the observed trend in USGS-44. The average storativity is 3×10^{-5}, and the average specific yield is 0.01. The Kv:Kh ranged from 1:40 to 1:250, with an average of 1:190 (Table 6).

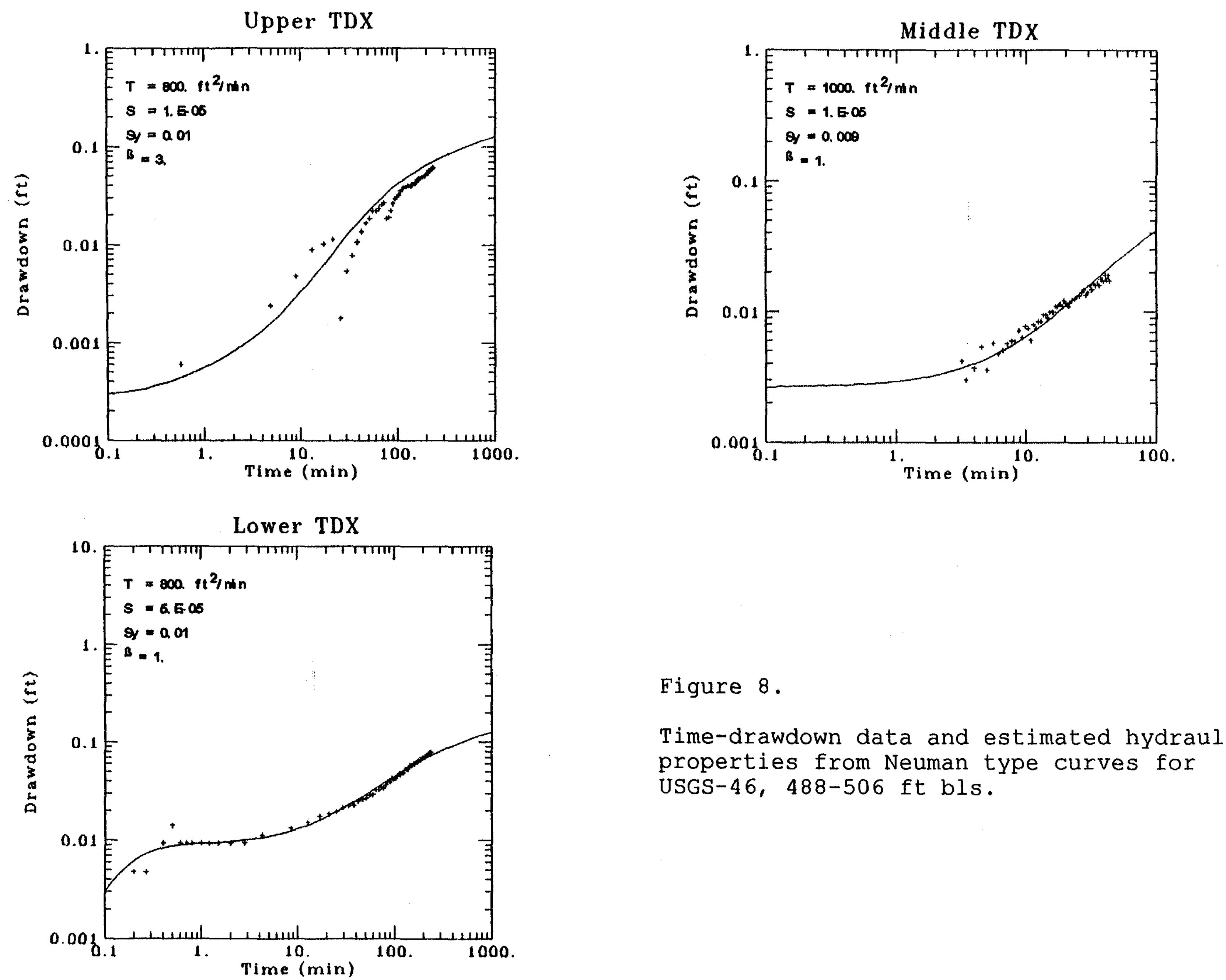


Figure 8.

Time-drawdown data and estimated hydraulic properties from Neuman type curves for USGS-46, 488-506 ft bls.

USGS-59

USGS-59 is located south of the Idaho Chemical Processing Plant, approximately 4000 feet from CPP-01 and 4200 feet from CPP-02 (Figure 3). Four intervals in this well were evaluated with the straddle packer in 1994 (Table 7). Due to a large breakout in the basalt at a depth of 561-570 feet bls, which would not accommodate the packer, the maximum depth tested was 556 feet bls. Figure 9 illustrates the time-drawdown data and corresponding best-fit Neuman type curves for the lower interval. When the aquifer tests were conducted in 1994 the water level in USGS-59 was about 459 feet below land surface, which is approximately the same depth as the bottom of the casing.

Transmissivity estimates for the Snake River Plain aquifer ranged from 200-1200 ft^2/min, with an average of 640 ft^2/min (Table 7). The average specific yield was 0.007, and the average storativity was 2×10^{-5}. The ratio of vertical to horizontal conductivity ranged from 1:60 to 1:640, with an average of 1:390. Transmissivity generally decreased with depth.

Summary

The results of the Neuman type curve analyses are summarized in Table 8. The average horizontal hydraulic conductivity (Kh) for each well was determined by dividing the average transmissivity by the assumed effective thickness of the aquifer (250 feet). The average vertical hydraulic conductivity (Kv) is Kh multiplied by the average Kv:Kh determined from the aquifer

Table 7. Estimated hydraulic properties of the Snake River Plain aquifer derived from matching time-drawdown data from USGS-59 to type curves developed for partially-penetrating wells.

Straddled Interval (feet below land surface)	TDX	Transmissivity (ft^2/min)	Storativity	Specific Yield	Beta	Screened Interval (feet below water table)	Pumping Well	Kv:Kh
462-480	U	NA	NA	NA	NA	None	CPP-01	NA
	M	600	0.000015	0.007	1	3-21 ft		1:260
	L	500	0.00002	0.004	0.5	21-192 ft		1:510
484-502	U	600	NM	0.006	0.5	0-25 ft	CPP-02	1:560
	M	300	0.00003	0.003	0.5	25-43 ft		1:560
	L	200	0.00003	0.002	2	43-192 ft		1:140
517-535	U	900	NM	0.009	0.5	0-58 ft	CPP-01	1:510
	M	1100	NM	0.009	1	58-76 ft		1:260
	L	500	0.00002	0.01	0.4	76-192 ft		1:640
538-556	U	1200	NM	0.009	0.8	0-79 ft	CPP-01	1:320
	M	800	NM	0.011	4	79-97 ft		1:60
	L	360	0.000007	0.006	0.5	97-192 ft		1:510
Average		640	0.00002	0.007	1.1			1:390

NA = Not available
NM = Not meaningful
TDX = Transducer (Upper, Middle, Lower)

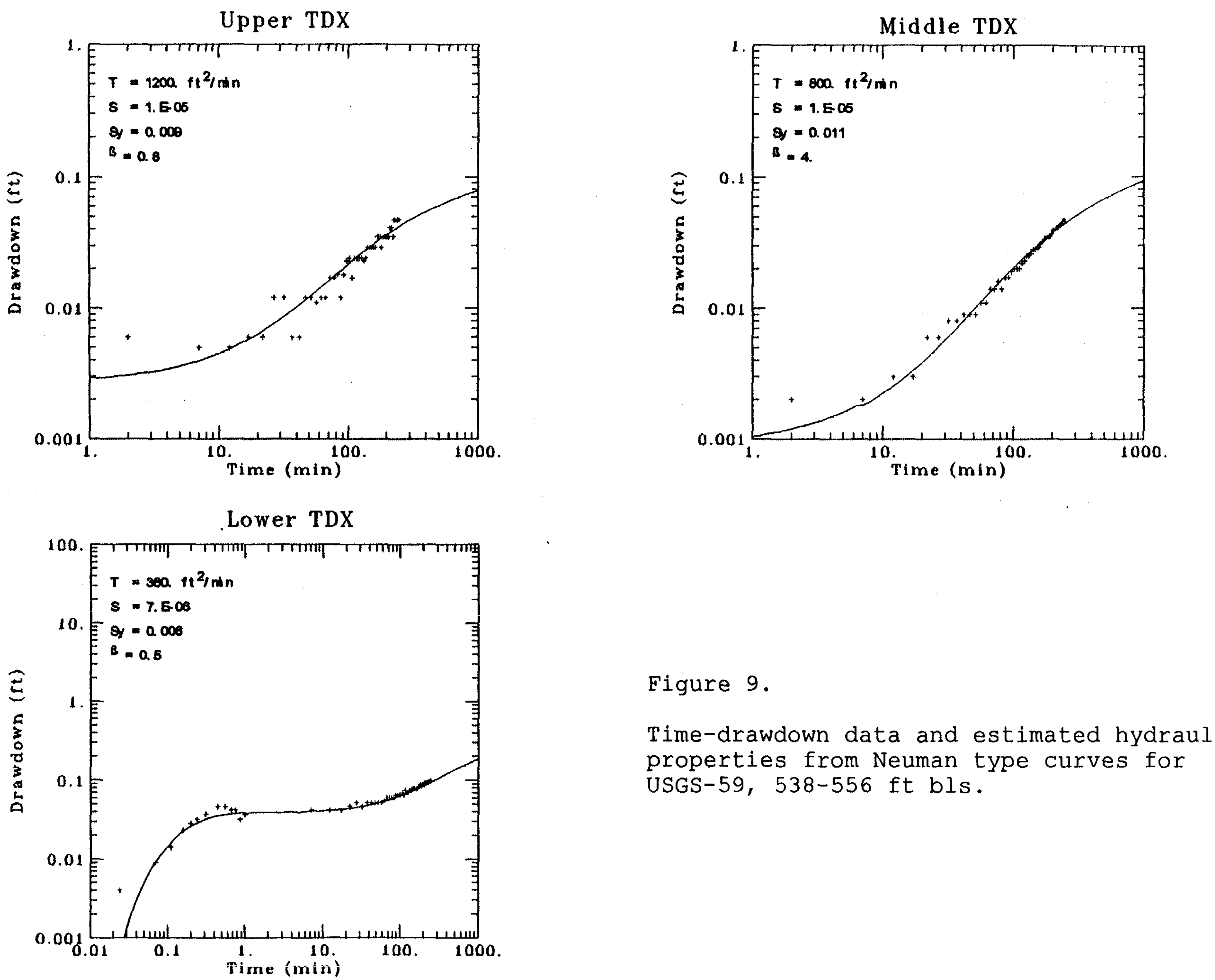


Figure 9.

Time-drawdown data and estimated hydraulic properties from Neuman type curves for USGS-59, 538-556 ft bls.

tests. Kh ranged from 2.3-3.6 ft/min for the four wells, and Kv ranged from 0.006 to 0.01 ft/min. The estimated specific yield varied from 0.007 to 0.016.

Table 8. Estimated hydraulic properties for the Snake River Plain aquifer determined from Neuman type curve matching.

Monitoring Well	Kh (ft/min)	Kv (ft/min)	Storativity	Specific Yield
USGS-44	3.4	0.01	NA	0.016
USGS-45	3.6	0.006	3×10^{-5}	0.009
USGS-46	2.3	0.01	3×10^{-5}	0.01
USGS-59	2.6	0.007	2×10^{-5}	0.007
Average	3.0	0.008	3×10^{-5}	0.01

The total thickness of the aquifer is not well defined. To evaluate the potential error introduced into the type curve solutions which may result from an incorrect estimate of aquifer thickness (250 feet), additional type curve solutions were developed assuming an aquifer thickness of 200 feet and 450 feet. Two hundred feet was used as a minimum thickness because the observation wells are screened over approximately 200 feet of the aquifer. The maximum thickness of 450 feet is based on the presence of a thick sedimentary interbed at that depth in a nearby well (Mann, 1986).

The aquifer test conducted from 553-571 feet bls in USGS-46 was selected for the sensitivity analysis because early time-drawdown data is available for the middle and lower transducers.

The type curves developed for the sensitivity analysis are shown in Figures 10 and 11, and the results are summarized in Table 9.

Increasing the saturated thickness from 250 feet to 450 feet results in an estimate of horizontal hydraulic conductivity (Kh) which is 17% to 33% of the value obtained assuming a thickness of 250 feet (Table 9). Conversely, decreasing the saturated thickness to 200 feet results in a greater estimate of Kh, with values being 129-188% of the value determined using an aquifer thickness of 250 feet. The estimates of specific yield and storativity did not change appreciably when other values were used for aquifer thickness (Table 9).

The values presented in Table 8 are based on estimates obtained using type curves developed for an unconfined aquifer with partially penetrating wells (Neuman, 1974). This method assumes the aquifer is a *single layer*, homogeneous system. However, the increased drawdown consistently measured below the top of Flow Group I suggests that, near the ICPP, the Snake River Plain aquifer behaves as a multi-layered system. The multi-layer conceptual model is developed in Chapter 4.

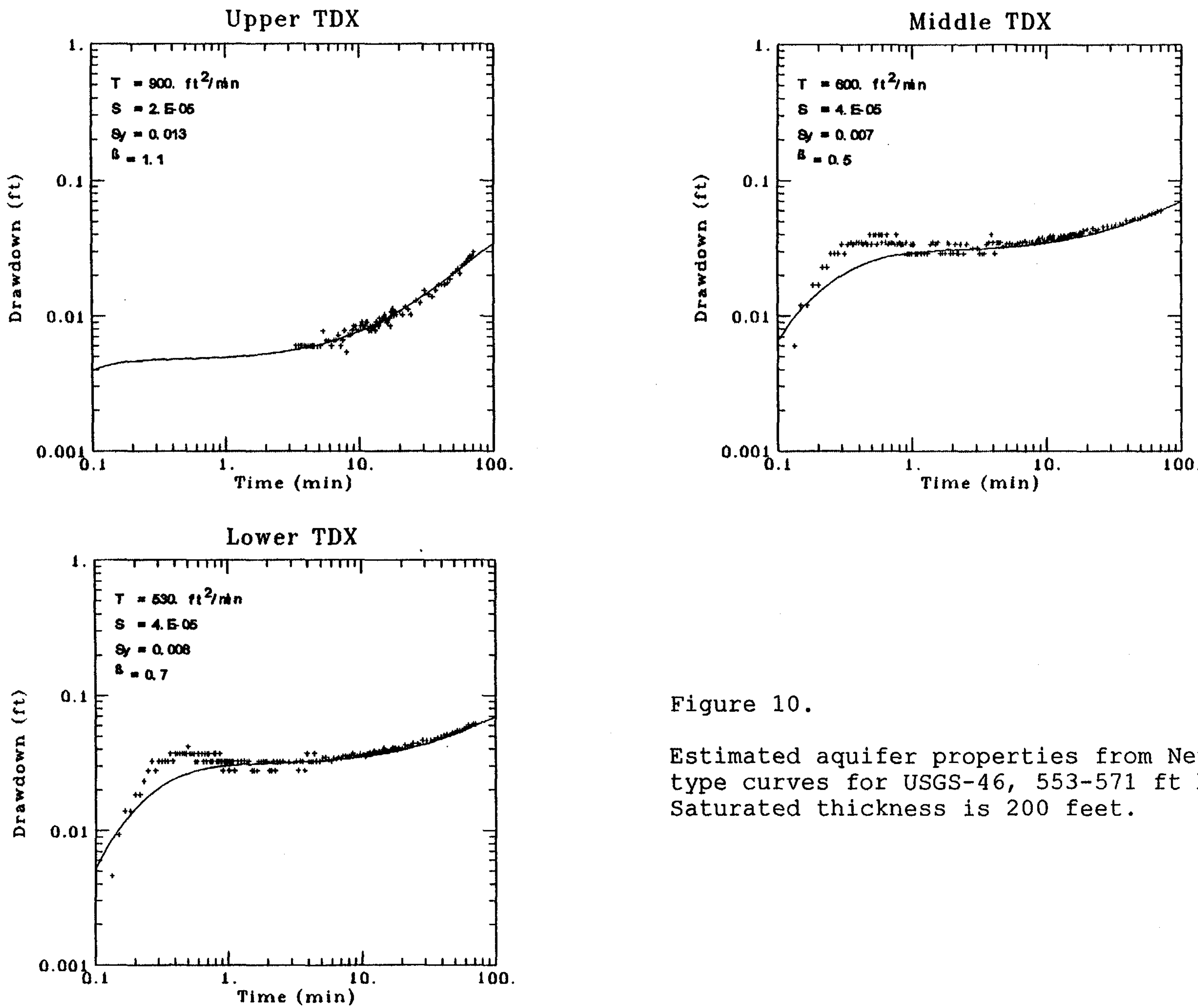


Figure 10.

Estimated aquifer properties from Neuman type curves for USGS-46, 553-571 ft bls. Saturated thickness is 200 feet.

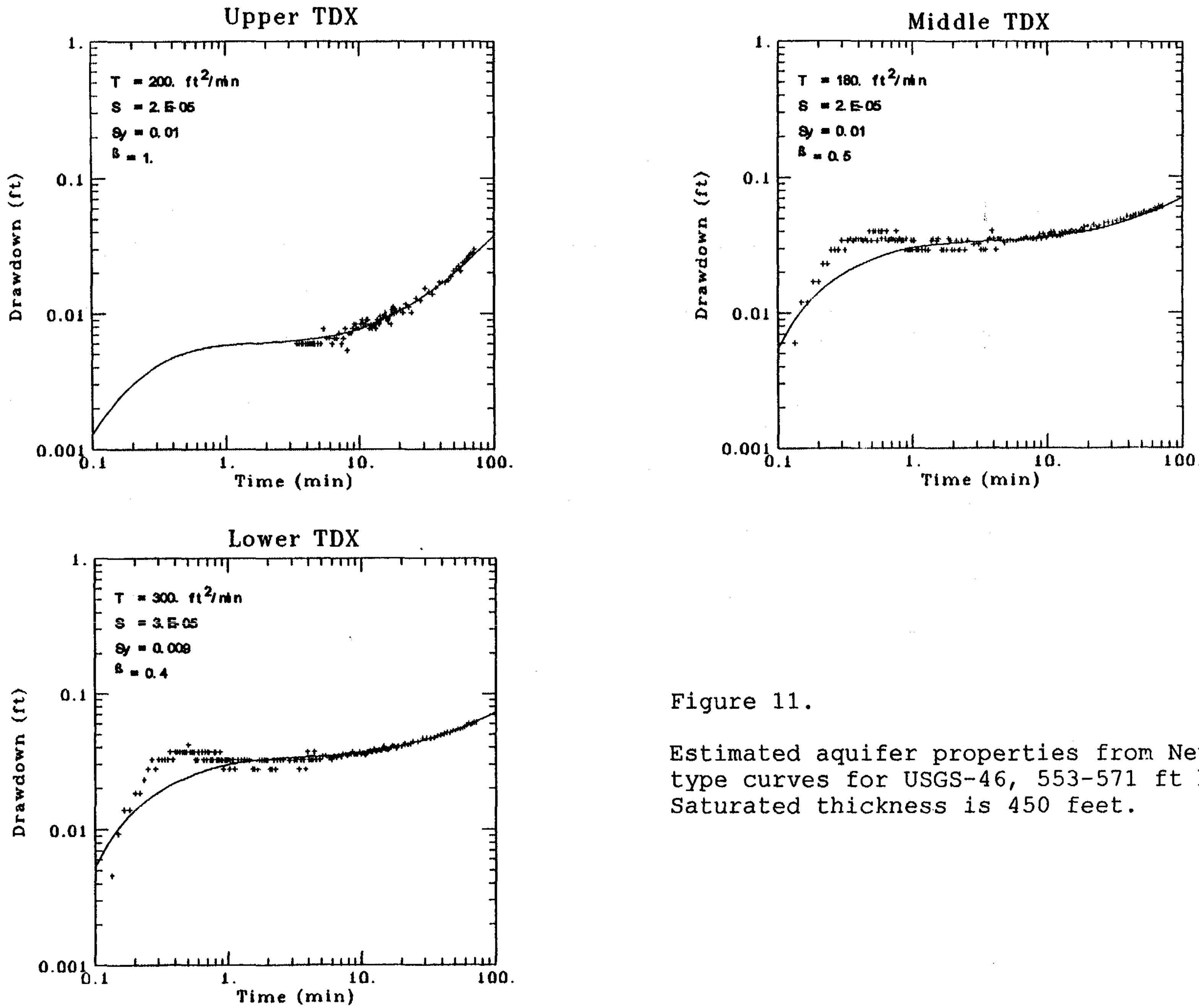


Figure 11.

Estimated aquifer properties from Neuman type curves for USGS-46, 553-571 ft bls. Saturated thickness is 450 feet.

Table 9. Results of the sensitivity analysis of aquifer thickness for USGS-46, 553-571 feet bls. Aquifer storativity and specific yield were relative insensitive to the changes in aquifer thickness. The estimates of the horizontal and vertical hydraulic conductivities (Kh and Kv) were inversely proportional to the aquifer thickness.

TDX	Aquifer Thickness (feet)	Kh (ft/min)	Percent of Baseline (b=250 feet)	Kv (ft/min)	Percent of Baseline (b=250 feet)	Storativity	Specific Yield
Upper	200	4.5	188%	0.027	113%	NA	0.013
	250	2.4	100%	0.024	100%	NA	0.013
	450	0.4	17%	0.011	46%	NA	0.01
Middle	200	3	176%	0.008	114%	0.00002	0.007
	250	1.7	100%	0.007	100%	0.00003	0.008
	450	0.4	24%	0.004	57%	0.00002	0.01
Lower	200	2.7	129%	0.01	111%	0.00003	0.008
	250	2.1	100%	0.009	100%	0.00004	0.007
	450	0.7	33%	0.008	89%	0.00004	0.009

NA = Not available (early-time data not collected)
TDX = Transducer

CHAPTER 4:

REFINEMENT OF CONCEPTUAL MODEL

Introduction

The Neuman type curve analysis is based on the simplifying assumption of a single, anisotropic aquifer unit. The time-drawdown data suggests that, near the ICPP, the Snake River Plain aquifer hydraulically functions as a layered aquifer. This interpretation is based on two lines of evidence: 1) during pumping of the ICPP production wells, there was more drawdown in zones below the top of the I-Flow than in zones above the I-Flow, and 2) drawdown measured by the middle transducer mimics the upper transducer in zones above the I-Flow, and tracks closely with the lower transducer in zones below the I-Flow.

In USGS-46, the drawdown measured by the middle transducer is substantially greater at depths more than 90 feet below the water table than at shallower intervals (Figure 12A). The transition closely corresponds to the top of Flow Group I, which is 86 feet below the water table (Table 10).

A similar response was observed in USGS-59, where drawdown increases markedly at depths greater than 97 feet below the water table (Figure 12B). The top of Flow Group I is at a depth of 101 feet below the water table in USGS-59 (Table 10). The fact that drawdown is greater below the top of the I-Flow suggests the presence of a semi-confining layer at this depth. The confining layer could be the sedimentary interbed at the top of the I-Flow.

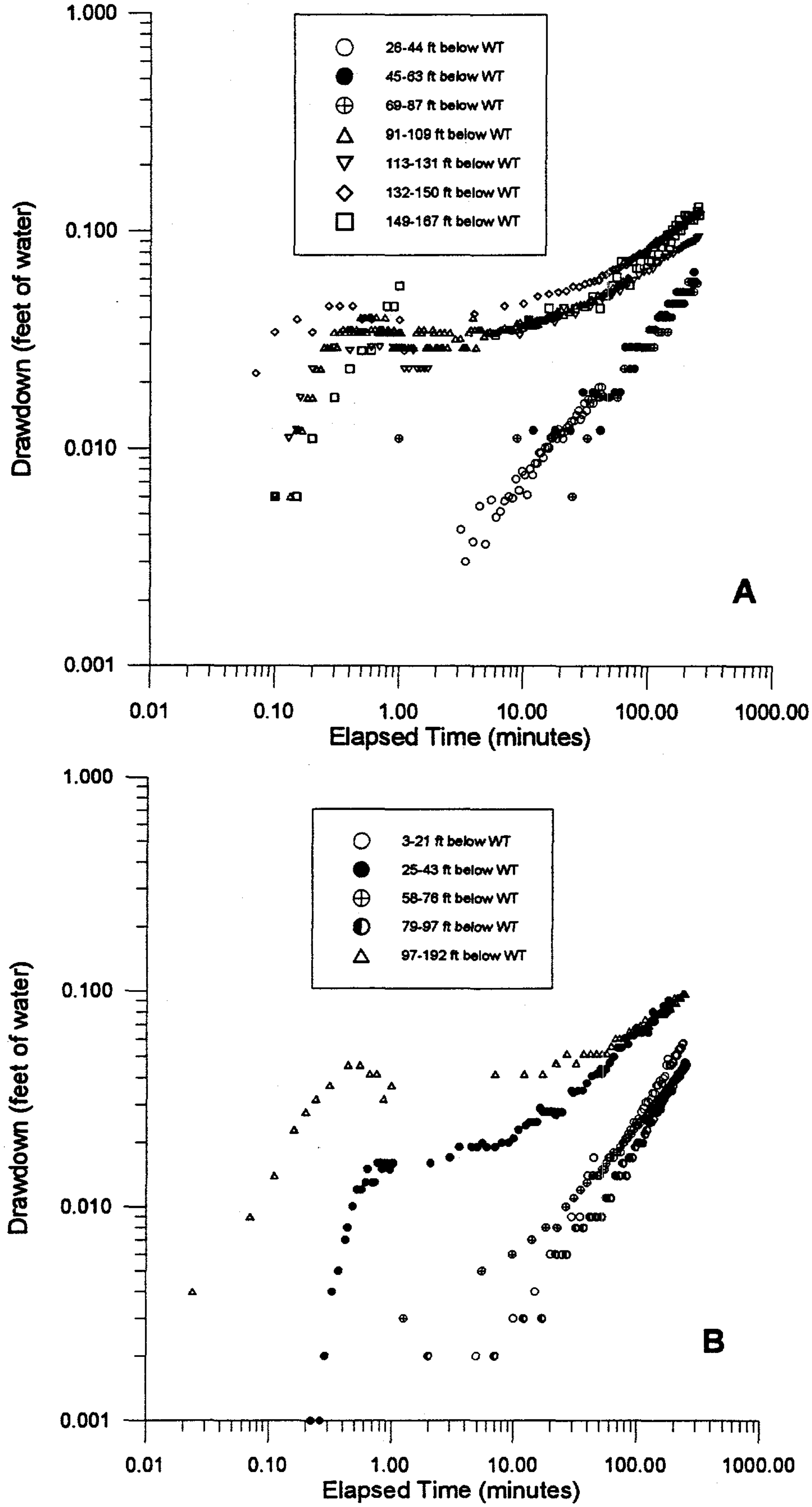


Figure 12. Time-drawdown response in observation wells from pumping of ICPP production wells. Depths in feet below water table (WT). A) USGS-46. B) USGS-59.

The drawdown measured from 25-43 feet below the water table falls between the response curves of the shallow and deep zones (Figure 12B). There is a large void/breakout in the basalt at a depth of 30-43 feet below the water table, suggesting the lower packer did not effectively seal of the borehole during the

Table 10. Depth to the top of the Flow Group I and the overlying sedimentary interbed in the ICPP production wells and the observation wells tested with the straddle packer (from Anderson, 1991; S.R. Anderson, 1995, personal communication).

Well	Depth below water table (depth bls) to top of Flow Group I	Depth below water table (depth bls) to top of interbed	Depth to water (bls)
USGS-44	60 feet (521 feet)	absent	461 feet
USGS-45	86 feet (550 feet)	77 feet (541 feet)	464 feet
USGS-46	86 feet (548 feet)	80 feet (542 feet)	462 feet
USGS-59	101 feet (558 feet)	97 feet (558 feet)	459 feet
CPP-01	31 feet (487 feet)	absent	456 feet
CPP-02	34 feet (490 feet)	absent	456 feet

aquifer test. Consequently, the time-drawdown data measured in this interval probably represents an average of deep and shallow zones in the aquifer; the data was not used in the comparisons of simulated and measured drawdown.

Drawdown data from USGS-44 also shows a distinct change in aquifer response with depth: an attenuated response in intervals less than 54 feet below the water table, and more drawdown in deeper zones (Figure 13). The distinction is not as clear due to the poor resolution of the transducers, which resulted from an improper setting of the integration time (see page 22). At USGS-44, the top of the I-Flow is 60 feet below the water table (Table 10).

At USGS-45, the top of the I-Flow is 86 feet below the water table, and the top of the overlying interbed is 77 feet below the water table (Table 10). The time-drawdown collected with the middle transducer in USGS-45 does not show the distinct change in response with depth which was observed in the other wells, probably due to difficulties in effectively sealing off the borehole with the straddle packer (Figure 14B). However, the time-drawdown data collected by the upper and lower transducers while testing the interval near the I-Flow (74-89 feet below the water table) clearly illustrates separate response curves, which supports the concept of a layered aquifer (Figure 14A).

The concept of a layered aquifer is supported by changes in drawdown with depth in all the observation wells tested with the straddle packer. The observed responses have the following significant characteristics:

1) Drawdown is apparent at earlier times in the intervals below the I-Flow and associated overlying interbed.

2) Drawdown is greater in intervals below the top of the I-Flow.

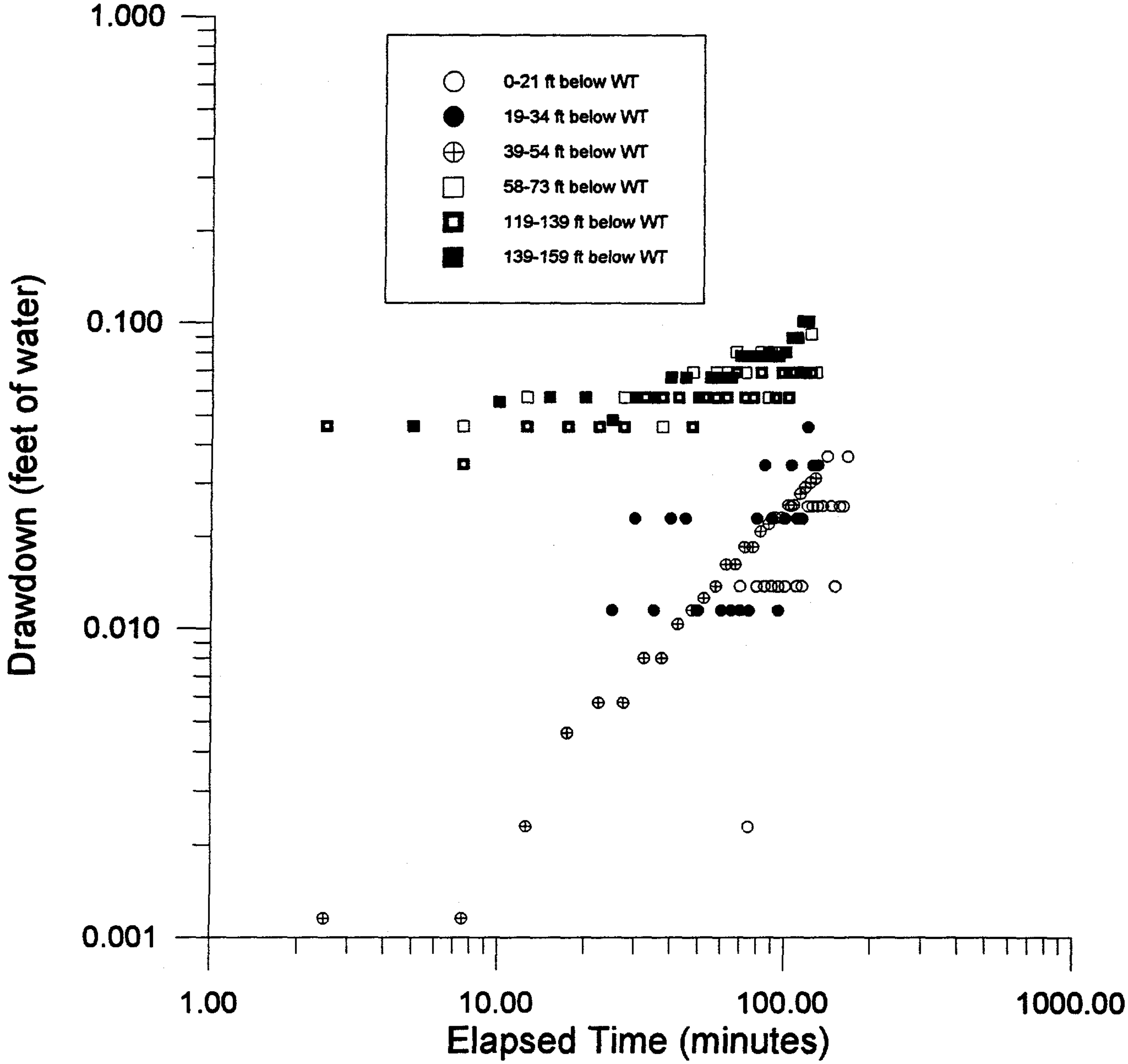


Figure 13. Time-drawdown response to ICPP production wells during straddle-packer testing in USGS-44. Depth in feet below water table (WT).

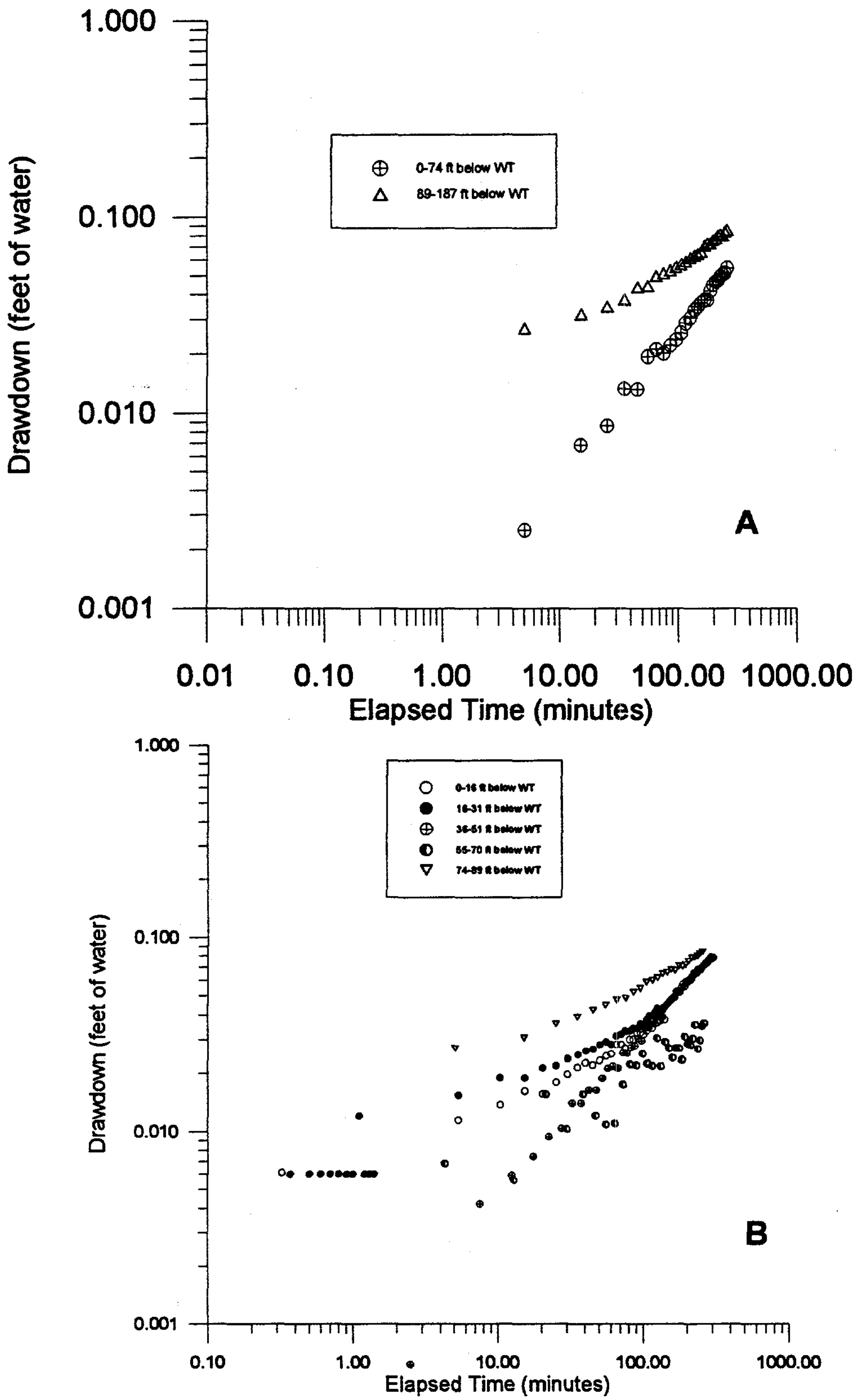


Figure 14. Time-drawdown response in USGS-45 from pumping at ICPP production wells. A) Data from the upper and lower transducers during testing of the interval 74-89 feet below the water table (WT). B) Data from the middle transducers in each interval tested.

3) In intervals below the I-Flow, an "S"-shaped response curve is apparent - typical of delayed water-table response (i.e. a leaky, confined aquifer).

Each of these characteristics are associated with the attenuation of response at the phreatic surface due to the release of water from storage during pore dewatering. The observed segregation of drawdown for intervals below the interbed overlying the top of the I-Flow strongly suggests that the interbed is acting as a confining bed and impedes the vertical movement of water.

Additional evidence supporting the concept of a layered aquifer is apparent from a comparison of observed drawdown among the three transducers in the straddle-packer assembly (above, within, and below the isolated interval) which measure drawdown throughout the vertical profile (Figure 15). It is apparent that, in most intervals, drawdown detected by the middle transducer closely mimics the drawdown measured by either the upper or lower transducer, with an abrupt transition that consistently occurs at the interbed at the top of the I-Flow. In zones within the I-Flow, the drawdown measured by the middle (isolated) transducer normally is very similar to that measured by the lower transducer. Above the I-Flow, the middle transducer responds in a pattern very similar to the upper transducer. The physical implication of these observations is that the aquifer is composed of two distinct hydrologic units, and the boundary between these two units corresponds approximately to the top of the I-Flow.

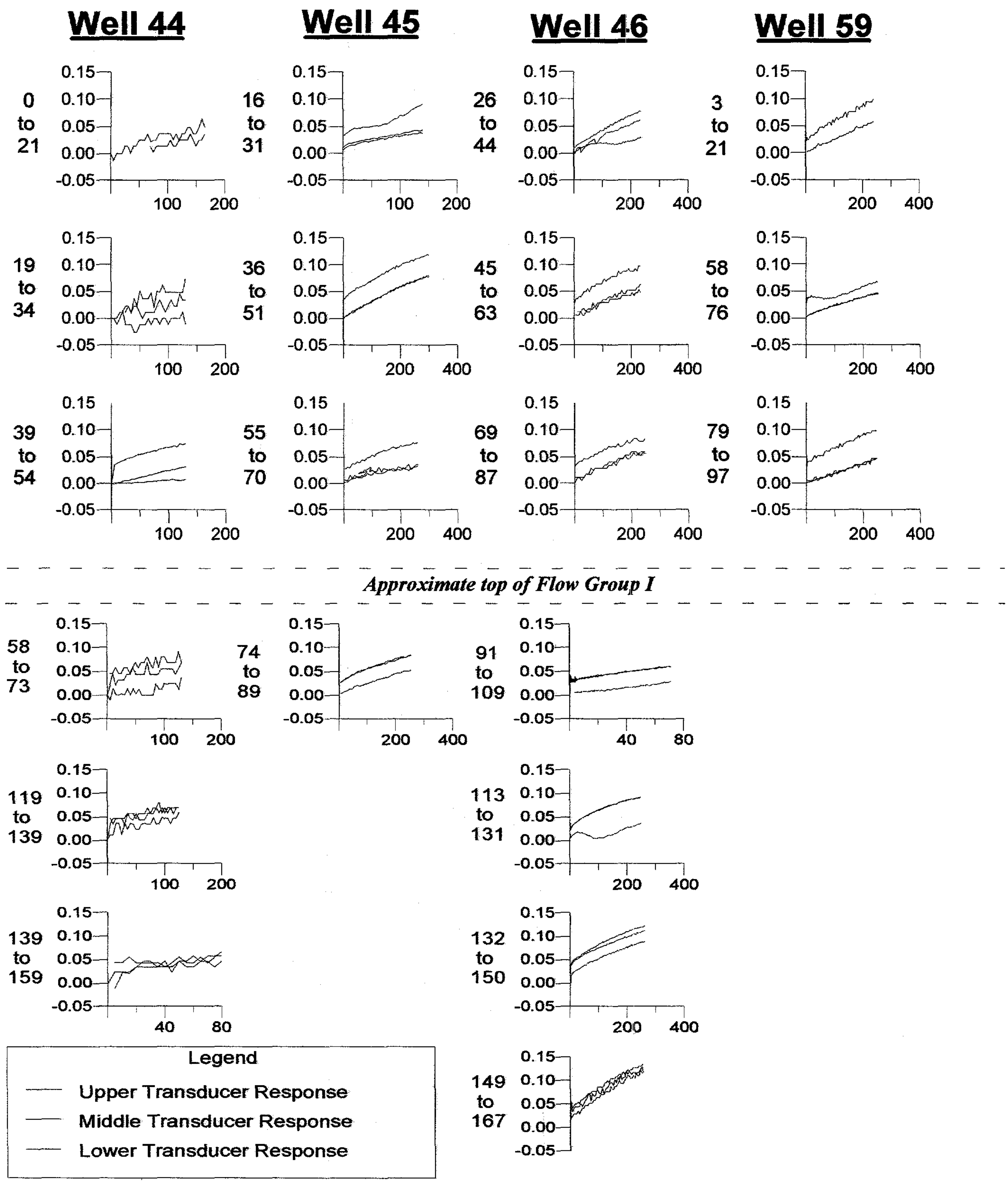


Figure 15. Measured drawdown in observation wells due to pumping of ICPP production wells. Vertical axis is drawdown in feet. Horizontal axis is time in minutes. Depth (feet below water table) of tested interval is noted on vertical axis.

The abrupt change in response at the top of the I-Flow is further evidence of the presence of a confining unit at or near the top of the I-Flow. In a homogeneous and anisotropic aquifer (as assumed for the Neuman type-curve analysis in Chapter 3), the response measured by the middle transducer would be an average of the drawdown observed in the upper and lower transducers.

Simulation of Alternative Conceptual Models

To evaluate the applicability of layered conceptual models, measured time-drawdown data was compared to simulated drawdown from a radial-flow model.

The most complete set of time-drawdown data (seven intervals) was collected from USGS-46. Therefore, this data was evaluated using three conceptual models:

1) One Layer System:
    - Single aquifer - Flow Groups E-I (homogeneous and anisotropic)

2) Two Layer System:
    - Upper aquifer - Flow Groups E-G (homogeneous & anisotropic)
    - Lower aquifer - Flow Group I (homogeneous & anisotropic)

3) Three Layer System:
    - Upper aquifer - Flow Groups E-G (homogeneous & anisotropic)
    - Confining unit - sedimentary interbed at the top of Flow Group I (homogeneous & isotropic)
    - Lower aquifer - Flow Group I (homogeneous & anisotropic)

The idealized cross section of the Snake River Plain aquifer near the ICPP, presented in Figure 16, suggests that the three layer system may best represent the aquifer near the ICPP.

Previous investigators have suggested that the Snake River Plain aquifer near the ICPP may consist of distinct, hydrostratigraphic units. Johnson and others (1994) noted that the response of the system to pumping from the ICPP production wells suggested a multi-layered system. Barrash and others (1994) recognized two distinct hydrostratigraphic units: 1) an upper unit consisting of Flow Groups E-H and the upper part of the I-Flow Group, and 2) a lower unit consisting of the interior of the I-Flow Group.

A radial-flow model based on the PLASM code (Prickett and Lonnquist, 1971; Johnson, 1989) was developed to simulate the three conceptual models. The model grid extended 40,000 feet from the production well to prevent boundary effects. The discharge rate at each node representing a screened interval of the pumping well was assumed to be proportional to the horizontal hydraulic conductivity.

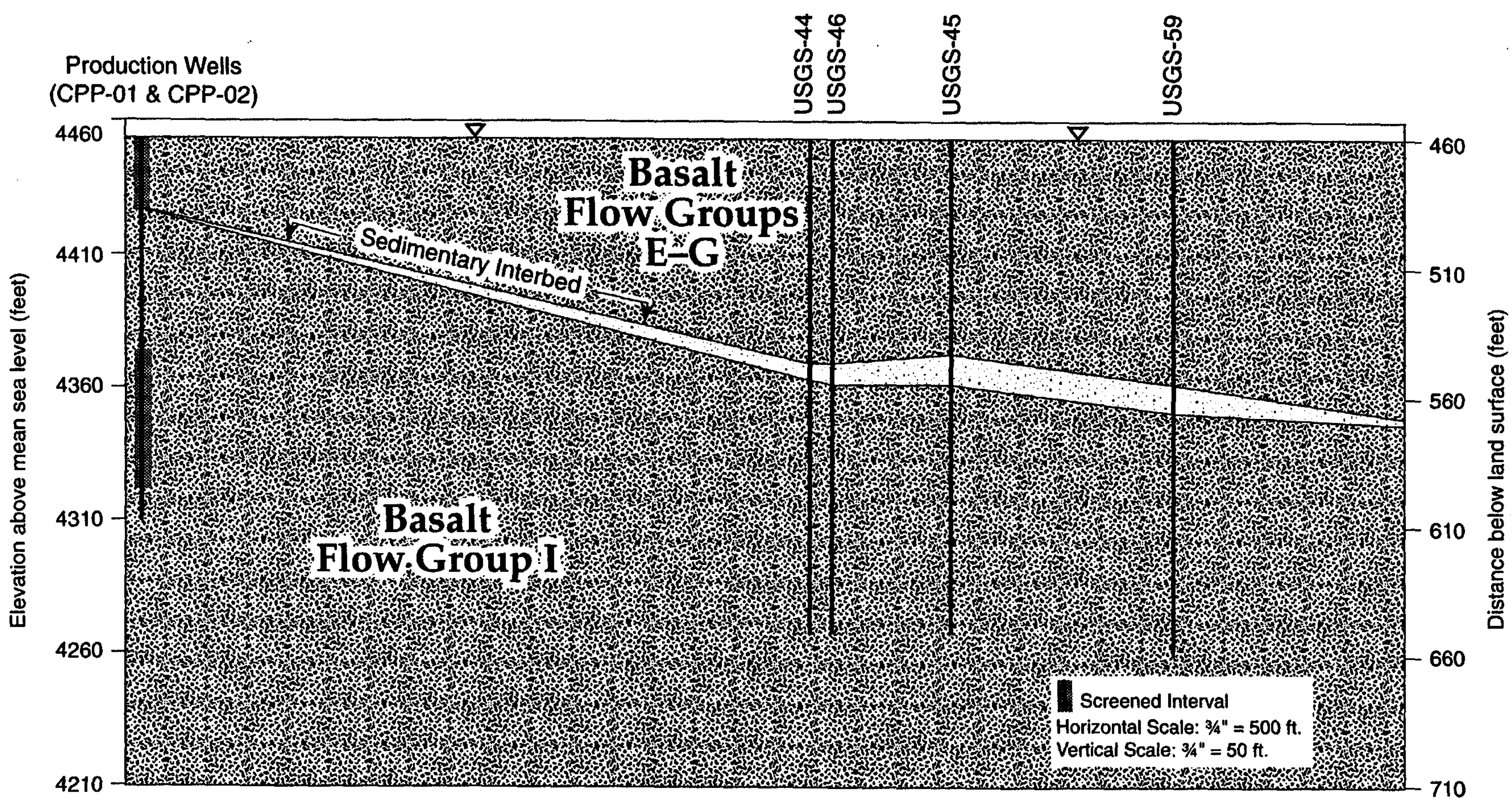


Figure 16. Idealized cross-section of the study area at ICPP. Water table is about 460 feet below land surface. The observation wells have open-hole construction below the water table.

One Layer Conceptual Model

The Snake River Plain aquifer was first evaluated as a one layer system (Figure 17A). Aquifer properties were based on the averages determined from the time-drawdown data for USGS-46 (Table 6). Simulated drawdown with this conceptual model resulted in a distinct vertical gradient in the aquifer; however, the modeled drawdown is greater than the observed drawdown in intervals above the I-Flow (86 feet below the water table) and less than the observed drawdown below the I-Flow (Figure 18A). Furthermore, the simulated drawdown curves for upper and lower zones in the aquifer converge at late times, contrary to the observed time-drawdown data, which have a distinct separation. As illustrated in Figure 18A, greater drawdown is observed at increasing depths in the aquifer due to partial penetration of the production well (i.e. vertical flow to the pumping wells); however, the simulated time-drawdown data does not show the distinct change in drawdown observed near the top of the I-Flow during packer testing. The differences between observed and simulated values result from the averaging of aquifer properties determined from different depths in the type curve matching. These differences imply that a single-layer model for the Snake River Plain aquifer is not appropriate.

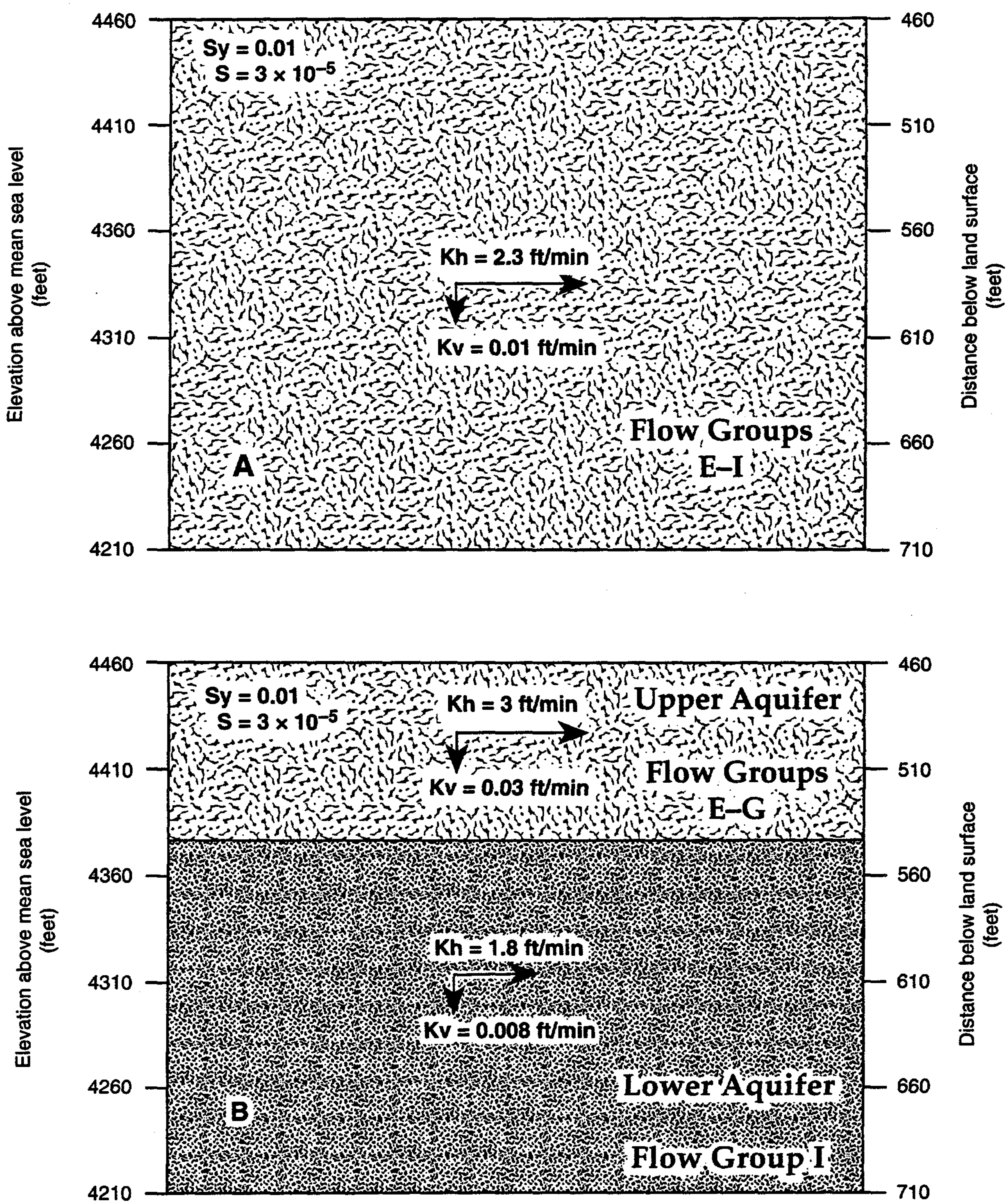


Figure 17. Conceptual models of the Snake River Plain aquifer near the ICPP.
A. One-layer model. B. Two-layer model.

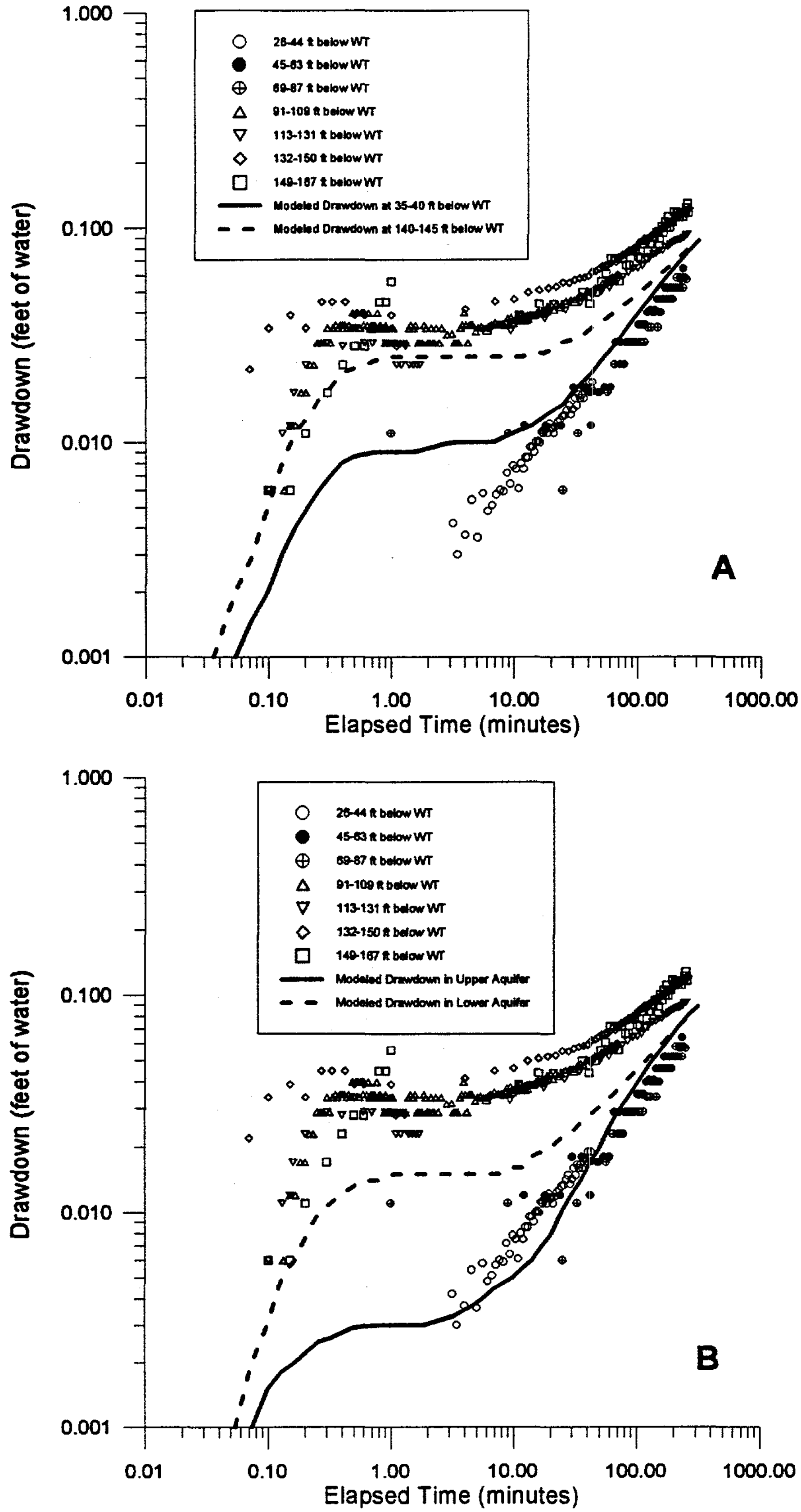


Figure 18. Simulated drawdown with the radial flow model versus observed drawdown in USGS-46. A) One-layer model. B) Two-layer model.

Two-Layer Conceptual Model

The two-layer conceptual model for the Snake River Plain aquifer near the ICPP is illustrated in Figure 17B. The hydraulic properties of the upper aquifer, consisting of basalt Flow Groups E-G, are the average from type-curve estimates using time-drawdown data from the middle transducer at depths of 488-506, 507-525, and 531-549 ft bls (Table 6). Hydraulic properties for the lower aquifer (Flow Group I) are an average of the estimates obtained with the Neuman type curves from intervals which were greater than 90 feet below the water table.

While the model results compare favorably with the observed drawdown in the three intervals in Flow Groups E-H, the model predicted less drawdown than measured in the lower intervals (Figure 18B). Significantly, this conceptual model did not produce the separation in the time-drawdown data observed at late times, but rather showed a convergence in the simulated time-drawdown curves at late times. In an effort to resolve this discrepancy, a three-layer conceptual model was developed.

Three-Layer Conceptual Model

A three-layer conceptual model was developed based on the recognition of *distinct geologic units* near the Idaho Chemical Processing Plant. The model consists of two distinct aquifers, one above and one below the sedimentary interbed at the top of Flow Group I (Figure 16).

As discussed in Chapter 1, the individual basalt flows above the interbed are typically thin, ranging from 10 to 26 feet thick in the observation wells tested with the straddle packer. In contrast, the basalt flows in Flow Group I, located below the sedimentary interbed, are 19 to >90 feet thick. Based solely on stratigraphic observations, the thin basalt flows (Flow Groups E-G) can be expected to have a higher horizontal transmissivity than the thick units of the Flow Group I, due to the presence of a higher number of permeable interflow zones.

The sedimentary interbed ranges from four to nine feet thick in USGS-45, -46, and -59, but is absent in USGS-44 (Anderson, 1991; S.R. Anderson, 1995, personal communication). Though lithologic descriptions of the interbed are not readily available, the driller's log for USGS-59 described the unit as consisting of red cinders and clay (Appendix A).

Hydraulic conductivity estimates are not available for the sedimentary interbed; however, four slug tests have been performed on perched water bodies in interbeds in the vadose zone at the ICPP. Hydraulic conductivity estimates of these sedimentary interbeds, which were between 105 and 150 ft below land surface, ranged from 4×10^{-3} to 7×10^{-5} ft/min (LITCO, 1994).

The hydraulic properties for the three-layer conceptual model were determined by trial and error model calibration (Figure 19). The model predictions of drawdown in the upper and lower aquifers closely mimic the observed drawdown data from

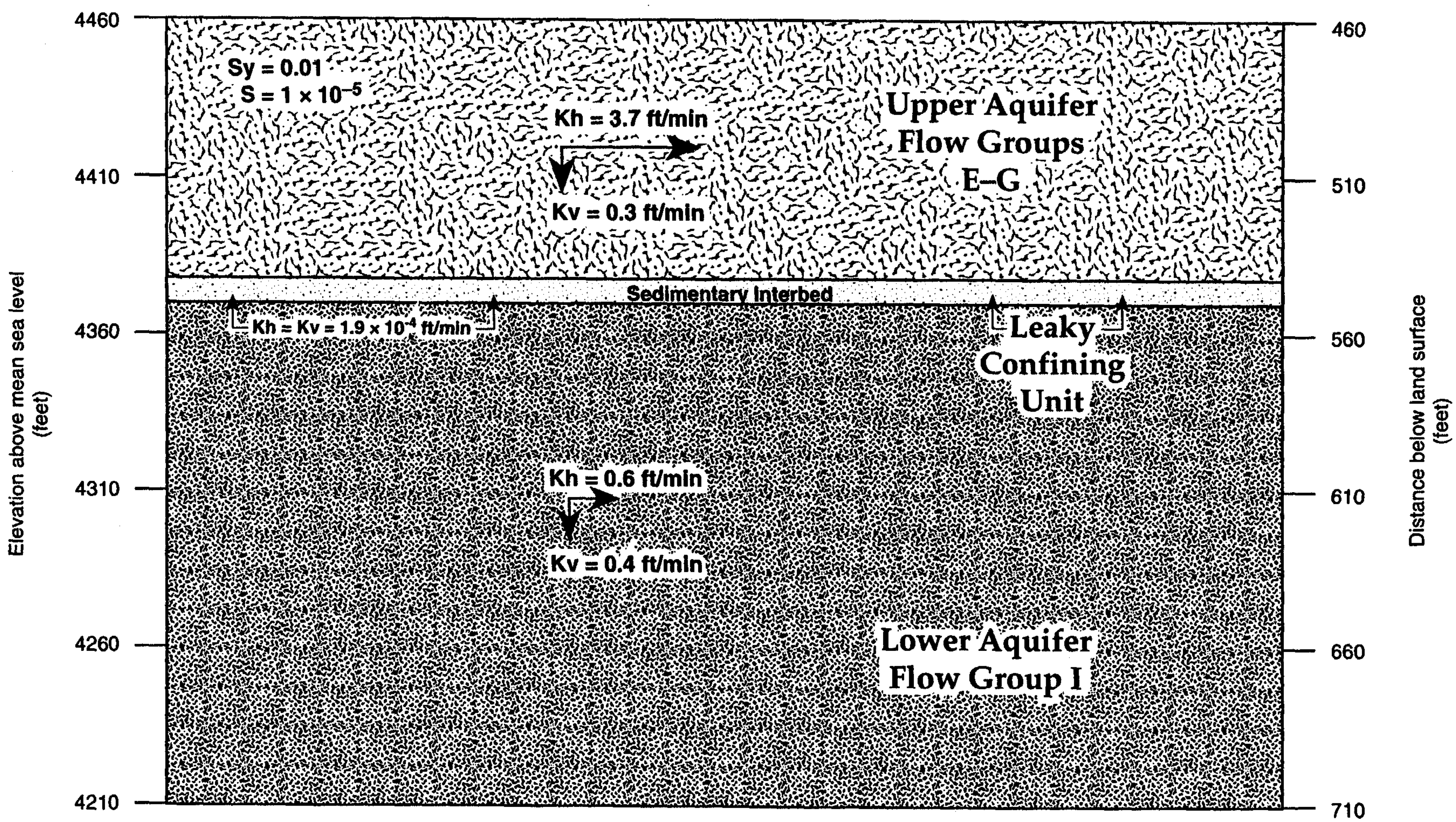


Figure 19. Three-layer conceptual model of the Snake River Plain aquifer near the ICPP used for the radial flow modeling for time-drawdown data collected from USGS-46.

USGS-46, and, importantly, the simulated drawdown shows the distinct break observed in the late-time drawdown data (Figure 20A).

To further test the validity of the three-layer conceptual model, simulated drawdown data from the radial flow model were compared to the time-drawdown data collected in USGS-44, USGS-45, and USGS-59. Specific yield, storativity, and the hydraulic conductivity of the confining unit were adjusted during model calibration (see Table 11). The simulated and observed time-drawdown data display similar patterns (i.e. greater drawdown in zones below the top of the I-Flow), and simulated drawdown is typically within a few hundredths of a foot of measured drawdown (Figures 20 and 21).

Summary

The differences between the observed drawdown and the drawdown simulated with the one- and two-layer models likely reflects conceptual differences between these models and the real system. This partially results from averaging, or homogenizing, properties of distinct layers of the Snake River Plain aquifer. The three-layer model provides the best match to the data sets, and most closely mimics the stratigraphic relations of the system. Geologic heterogeneity and variations in aquifer thickness may hamper efforts to provide a better match to the time-drawdown data.

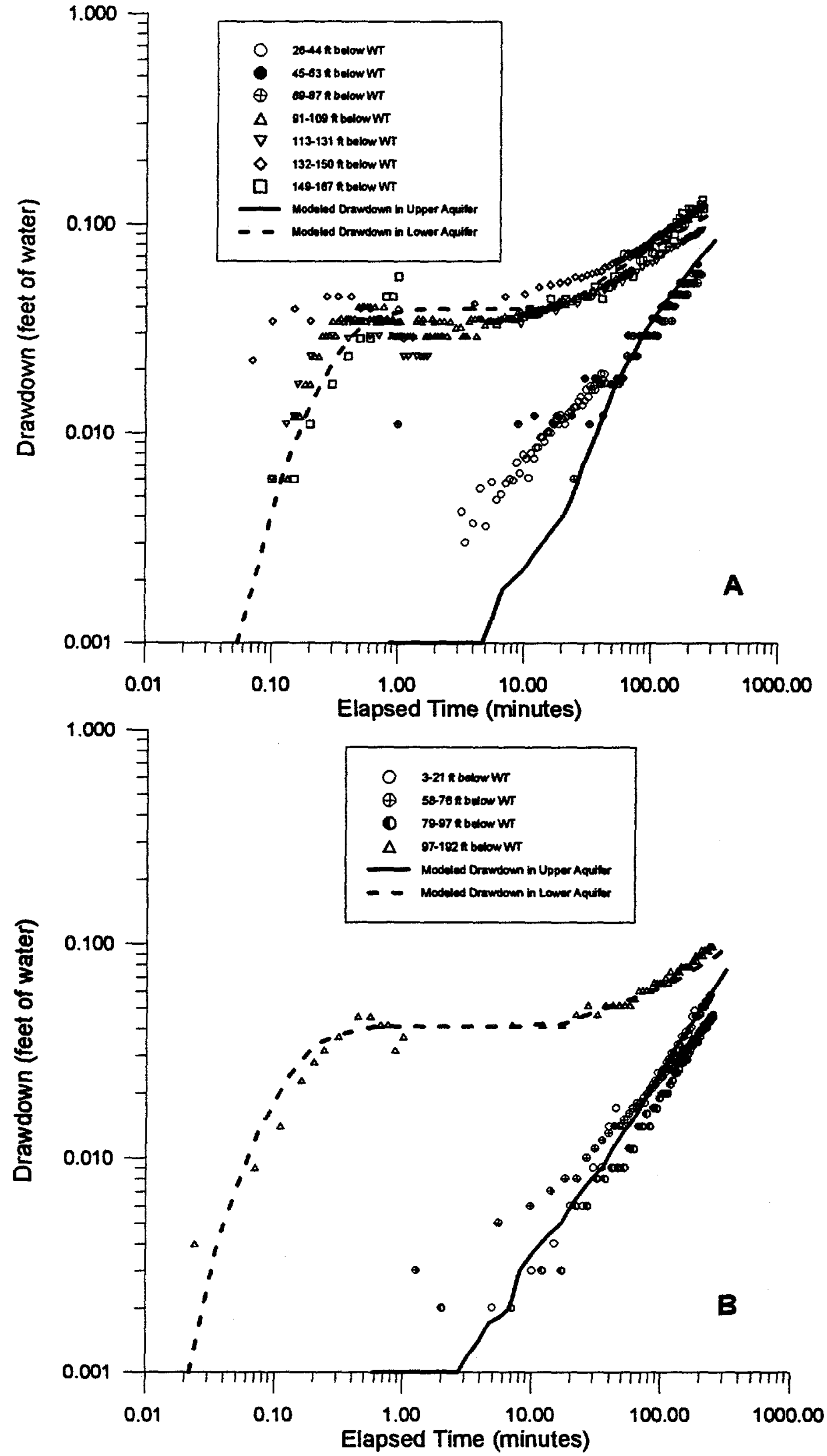


Figure 20. Simulated drawdown with the three-layer model versus measured drawdown in the observation wells. A) USGS-46. B) USGS-59.

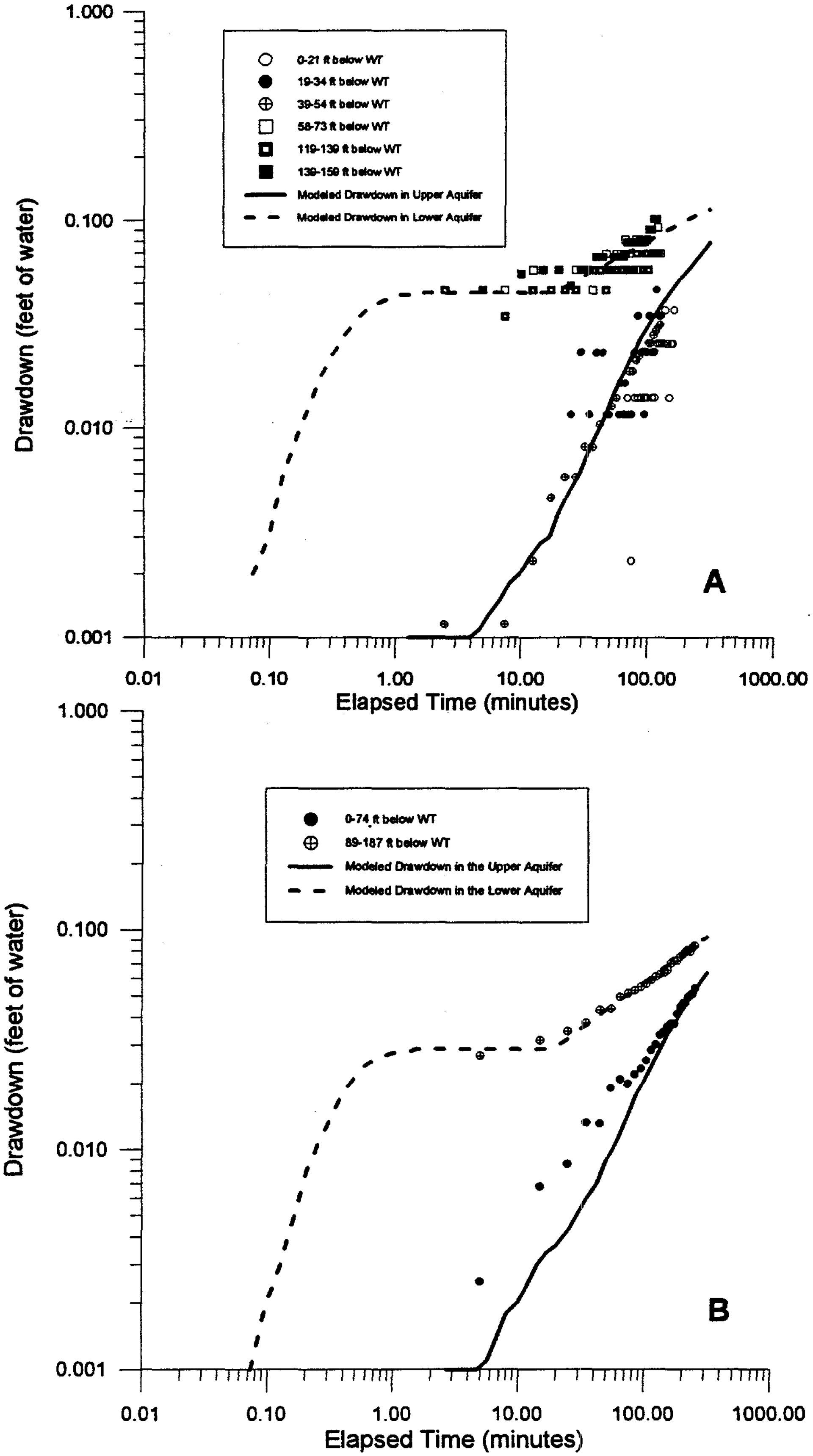


Figure 21. Simulated drawdown with the three-layer model versus measured drawdown in the observation wells. A) USGS-44. B) USGS-45.

The estimated properties of the Snake River Plain aquifer, based on optimization of the radial flow model for the three-layer conceptual model developed using time-drawdown data collected in USGS-44, USGS-45, USGS-46, and USGS-59, are summarized in Table 11. Model calibration was accomplished by varying specific yield, storativity, and the hydraulic conductivity of the leaky confining layer; the hydraulic conductivities of the upper and lower layers, determined from model calibration to time-drawdown data from USGS-46, were held constant.

Table 11. Estimated hydraulic properties from optimization of the three-layer radial flow model for the Snake River Plain aquifer. (NM = not meaningful - no early-time data)

	USGS-44	USGS-45	USGS-46	USGS-59
Upper Aquifer Kh Kv	 3.7 ft/min 0.3 ft/min	 3.7 ft/min 0.3 ft/min	 3.7 ft/min 0.3 ft/min	 3.7 ft/min 0.3 ft/min
Confining Unit Kh=Kv	1.5×10^{-4} ft/min	1.5×10^{-4} ft/min	1.9×10^{-4} ft/min	0.7×10^{-4} ft/min
Lower Aquifer Kh Kv	 0.6 ft/min 0.4 ft/min	 0.6 ft/min 0.4 ft/min	 0.6 ft/min 0.4 ft/min	 0.6 ft/min 0.4 ft/min
Storativity	NM	NM	1×10^{-5}	3×10^{-6}
Specific Yield	0.01	0.01	0.01	0.006

Assuming the effective porosity of the aquifer is 0.01 (i.e. the specific yield), storage from the compressibility of water (i.e. no compression of the aquifer skeleton) would be 3.5×10^{-6}, which is less than the storativity of 1×10^{-5} estimated from the modeling. This indicates that some of the water in storage in the lower aquifer is derived from compression of the aquifer skeleton.

The average horizontal hydraulic conductivity (Kh_{avg}) of the three-layer system is 1.7 ft/min, and the average vertical hydraulic conductivity is 7.3 x 10^{-3} ft/min (Appendix C). Multiplying Kh_{avg} by the aquifer thickness (245 feet) results in a transmissivity estimate of 420 ft^2/min. Ackerman (1991) assumed the aquifer was isotropic, therefore the calculated transmissivities of 50 ft^2/min for CPP-01 and 110 ft^2/min for CPP-02 which he reported are considerably less than the estimate from this study.

The calibrated radial flow ground-water model satisfactorily reproduces the drawdown measured during the ICPP production well pumping tests analyzed by Ackerman (1991). These tests were conducted in August 1981 at a discharge rate of 2500 gpm; the duration of pumping was 760 minutes for CPP-01 and 720 minutes for CPP-02 (Ackerman, 1991). The maximum drawdown measured in the production wells during pumping was approximately 4.5 feet in CPP-01 and 2.8 feet in CPP-02. Simulation of the 1981 pumping tests with the radial flow model resulted in a predicted drawdown in the production well of about 2.4 feet. The similarity of measured and simulated drawdowns further supports the aquifer properties and three-layer conceptual model developed from multiple-well aquifer tests conducted with the straddle packer.

CHAPTER 5:

SUMMARY

The Idaho INEL Oversight Program, in association with the University of Idaho, Idaho Geological Survey, Boise State University, and Idaho State University, developed a research program to determine the hydraulic properties of the Snake River Plain aquifer and characterize the vertical distribution of contaminants. A straddle-packer was deployed in four observation wells near the Idaho Chemical Processing Plant at the Idaho National Engineering Laboratory. Pressure transducers mounted in the straddle-packer assembly were used to monitor the response of the Snake River Plain aquifer to pumping at the ICPP production wells, located 2600 to 4200 feet from the observation wells. The time-drawdown data from these tests were used to evaluate various conceptual models of the aquifer.

Aquifer properties were estimated by matching time-drawdown data to type curves for partially penetrating wells in an unconfined aquifer. This approach assumes a single aquifer unit which is homogeneous and anisotropic. The hydraulic properties of the aquifer obtained from the type curve analyses were:

- Storativity = 3×10^{-5}
- Specific Yield = 0.01
- Transmissivity = 740 ft^2/min
- Anisotropy (Kv:Kh)= 1:360

Further evaluation of the time-drawdown data collected at various depth intervals in the aquifer indicate that drawdown generally increased with depth. Time-drawdown data were compared to the stratigraphy of the basalt flows and sedimentary interbeds at the Idaho National Engineering Laboratory developed by Anderson (1991). The greatest drawdown was observed in tested intervals below the top of Flow Group I.

To evaluate the implications of this observation, a radial flow model was used to simulate three conceptual models for the Snake River Plain aquifer near the Idaho Chemical Processing Plant:

1) One Layer System:
   - Single aquifer - Flow Groups E-I (homogeneous and anisotropic)
2) Two Layer System:
   - Upper aquifer - Flow Groups E-G (homogeneous and anisotropic)
   - Lower aquifer - Flow Group I (homogeneous and anisotropic)
3) Three Layer System:
   - Upper aquifer - Flow Groups E-G (homogeneous and anisotropic)
   - Confining unit - sedimentary interbed at the top of Flow Group I (homogeneous and isotropic)
   - Lower aquifer - Flow Group I (homogeneous and anisotropic)

The three-layer system, in which the upper 70 feet of the aquifer is unconfined (460-545 feet bls), the sedimentary interbed at the top of Flow Group I is a leaky confining layer (545-550 feet bls), and the basalt units in Flow Group I represent a leaky confined aquifer (550-710 feet bls), provided the best match of simulated drawdown to observed drawdown. Estimates of the hydraulic properties of each layer were determined by trial and error model calibration. This optimization resulted in the following average estimates for the hydraulic properties of the composite, three-layer system:

- Storativity = 7×10^{-6}
- Specific Yield = 0.009
- Transmissivity = 430 ft^2/min
- Anisotropy (Kv:Kh)= 1:230

The estimated hydraulic properties for each of the three layers are as follows:

1) Upper aquifer (unconfined)
   Horizontal conductivity = 3.7 ft/min
   Vertical conductivity = 0.3 ft/min

2) Confining layer (leaky)
   Horizontal conductivity = 1.4×10^{-4} ft/min
   Vertical conductivity = 1.4×10^{-4} ft/min

3) Lower aquifer (leaky, confined)
   Horizontal conductivity = 0.6 ft/min
   Vertical conductivity = 0.4 ft/min

Calibration of the radial flow model and type curve analysis resulted in similar estimates of the hydraulic properties of the aquifer system, despite major differences in the conceptual models (i.e. one layer versus three layers).

For aquifer characterization studies with less quantitative objectives, such as an evaluation of an area's water supply potential, type-curve analysis may be adequate. However, for more complex needs, such as contaminant transport modeling, it may be necessary to refine the conceptual model. Utilization of a straddle-packer system during pumping tests can aid in the recognition of individual hydrostratigraphic units in an aquifer. Radial flow models allow for less restrictive conceptual models than existing type curve solutions, and provide a useful tool for the estimation of hydraulic properties in layered aquifers.

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APPENDIX A

LITHOLOGIC WELL LOGS
AND
CONSTRUCTION DIAGRAMS

(from Sehlke and others, 1993)

APPENDIX A

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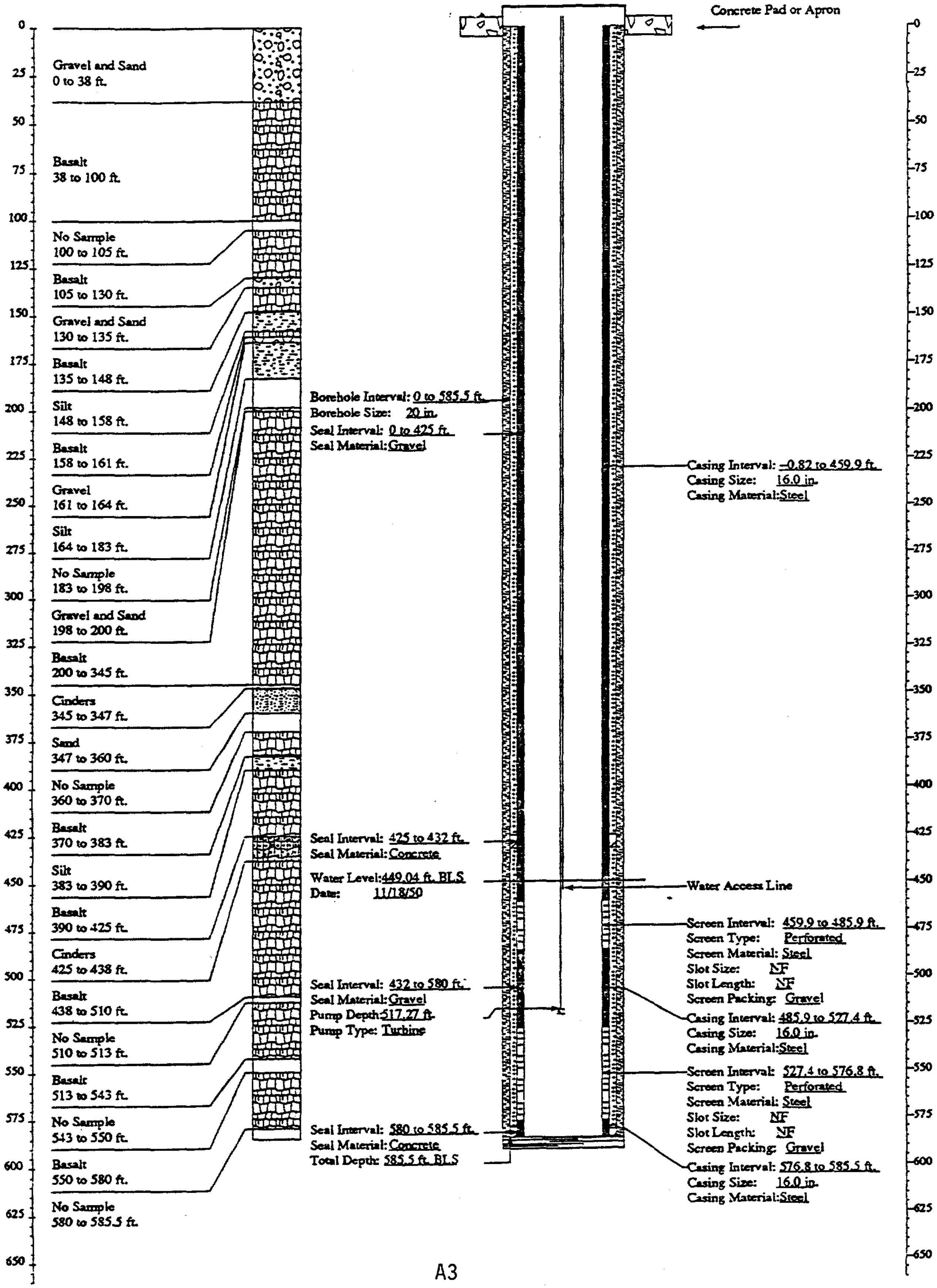
CPP-01



Concrete Pad or Apron
Gravel and Sand
0 to 38 ft.
Basalt
38 to 100 ft.
No Sample
100 to 105 ft.
Basalt
105 to 130 ft.
Gravel and Sand
130 to 135 ft.
Basalt
135 to 148 ft.
Silt
148 to 158 ft.
Basalt
158 to 161 ft.
Gravel
161 to 164 ft.
Silt
164 to 183 ft.
No Sample
183 to 198 ft.
Gravel and Sand
198 to 200 ft.
Basalt
200 to 345 ft.
Cinders
345 to 347 ft.
Sand
347 to 360 ft.
No Sample
360 to 370 ft.
Basalt
370 to 383 ft.
Silt
383 to 390 ft.
Basalt
390 to 425 ft.
Cinders
425 to 438 ft.
Basalt
438 to 510 ft.
No Sample
510 to 513 ft.
Basalt
513 to 543 ft.
No Sample
543 to 550 ft.
Basalt
550 to 580 ft.
No Sample
580 to 585.5 ft.
Borehole Interval: 0 to 585.5 ft.
Borehole Size: 20 in.
Seal Interval: 0 to 425 ft.
Seal Material: Gravel
Seal Interval: 425 to 432 ft.
Seal Material: Concrete
Water Level: 449.04 ft. BLS
Date: 11/18/50
Seal Interval: 432 to 580 ft.
Seal Material: Gravel
Pump Depth: 517.27 ft.
Pump Type: Turbine
Seal Interval: 580 to 585.5 ft.
Seal Material: Concrete
Total Depth: 585.5 ft. BLS
Casing Interval: -0.82 to 459.9 ft.
Casing Size: 16.0 in.
Casing Material: Steel
Water Access Line
Screen Interval: 459.9 to 485.9 ft.
Screen Type: Perforated
Screen Material: Steel
Slot Size: NF
Slot Length: NF
Screen Packing: Gravel
Casing Interval: 485.9 to 527.4 ft.
Casing Size: 16.0 in.
Casing Material: Steel
Screen Interval: 527.4 to 576.8 ft.
Screen Type: Perforated
Screen Material: Steel
Slot Size: NF
Slot Length: NF
Screen Packing: Gravel
Casing Interval: 576.8 to 585.5 ft.
Casing Size: 16.0 in.
Casing Material: Steel
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
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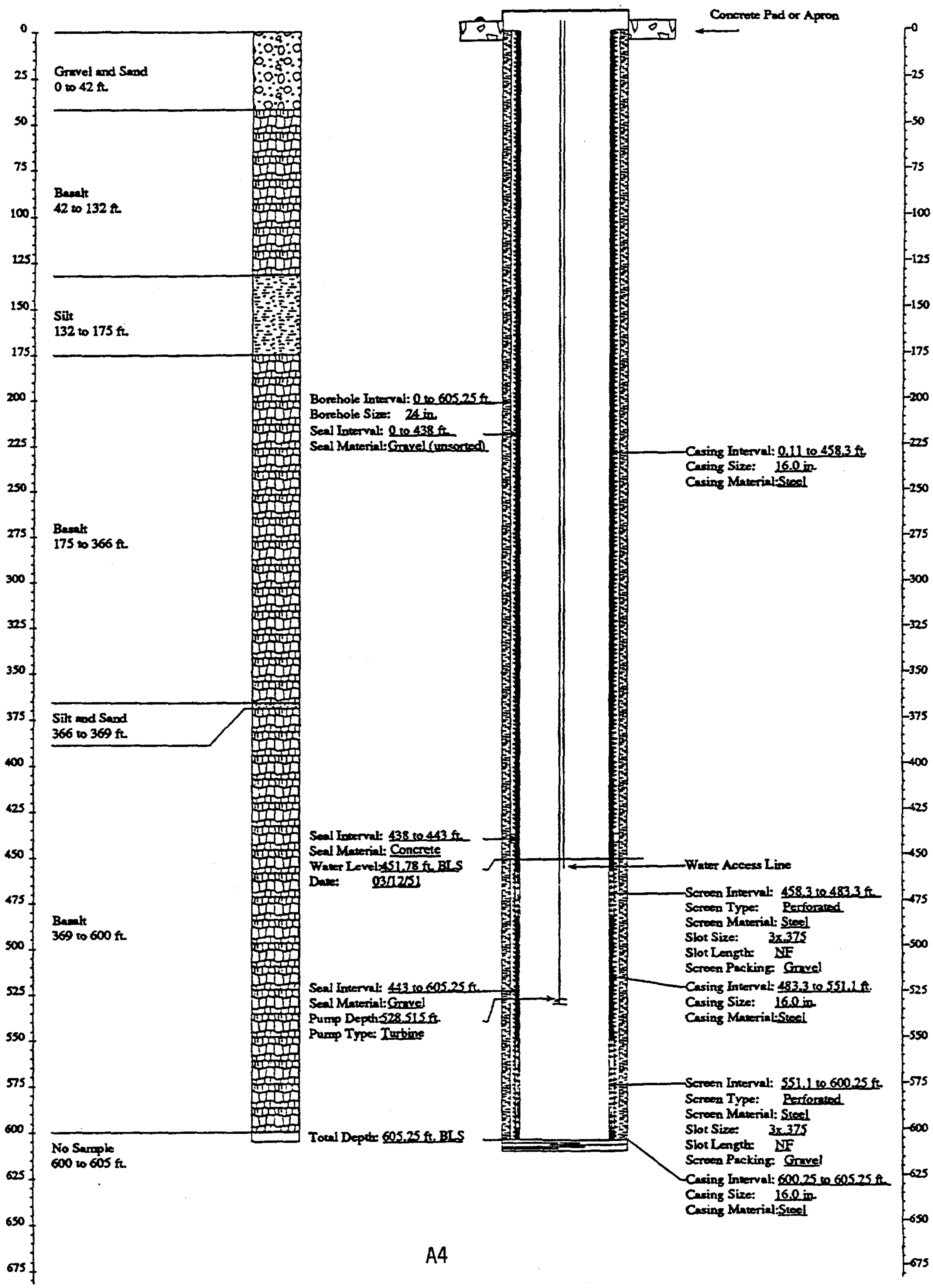
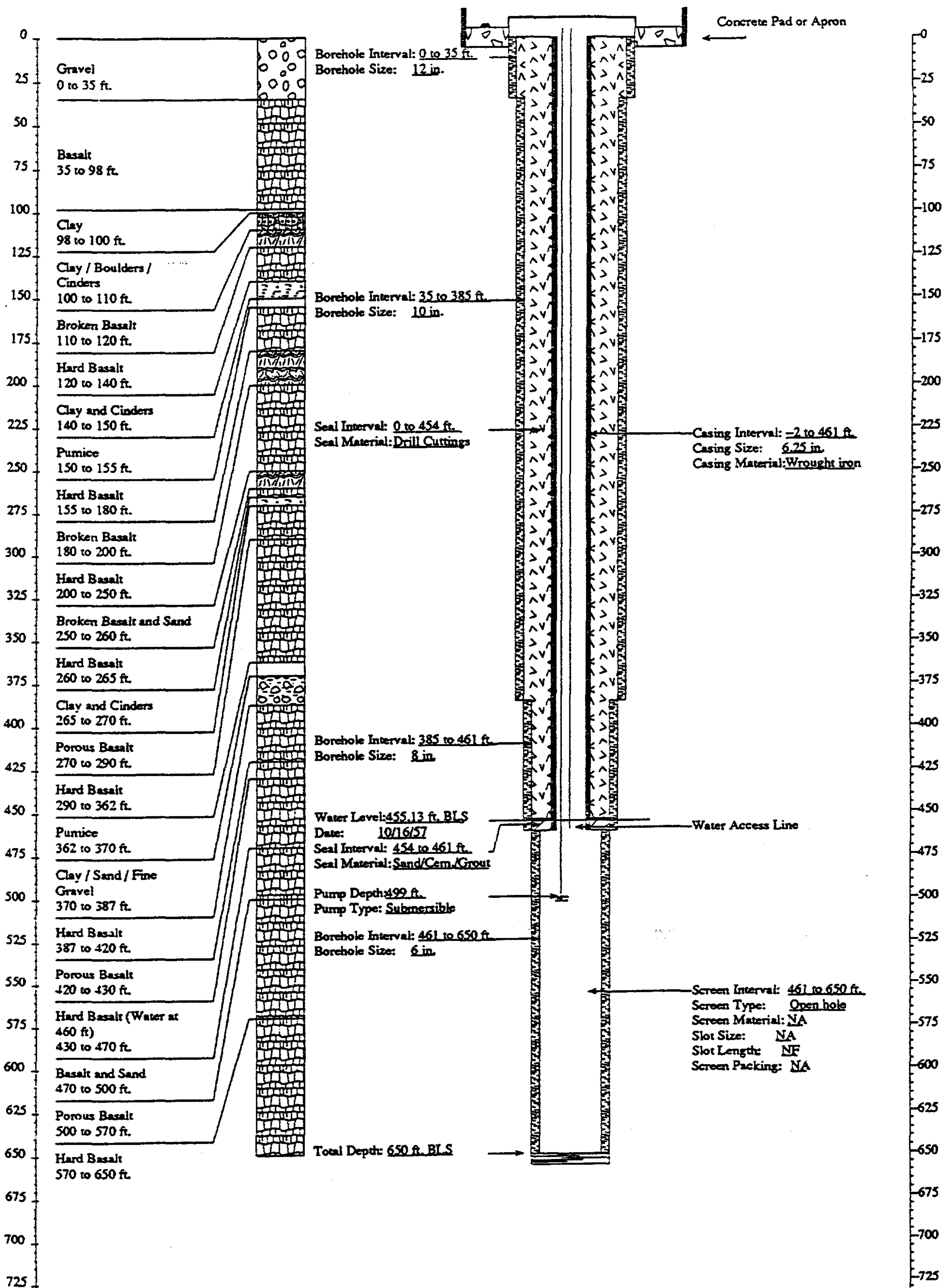
550
575
600
625
650

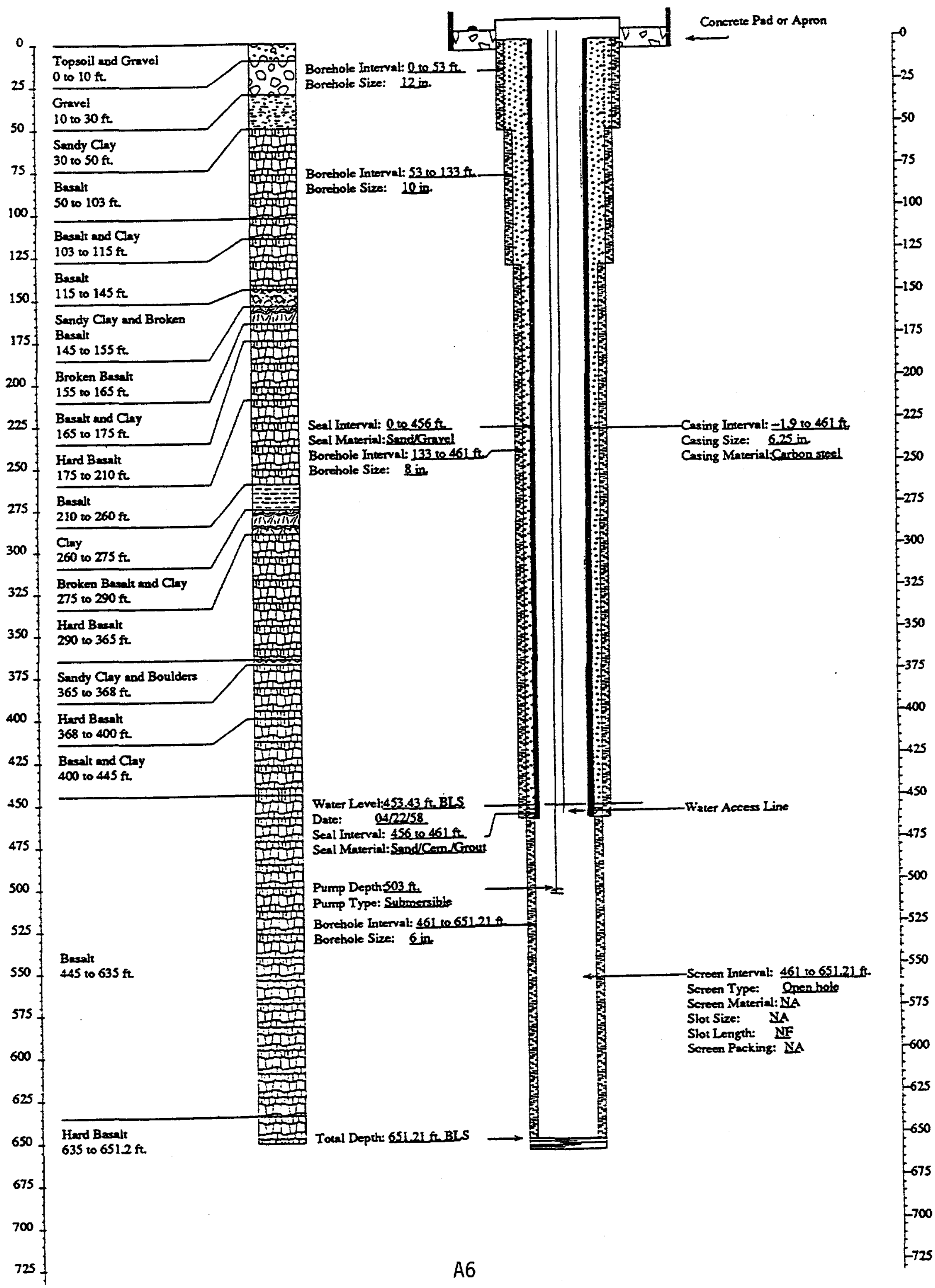
CPP-02


Concrete Pad or Apron
Gravel and Sand
0 to 42 ft.
Basalt
42 to 132 ft.
Silt
132 to 175 ft.
Basalt
175 to 366 ft.
Silt and Sand
366 to 369 ft.
Basalt
369 to 600 ft.
No Sample
600 to 605 ft.
Borehole Interval: 0 to 605.25 ft.
Borehole Size: 24 in.
Seal Interval: 0 to 438 ft.
Seal Material: Gravel (unsorted)
Casing Interval: 0.11 to 458.3 ft.
Casing Size: 16.0 in.
Casing Material: Steel
Seal Interval: 438 to 443 ft.
Seal Material: Concrete
Water Level: 451.78 ft. BLS
Date: 03/12/51
Water Access Line
Screen Interval: 458.3 to 483.3 ft.
Screen Type: Perforated
Screen Material: Steel
Slot Size: 3x.375
Slot Length: NF
Screen Packing: Gravel
Casing Interval: 483.3 to 551.1 ft.
Casing Size: 16.0 in.
Casing Material: Steel
Seal Interval: 443 to 605.25 ft.
Seal Material: Gravel
Pump Depth: 528.515 ft.
Pump Type: Turbine
Screen Interval: 551.1 to 600.25 ft.
Screen Type: Perforated
Screen Material: Steel
Slot Size: 3x.375
Slot Length: NF
Screen Packing: Gravel
Total Depth: 605.25 ft. BLS
Casing Interval: 600.25 to 605.25 ft.
Casing Size: 16.0 in.
Casing Material: Steel
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650
675

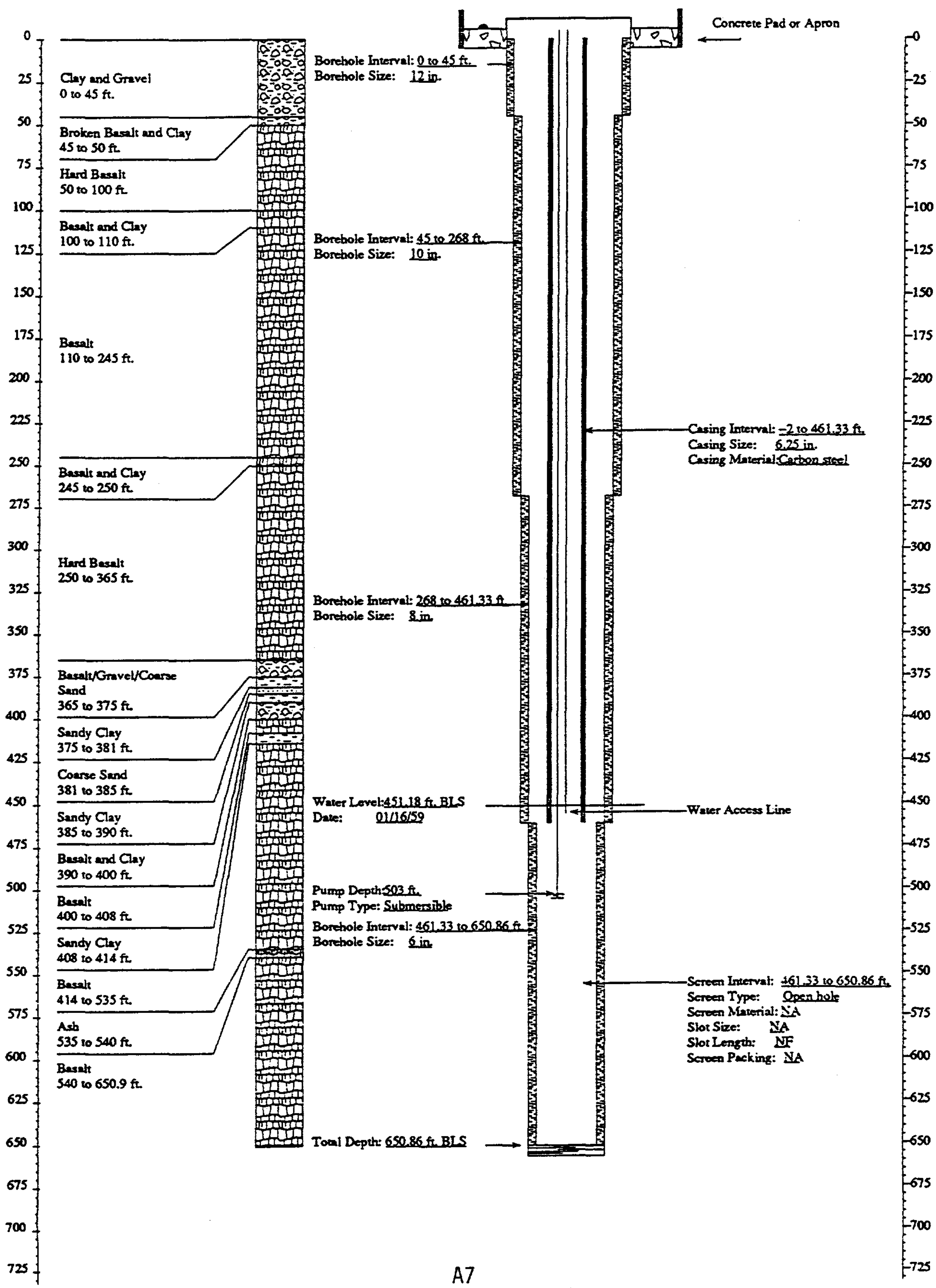
USGS-44


Concrete Pad or Apron
Gravel
0 to 35 ft.
Basalt
35 to 98 ft.
Clay
98 to 100 ft.
Clay / Boulders / Cinders
100 to 110 ft.
Broken Basalt
110 to 120 ft.
Hard Basalt
120 to 140 ft.
Clay and Cinders
140 to 150 ft.
Pumice
150 to 155 ft.
Hard Basalt
155 to 180 ft.
Broken Basalt
180 to 200 ft.
Hard Basalt
200 to 250 ft.
Broken Basalt and Sand
250 to 260 ft.
Hard Basalt
260 to 265 ft.
Clay and Cinders
265 to 270 ft.
Porous Basalt
270 to 290 ft.
Hard Basalt
290 to 362 ft.
Pumice
362 to 370 ft.
Clay / Sand / Fine Gravel
370 to 387 ft.
Hard Basalt
387 to 420 ft.
Porous Basalt
420 to 430 ft.
Hard Basalt (Water at 460 ft)
430 to 470 ft.
Basalt and Sand
470 to 500 ft.
Porous Basalt
500 to 570 ft.
Hard Basalt
570 to 650 ft.
Borehole Interval: 0 to 35 ft.
Borehole Size: 12 in.
Borehole Interval: 35 to 385 ft.
Borehole Size: 10 in.
Seal Interval: 0 to 454 ft.
Seal Material: Drill Cuttings
Casing Interval: -2 to 461 ft.
Casing Size: 6.25 in.
Casing Material: Wrought iron
Borehole Interval: 385 to 461 ft.
Borehole Size: 8 in.
Water Level: 455.13 ft. BLS
Date: 10/16/57
Seal Interval: 454 to 461 ft.
Seal Material: Sand/Cem./Grout
Water Access Line
Pump Depth: 499 ft.
Pump Type: Submersible
Borehole Interval: 461 to 650 ft.
Borehole Size: 6 in.
Screen Interval: 461 to 650 ft.
Screen Type: Open hole
Screen Material: NA
Slot Size: NA
Slot Length: NF
Screen Packing: NA
Total Depth: 650 ft. BLS
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650
675
700
725

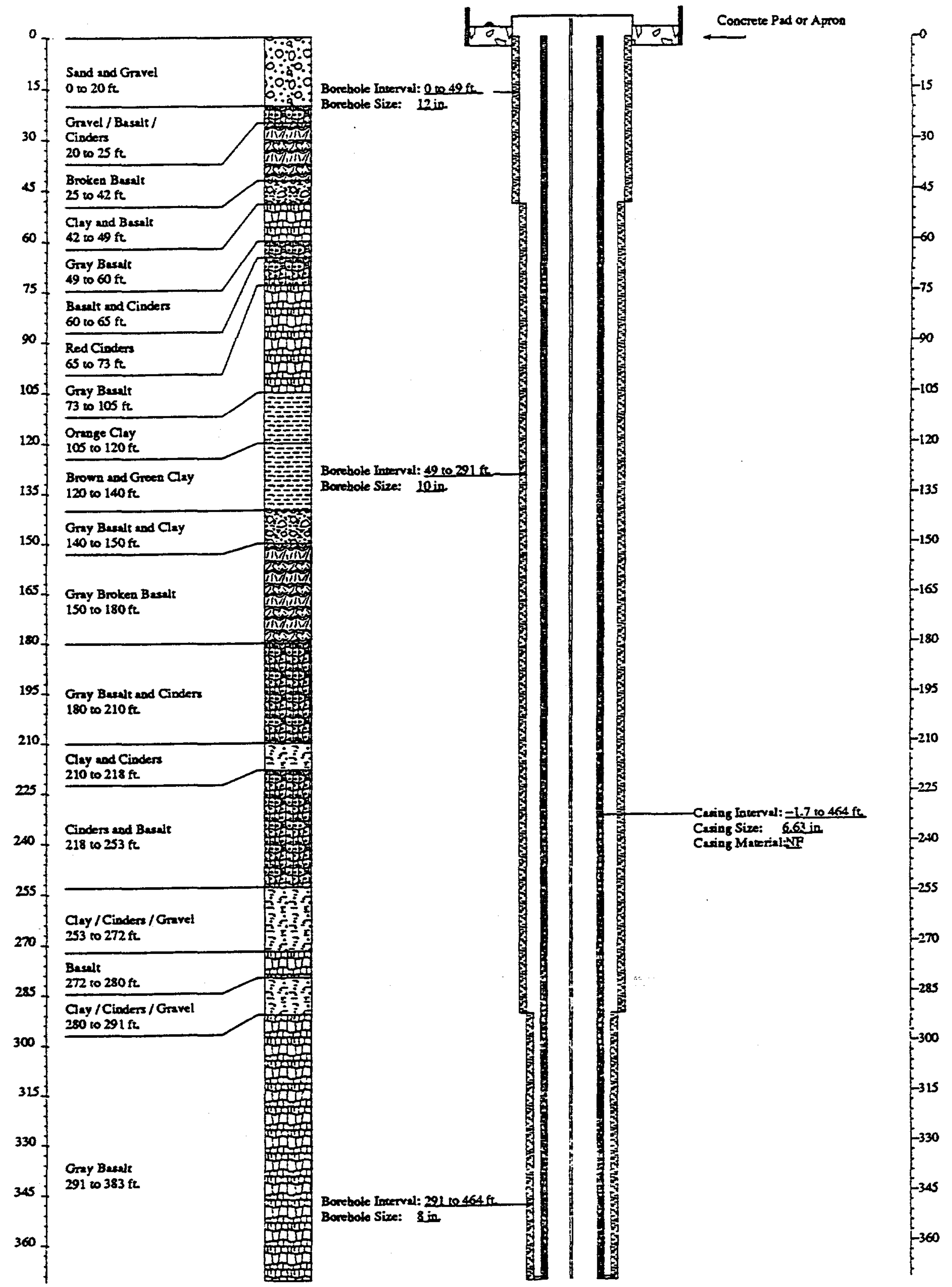
USGS-45


Concrete Pad or Apron
Topsoil and Gravel 0 to 10 ft.
Gravel 10 to 30 ft.
Sandy Clay 30 to 50 ft.
Basalt 50 to 103 ft.
Basalt and Clay 103 to 115 ft.
Basalt 115 to 145 ft.
Sandy Clay and Broken Basalt 145 to 155 ft.
Broken Basalt 155 to 165 ft.
Basalt and Clay 165 to 175 ft.
Hard Basalt 175 to 210 ft.
Basalt 210 to 260 ft.
Clay 260 to 275 ft.
Broken Basalt and Clay 275 to 290 ft.
Hard Basalt 290 to 365 ft.
Sandy Clay and Boulders 365 to 368 ft.
Hard Basalt 368 to 400 ft.
Basalt and Clay 400 to 445 ft.
Basalt 445 to 635 ft.
Hard Basalt 635 to 651.2 ft.
Borehole Interval: 0 to 53 ft.
Borehole Size: 12 in.
Borehole Interval: 53 to 133 ft.
Borehole Size: 10 in.
Seal Interval: 0 to 456 ft.
Seal Material: Sand/Gravel
Borehole Interval: 133 to 461 ft.
Borehole Size: 8 in.
Casing Interval: -1.9 to 461 ft.
Casing Size: 6.25 in.
Casing Material: Carbon steel
Water Level: 453.43 ft. BLS
Date: 04/22/58
Seal Interval: 456 to 461 ft.
Seal Material: Sand/Cem./Grout
Water Access Line
Pump Depth: 503 ft.
Pump Type: Submersible
Borehole Interval: 461 to 651.21 ft.
Borehole Size: 6 in.
Screen Interval: 461 to 651.21 ft.
Screen Type: Open hole
Screen Material: NA
Slot Size: NA
Slot Length: NF
Screen Packing: NA
Total Depth: 651.21 ft. BLS
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650
675
700
725

USGS-46

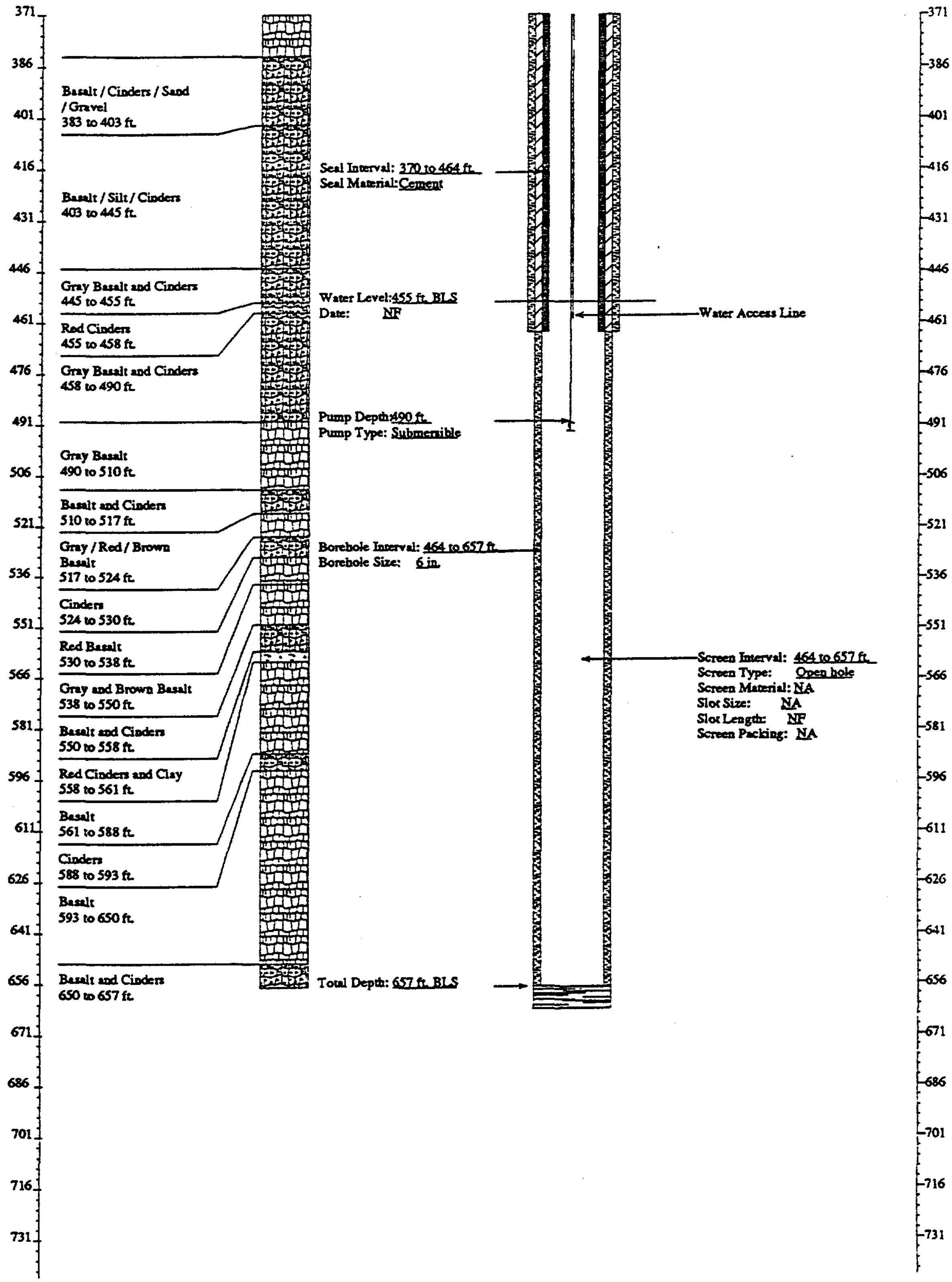

Concrete Pad or Apron
Clay and Gravel
0 to 45 ft.
Broken Basalt and Clay
45 to 50 ft.
Hard Basalt
50 to 100 ft.
Basalt and Clay
100 to 110 ft.
Basalt
110 to 245 ft.
Basalt and Clay
245 to 250 ft.
Hard Basalt
250 to 365 ft.
Basalt/Gravel/Coarse Sand
365 to 375 ft.
Sandy Clay
375 to 381 ft.
Coarse Sand
381 to 385 ft.
Sandy Clay
385 to 390 ft.
Basalt and Clay
390 to 400 ft.
Basalt
400 to 408 ft.
Sandy Clay
408 to 414 ft.
Basalt
414 to 535 ft.
Ash
535 to 540 ft.
Basalt
540 to 650.9 ft.
Borehole Interval: 0 to 45 ft.
Borehole Size: 12 in.
Borehole Interval: 45 to 268 ft.
Borehole Size: 10 in.
Borehole Interval: 268 to 461.33 ft.
Borehole Size: 8 in.
Water Level: 451.18 ft. BLS
Date: 01/16/59
Pump Depth: 503 ft.
Pump Type: Submersible
Borehole Interval: 461.33 to 650.86 ft.
Borehole Size: 6 in.
Total Depth: 650.86 ft. BLS
Casing Interval: -2 to 461.33 ft.
Casing Size: 6.25 in.
Casing Material: Carbon steel
Water Access Line
Screen Interval: 461.33 to 650.86 ft.
Screen Type: Open hole
Screen Material: NA
Slot Size: NA
Slot Length: NF
Screen Packing: NA
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650
675
700
725

USGS-59



Concrete Pad or Apron
Sand and Gravel 0 to 20 ft.
Gravel / Basalt / Cinders 20 to 25 ft.
Broken Basalt 25 to 42 ft.
Clay and Basalt 42 to 49 ft.
Gray Basalt 49 to 60 ft.
Basalt and Cinders 60 to 65 ft.
Red Cinders 65 to 73 ft.
Gray Basalt 73 to 105 ft.
Orange Clay 105 to 120 ft.
Brown and Green Clay 120 to 140 ft.
Gray Basalt and Clay 140 to 150 ft.
Gray Broken Basalt 150 to 180 ft.
Gray Basalt and Cinders 180 to 210 ft.
Clay and Cinders 210 to 218 ft.
Cinders and Basalt 218 to 253 ft.
Clay / Cinders / Gravel 253 to 272 ft.
Basalt 272 to 280 ft.
Clay / Cinders / Gravel 280 to 291 ft.
Gray Basalt 291 to 383 ft.
Borehole Interval: 0 to 49 ft.
Borehole Size: 12 in.
Borehole Interval: 49 to 291 ft.
Borehole Size: 10 in.
Borehole Interval: 291 to 464 ft.
Borehole Size: 8 in.
Casing Interval: -1.7 to 464 ft.
Casing Size: 6.63 in.
Casing Material: NF
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360

USGS-59


371
386
401
416
431
446
461
476
491
506
521
536
551
566
581
596
611
626
641
656
671
686
701
716
731
Basalt / Cinders / Sand / Gravel
383 to 403 ft.
Basalt / Silt / Cinders
403 to 445 ft.
Gray Basalt and Cinders
445 to 455 ft.
Red Cinders
455 to 458 ft.
Gray Basalt and Cinders
458 to 490 ft.
Gray Basalt
490 to 510 ft.
Basalt and Cinders
510 to 517 ft.
Gray / Red / Brown Basalt
517 to 524 ft.
Cinders
524 to 530 ft.
Red Basalt
530 to 538 ft.
Gray and Brown Basalt
538 to 550 ft.
Basalt and Cinders
550 to 558 ft.
Red Cinders and Clay
558 to 561 ft.
Basalt
561 to 588 ft.
Cinders
588 to 593 ft.
Basalt
593 to 650 ft.
Basalt and Cinders
650 to 657 ft.
Seal Interval: 370 to 464 ft.
Seal Material: Cement
Water Level: 455 ft. BLS
Date: NF
Water Access Line
Pump Depth: 490 ft.
Pump Type: Submersible
Borehole Interval: 464 to 657 ft.
Borehole Size: 6 in.
Screen Interval: 464 to 657 ft.
Screen Type: Open hole
Screen Material: NA
Slot Size: NA
Slot Length: NF
Screen Packing: NA
Total Depth: 657 ft. BLS

APPENDIX B

TIME-DRAWDOWN DATA
AND
TYPE CURVES

APPENDIX B

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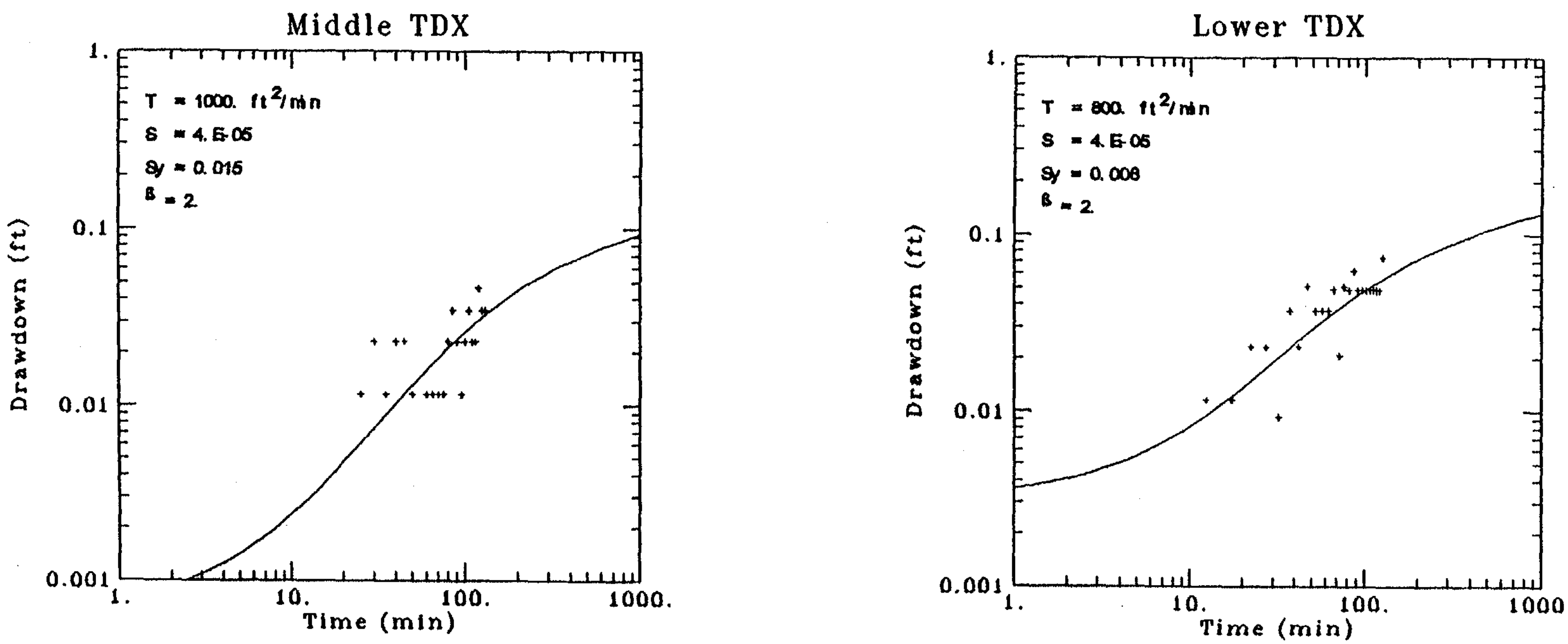


Figure B-1.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-44, 480-495 feet bls.

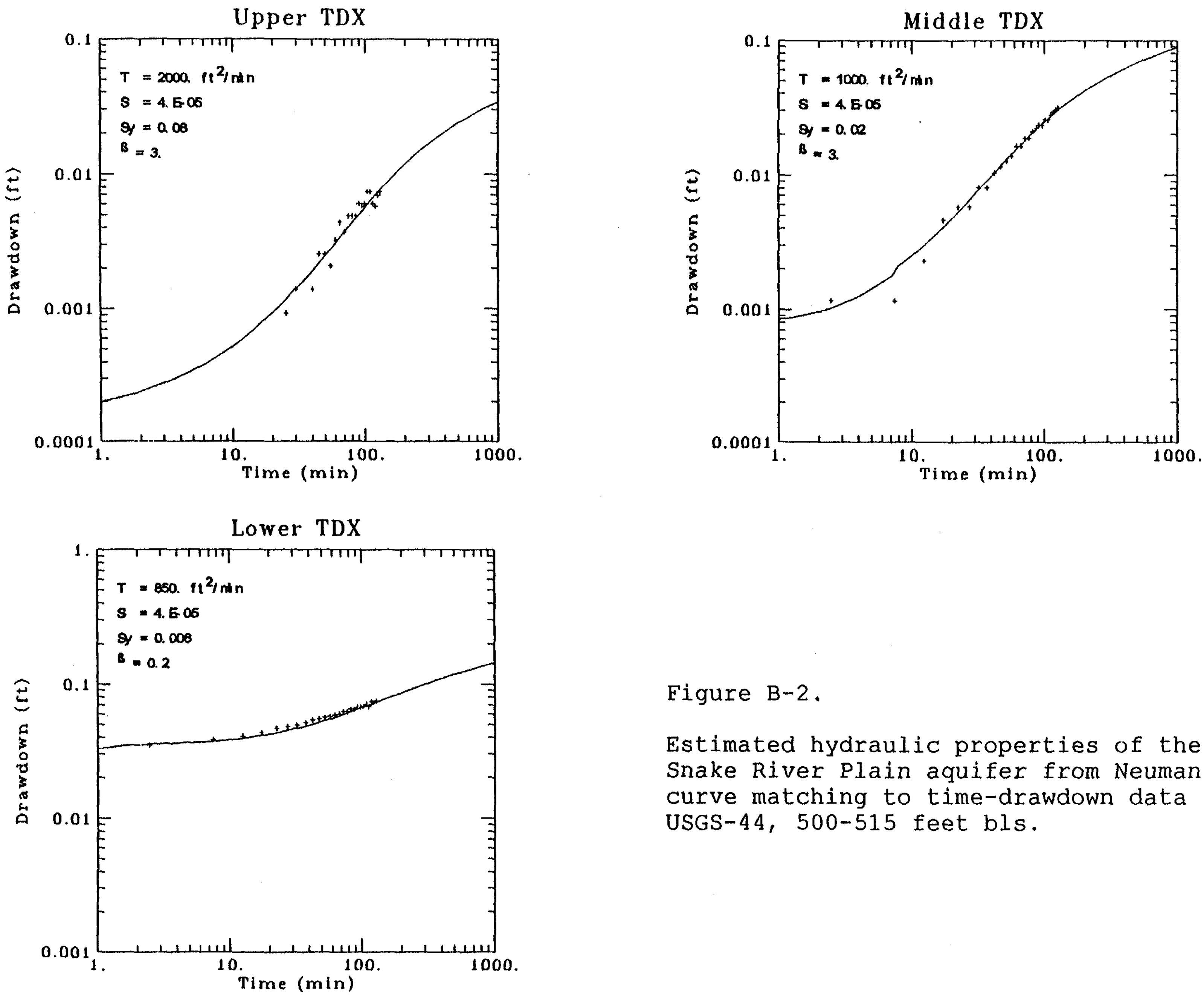


Figure B-2.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-44, 500-515 feet bls.

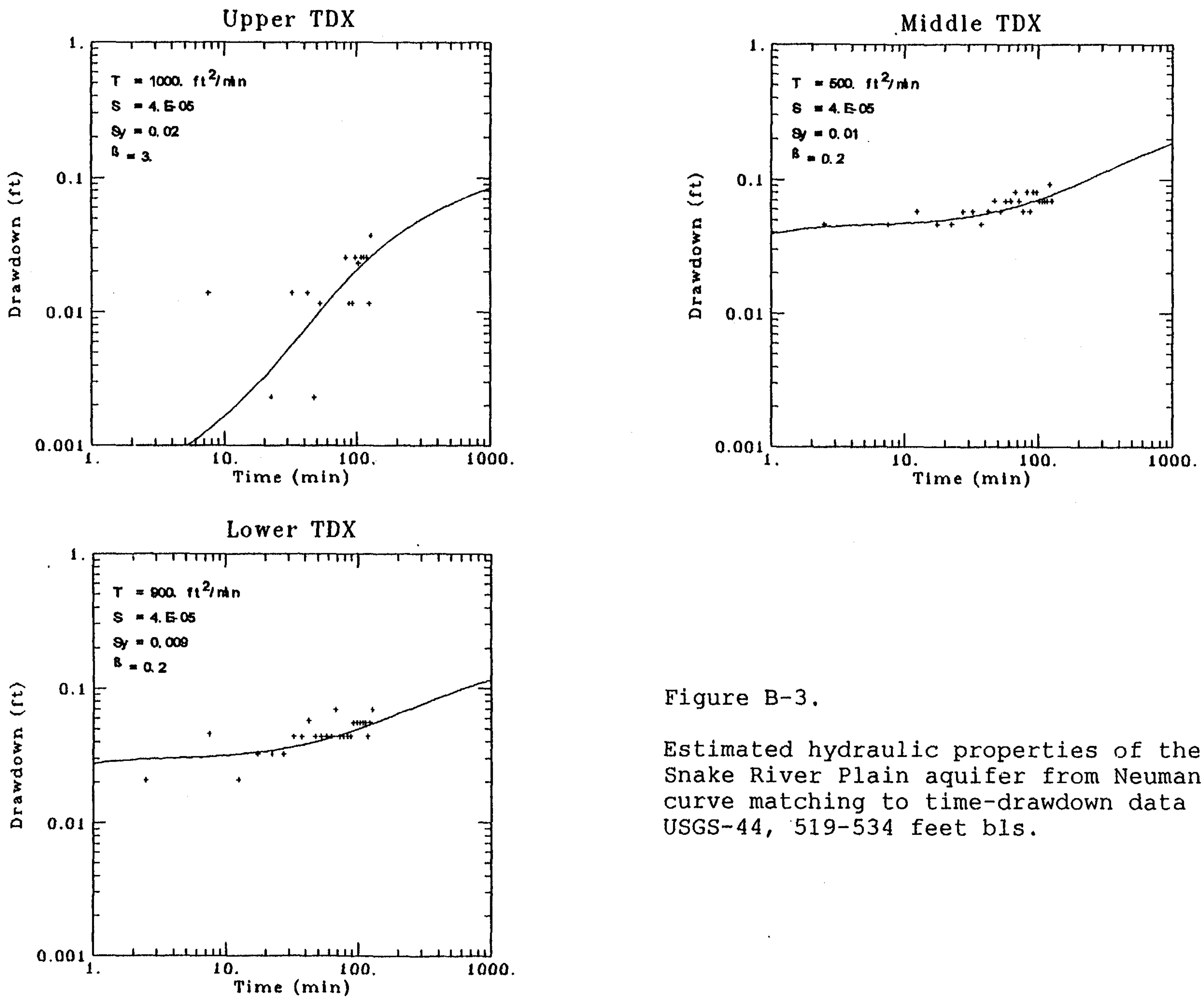
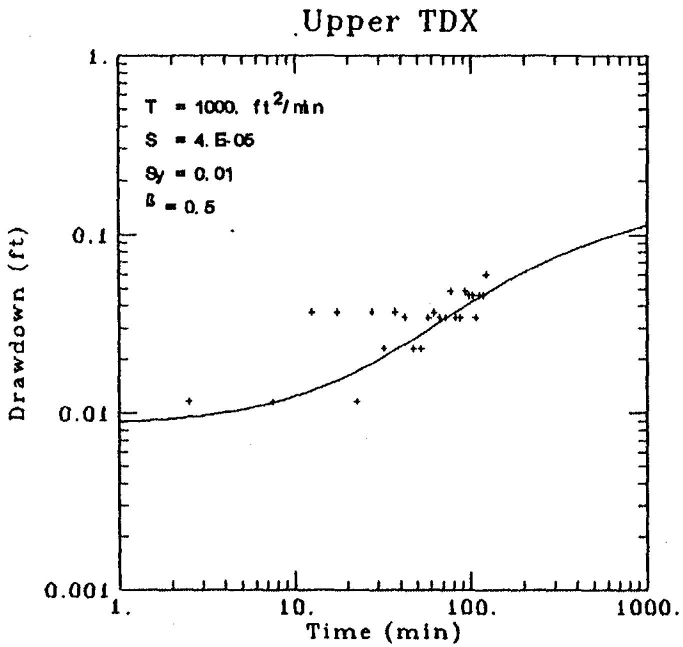
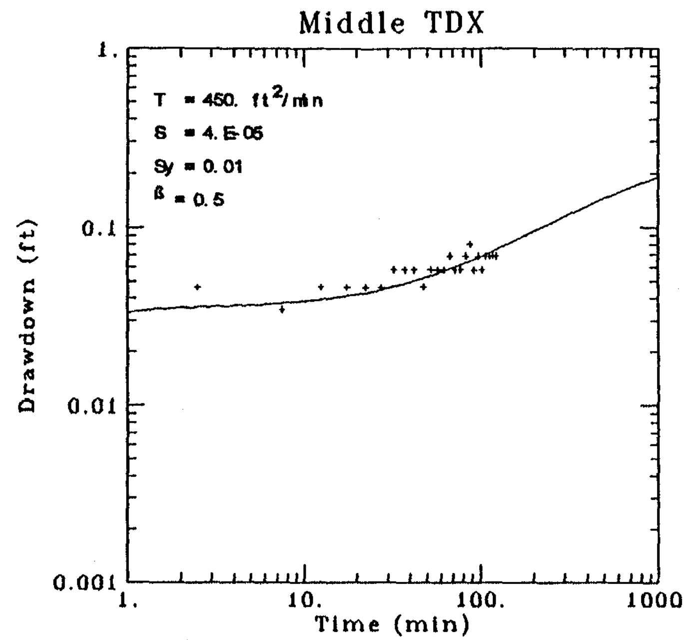


Figure B-3.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-44, 519-534 feet bls.





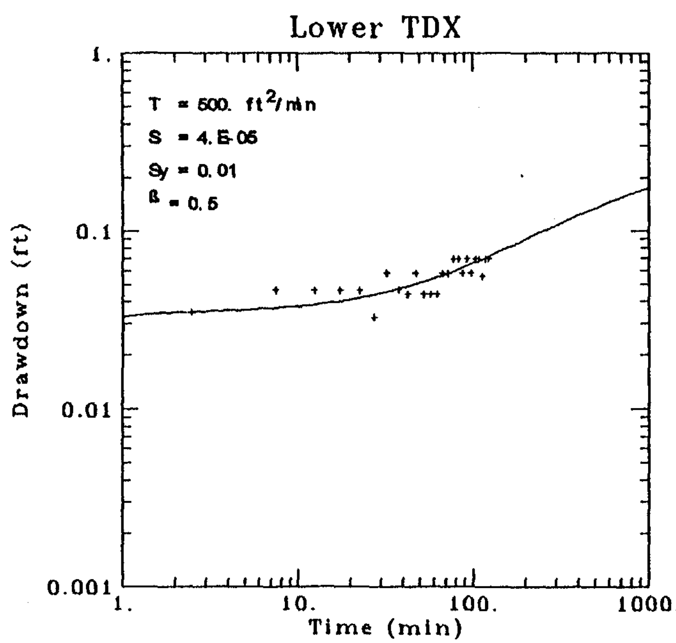
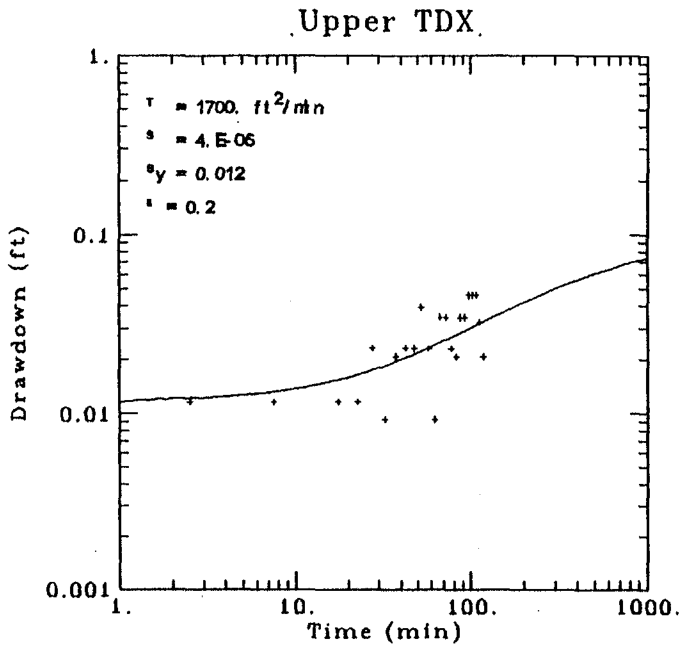
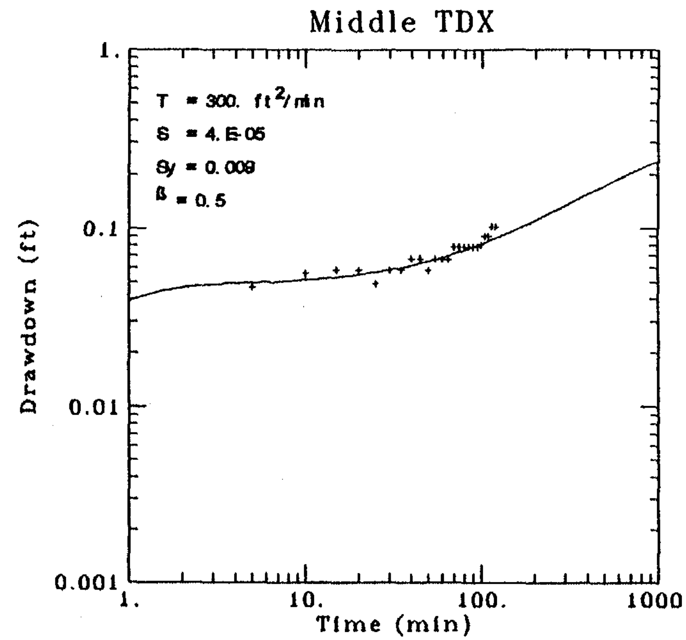


Figure B-4.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-44, 580-600 feet bls.





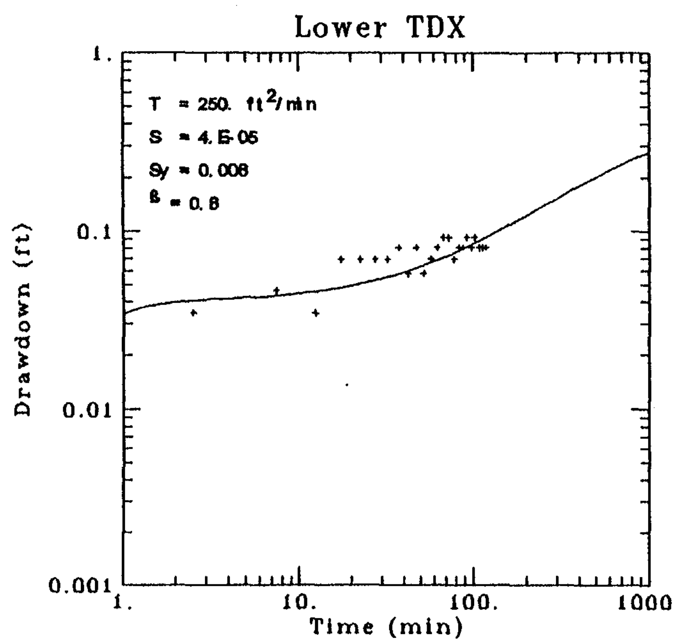
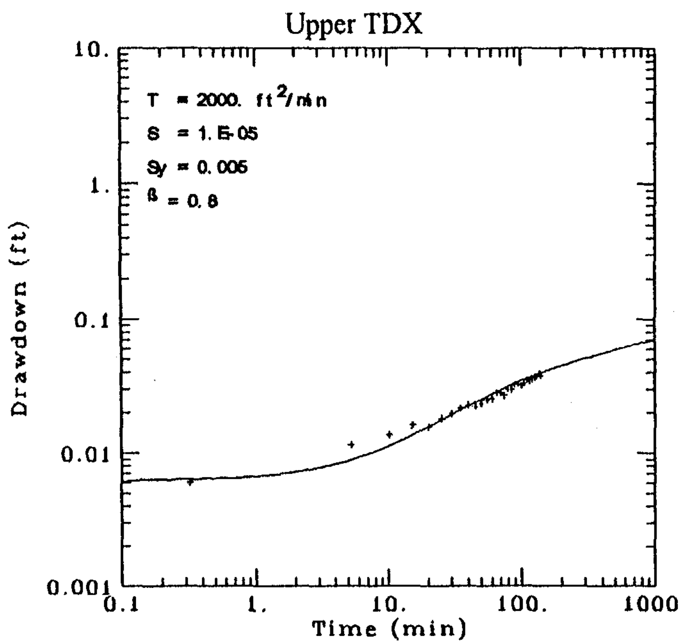
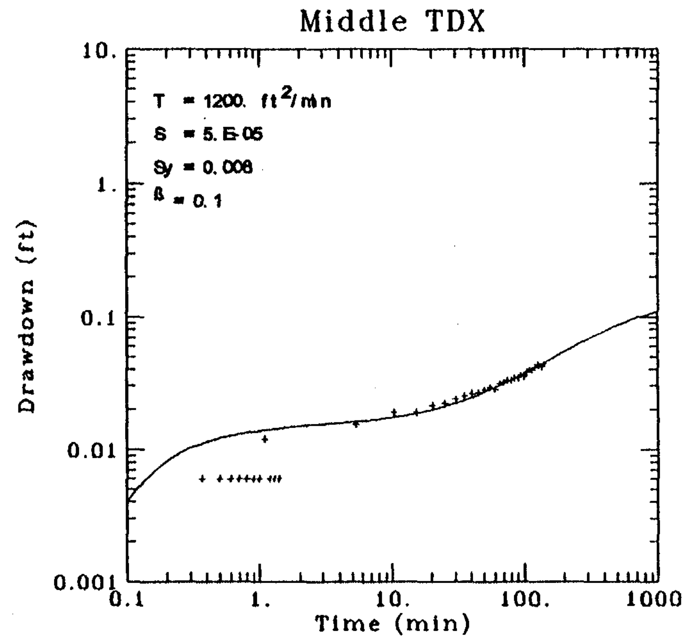


Figure B-5.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-44, 600-620 feet bls.





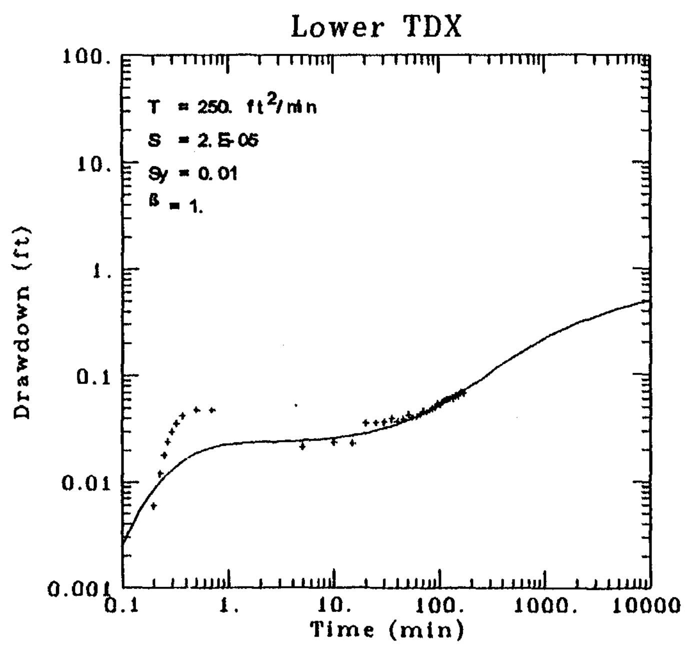
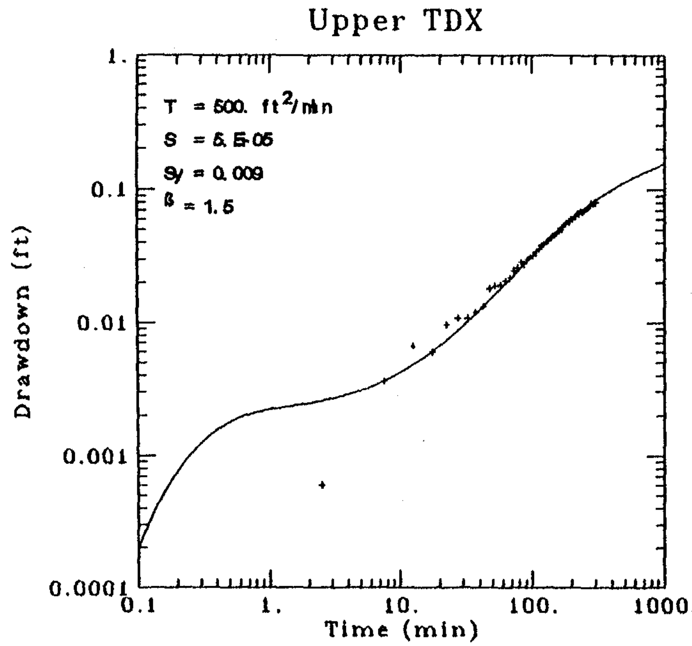
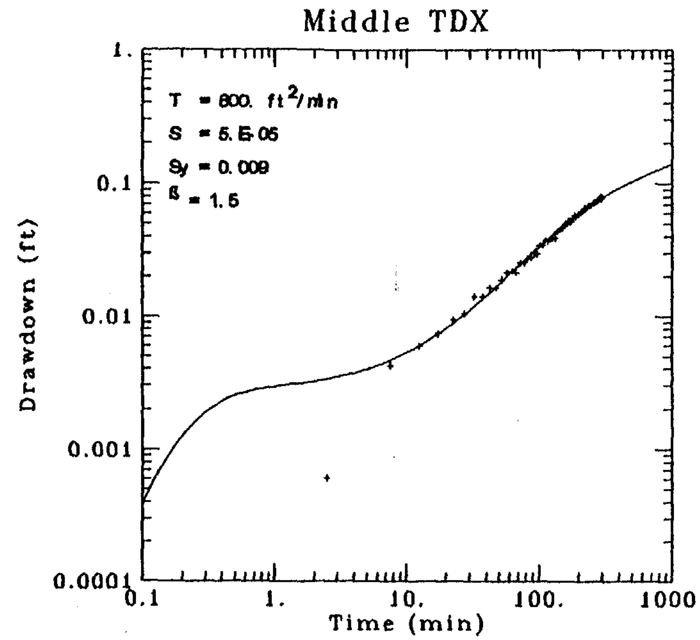


Figure B-6.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-45, 480-495 feet bls.





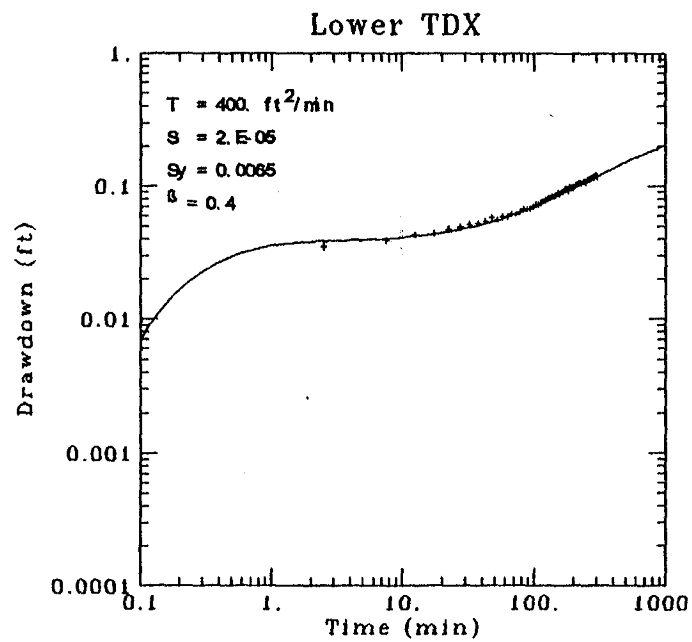


Figure B-7.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-45, 500-515 feet bls.

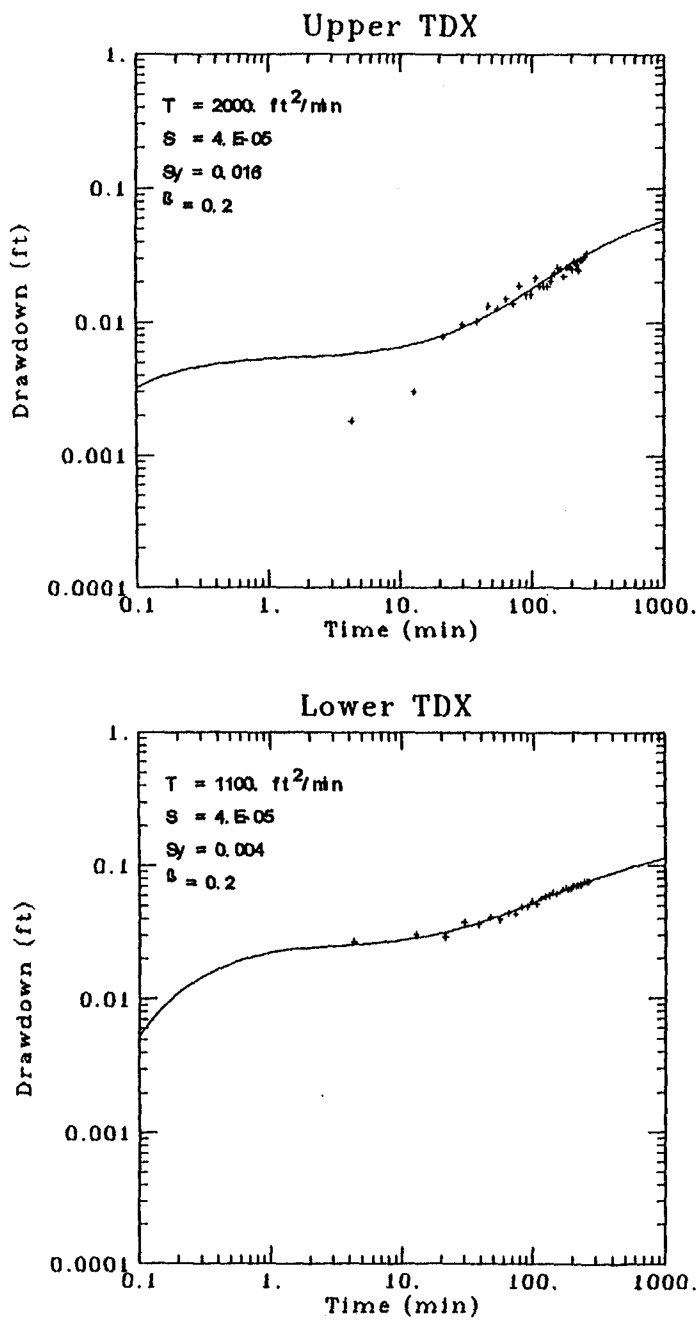
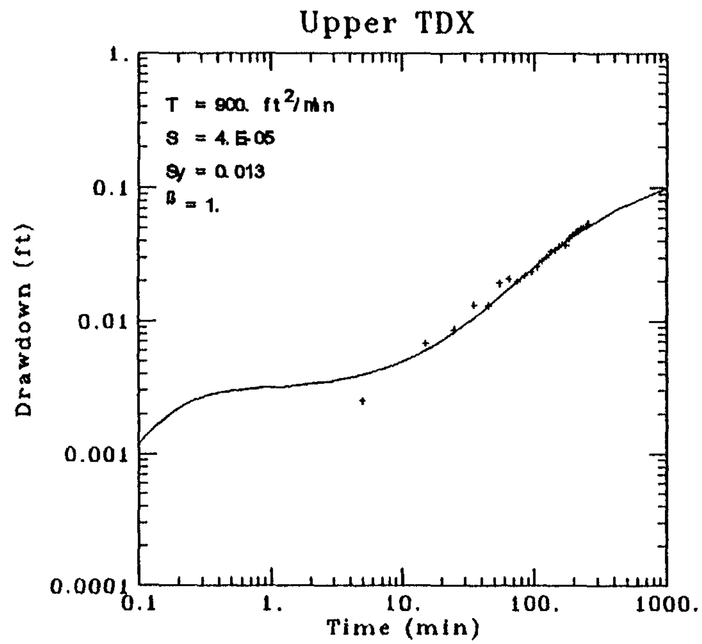
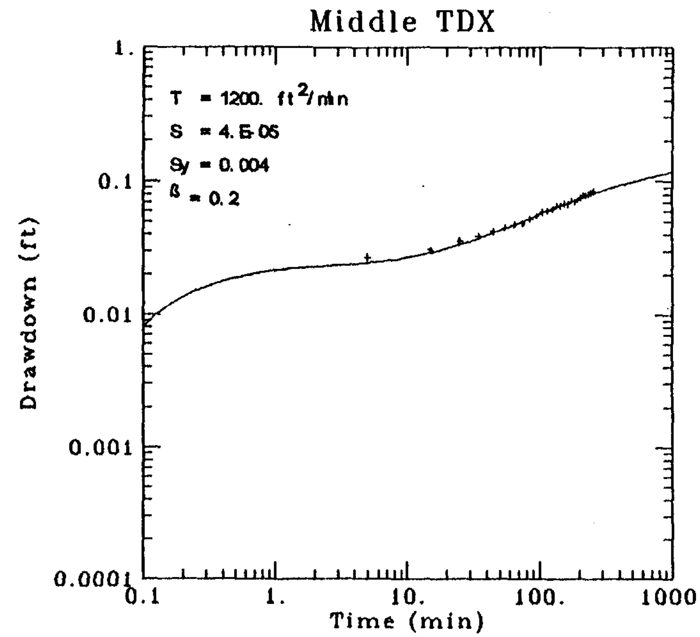


Figure B-8.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-45, 519-534 feet bls.





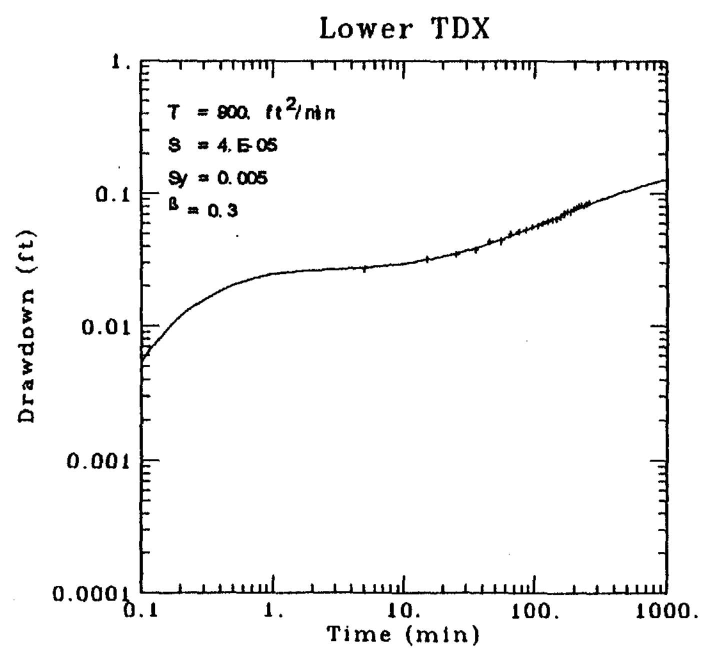


Figure B-9.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-45, 538-553 feet bls.

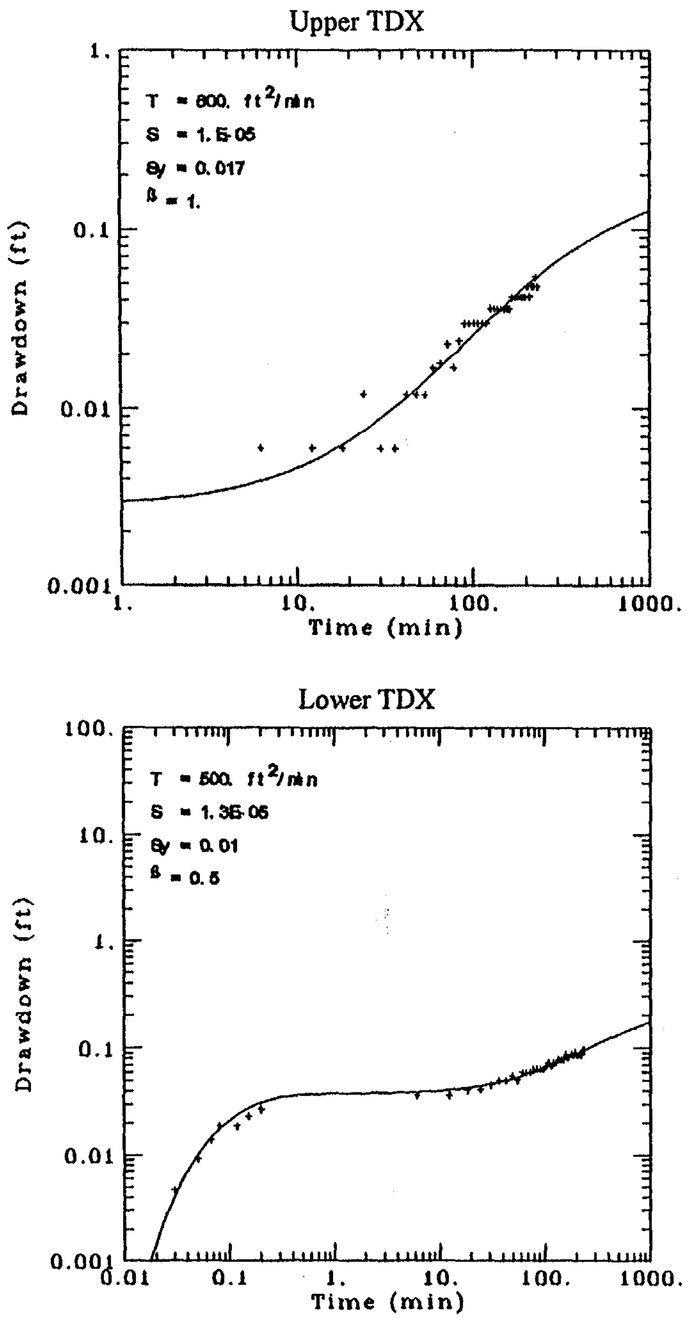
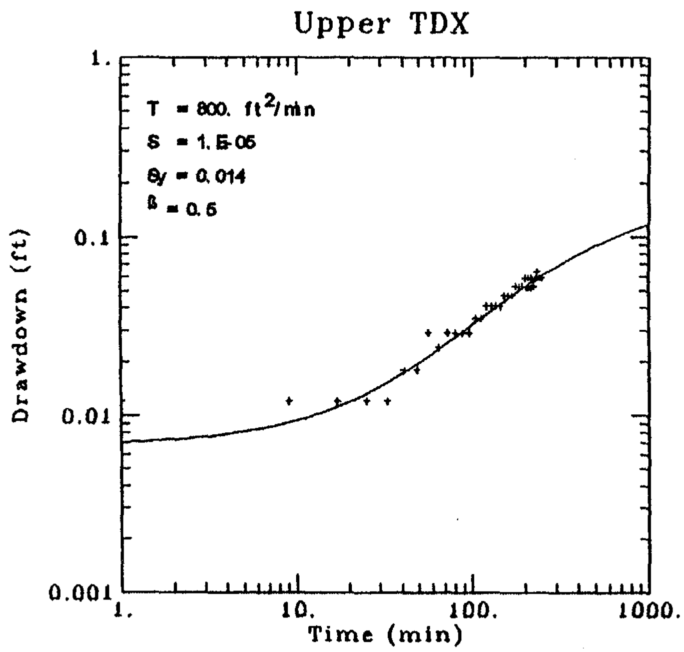
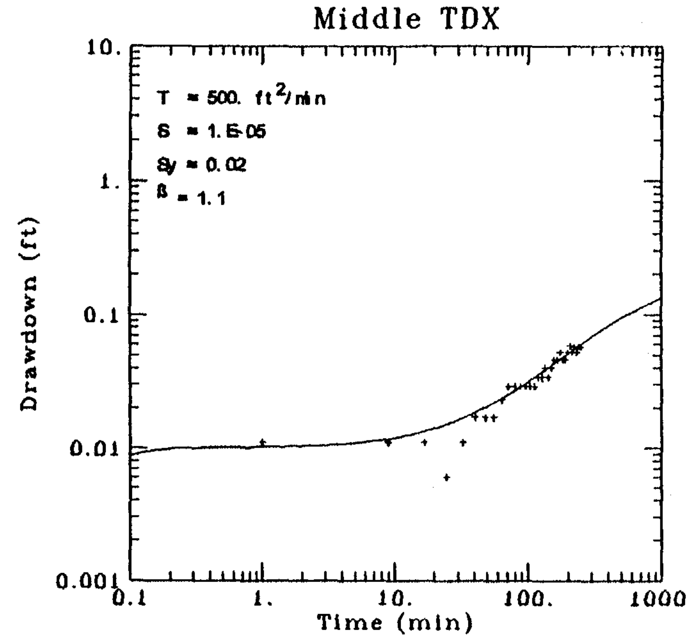


Figure B-10.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-46, 507-525 feet bls.





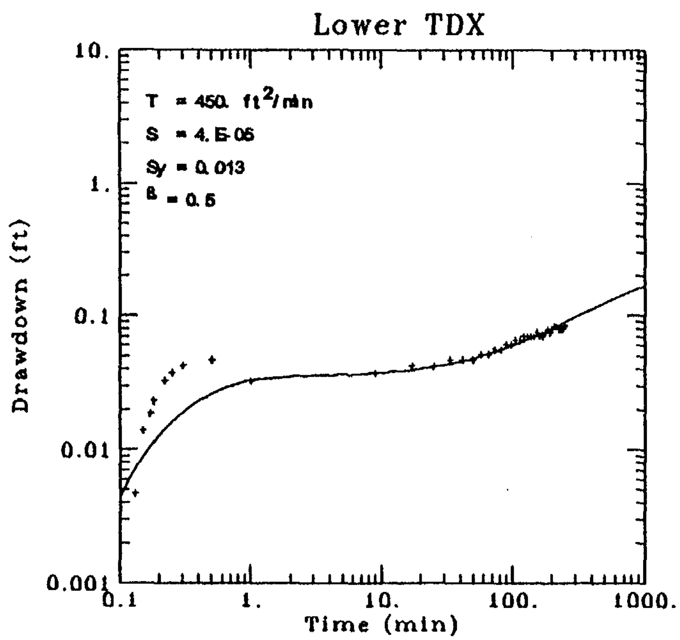
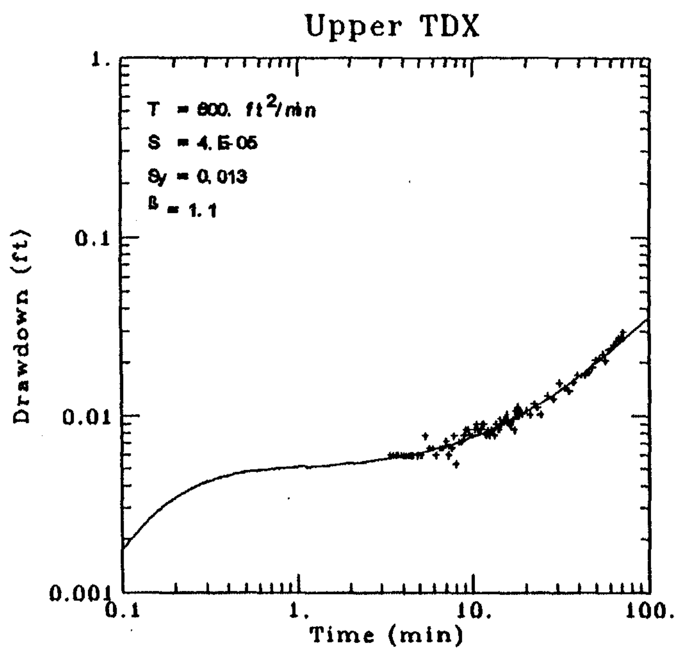
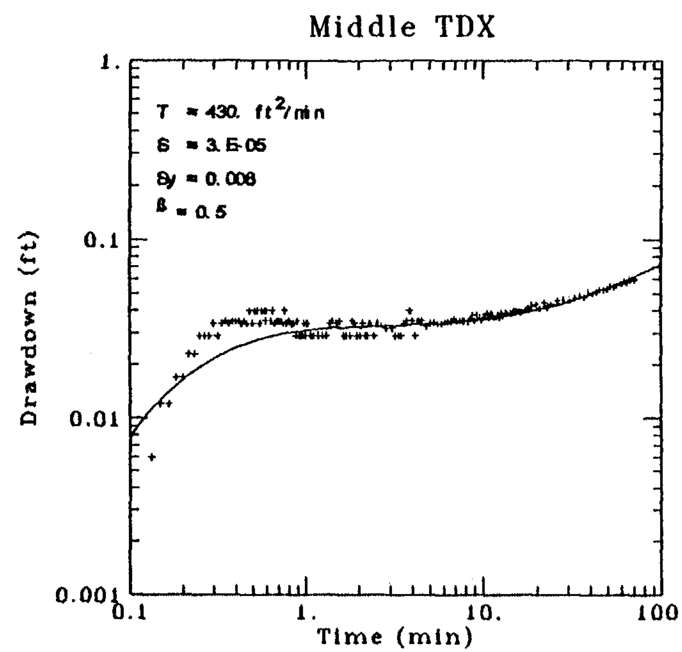


Figure B-11.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-46, 531-549 feet bls.





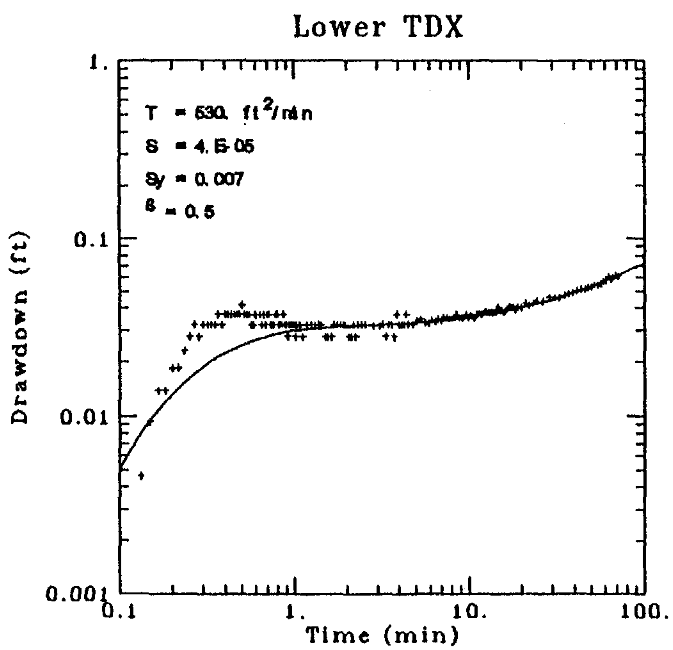


Figure B-12.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-46, 553-571 feet bls.

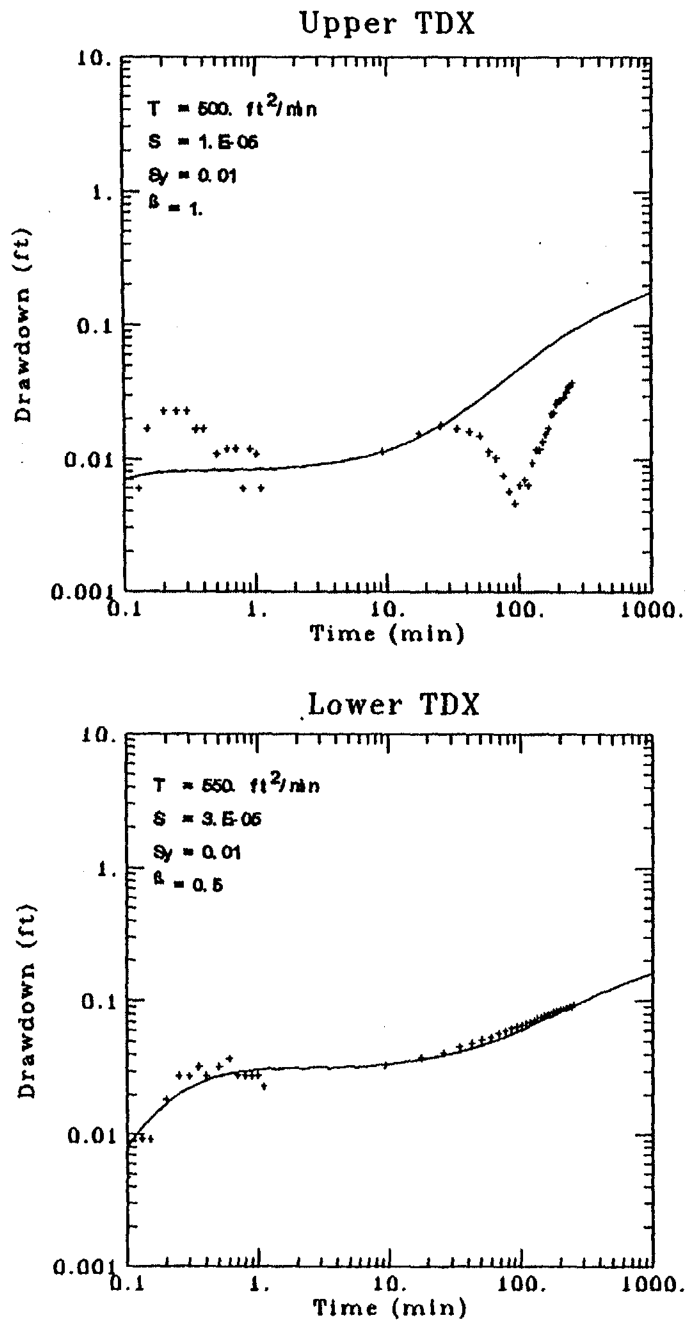
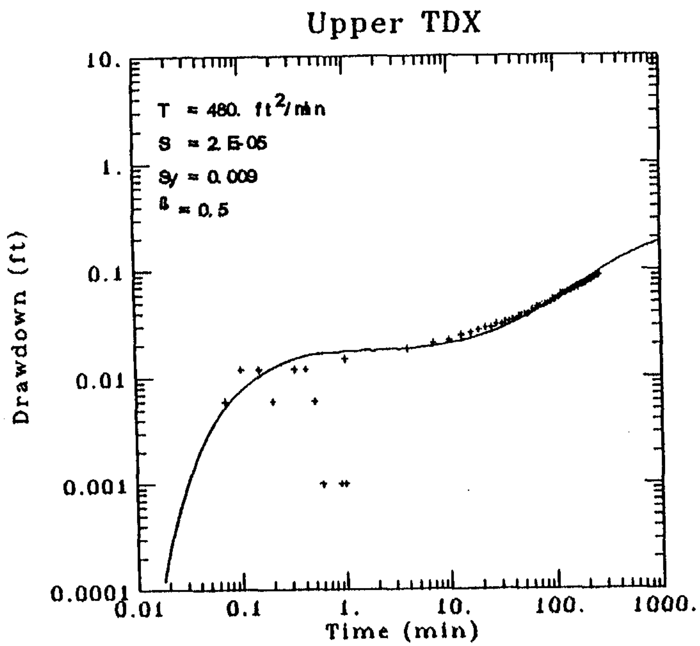
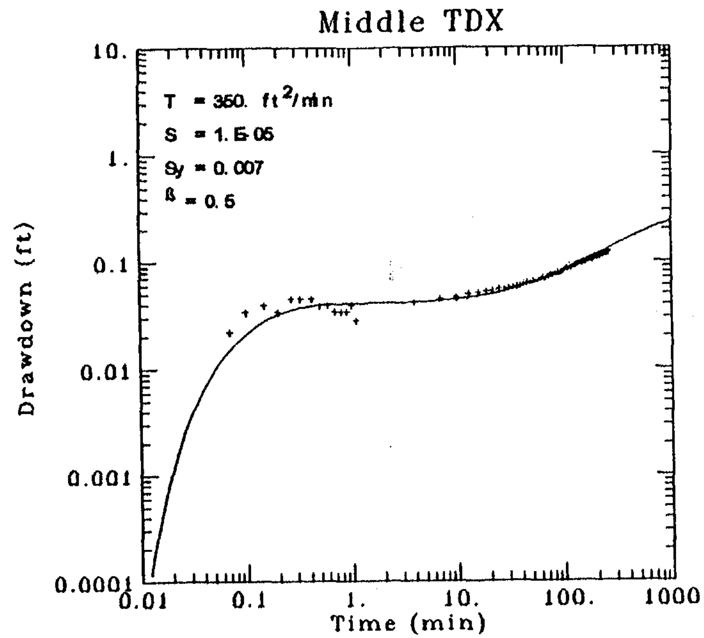


Figure B-13.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-46, 575-593 feet bls. Type curve match for data from upper transducer presented for information purposes only.





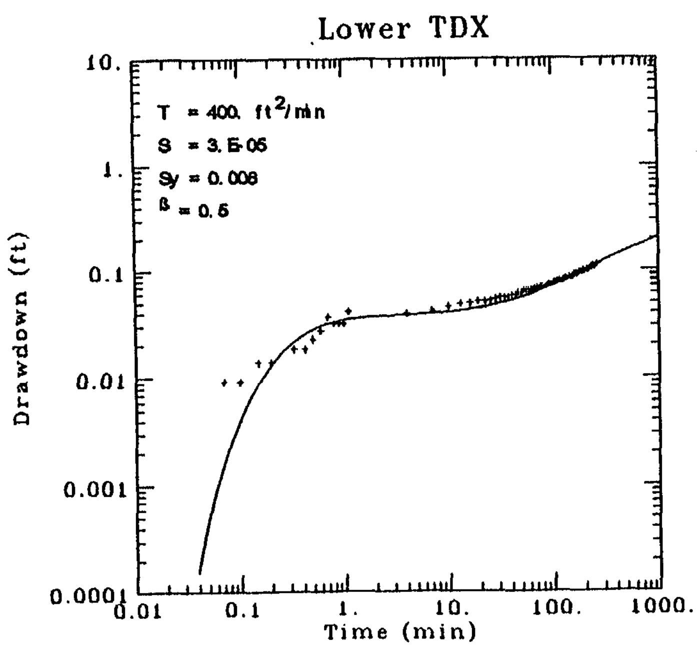


Figure B-14.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-46, 594-612 feet bls.

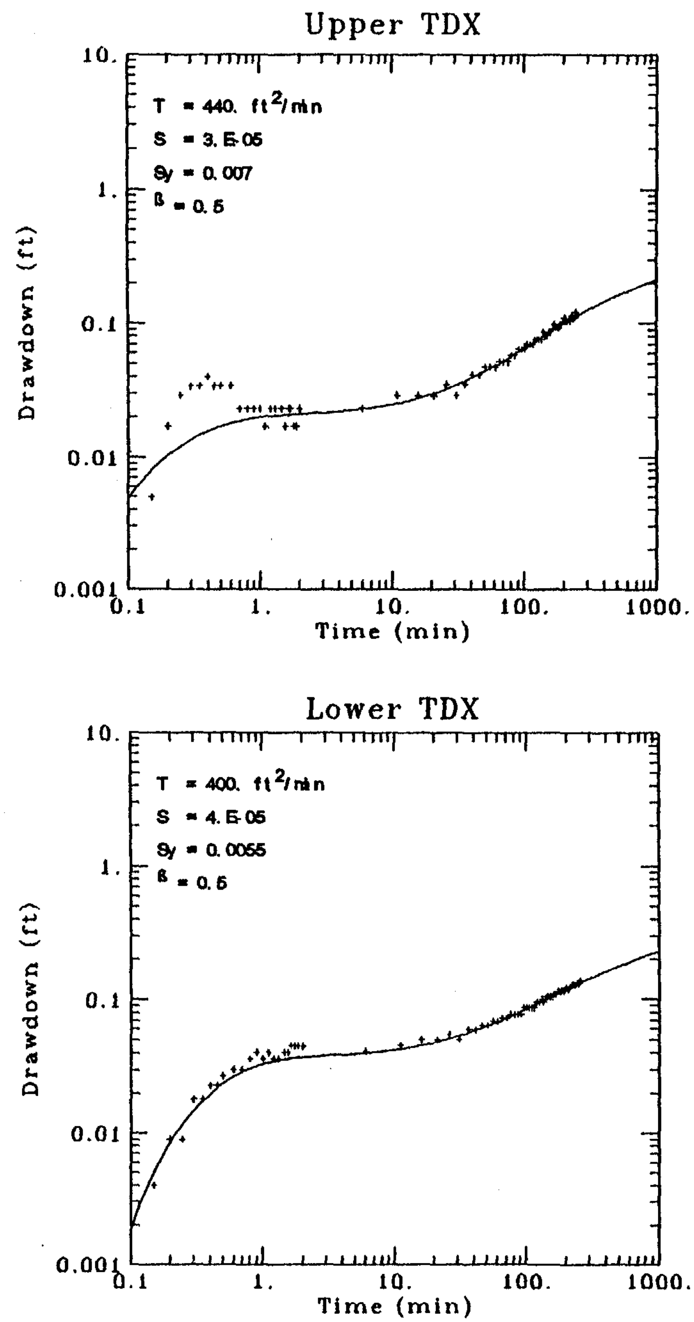


Figure B-15.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-46, 611-629 feet bls.

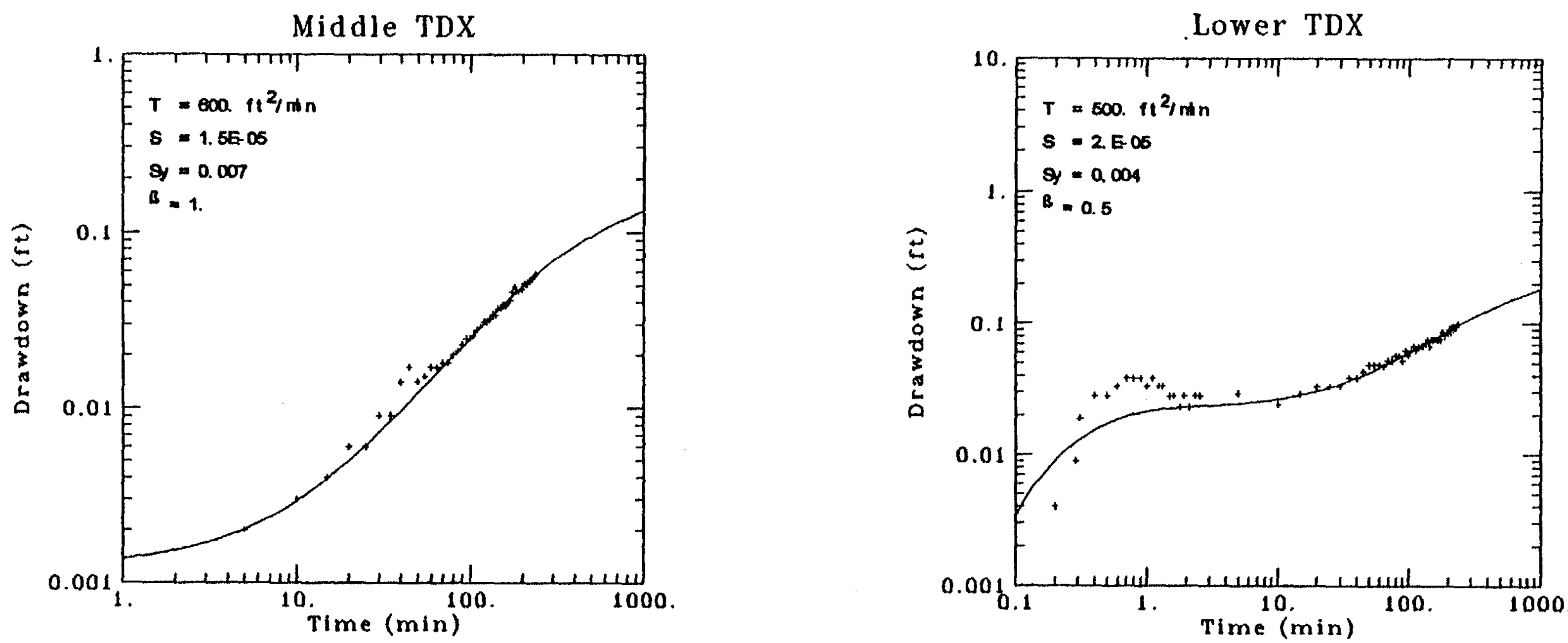
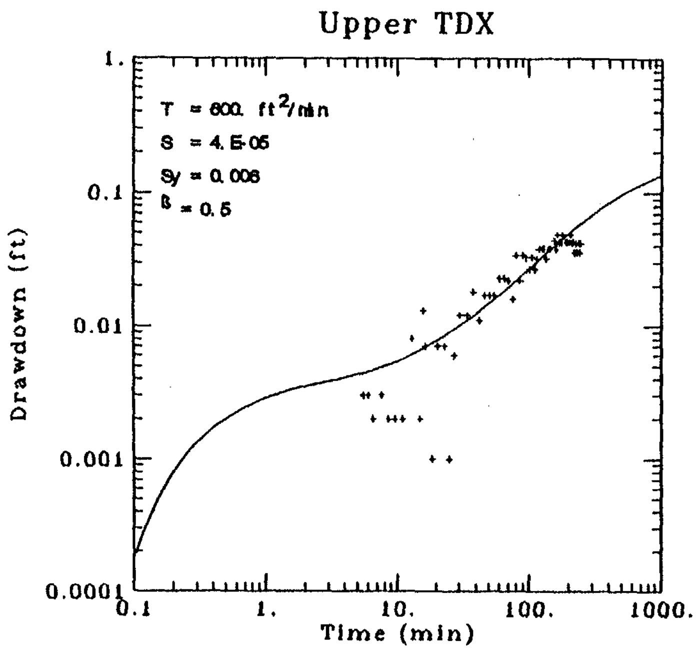
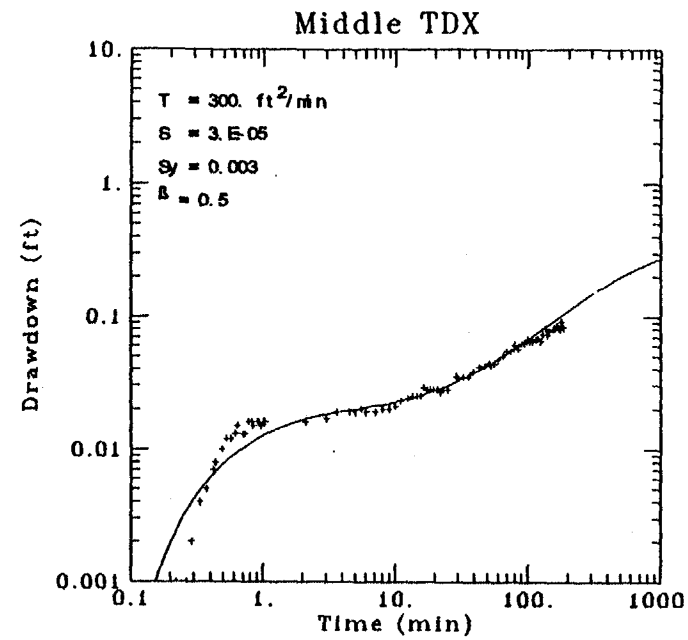


Figure B-16.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-59, 462-480 feet bls.





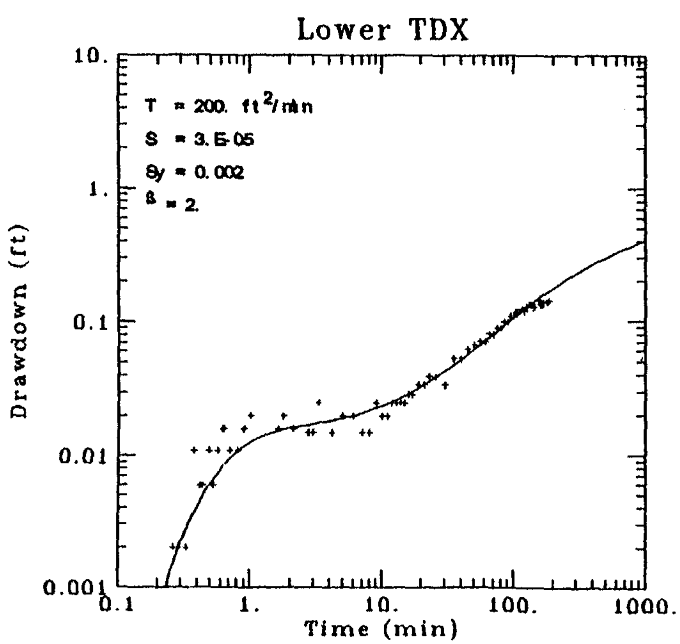
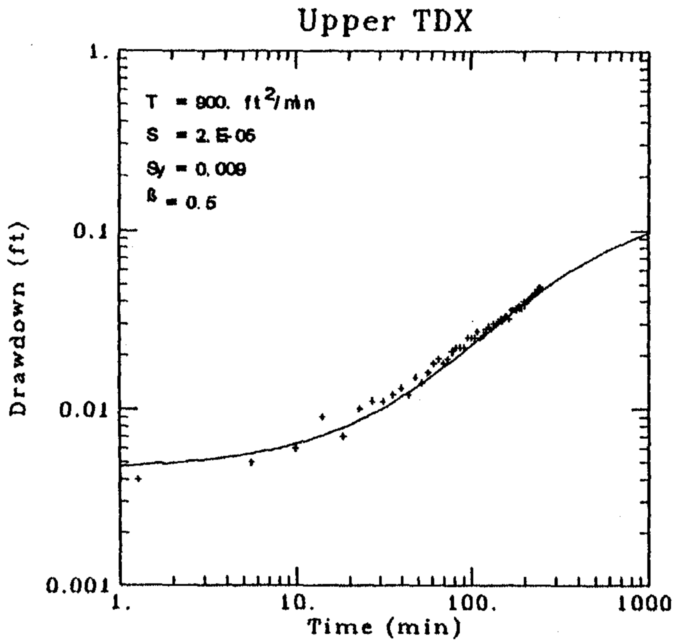
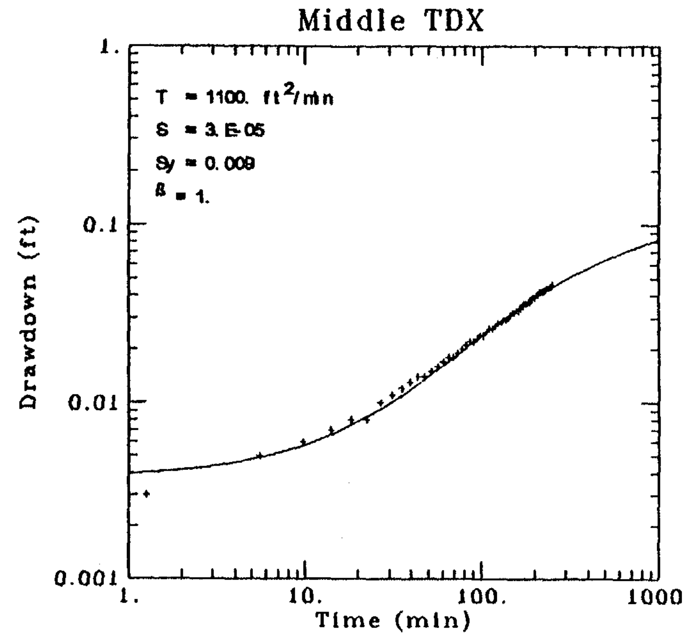


Figure B-17.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-59, 484-502 feet bls.





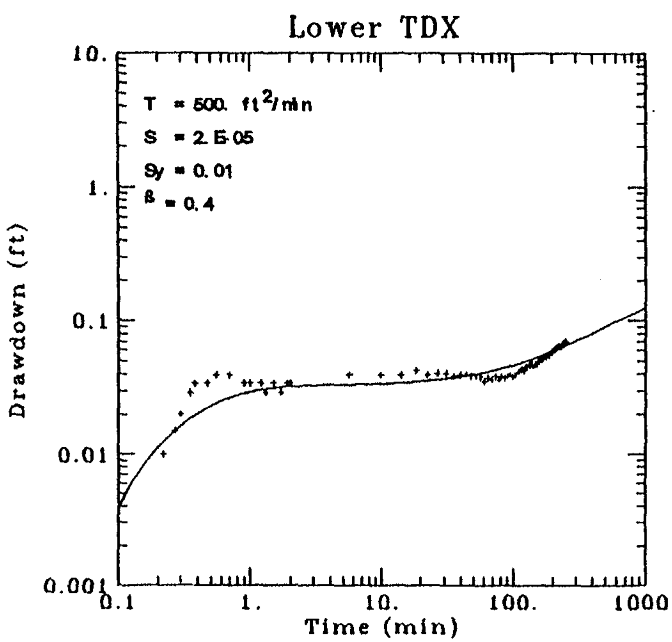


Figure B-18.

Estimated hydraulic properties of the Snake River Plain aquifer from Neuman type curve matching to time-drawdown data from USGS-59, 517-535 feet bls.

APPENDIX C

CONTRIBUTION OF WATER FROM STORAGE FROM THE COMPRESSIBILITY OF WATER

AND

CALCULATION OF HYDRAULIC CONDUCTIVITY

A) Calculation of water in storage derived from the compressibility of water.

The specific storage of an aquifer refers to the amount of water per unit volume of an aquifer that is expelled from storage due to the compressibility of pore water and the aquifer skeleton. Specific storage can be calculated using the following equation:

$$S_s=\rho g(\alpha+\eta \beta) \qquad (1)$$

where,

S_s = specific storage
ρ = density of the water (1.94 $lb\text{-}sec^2/ft^4$)
g = acceleration of gravity (32.2 ft/sec^2)
α = compressibility of the aquifer skeleton
η = porosity
β = compressibility of water (2.3×10^{-8} ft^2/lb)

To calculate the contribution of water from storage resulting from the compressibility of water, equation (1) reduces to:

$$S_s = \rho g(\eta \beta) \qquad (2)$$

Assuming the porosity (η) is equal to the specific yield of 0.01 determined from model calibration (Chapter 4),

$$S_s = \rho g(\eta \beta)$$

$$S_s = (1.94\ lb\text{-}sec^2/ft^4)(32.2\ ft/sec^2)(0.01*(2.3 \times 10^{-8}\ ft^2/lb))$$

$$S_s = 1.4 \times 10^{-8}/ft$$

The storativity of an aquifer is defined by the following equation:

$$S = S_s*b \qquad (3)$$

where,

S = storativity
S_s = specific storage
b = aquifer thickness

Using equation (3), and assuming the aquifer thickness is 250 feet, the water in storage derived entirely from the compressibility of water is:

$$S = 1.4 \times 10^{-8}/ft * 250\ ft$$
$$S = 3.5 \times 10^{-6}$$

B) Calculation of the average vertical and horizontal hydraulic conductivity of the system.

The average hydraulic conductivity of the three-layer system was calculated using the following equations:

1) $Kh_{avg} = (Kh_1*d_1)/D + (Kh_2*d_2)/D + (Kh_3*d_3)/D$

where,

Kh_{avg} = average horizontal hydraulic conductivity
Kh_i = horizontal hydraulic conductivity of layer i
d_i = thickness of layer i
D = thickness of system

eliminating layer 2 due to the small Kh yields

$Kh_{avg} = (3.7\ ft/min*85\ ft)/245\ ft + (0.6\ ft/min*160\ ft)/245\ ft$

$Kh_{avg} = 1.7\ ft/min$

2) $$Kv_{avg} = \frac{D}{(d_I/Kv_{1)}) + (d_2/Kv_2) + (d_3/Kv_3)}$$

where,

Kv_{avg} = average vertical hydraulic conductivity
Kv_i = vertical hydraulic conductivity of layer i
d_i = thickness of layer i
D = thickness of system

$$Kv_{avg} = \frac{250}{(85\ ft/0.3\ ft/min)+(5\ ft/1.5E-04\ ft/min)+160\ ft/0.4\ ft/min)}$$

$Kv_{avg} = 7.3 \times 10^{-3}\ ft/min$