# HYDROGEOLOGY OF THE UPPER AQUIFER OF THE PULLMAN-MOSCOW BASIN AT THE UNIVERSITY OF IDAHO AQUACULTURE SITE

A thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Hydrology

in the

College of Graduate Studies

University of Idaho

by

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January 1994

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# AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Present utilization of the upper aquifer in the Pullman-Moscow Basin is mostly for a few low-yield domestic wells. Major municipalities and the two area universities pump largely from the lower aquifer in the underlying Grande Ronde Basalt. The current ground water management plan emphasizes conservation of this deeper system and use of the upper aquifer for new small yield ground water development. To comply with this basin-wide plan, the new Aquaculture Research Laboratory at the University of Idaho has developed a system of supply wells that tap the upper aquifer system.

The upper aquifer at the Aquaculture site consists of several interconnected aquifers hosted by the Miocene-age Wanapum Basalt and an underlying sediment interbed. Aquifers in the basalt are localized in sub-horizontal fractures within the Lolo flow, and generally produce sustained yields of less than 50 gallons per minute. The sediment interbed is up to 300 feet thick in this area, and consists of poorly consolidated layers of clay and sandstone-siltstone with thick interbedded layers of unconsolidated sand with minor silt and clay.

Two primary aquifers have been developed in wells within the unconsolidated sand layers in the upper one-third of the sediment interbed at the Aquaculture site. Hydraulic testing

in two wells constructed at this site in 1993, show transmissivity values of approximately 1110 $ft^2$/day for the lower sand aquifer, and a combined transmissivity of 2360 $ft^2$/day for the upper and lower sand aquifers. A downward vertical gradient occurs between the two sand aquifers.

Through the use of proper well design and construction, a long-term sustained production of several hundred gallons per minute can be achieved from these wells. No significant long-term decline in water levels is anticipated in the sediment aquifers based on the current pumping rate at the Aquaculture facility. Minor aquifers at the top of the sediment unit and in some hydraulically connected fracture zones in the basalt, may experience significant water level decline.

# ACKNOWLEDGMENTS

I wish to express by personal thanks to my major professor, Dr. Dale Ralston, for his guidance and encouragement during my graduate studies and during this project. I would also like to thank the other members of my committee, Dr. Kenneth Sprenke and Dr. Ian McCann. My thanks are extended to Dr. Christine Moffitt for providing information regarding the Aquaculture Laboratory and for giving permission to conduct the October test at the Aquaculture site.

My appreciation is also extended to the members of the Hydrogeology 568 class who participated in the February, 1993 aquifer test at the Aquaculture well. Thanks are also extended to Hal Powe and Dan McHale for assisting with the October aquifer test.

Finally, a very special thanks go to my wife Diane for her patience and encouragement, without which the completion of my studies would not have been possible.

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# CHAPTER 1

# INTRODUCTION

## STATEMENT OF THE PROBLEM

The primary water supply for the Moscow-Pullman area is derived from basalt and sediment hosted aquifers in the Wanapum and Grande Ronde Formations of the Columbia River Basalt Group. Historically, pumpage from the shallow Wanapum aquifer supplied most of the area's water dating from the 1890s to the mid-1960's. During this period water levels in the Wanapum aquifer declined 100 to 130 feet from pre-development-era levels. The primary water supply has been the deeper more prolific Grande Ronde aquifer since the mid-1960's. Significant water level decline has been observed in this aquifer during the ensuing four decades, while water wells in the Wanapum aquifer have partially recovered. Concern over the water level decline in the Grande Ronde aquifer has prompted the two cities, the University of Idaho and Washington State University to initiate a plan for management of the ground water resources within this basin. The adopted plan, formally presented to the public in September 1992, calls for the control, by each of the six member entities, of the present and future use of water obtained from the lower aquifer. The plan emphasizes both the protection and the conservation of this valuable resource, and establishes discrete limits regarding future pumpage. Development of alternative sources of water is encouraged in the plan.

A proposal for and the subsequent construction of an experimental aquaculture laboratory for fishery research at the University of Idaho was conceived during the early 1990's. This laboratory, constructed near the western edge of the campus, requires a stable ground water source of about 150 gallons per minute, with specific requirements for water temperature and water chemistry. The location of this facility is shown in figure 1.1. To avoid an increase in pumpage from the lower aquifer, a decision was made to use water from the upper aquifer located in the Wanapum Formation to serve this new facility. Because of greatly reduced pumpage from this source during the past several decades, water levels in the upper aquifer have recovered to an elevation of about 2480 feet (AMSL). As a result, renewed interest has developed for the use of this resource to supplement present and future demands on the lower aquifer in the Moscow area.

U.I. Well No. 5, was drilled at the Aquaculture site in May, 1991. The well penetrated 172 feet of basalt containing several water-bearing fracture zones, finally entering a sand layer at the base of the flow at a depth of 240 feet. To avoid pumping sand, only water-bearing zones in the basalt

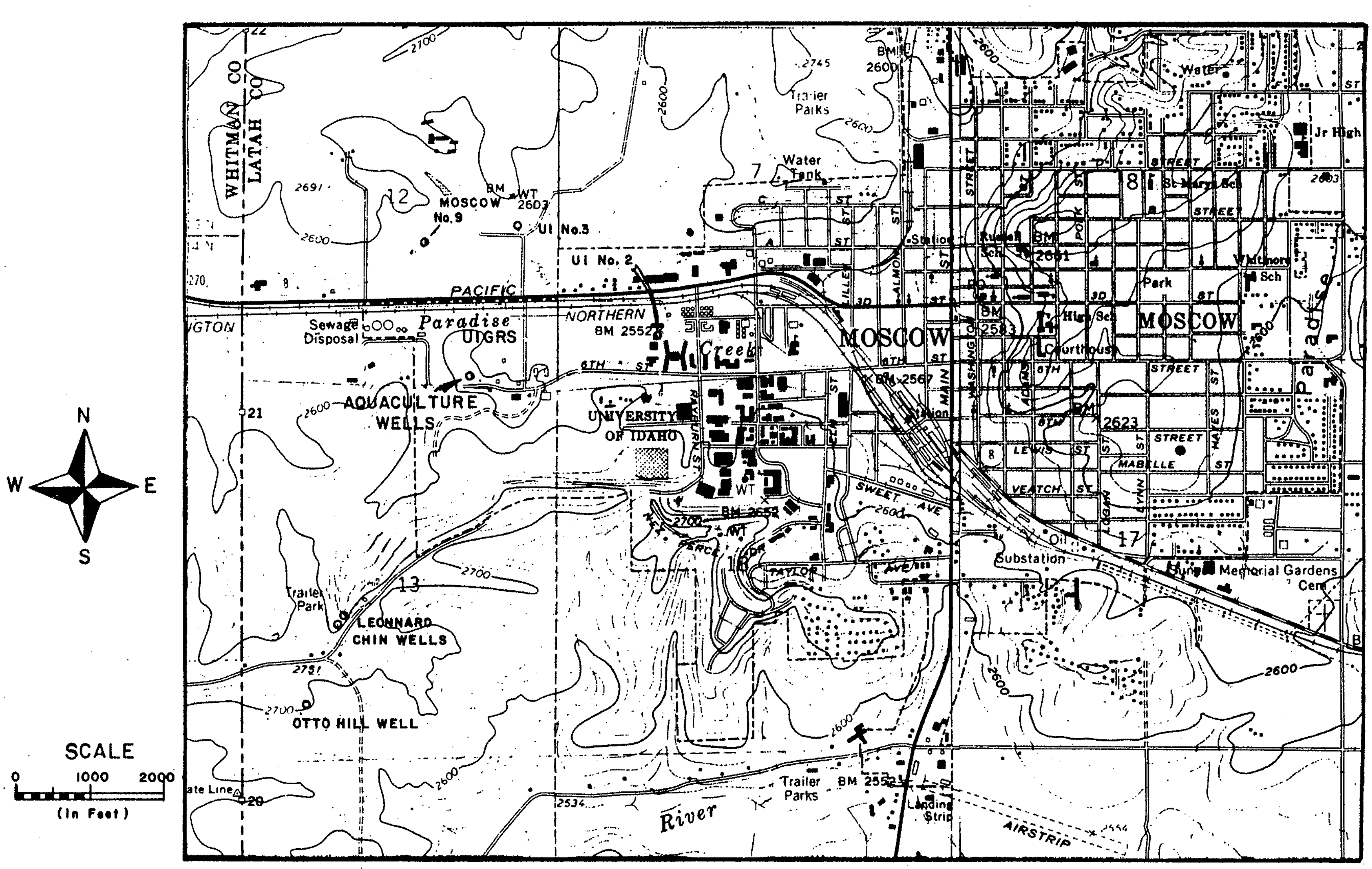



Figure 1.1 General locations map showing city of Moscow and Aquaculture Laboratory area.

were screened during well completion. Although short-term yields of up to several hundred gallons per minute were possible, the well failed to produce the needed volume of water when pumped for extended periods.

The failure of U.I. Well No. 5 to produce the required flow of water emphasized the need for a better understanding of the hydrogeology of the upper aquifer at the Aquaculture site. Subsequent studies by the faculty and graduate students in the Hydrology program at the University of Idaho have aided in developing a better understanding of this ground water system. Two additional wells were completed in the upper aquifer at the Aquaculture site in 1993. Each of these new wells is capable of supplying the present needs of this facility. This study presents a compilation of information regarding the hydrogeology of the upper aquifer at the Aquaculture site based on data obtained from recent development. Emphasis is placed on the characterization of the sediment interbed section of this aquifer system. The sediments contain the most prolific water-bearing zones within the upper aquifer, yet have received very little attention during the last three decades. The purpose of this analysis is to help in planning further development and future management of ground water resources in the Moscow area.

# PURPOSE AND OBJECTIVES

The purpose of this study is to gain a better understanding of the hydrogeology of the upper aquifer system in the vicinity of the University of Idaho Aquaculture Research Laboratory. The general objective is to characterize the short-term and long-term potential of the upper aquifer at this facility. The specific objectives of the study are to:

1) Review the literature regarding the hydrogeology of the upper aquifer in the Moscow area.
2) Develop a conceptual model of the hydrogeology for the upper aquifer in the vicinity of the Aquaculture site.
3) Conduct and describe aquifer tests for the U.I. Wells Number 6 and Number 7 at the Aquaculture site.
4) Analyze the aquifer test results for wells U.I. No. 6 and U.I. No. 7.
5) Compile, present and evaluate results from water level field measurements made at the University of Idaho Groundwater Research Site (UIGRS) as these data relate to the study of the of the hydrogeology of the upper aquifer at the Aquaculture site.
6) Develop a model for predicting long-term water yield at the Aquaculture facility.
7) Summarize the results of this study and present recommendations for future studies.

# METHODOLOGY

Geological and stratigraphic data for this study include drill hole logs from the three wells at the Aquaculture site along with logs from wells at the University of Idaho Ground Water Research Site (UIGRS) and other wells in the vicinity of the study area. Several roadside exposures of the Wanapum basalt in the area west of Moscow provided insight into fracture patterns and flow structure in this formation. Previous studies on the geology and hydrogeology of the Pullman-Moscow Basin provided valuable information.

Aquifer tests were run on wells UI No. 6 and UI No. 7 during the spring of 1993. An aquifer test on well UI No. 6 was performed in late-February as a graduate course class project. During this test, well No. 6 was pumped continuously at a rate of 125 gallons per minute for a period of seven days. Recovery data were collected in the pumping well for 10 days following shut-off of the pump. Thirteen monitor wells located at the UIGRS, along with wells UI No. 2 and UI No. 5 provided drawdown data during the pumping and recovery periods. Water level data obtained from this test were corrected for barometric efficiency, and correction factors were applied to some of the wells at the UIGRS for stream-flow impact. The Jacob semi-log methods (Cooper and Jacob, 1946) and the Neuman-Witherspoon ratio method (Neuman and Witherspoon, 1972) provided estimates of hydraulic properties for the aquifer.

A series of pumping step-drawdown tests determined the flow obtainable from well UI No. 7. Drawdown measured in well UI No. 6 and well UI No. 7, was used to estimate aquifer parameters.

A second, two-hour-long pump test was performed in well UI No.6 during early October, 1993. Water levels were monitored in the pumping well and in well UI No. 7 during this test.

Static ground water elevation data ~~is~~ are available for the UIGRS on a semi-continuous basis since December, 1987. Data from January to December, 1993 were used to study short-term and long-term effects on the upper aquifer from pumping at the Aquaculture facility.

## LOCATION OF STUDY AREA

The study area is on the campus of the University of Idaho at Moscow, Latah County, Idaho. Hydrologically the area is part of the Pullman-Moscow ground water basin. This basin spans the border of Washington State and Idaho. The Aquaculture Research facility is at the western edge of the campus in section 12, T39N, R6W. The UIGRS is approximately 1000 feet northeast of the Aquaculture facility.

# PREVIOUS INVESTIGATIONS

A wealth of information regarding the geology and hydrogeology of the Pullman-Moscow Basin exists in the current literature. Russell (1897) is probably the first to investigate the groundwater resources of this area. Russell's report provides invaluable information regarding water levels in the upper aquifer in the basin prior to major development. Reports by Stevens (1960), Foxworthy and Washburn (1963), Ross (1965), Sokol (1966), Lin (1967), Walters and Glancy (1969), Jones and Ross (1972), Barker (1979), Hooper and Webster (1982), Smoot and Ralston (1987) and Lum and others (1990) provide useful information on the geology and hydrogeology of the Pullman-Moscow Basin. The geochemistry of the basalt aquifers in the basin is described by Najjar (1972) and Cotton (1982). Numerical ground water models for the Pullman-Moscow Basin are described by Barker (1979), Lum and others (1990) and Brown (1991).

Since the construction of the UIGRS at the University of Idaho campus in 1987, several studies have been made regarding the hydrogeology of the upper aquifer at this research site. A dissertation by Li (1991) presents a thorough discussion of the hydrogeology of the fractured basalt aquifers in the upper aquifer at this site. Patrick (1990) and Pardo (1993) discuss the relationship between surface water and ground water at the UIGRS. None of these studies address ground water flow within the sediment layer underlying the basalt flow in the upper aquifer.

# CHAPTER 2

# GEOLOGY AND HYDROGEOLOGY

## REGIONAL GEOLOGY

The University of Idaho campus is in the Pullman-Moscow ground water basin which forms a small embayment at the eastern margin of the Columbia River Plateau. A generalized geologic map of the basin is shown in figure 2.1. A series of low mountains that are part of the western edge of the Rocky Mountain Province form the eastern, northern and southern margins of this basin. These highlands are Cretaceous-age granitic rocks, genetically a part of the central Idaho batholith, and metasedimentary rocks belonging to the Precambrian Belt Series Super Group. These crystalline rocks underlay most of the basin. The top of these rocks ranges in depth up to several thousands of feet in sections of the basin west of Pullman. A generalized stratigraphic section for the Moscow area is shown in figure 2.2.

Miocene basalt containing abundant interbedded sediments overlies the crystalline basement. These rocks are a part of the Columbia River Basalt Group which covers most of southeastern Washington, northeastern Oregon and parts of extreme west-central Idaho. The flood basalt emanated as a

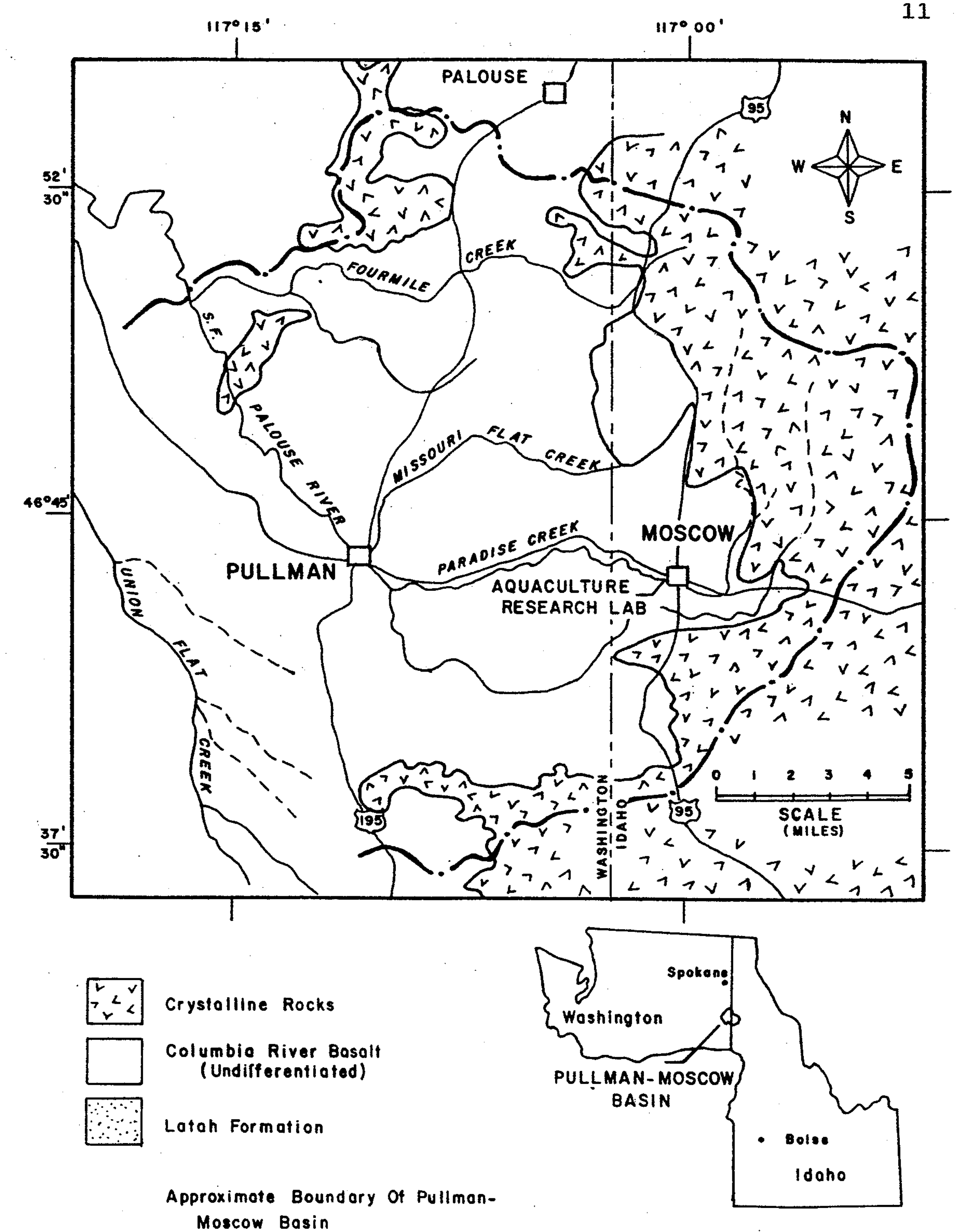



Figure 2.1 Generalized geologic map of the Pullman-Moscow Basin. From Barker (1979).

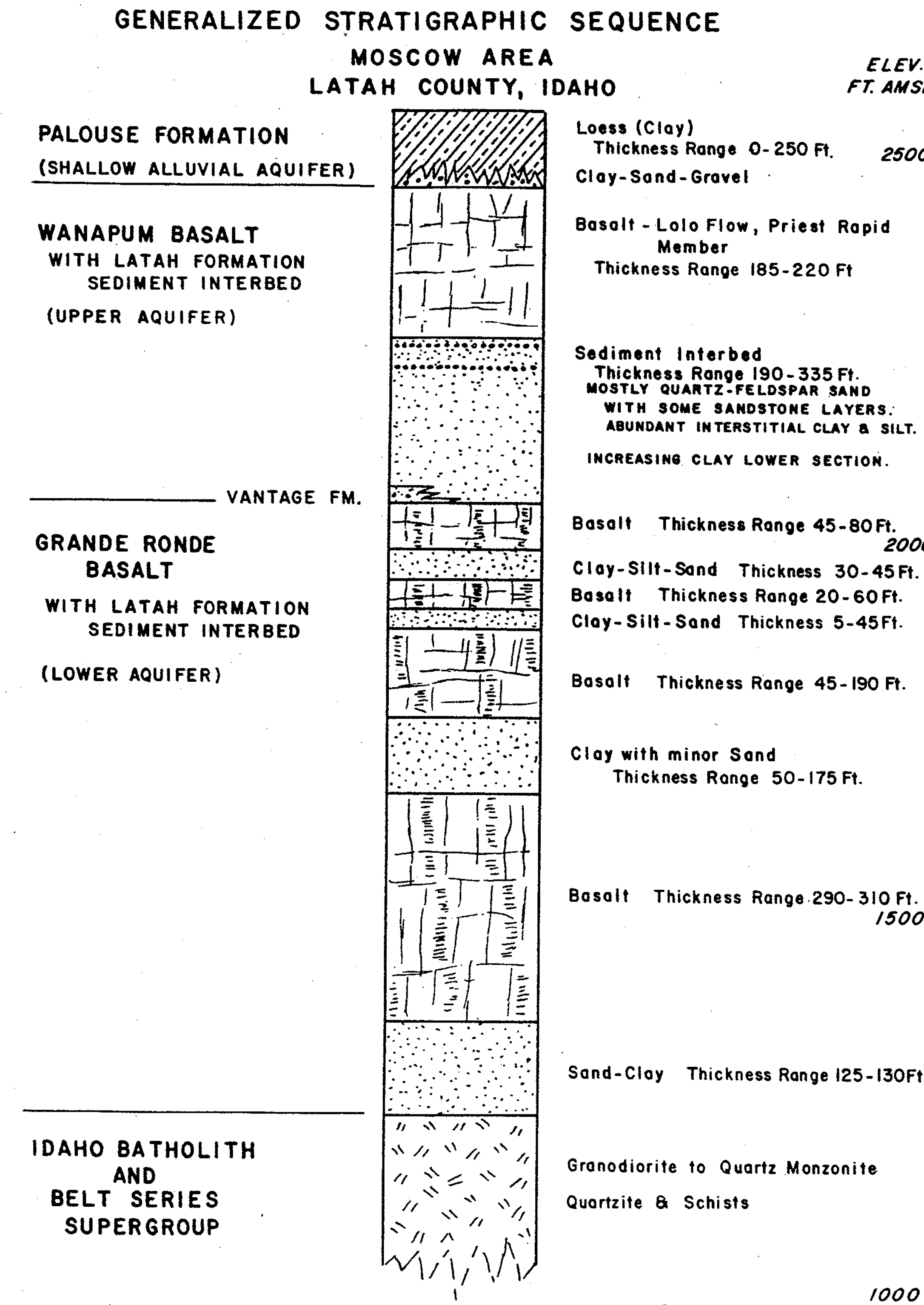



Figure 2.2 Generalized stratigraphic section for the Pullman-Moscow Basin.

series of flows from fissures located in southeastern Washington and northeastern Oregon (Swanson and others, 1980). The basalt traveled eastward in successive flows covering the low elevations in the ancestral Pullman-Moscow Basin. The exact number of flows is unknown; however, water well drill logs indicate that at least three and possibly four separate flows are present in the Moscow area (Jones and Ross, 1972). The thicker basalt section in the western part of the basin may contain as many as 15 separate basalt flows (Ralston personal communication, 1993). The thickness of individual flows average 40 to 80 feet, but flows up to 200-feet-thick have been observed (Lum and others, 1990). The total thickness of the basalt is about 1300 feet at Moscow and ranges up to over 3000 feet in the west portion of the basin (Li, 1991).

Thick layers of interbedded sediments within the basalt sequence are common in the eastern part of the basin. These sediments are generally thinner and fewer in number in the western portion of the basin. As basalt flows advanced eastward, outflow from streams draining the eastern highlands was dammed forming small lakes along the margins of the basin. At least three major episodes of ponding occurred in the Moscow area (Jones and Ross, 1972). These sediments were subsequently buried by successive advancing basalt flows except at the extreme east edge of the depression. Both lacustrine and alluvial materials are present in these interflow sediments. The interbedded sediments in the eastern part of the basin are classified as part of the Latah formation (Stevens, 1960; Jones and Ross, 1972; Alt and Hyndman, 1991). High quality kaolinite clay deposits up to several hundred feet thick have been mined from the Latah formation just to the east of Moscow (Alt and Hyndman, 1991). Most if not all interbeds of the Latah formation thin and pinch out to the west of Moscow. An areally extensive interbed is present in the west portion of the basin and marks the contact between the Wanapum and Grande Ronde Basalt. This interbed is referred to as the Vantage Member and is part of the Miocene Ellensburg Formation. The Vantage Member probably grades laterally into the upper sediment interbed of the Latah formation in the Moscow area.

The Columbia River Basalt Group in the Pullman-Moscow Basin includes the Wanapum Basalt and the Grande Ronde Basalt, both of which are members of the Yakima Basalt Subgroup (Swanson et al, 1979, 1980). The Wanapum Basalt is the uppermost basalt formation in the basin. Only the lower Priest Rapid Member of the Wanapum is present in the Pullman-Moscow Basin. Near Moscow this member ranges up to 250 feet in thickness. In the extreme western portion of the basin erosion has removed much of the Wanapum, leaving the underlying Grande Ronde Basalt exposed at the surface. The Wanapum Basalt ~~is~~ differs geochemically from the Grande Ronde Basalt by its higher concentration of phosphorus and titanium unconsolidated deposits, which consist of loess and associated alluvial and colluvial materials, range in thickness from zero up to several hundred feet. The loess originated from soils in the Pasco Basin about 95 miles to the west, and were deposited as large dunes that now form the present topography of this area (Lum and others, 1990).

Structural deformation in the Pullman-Moscow Basin has been minimal, and few major structural features exist. Information obtained from geologic well logs and geophysical surveys indicate a gentle northwest dip of several degrees in the basalt flows. A generalized east-west geologic cross-section through the Moscow area is shown in figure 2.3. Lum and others (1990) report that the basalt dips slightly in the opposite direction in the Idaho portion of the basin, possibly due to compaction from loading of the underlying sediment interbeds. Cross-sections constructed through the basin from well log data show a very slight easterly dip, with a predominance of undulating near-horizontal flow attitudes.

## GEOLOGY OF THE AQUACULTURE SITE

The interpretation given here of the geology at the Aquaculture site is based on the literature of the Moscow area along with information in well logs from the site and areas adjoining this facility. Much of the information on the basalt aquifers is from analysis of data from the UIGRS.

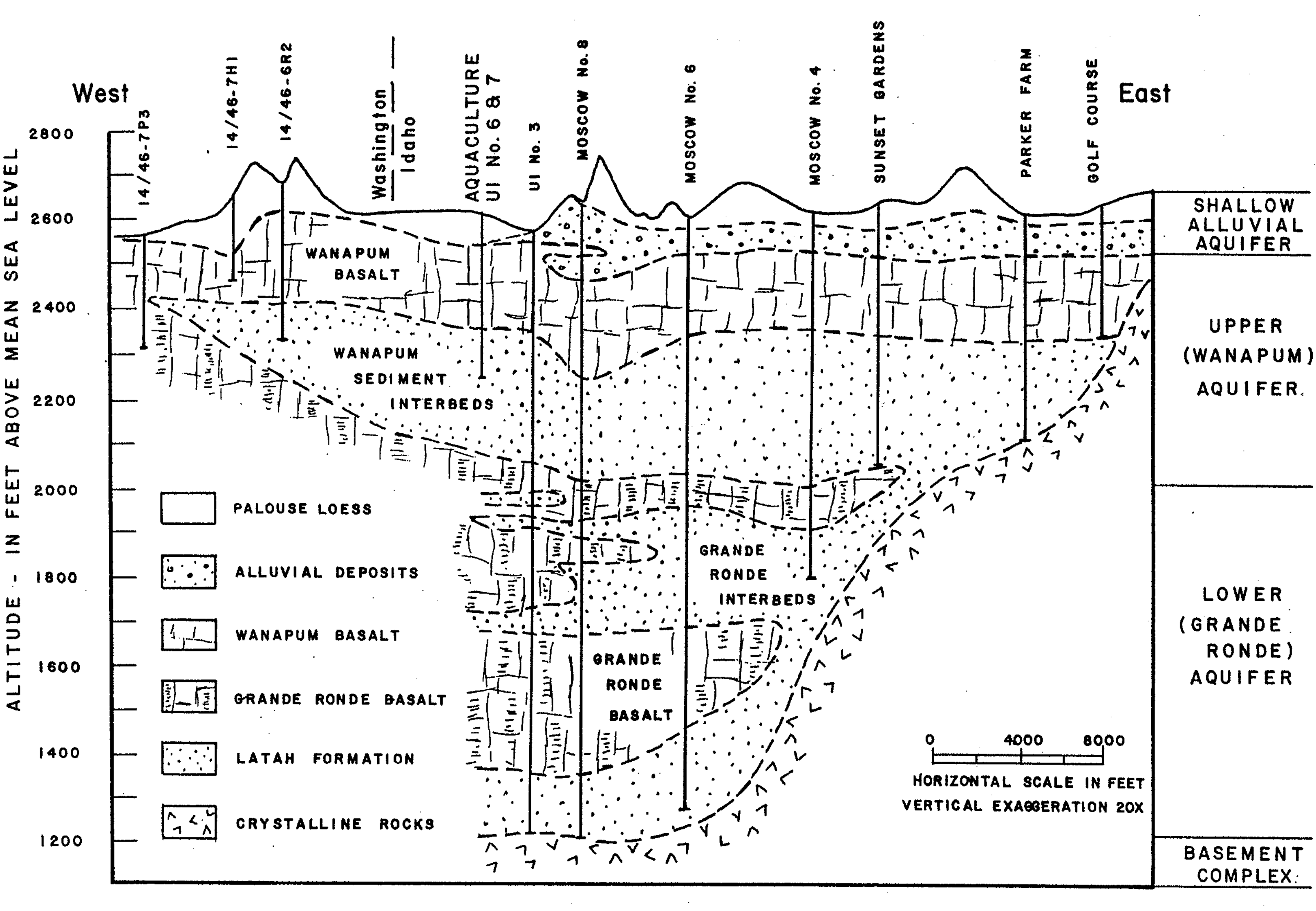
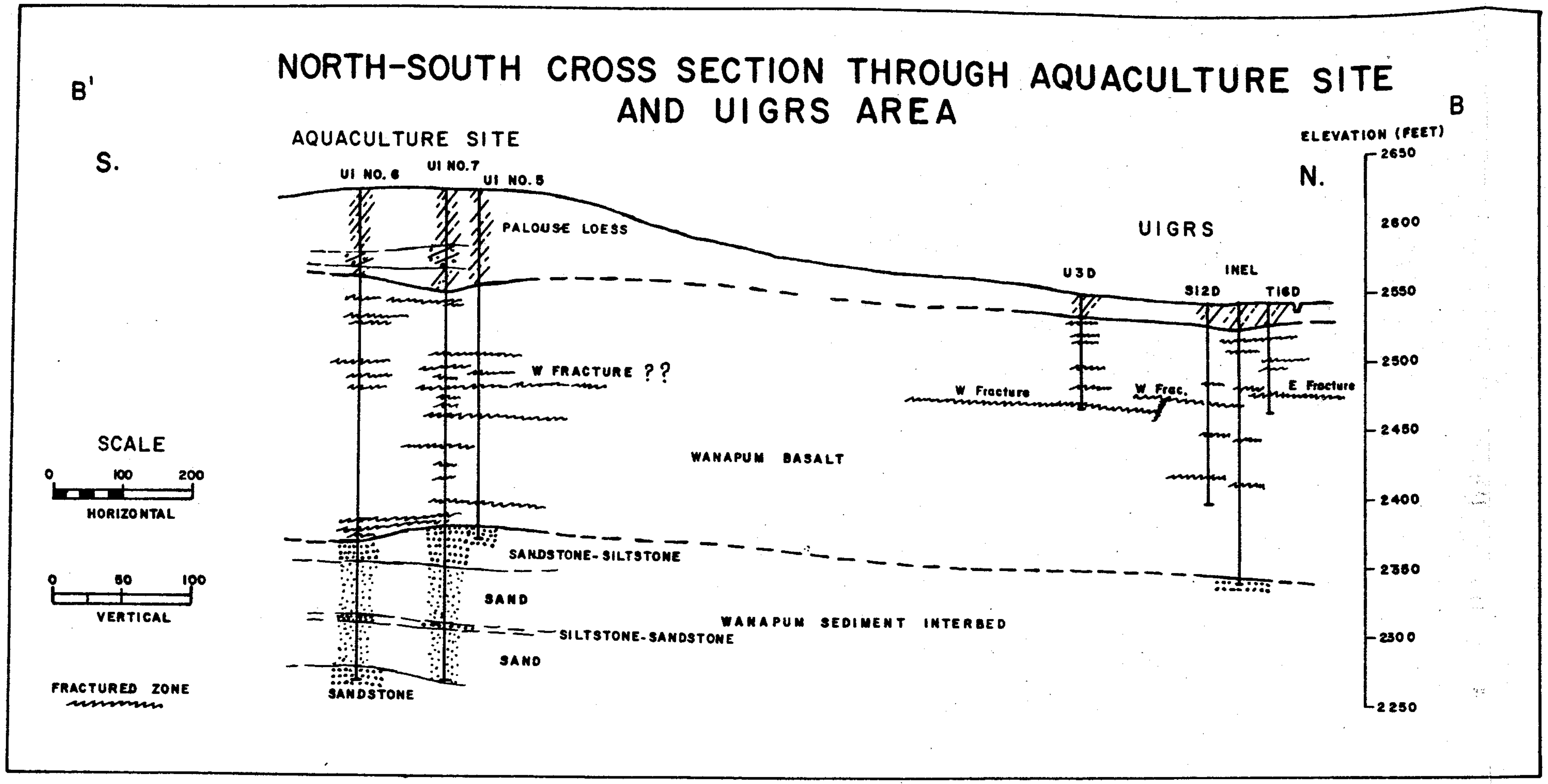



Figure 2.3 Generalized East-West geologic cross-section through the Moscow area.
Modified from Lin(1967), Jones and Ross (1972), and Barker (1979).

Figure 2.4 is a north-south geologic cross-section constructed through the Aquaculture site and adjacent areas. The Aquaculture Laboratory facility sits on a small hill that consists of a thick deposit of Palouse loess. The loess and associated alluvial deposits cover the entire study area with no outcrops of bedrock. The thickness of the Palouse Formation in this area is highly variable, ranging from 13 to 17 feet at the UIGRS up to about 75 feet at the Aquaculture well site. The formation consists of fine-grained, dark-brown loess and silty clay in the upper section, in the intermediate section of gray clay, and mixed clay and medium to coarse sand and gravel in the basal section. Locally, one or more of these materials may be absent.

Li (1991) reported that the basalt section in the Wanapum at the UIGRS consists of a single flow, the Lolo flow of the Priest Rapid Member of the Wanapum Basalt. The upper contact of the Wanapum Basalt forms an undulating surface that ranges in elevation from about 2532 feet (AMSL) at the UIGRS to between 2546 and 2560 feet (AMSL) at the Aquaculture well site. The base of the flow is located at an elevation of 2343 feet (AMSL) at the UIGRS and between 2370 to 2379 feet (AMSL) at the Aquaculture wells. The total thickness is 167 to 190 feet. The thickness varies notably over short distances. At well UI No. 7 the thickness is 167 feet, whereas 122 feet to the south at well UI No. 6 the basalt is



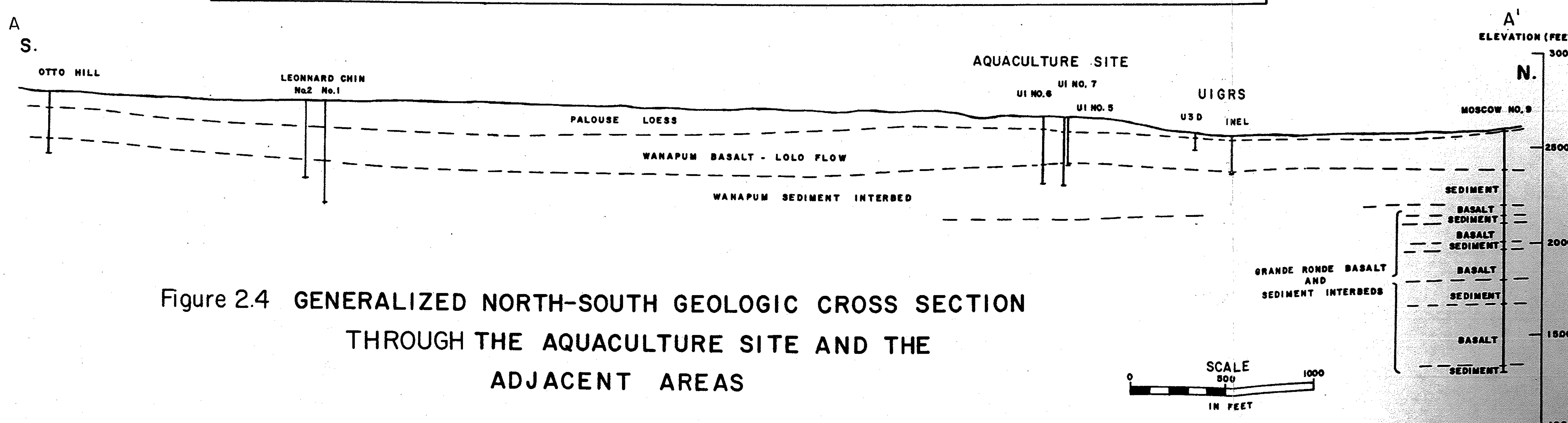




Figure 2.4 GENERALIZED NORTH-SOUTH GEOLOGIC CROSS SECTION THROUGH THE AQUACULTURE SITE AND THE ADJACENT AREAS

190 feet thick. At the UIGRS only the INEL well fully penetrates the Lolo flow.

Li (1991) described two types of interflow structures in the Lolo flow. He based his observations on outcrops at a highway department rock quarry located about five miles west of the UIGRS. The structures are: 1) thick columnar sections with alternating entablature and colonnade in the lower section and hackly entablature in the upper section; and 2) dense massive dark-gray basalt lacking distinct flow tops and vesicular zones. The upper one-third of the Lolo flow contains oxidized flow tops with large frothy blocks and abundant sub-horizontal conchoidal fractures. Examination of drill hole cuttings from wells at the Aquaculture site indicate similar features.

Underlying the Lolo flow is a thick section of sediments. Although geologically correlative with the Latah formation, this layer is hydrologically regarded as part of the Wanapum Basalt aquifer system (upper aquifer). This sediment layer is wide-spread in the eastern part of the Pullman-Moscow Basin, but generally pinches out to the west of Moscow. All three Aquaculture wells (UI No.'s 5, 6 and 7) were bottomed in the upper one-third of this sediment unit. Drill logs from wells UI No. 3 and Moscow No. 6 and No. 9 show this layer to be up to 300 feet thick to the east and north of the study area. Well UI No. 5 penetrated only the upper seven feet of the sediments. Wells UI No. 6 and No. 7 penetrated 111 and

113 feet of sediments, respectively. At the Aquaculture site the top of the sediments is an olive-brown poorly cemented sandstone-siltstone layer ranging from 17 to 31 feet thick. Underlying this layer is 40 to 76 feet of light-tan, fine-to-medium-grained, unconsolidated silt and sand. The sand grades downward into a 2 to 6 foot-thick layer of poorly to moderately consolidated siltstone and sandstone. A two-foot layer of light and dark-gray thinly laminated siltstone is present in well UI No. 7 at the top of this sandstone layer. The siltstone facies is not present in well UI No. 6, 122 feet to the south of well UI No. 7. Underlying the siltstone-sandstone layer are 40 to 50 feet of the same unconsolidated sand and silt described above this layer. The last nine feet in well UI No. 7 encountered a hard, compact, moderately consolidated siltstone-sandstone layer with apparent low permeability.

The sand-silt material consists mostly of angular, glassy quartz grains with abundant tan sub-rounded feldspar grains. Abundant biotite, minor muscovite and minor amounts of a vitreous yellow mineral (sphene or olivine ?) make up the accessory minerals. Dark-brown fragments of wood are locally abundant within the sand-silt layer. Variable amounts of light-tan to dark-brown clay are present in most of these sediment layers. Much of the clay-sized fraction was lost in the drill hole sampling, making an estimate of the actual clay content difficult to determine.

The underlying stratigraphy of the sediment unit below the bottom of well UI No. 6 (elevation 2268 feet AMSL) can only be inferred from the few other deep wells that are located several thousands of feet to the north and east of the Aquaculture site. Logs from these wells indicate a higher percentage of clay within the lower two-thirds of this unit.

The Grande Ronde Basalt underlies the sediment unit. At least three sections of Grande Ronde Basalt separated by interbedded sediments are indicated in logs from deep wells in this part of the basin. On the basis of logs from these other wells, the crystalline basement is estimated to lay at a depth of about 1400 feet below the Aquaculture site.

## REGIONAL HYDROGEOLOGY

Ground water comes from three separate hydrostratigraphic units in the Pullman-Moscow Basin. These are: 1) the loess and shallow alluvial sediments; 2) the basalt and associated interbeds; and 3) the crystalline basement rocks. The shallow unconfined aquifer in the loess probably was an important source of groundwater during the early years of development in the basin, but is now used only as a source for small domestic and stock wells. The loess and shallow alluvial deposits yield up to 30 gallons per minute to wells in the basin (Baines, 1992). Static water levels generally range from surface to a depth of 60 feet, but may be deeper where thick deposits of loess are present (Lum and others, 1990). Water levels fluctuate in response to seasonal changes in precipitation and climate. Recharge to the loess aquifer is primarily from infiltration of precipitation, with the highest rates occurring in the eastern part of the basin. Streams that flow across the basin can lose or gain water to the loess aquifer depending on the season and specific location.

Ground water systems in the basalt and associated interbeds are classified into the Wanapum and Grande Ronde aquifers. The Wanapum or upper aquifer was the primary source of ground water in the basin from the late-1890's up through the mid-1960's. Historically, at least a half-dozen wells in the Moscow area produced water from the sediment layer underlying the Lolo flow. The most significant of these wells was UI No. 2 located on the University campus. Peak annual production from this well was 190 million gallons in 1962 (Baines, 1992). Jones and Ross (1972) reported that by the late-1960's total pumpage from the upper aquifer was reduced to no more than 100 gallons per minute. Water levels in the Moscow area in the upper aquifer declined from near-surface in the late-1890's to nearly 120 feet below land surface by the early 1960's (Jones and Ross, 1972). Since the decline in use, water levels have recovered to approximately 50 to 60 feet below land surface (Ralston personal communication). Baines (1992) reported that wells in the Wanapum Basalt yield up to 1500 gallons of water per minute. Recharge to the upper aquifer occurs mostly from infiltration of precipitation, both through the loess and through unconfined Latah formation sediments along the eastern margin of the basin. Local recharge may also occur where streams such as Paradise Creek cut down to the Wanapum Basalt.

The Grande Ronde aquifer has been the primary source of ground water for the major water users in the basin since the mid-1960's. Jones and Ross (1972) described two aquifers in what is now designated the Grande Ronde Basalt. They referred to these aquifers as the middle and lower aquifers. The middle aquifer is located at an elevation of 1760 to 1905 feet (AMSL), and the lower aquifer is between 1200 and 1600 feet (AMSL) in elevation. Later authors have combined these into a single lower aquifer. Wells completed in the Grande Ronde yield up to 3000 gallons per minute (Baines, 1992). Water levels in the Grande Ronde Basalt have steadily declined at a rate of about 1 to 2 feet per year since the mid-1960's (Lum and others, 1990). Water levels in the principal wells by the late-1980's were at elevations of about 2260 feet (AMSL) at Pullman and 2250 feet (AMSL) at Moscow (Bloomsburg, 1992). Recharge to the Grande Ronde aquifer is from downward infiltration through discontinuous zones of poorly consolidated, unconfined sediments along the east margin of the basin, and from downward infiltration along fractures in the Wanapum Basalt.

Water-bearing zones in the Wanapum and Grande Ronde formations occur in complex fractured zones near the tops and bottoms of basalt flows (Lum and others, 1990) and in permeable zones within the sediment interbeds. Lateral continuity along water-bearing fractures is questionable and many fracture zones are probably limited to small areas. Some, however, may be interconnected by permeable sub-vertical fractures forming crudely en echelon water-bearing zones of considerable lateral extent. The basalt matrix between permeable zones, being massive and dense with very low porosity, forms aquicludes. Ground water movement in both the Wanapum and Grande Ronde is predominantly horizontal in an east to west direction.

Granitic and metasedimentary rocks most likely compose the crystalline basement of the basin in the Moscow area. These rocks outcrop in surrounding highland areas such as the Palouse Range, Paradise Ridge and Kamiak Butte in the east part of the basin. Wells completed in the crystalline rocks seldom have yields of more than 5 gallons per minute. Water-bearing zones generally are restricted to shallow weathered zones or permeable fracture zones or faults. The crystalline rocks probably underlay most of the basin, but have not been productive as a source of ground water within the core of the basin. Two wells in the Moscow area, Moscow No. 8 and UI No. 3, fully penetrate the basalt, and encounter granite at an elevation of approximately 1250 feet (AMSL) (Jones and Ross, 1972). Neither well produced significant water from these basement rocks (Jones and Ross, 1972).

## HYDROGEOLOGY OF THE AQUACULTURE SITE

At the Aquaculture site and adjacent UIGRS, water-bearing zones have been found in the shallow loess and alluvial deposits, in fractures in the Lolo basalt flow and in the thick sediment interbed underlying this flow. The deepest wells at this site, bottomed in the upper section of the sediment interbed.

The shallowest aquifer is in the Palouse loess and alluvium. The Aquaculture facility is on a small hill of eolian loess and associated alluvial-colluvial materials. Well logs show that these deposits are up to 72 feet thick at well UI No. 7. The loess thins significantly in the narrow valleys to the north and east, and is only 13 to 19 feet thick at the UIGRS. Aquifers in this formation generally are unconfined and are heterogeneous and anisotropic. Well yields from the loess aquifer are generally small. Li (1991) reported a maximum yield in wells completed in the loess at the UIGRS of 1 to 2 gallons per minute. Nine wells at the UIGRS are completed in the loess or alluvial-colluvial material at the loess and Wanapum contact. Studies by Li (1991), Pardo (1993), and Patrick (1990) have shown that the shallow aquifer receives significant recharge along the northeast margin of the research site from Paradise Creek during periods of high stream flow. Ground water was not identified in the loess at the Aquaculture site based on the logs from the three wells drilled at this site. The shallow alluvial aquifer is not an important source of ground water at this location.

Ten wells have been drilled into the Lolo flow at the UIGRS. Li (1991) identified two significant water-bearing fractures in the Lolo flow that he named the E-fractured aquifer and the W-fractured aquifer. He reported that both zones have limited areal extent and become minor fractures at distances of a few hundreds of feet. Both aquifers are confined and are highly heterogeneous and anisotropic. Li classified each aquifer on the basis of water level data measured in wells completed opposite one fracture system, the results from aquifer tests, and microbial ecology data obtained from water samples taken from these wells.

The E-fractured zone at the UIGRS has a thickness of 1 to 3 feet and ranges in depth from 65 to 75 feet. This aquifer is limited to the northeast portion of the research site, but may actually extend beyond the site to the northeast and east. Li (1991) inferred that the E-fracture represents a horizontal break at the contact of an entablature and colonnade structures. The fracture is hydraulically connected to the shallow alluvial aquifer and with Paradise Creek through vertical or sub-vertical fractures. Wells completed in the E-fractured zone have static water level elevations between 2536 and 2541 feet AMSL (Li, 1991). These levels are approximately equal to the static water levels reported for wells completed in the shallow alluvial aquifer. Based on a series of aquifer tests that he ran at the UIGRS, Li (1991) estimated transmissivity values in the E-fractured aquifer ranging between 14 and 580 $ft^2$/day. Storativity values ranged from $2X10^{-5}$ to $5X10^{-4}$.

The W-fractured aquifer is present in the west and south portions of the research site. The depth below surface ranges between 70 and 85 feet (2465 to 2480 feet AMSL) except in well D19D at the extreme west end of the site where the depth is 139 feet (2405 feet AMSL). Li (1991) suggested that this dramatic change in depth is a result of the W-fracture actually consisting of two horizontal zones interconnected by a vertical columnar fracture, forming a crude Z-shaped structure. The W-Fracture zone averages between 0.5 and 1.0 foot in thickness. Static water levels in the W-Fractured aquifer wells have an annual elevation range between 2519 and 2521 feet AMSL (Li, 1991). These levels are approximately 19 to 20 feet lower in elevation than the static water levels reported from the E-Fractured aquifer wells. Water yields of up to 60 gallons per minute are reported from wells completed in the W-fractured aquifer (Li, 1991); Prado, 1993). Typically, however, these wells have yields of between 1 and 3 gallons per minute. Transmissivity values range between 0.4

and 3 $ft^2$/day while storativity is between 5X10$^{-7}$ to 5X10$^{-5}$ (Li, 1991). Results from aquifer tests and water level monitoring at the UIGRS show that there is a poor hydraulic connection between the W-Fractured aquifer and the shallow alluvial aquifer, Paradise Creek, and the E-Fractured zone. The E-Fractured aquifer has not been identified within the Lolo flow at the Aquaculture well site.

Observations, made at the Aquaculture site during the drilling of wells UI No. 6 and No. 7 and during subsequent aquifer tests on these wells, indicate that the W-Fractured aquifer does underlay the Aquaculture site. Rapid water level declines were noted in several W-Fractured wells at the UIDRS during the drilling and development of wells UI No. 6 and UI No. 7. This indicates some degree of hydraulic connectivity. The W-Fractured zone appears to correlate with a zone of fracturing encountered at a depth of 139 to 145 feet (2474 to 2480 feet AMSL) in well UI No. 6. The elevation of this zone is similar to that of the W-Fractured aquifer in wells U3D, S12D2 and J16D at the UIGRS, but is approximately 70 to 75 feet higher than the W-Fracture in well D19D. Other water-bearing fractured zones were noted in the well log from UI No. 6 at depths from 120 to 125 feet and from 130 to 134 feet; these might also represent this zone. In well UI No. 7, a water-bearing fracture zone located at a depth of 180 to 195 feet (2423 to 2438 feet AMSL) produced an estimated flow of 50 to 80 gallons per minute. The geologic log from well

UI No. 5, located only 20 feet north of UI No. 7, shows a water-bearing section between 2446 and 2462 feet (AMSL). This zone reportedly produced a flow of about 150 gallons per minute. Although, located at different elevations, these zones may hydraulically represent the W-Fractured aquifer. No hydraulic testing was done on any of these zones in wells UI No. 6 and No. 7, and it is difficult now to correlate individual fractures. The variations in the elevations of water-bearing fractures within this section of the basalt flow indicate a complex structural zone with a moderate to high degree of hydraulic interconnection.

The E- and W-Fractured aquifers are bounded above and below by basalt aquitards. The upper aquitard which separates the shallow alluvial aquifer from the E-Fractured aquifer consists of a weathered frothy vesicular flow top in the upper portion, grading downward into an entablature structure. Leakage through this aquitard into the E-Fractured aquifer is primarily through vertical joints and fractures in the basalt.

A middle basalt aquitard separates the E- and W-Fractured aquifers at the UIGRS. Li (1991) considered this aquitard to consist of entablature with minor horizontal fractures and vertical joints. The hydraulic connection between these two aquifers is poorly developed. Li (1991) estimated a lumped parameter (K' X Ss') for the upper and middle aquitards of from $2X10^{-7}$ to $8X10^{-5}$ 1/day and for the middle and lower aquitards of from $2X10^{-10}$ to $2X10^{-7}$ 1/day.

The lower aquitard separates the W-Fractured aquifer from the sediment layer underlying the Lolo flow. At the Aquaculture site this section consists mostly of hard, massive dark-gray basalt. The basalt is locally fractured, and near the base of the flow is altered and vesicular. Hydraulic connectivity between the W-Fractured aquifer and the sediment layer is poor to moderate. Leakage between the two aquifers occurs through vertical fractures and columnar joints.

The primary aquifers at the Aquaculture Research Laboratory site are in the sediment unit that underlies the Lolo flow. Previous investigators have regarded the sediment interbed as behaving hydraulically as a single aquifer. However, my results show that the sediments are hydraulically heterogeneous and anisotropic. Poor to moderately consolidated silt and sand layers within this sequence form aquitards that separate and bound the more permeable aquifer layers of unconsolidated sand and silt. The lateral extent of the individual aquifers and aquitards in this section are unknown.

# CHAPTER 3

# DEVELOPMENT OF AQUACULTURE WELLS

## BACKGROUND INFORMATION

The Aquaculture laboratory was developed to conduct research in rearing juvenile salmon and research in diseases relating to salmon. Under a current water rights permit from the Idaho Department of Water Resources, the laboratory is allowed an annual appropriation of 48 million gallons of water over a six-month pumping season. The laboratory presently requires a continuous source of about 150 gallons per minute of fresh water meeting specific standards for water chemistry and temperature. Wells completed in the upper aquifer are used as the primary source of water for the laboratory. The upper aquifer water has the advantages of needing no de-chlorination and of requiring less cooling.

Water is presently pumped from well UI No. 6 into a series of underground holding sumps. The water is chilled before use in the rearing tanks from a ground water temperature of 13° C down to 9° C. A backup water distribution system is on line to use the University's lower aquifer system in the event sufficient water can not be obtained from the primary source.

Development of the upper aquifer at the Aquaculture

Research Laboratory has occurred through two separate programs: one in 1991 and another in 1993. Three wells have been completed at the site. The location of these wells and the monitor well system developed at the adjoining UIGRS are shown in figure 3.1. Wells at the laboratory site were drilled using an air rotary drill equipped with a top head casing driver. Prior to entering the hole, all equipment was steam cleaned and disinfected with a 50 ppb chlorine solution to prevent bacteria contamination.

## DESCRIPTION OF WELL UI NO. 5

Well UI No. 5 was drilled at the Aquaculture site in early February, 1991. The well is located approximately 150 feet east of the laboratory building near the crest of a small hill. The well is housed in a small insulated metal frame pump house.

Well UI No. 5 was drilled to a depth of 247 feet below land surface. The first 68 feet of this drill hole penetrated loess and associated alluvial/colluvial materials of the Palouse Formation. From 68 to 240 feet the hole encountered basalt of the Lolo flow. Water-bearing fractured zones were noted in the drillers log at 156 to 172 feet and at 230 to 240 feet. The combined water yield from these two zones was estimated on the drillers log at 300 gallons per minute. The hole encountered gravel and silt from 240 to 245

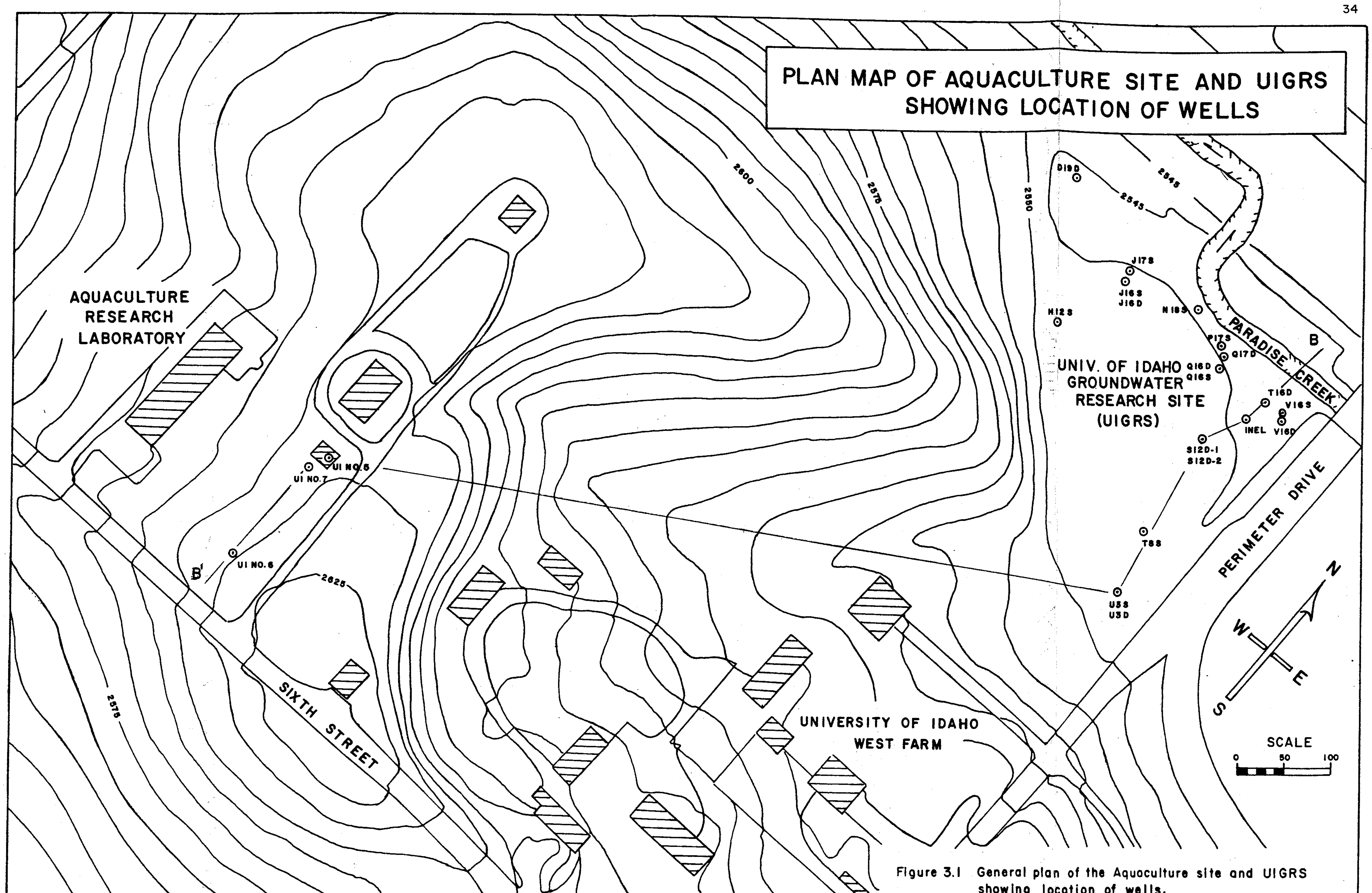



Figure 3.1 General plan of the Aquaculture site and UIGRS showing location of wells.

feet, underlain by gray shale and sand to 247 feet. To avoid pumping of sand, only the two aquifers located in the basalt were developed in this well. A geology and well completion log of this well is shown in figure 3.2.

The well was cased from 0 to 87 feet with 16-inch steel casing and from 87 to 160 feet with 12-inch steel casing. Ten feet of 12-inch diameter 30 slot well screen was installed in the well at 160 to 170 feet. A second 20-foot section of 12-inch diameter 30 slot well screen was placed at 220 to 240 feet. A 50-foot section of 12-inch steel casing separates the two sections of well screen. The last seven feet of the well was cased with 12-inch steel casing. Two neoprene packers plus a bentonite plug were placed at the bottom of the well. A series of three neoprene packers were installed between 80 and 90 feet, and a bentonite seal filled the outer annulus of the well from 87 feet to the surface. A 10 horsepower submersible pump was set in the well at a depth of 240 feet.

A pumping test was performed on this well by the drill contractor on February 13, 1991. The well was pumped for a period of four hours at a rate of 187 to 210 gallons per minute. After 2.75 hours of pumping the water level had dropped below the bottom of the airline at 210 feet preventing any further water level measurements. The static water level at the time of this test is not known. A static water level measurement recorded in this well on February 18, 1993 was

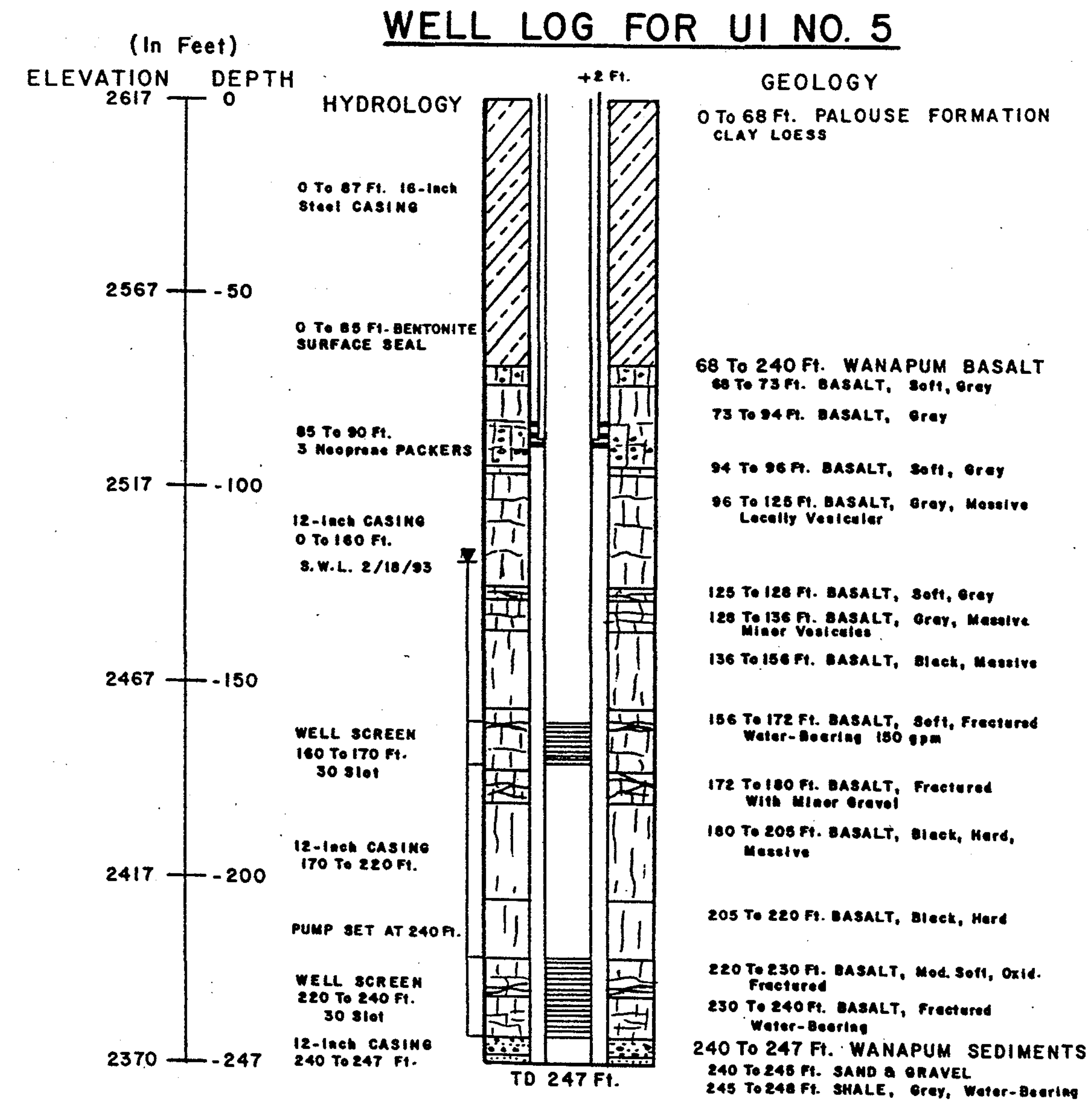



Figure 3.2 Geology and well completion log for well UI No. 5.

120.9 feet. Several "surge" tests were made on this well by the Aquaculture laboratory staff to determine an appropriate pumping rate. These tests lasted from minutes to hours and involved pumping rates ranging from 80 to 200 gallons per minute. The final test was run for eight hours at a constant rate of 80 gallons per minute. The water level remained above the pump intake at 237 feet during this series of tests.

Based on these preliminary pump tests, a permanent pump was set in the well and a pump house constructed at the site. Pumping by the Aquaculture laboratory during the spring of 1991 determined that the well was not capable of sustaining a yield meeting the required needs of this facility. A sustained yield of only 50 to 70 gallons per minute was attained from well UI No. 5. As a result, approximately 80 percent of the water used to operate the laboratory during the 1991 and 1992 seasons was obtained from the University's deep aquifer system.

## DESCRIPTION OF WELL NO. 6

UI well No. 6 was drilled as a test well in January, 1993. The well is located approximately 140 feet south of UI No. 5. The objective in drilling this well was to test the flow yield and determine the hydraulic properties of the sediment aquifer underlying the Lolo basalt in the vicinity of the Aquaculture laboratory. The well construction and geologic log for this well are shown in figure 3.3.

Well UI No. 6 was drilled to a depth of 351 feet. From surface to a depth of 60 feet the well penetrates loess and alluvial-colluvial materials of the Palouse Formation. No significant water is noted in this formation in the drillers log. The Lolo basalt is encountered from 60 feet to 250 feet. Water-bearing fractured zones were noted at 85 to 94 feet and at 120 to 145 feet. Fractured basalt is encountered at 235 to 250 feet at the bottom of the flow; however, no increase in the flow of water is noted in the log.

The sediment interbed of the upper aquifer system is penetrated in well UI No. 6 from 250 to 351 feet. The upper 17 feet of this formation consists of poor to moderately consolidated, light-gray siltstone and sandstone. This layer grades downward into a 37-foot-thick section of unconsolidated, fine-to-medium grained sand with minor silt and clay. A section of this sand layer between 279 and 305 feet in depth is reported in the log to be water-bearing with an estimated flow of about 125 gallons per minute. Underlying and gradational with the sand layer is a six-foot thick layer of moderately consolidated siltstone-sandstone that forms an aquitard between the overlaying and underlying sand aquifers. This aquitard was not recognized during the initial logging of the well. A second section of unconsolidated sand underlies this aquitard and is present at a depth of 311 to 342 feet. A flow estimated at 75 gallons

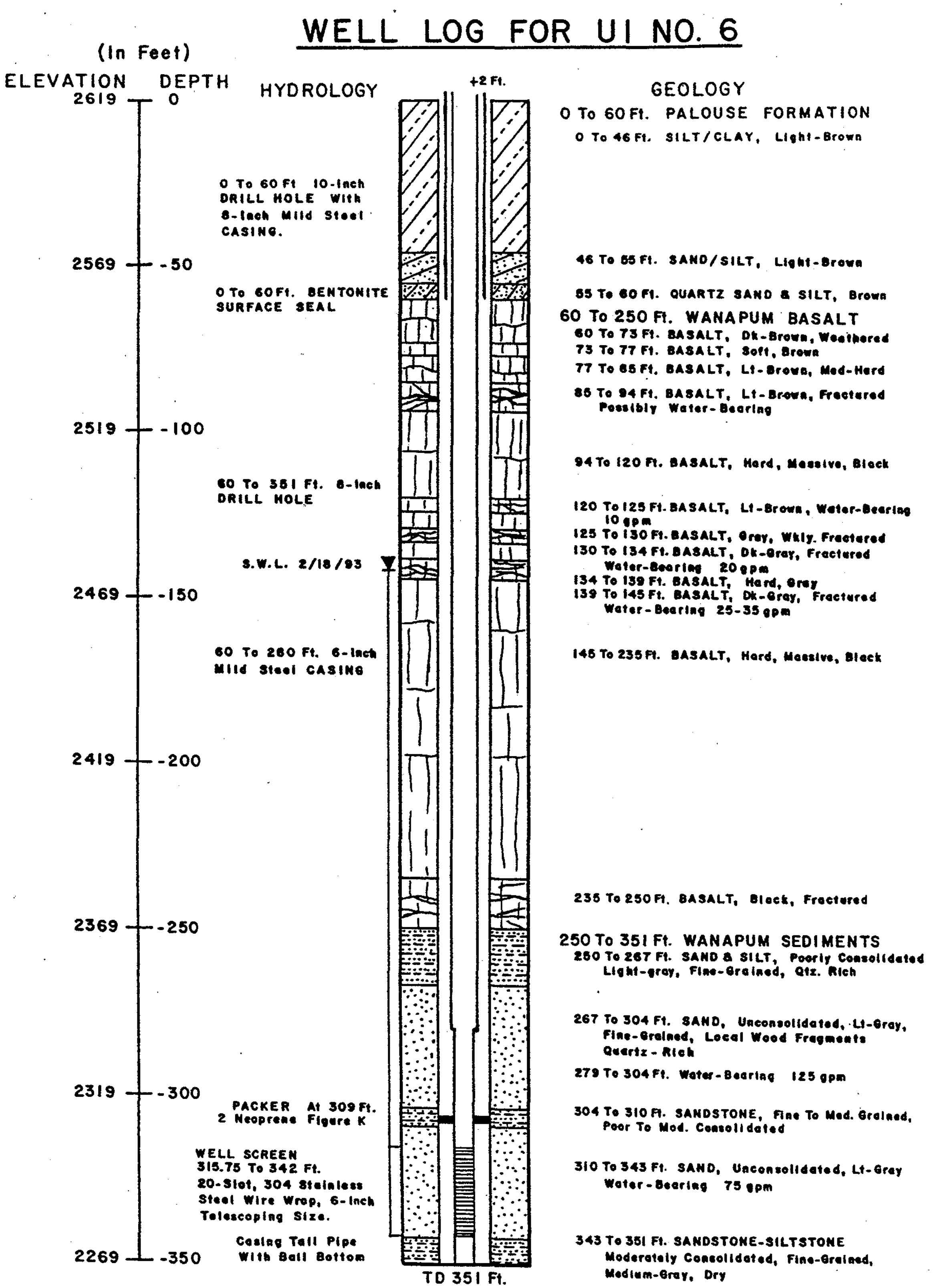



Figure 3.3 Geology and well completion log for well UI No. 6.

per minute is recorded in the drillers log in this aquifer. From 342 to 351 feet the well penetrated moderately consolidated sandstone-siltstone that forms a second aquitard layer.

Well UI No. 6 is drilled as a 10-inch diameter hole from surface to a depth of 60 feet, and is an 8-inch diameter hole from 60 feet to the bottom at 351 feet. The well is cased with 8-inch mild steel casing to a depth of 60 feet, and with 6-inch mild steel casing from 60 feet to 312 feet. A 5-inch diameter mild steel casing blank riser pipe joins the 6-inch casing with a 26.5-foot section of 20 slot 304 stainless steel wire wrap 6-inch diameter telescoping well screen. The well screen is located at a depth of 315.75 to 342 feet and is open only to the lower sand aquifer. A 5-inch diameter blank mild steel casing tail pipe with a bail bottom plate seals the well at the bottom of the screened section. Two neoprene Figure K packers are installed above the well screen at a depth of about 309 feet. A sanitary surface seal consisting of hydrated bentonite clay is installed in the annular space between the casing and the wall of the drill hole from surface to a depth of 60 feet. A 15-horsepower submersible pump is installed in the well at a depth of approximately 220 feet below land surface.

## DESCRIPTION OF WELL UI NO. 7

Based on the favorable results obtained from test well UI No. 6, a second, production well was drilled at the Aquaculture site in mid-April, 1993. This well referred to as UI No. 7 is located approximately 20 feet to the south of well UI No. 5. The well construction and log for the geology and hydrology for this well are shown in figure 3.4.

The geology of well UI No. 7 consists of light-to-medium brown loess from the collar of the hole to a depth of 72 feet. No significant ground water is present in this formation. The Lolo basalt is encountered from 72 feet to 239 feet. Water-bearing fractured zones are present in the basalt at 110 to 121 feet, 180 to 195 feet and from 200 to 239 feet. A water yield estimated at 50 to 80 gallons per minute is posted in the drillers log for the zone at 180 to 195 feet. From 239 feet to the bottom of the hole at 350 feet, the well penetrates the sediment interbed underlying the Lolo flow. The upper 31 feet of this section consists of poorly consolidated medium-tan, fine-grained sandstone. Underlying this layer is a 40-foot section of fine-to-medium grained unconsolidated sand. At 310 to 312 feet the hole penetrates a light-gray, thinly laminated, well-consolidated siltstone. The siltstone grades sharply downward into a thin layer of medium-grained sandstone. No water occurs in this siltstone-sandstone layer, and the unit forms a low permeability

## WELL LOG FOR UI NO. 7

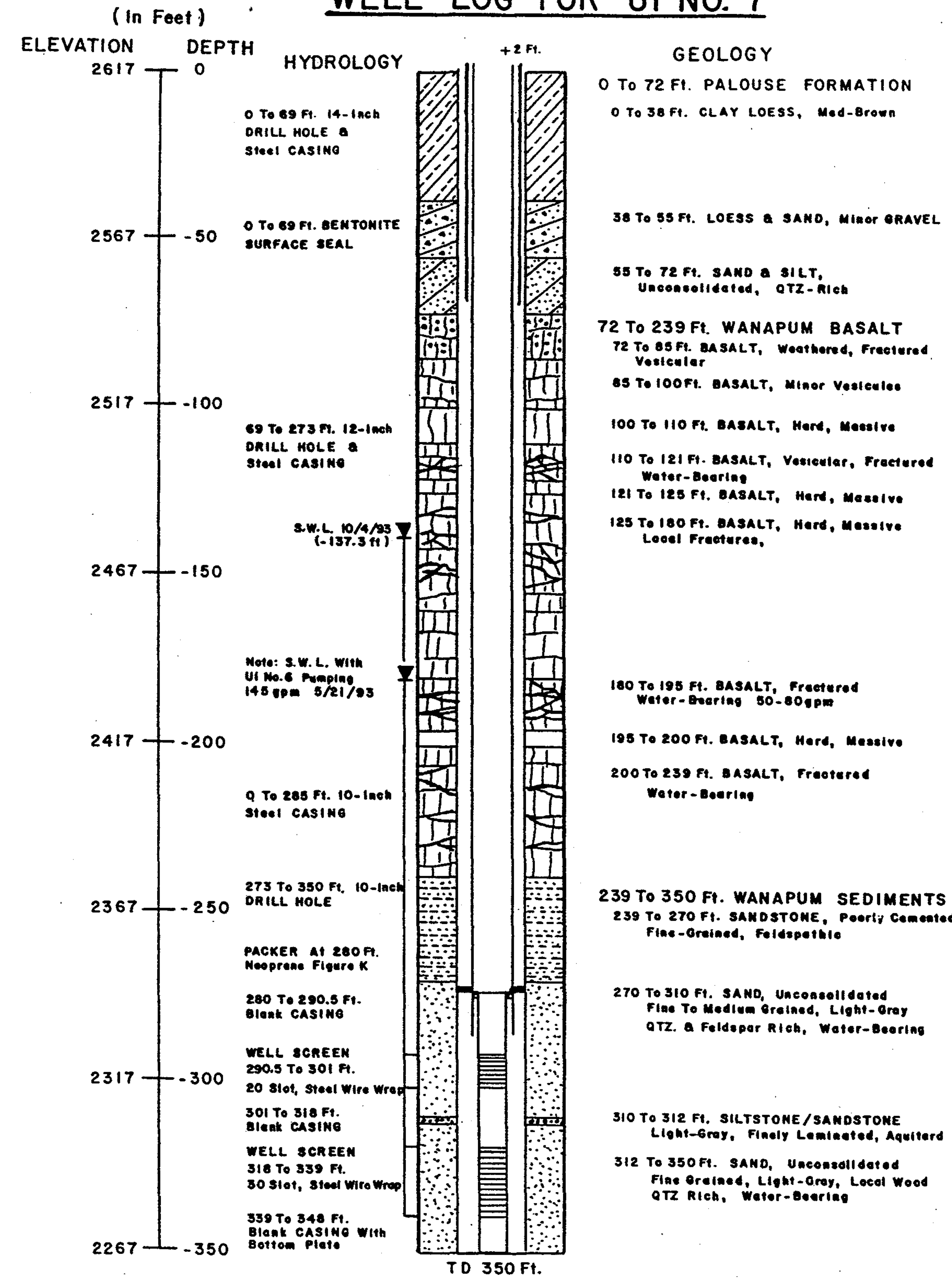



Figure 3.4 Geology and well completion log for well UI No. 7.

aquitard between two thick sand layers. A second section of unconsolidated sand is present below the siltstone-sandstone aquitard. This sand layer has a minimum thickness of 36 feet and continues to the bottom of the well. Both sand layers are highly water-bearing although no estimate of the flow rate for either aquifer is on the drillers log.

UI No. 7 is drilled as a 14-inch diameter hole from surface to a depth of 69 feet. From 69 to 273 feet the hole is 12 inches in diameter. The lower section of the drill hole from 273 to 350 feet is 10 inches in diameter. A 10-inch outside diameter steel casing is installed in the well from land surface to a depth of 285 feet.

The well screen assembly is at a depth of 280 to 348 feet. A 10-foot section of 6-inch mild steel casing blank is installed at the top of the well screen assembly at 280 to 290 feet. Two sections of 6-inch 304 stainless steel wire wrap telescoping well screen are emplaced below the casing blank. The upper section of well screen consists of a 10.5-foot-long section of 20 slot screen at 290.5 to 301 feet. This screen is open in the upper sand aquifer. A 17-foot section of blank casing separates the two screened intervals. The lower section of well screen is at a depth of 318 to 339 feet, and consists of a 21-foot long section of 30 slot screen. This section of well screen is open in the lower sand aquifer. A nine-foot section of blank mild steel casing with a bottom plate seal is attached to the lower section of well screen.

A neoprene Figure K packer is in the well at approximately 280 feet to seal the annular space between the screen assembly and 10-inch casing. A sanitary bentonite clay seal fills the annulus between the rock wall of the hole and the casing pipe from surface to a depth of 70 feet. No pump is in the well. The well has not been used during the 1993 season to supply water to the Aquaculture laboratory.

## AREA WELLS COMPLETED IN UPPER AQUIFER

Several other wells located within a one-mile radius of the Aquaculture site are completed in the upper aquifer, and were given a cursory review during this study. Included in this list are well UI No. 2, the INEL-D well, the Dr. Callahan well, the Otto Hill well and two wells on the Lennard Chin property. Well logs showing the available geology and well completion data are shown in figures 3.5 through 3.8. No log is available for the Chin No.1 well. The location and collar elevation for the Dr. Callahan and Otto Hill wells as shown in figure 3.8 and in cross-section A-A′ in figure 2.4 are only approximate.

The Lennard Chin, Dr. Callahan and Otto Hill wells are located 3600, 4300 and 5000 feet respectively, to the southwest of the Aquaculture site. The same stratigraphic units as those described in the Aquaculture wells are present in these wells. The Lolo basalt ranges in thickness in these

# WELL LOG FOR THE INEL WELL

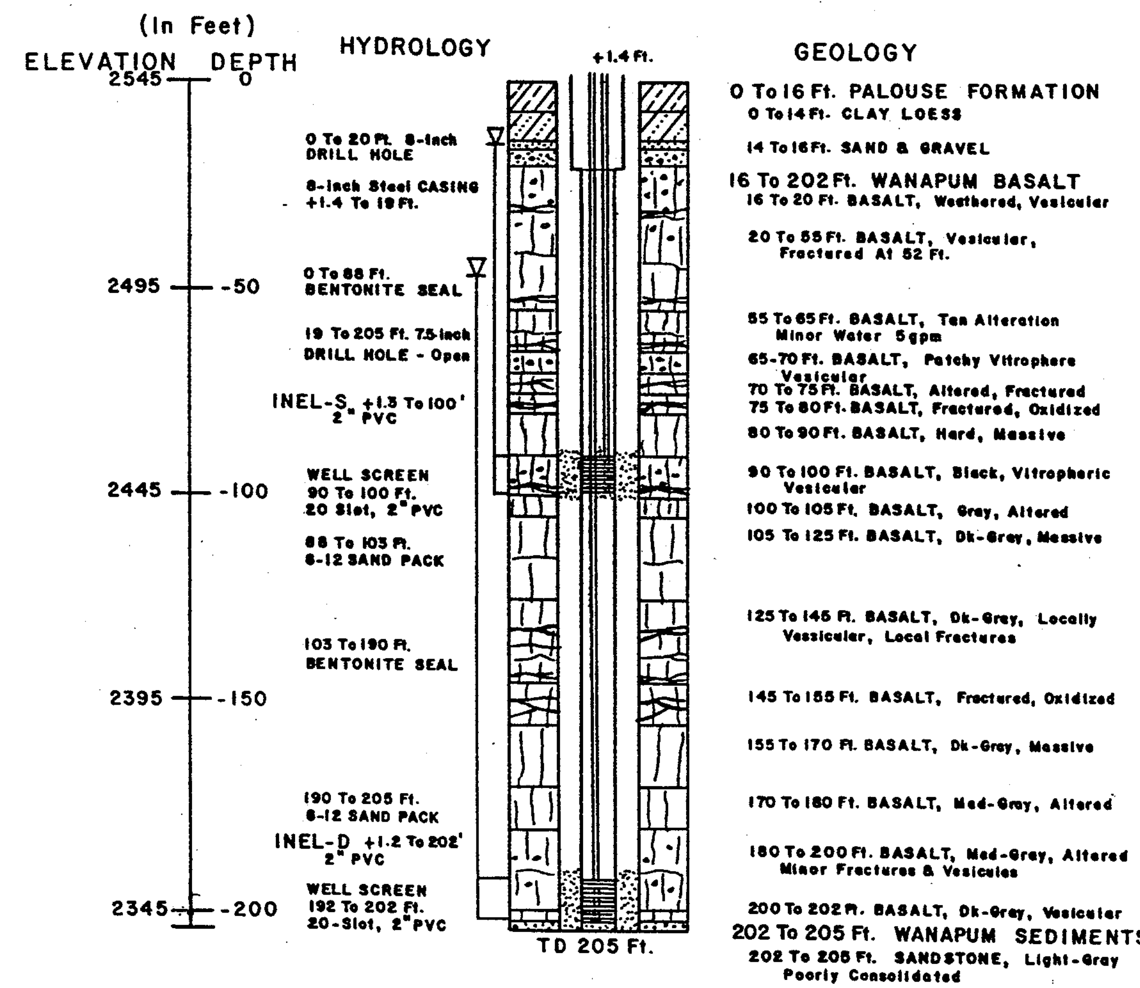



Figure 3.5 Geology and well completion log for wells INEL-D and INEL-S located at the UIGRS.

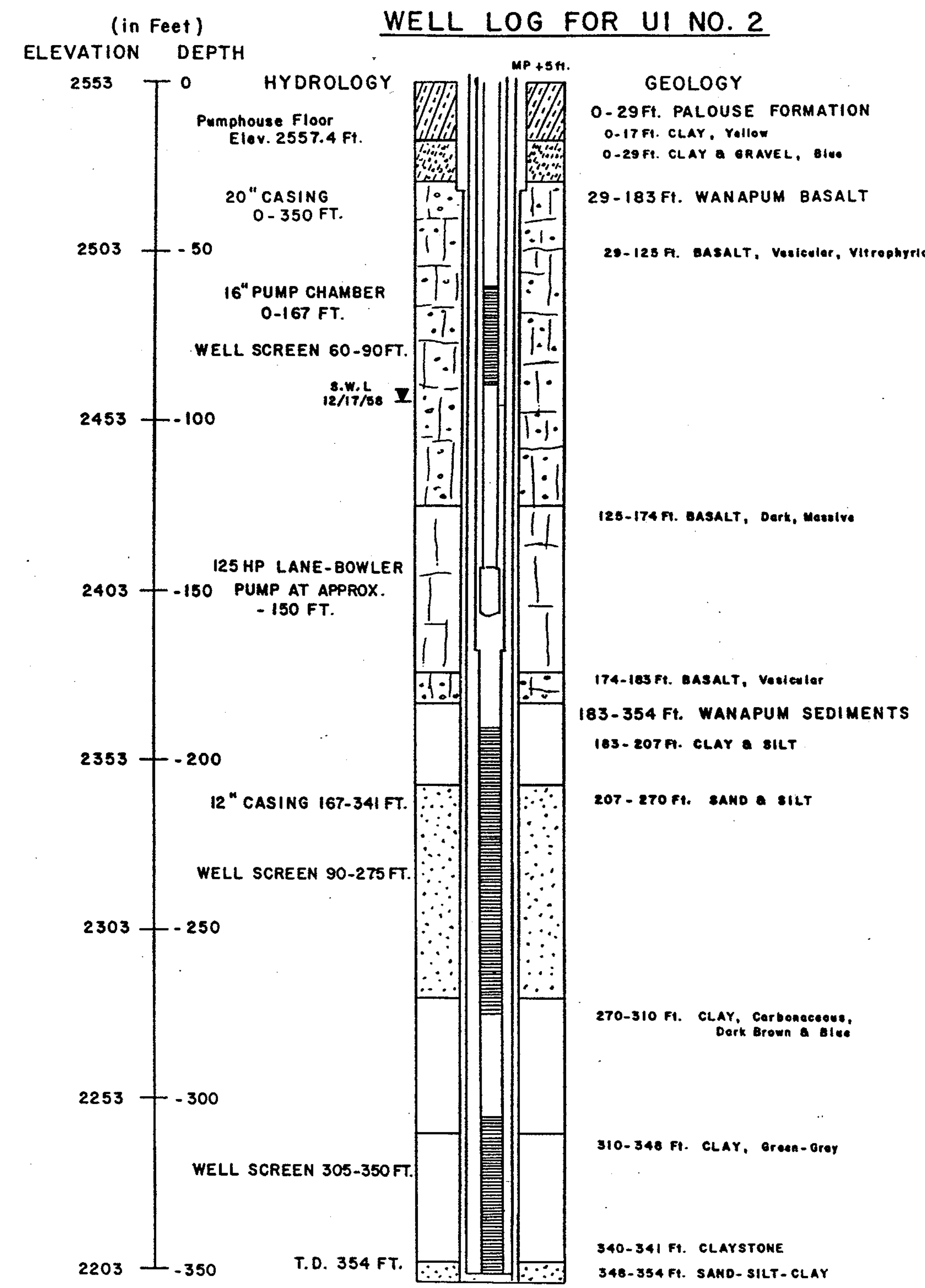



Figure 3.6 Geology and well completion log for well UI No. 2.

## WELL LOG FOR DR. CALLAHAN & OTTO HILL WELLS

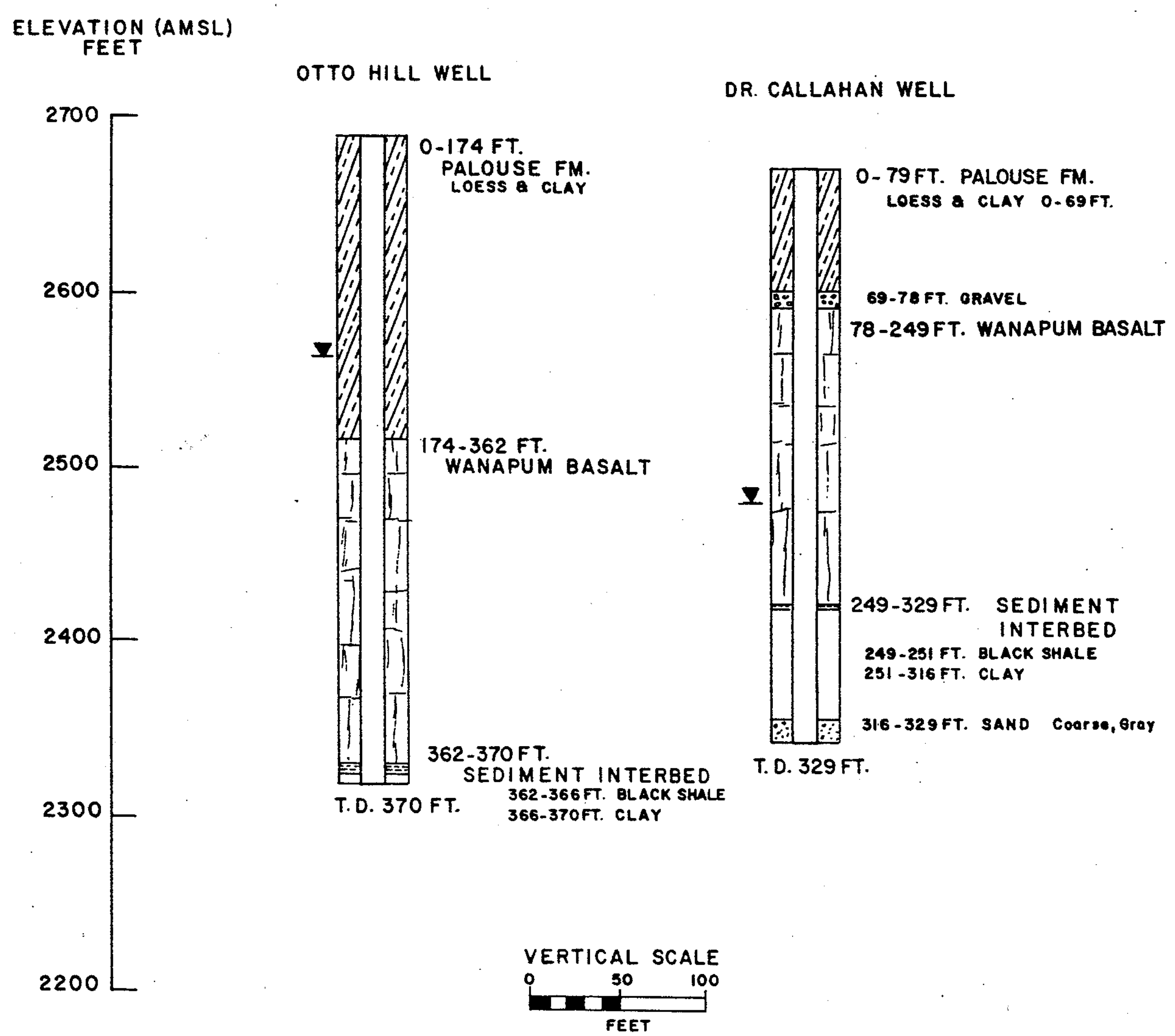



Figure 3.8 Geology log for Dr. Callahan and Otto Hill wells.

wells between 171 feet (Dr. Callahan well) and 191 feet (Lennard Chin No. 2 well). The top and bottom of this flow are at elevations of approximately 2550 feet (AMSL) and 2360 feet (AMSL), respectively, in the Lennard Chin No. 2 well. These elevations correlate closely with the respective flow elevations recorded at the Aquaculture site.

The sediment interbed underlying the Lolo basalt is penetrated in each well. A thin black shale layer from 2 to 9 feet thick was encountered immediately below the basalt. A thick clay layer, 65 to 70 feet thick, underlies the black shale. Both the Chin and the Dr. Callahan wells are bottomed in an unconsolidated sand below the thick clay layer. The top of this sand layer is located at an elevation of approximately 2280 feet in the Chin No. 2 well. This compares with approximate elevations of 2312 to 2350 feet (AMSL) for the upper sand aquifer and 2270 to 2308 feet (AMSL) for the lower sand aquifer at the Aquaculture wells. On the bases of these observations, the sand aquifer in the Lennard Chin and Dr. Callahan wells is correlative with the lower sand aquifer at the Aquaculture site.

# CHAPTER 4

# DESCRIPTION OF LONG-TERM HYDROGRAPHS

## BACKGROUND INFORMATION

Hydrographs showing long-term water level elevations were constructed for well UI No. 6 and for UIGRS wells completed in the upper aquifer. Water levels were not monitored in wells UI No. 5 and UI No. 7 except during aquifer tests. The available hydrographs show the effects on water levels both from short-term aquifer tests and from long-term pumping of well UI No. 6. The effects observed in these hydrographs from the short-term tests are described in chapter 6.

Continuous long-term pumping of well UI No. 6 by the Aquaculture laboratory started in early April, 1993 and was terminated in mid-September, 1993. The total volume of water pumped was approximately 24.5 million gallons. The initial pumping rate was 150 gallons per minute. The pumping rate was gradually reduced to about 140 gallons per minute by early July to meet the actual need of the Aquaculture facility. Problems were encountered with a booster pump located, between the storage sump and the laboratory chiller, in early July, and by late August the pumping rate had declined to about 75 gallons per minute. Water level depths in the pumping well were monitored daily at the laboratory using an air-line gage.

Unfortunately, the gage was mis-read during the first two months of pumping, and no accurate measurements were obtained during that period.

LONG-TERM HYDROGRAPH - AQUACULTURE WELL UI NO. 6

A long-term hydrograph showing water level elevations in well UI No. 6 for the period January to December, 1993 is shown in figure 4.1. A bar graph showing the volume of water pumped each day from this well is included with this hydrograph. During the period of fairly stable pumping, between April 13 and July 12, the water level dropped 41.5 feet, from a static elevation of 2474 feet (AMSL) down to an elevation of 2432.5 feet (AMSL). As the pumping rate declined during July and August, the water level slowly recovered, reaching an elevation of 2449.5 feet (AMSL) by late August. A fairly stable water level elevation of approximately 2449 feet (AMSL) was maintained during the duration of the pumping period. A spike in the hydrograph in mid-September reflects several days of non-pumping followed by a one day surge test at the laboratory on September 25. Following a nine day period of dormancy, a static water level elevation of 2471.7 feet (AMSL) was measured in the well on October 4. A water level measurement was taken on January 12, 1994 to determine if the level had recovered to the pre-pumping static elevation. A water level elevation of 2481.1

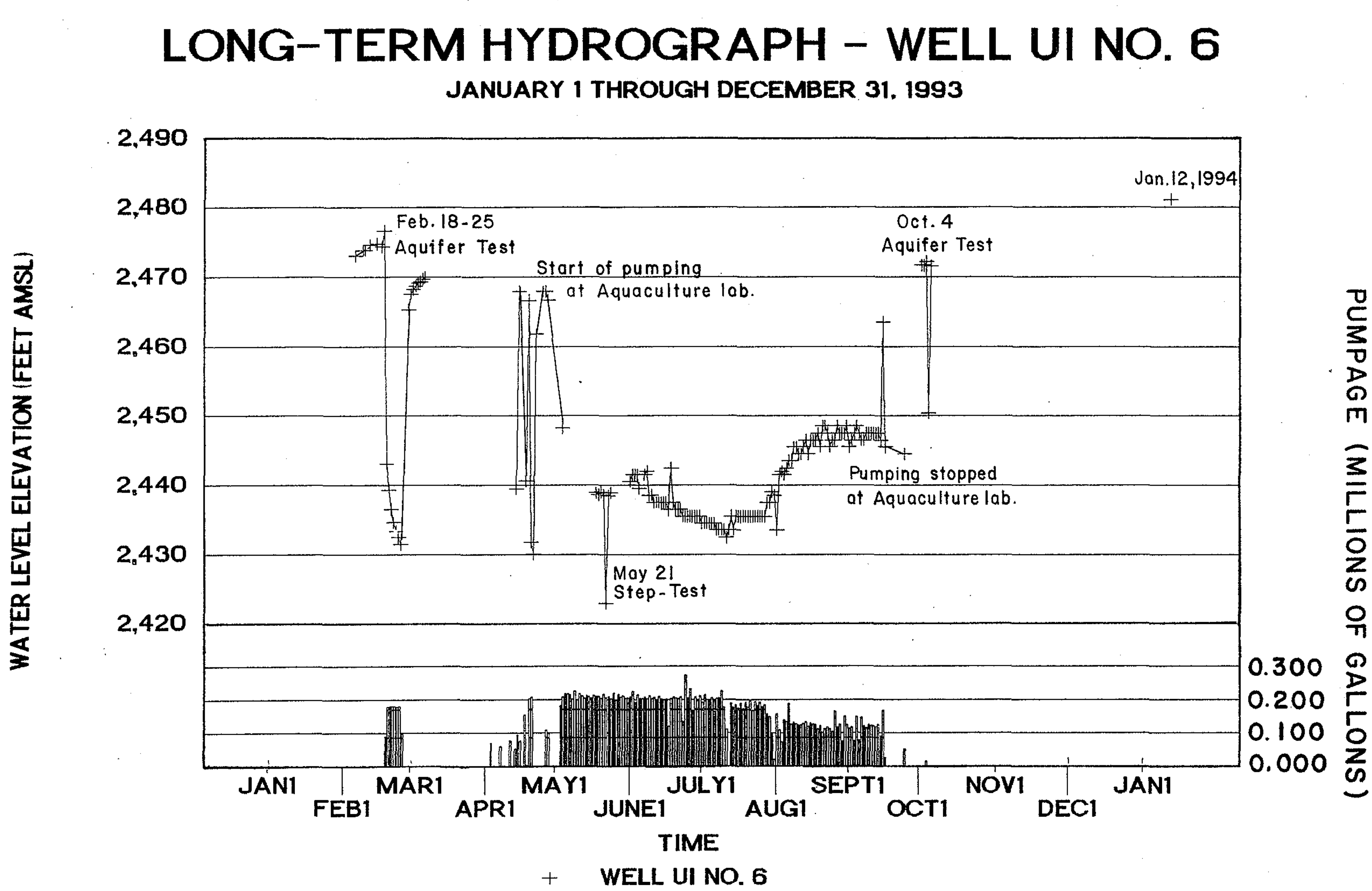



Figure 4.1 Long-term hydrograph showing water level elevations and pumpage in well UI No. 6 during January 1 through December 31, 1993.

feet (AMSL) was recorded. This is 4.5 feet higher than the static water level elevation recorded at the start of the aquifer test on February 18, 1993. Pumping of the well during development probably caused a lowering of the water level in the aquifer in February, 1993.

## LONG-TERM HYDROGRAPHS - UIGRS WELLS

Water level elevations were monitored on a semi-daily schedule in all wells at the UIGRS during the period January to December, 1993. Long-term hydrographs for the INEL well, wells completed in the E- and W-Fractured aquifers, and for two wells in the shallow alluvial aquifer, include water level elevation data for both 1993 and for comparison, 1991; the most recent previous year for which complete data are available. Well UI No. 5 was pumped by the Aquaculture laboratory during the period July 9 through September 23, 1991. Pumping rates during this period averaged from 12 to 22 gallons per minute. No drawdown effects from pumping well UI No. 5 are reflected in the 1991 water level elevation curves on these long-term hydrographs. A composite long-term hydrograph showing a comparison of representative W-Fractured and E-Fractured wells with the INEL-D well, is shown in figure 4.2.

### INEL-D WELL

The greatest response to pumping of well UI No.6 occurred

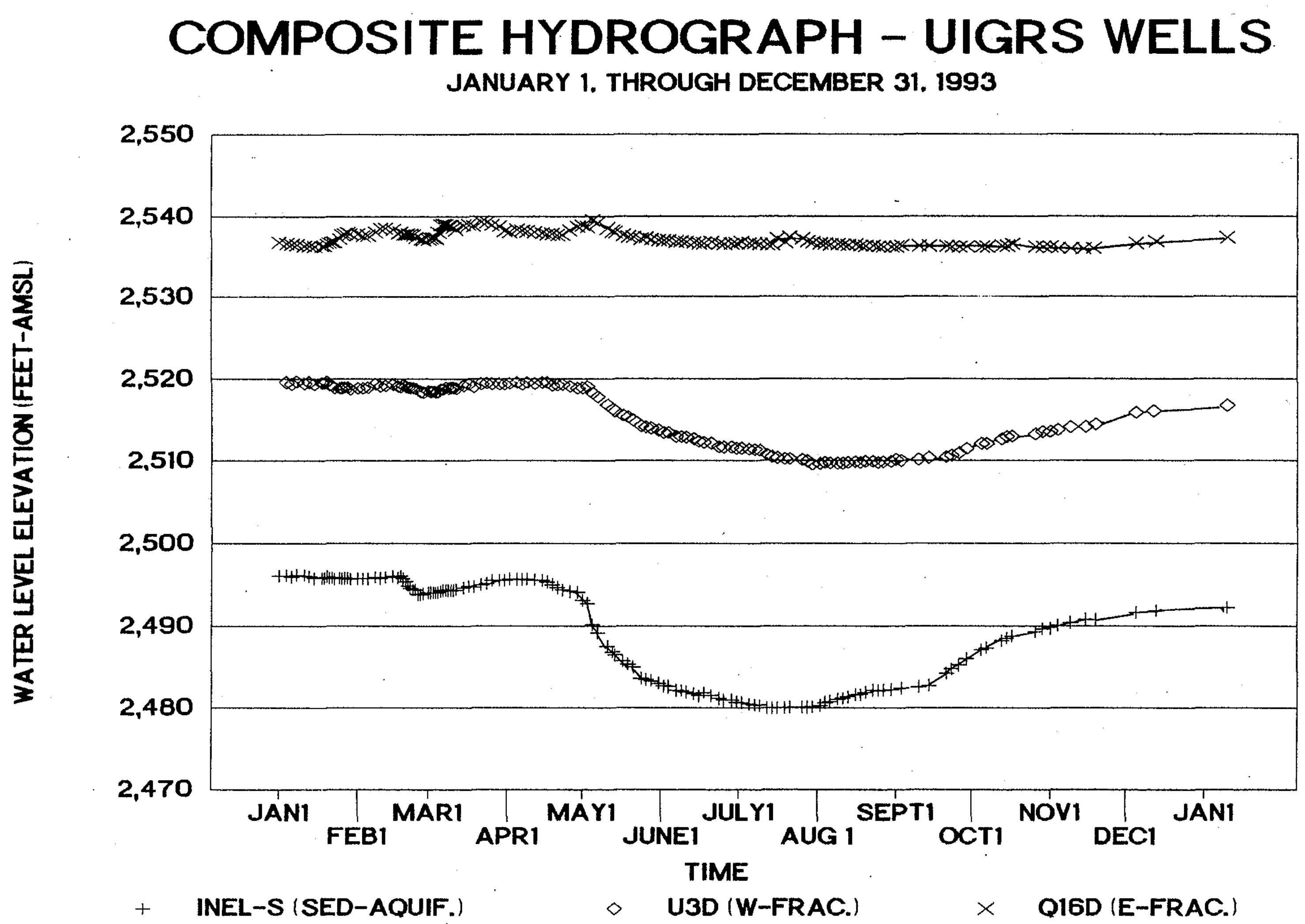



Figure 4.2 Composite long-term hydrograph showing water level elevations in wells INEL-D, U3D, and Q16D during January 1 through December 31, 1993.

in well INEL-D. The long-term hydrograph for this well showing water level elevations during the period January to December, 1993, is shown in figure 4.3. The INEL well was drilled in 1992; therefore, no data are available from a prior year for comparison. Both the seven-day pump test in February and the long-term pumping are apparent in the hydrograph for this well. During the long-term pumping of well UI No. 6, the water level in INEL-D dropped 15.85 feet from a static elevation of 2495.84 feet (AMSL) on April 9 to 2479.99 feet (AMSL) on July 14. A slow recovery in the water level in response to the reduced pumping rate in well UI No. 6 was observed beginning in mid-July. By September 16, the last day of steady pumping during 1993, the water level had recovered 1.74 feet to an elevation of 2481.73 feet (AMSL). The water level continued to recover at a slow rate following the termination of pumping in well UI No. 6. On January 10, 1994 the water level was at 2491.24 feet (AMSL), 4.6 feet below the static elevation at the start of the six-month pumping period. Full recovery of the INEL-D well was not observed nearly four months after the termination of pumping well UI No. 6.

<u>W-FRACTURED WELLS</u>

Five wells at the UIGRS are completed in the W-Fractured aquifer. Included in this category are wells J16D, D19D, U3D, S12D2 and INEL-S. Well INEL-S is included here based on its similarity in water level elevation and drawdown response

## LONG-TERM HYDROGRAPH FOR WELL INEL-D

JANUARY 1, THROUGH DECEMBER 31, 1993

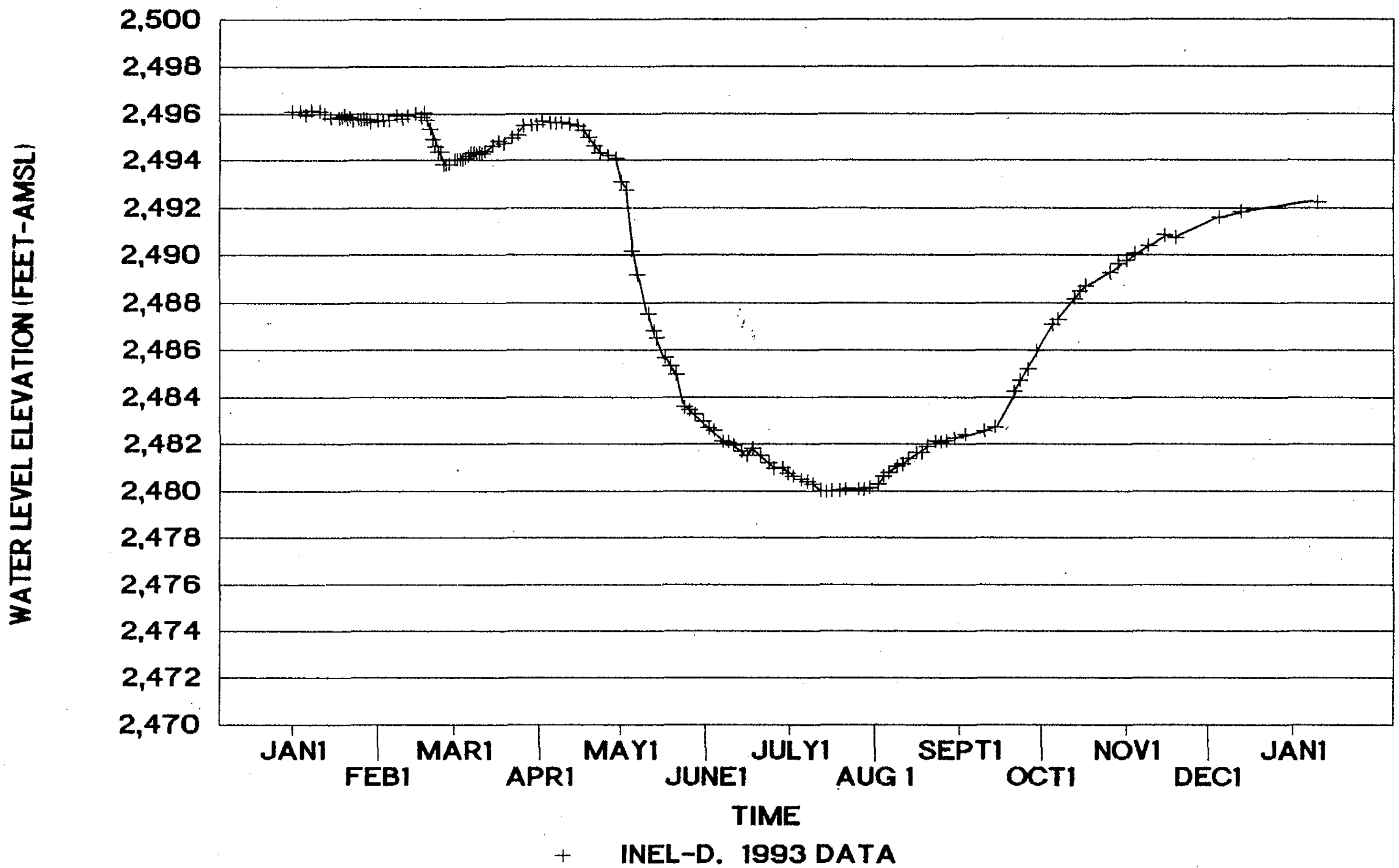



Figure 4.3 Long-term hydrograph showing water level elevations in well INEL-D during January 1 through December 31, 1993.

to that observed in the other W-Fractured wells. Long-term hydrographs for these wells are shown in figures 4.4 through 4.8. The initial response to long-term pumping in well UI No. 6 was observed in all W-Fractured wells in early May. Maximum drawdown was recorded in these wells around August 1. Respective maximum drawdowns of 9.53, 10.94, 9.53, 9.46 and 9.21 feet were observed in wells J16D, D19D, U3D, S12D2 and INEL-S. Water levels began to slowly rise again after August 1, with recoveries ranging from 0.74 feet in S12D2 to 0.82 feet in D19D by September 16. These recoveries are attributable to the reduction in the pumping rate in well UI No. 6 during this period. Water levels in these wells continued to rise slowly following the shut-off of the pump in well UI No. 6. Water levels in the W-Fractured aquifer wells had not recovered to pre-pumping static levels by January 10, 1994. The shortfall in water level recovery on this date in these wells ranged from 2.30 feet in well INEL-S to 4.39 feet in well D19D.

E-FRACTURED AND SHALLOW ALLUVIAL AQUIFER WELLS

Four wells at the UIGRS completed in the E-Fractured aquifer were monitored during the period January to December, 1993. These wells are V16D, T16D, Q16D and Q17D. Two wells J16S and Q16S, completed in the shallow alluvial aquifer were also monitored. Long-term hydrographs for these wells are shown in figures 4.9 through 4.14.

Drawdown patterns and water level elevations in the E-

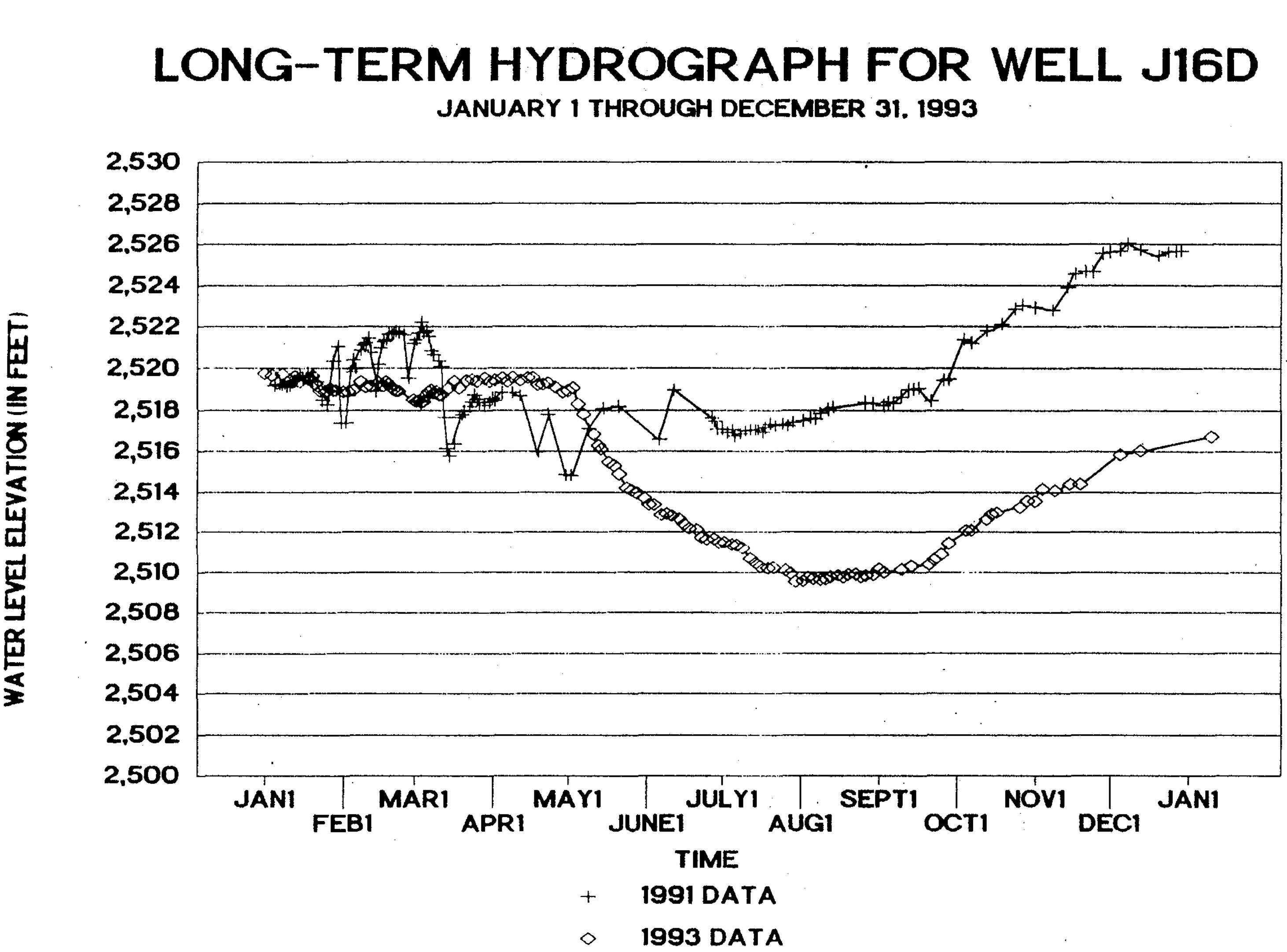



Figure 4.4 Long-term hydrograph showing water level elevations in well J16D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

## LONG-TERM HYDROGRAPH FOR WELL D19D

**JANUARY 1 THROUGH DECEMBER 31, 1993**

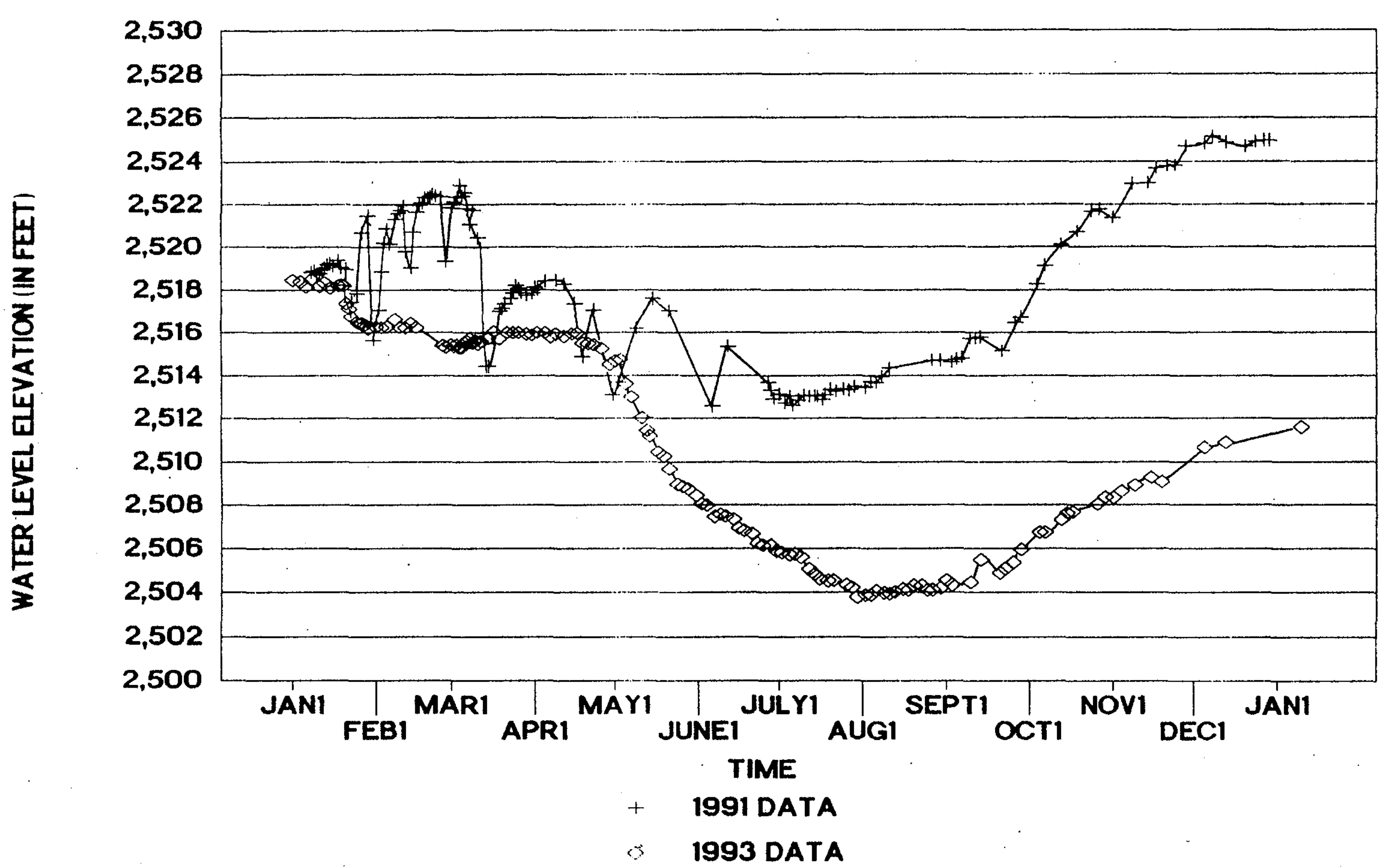



Figure 4.5 Long-term hydrograph showing water level elevations in well D19D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

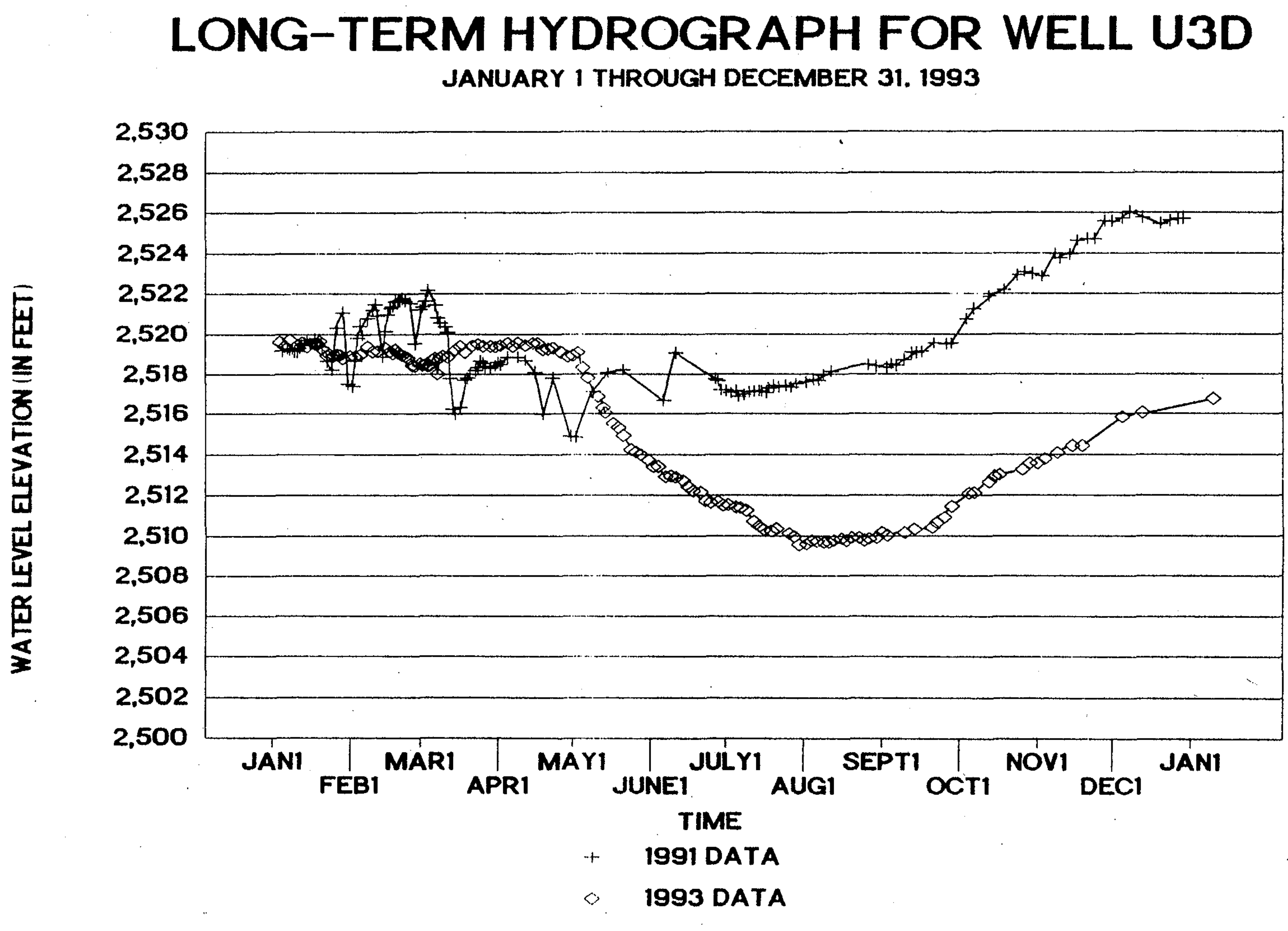



Figure 4.6 Long-term hydrograph showing water level elevations in well U3D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

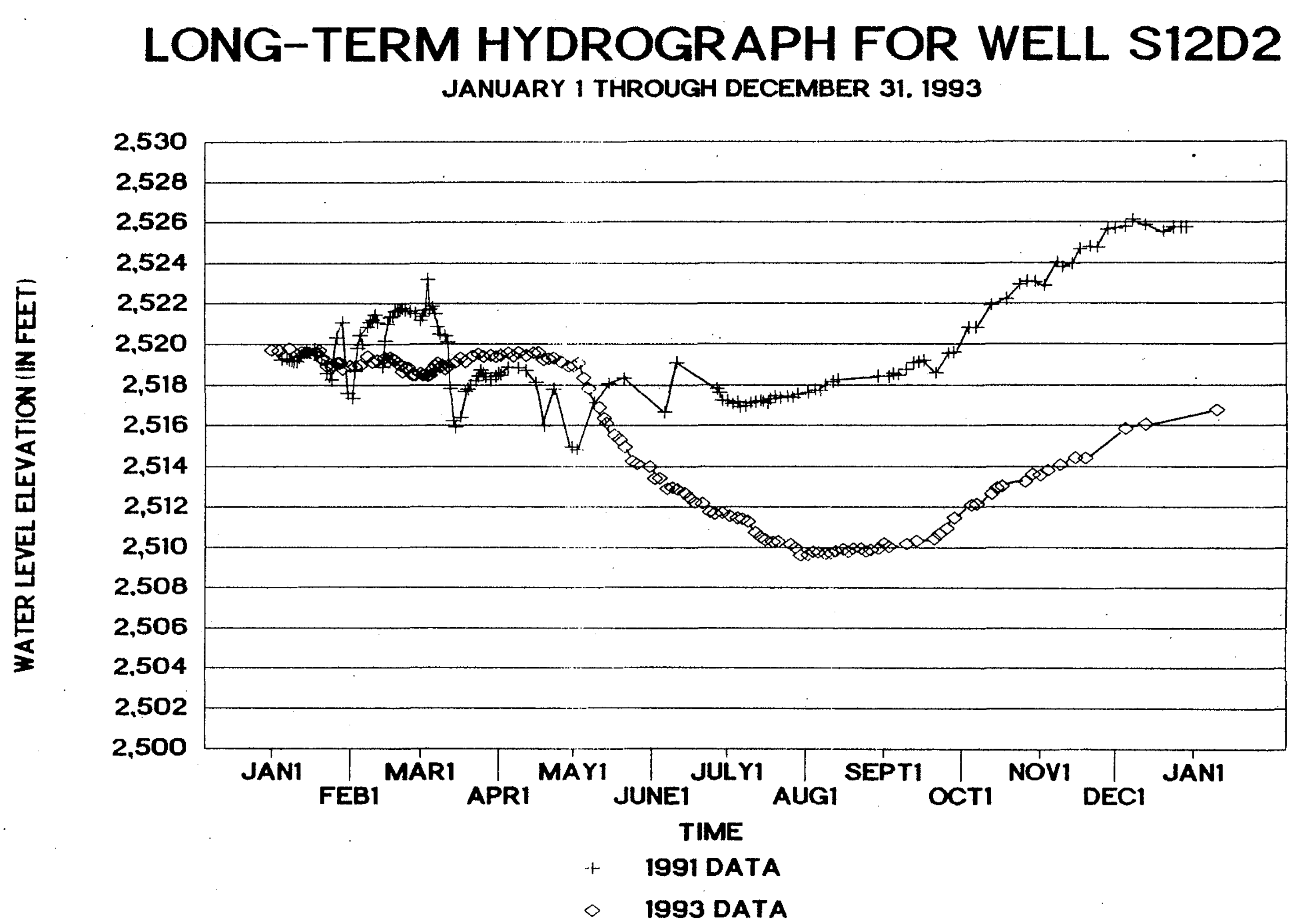



Figure 4.7 Long-term hydrograph showing water level elevations in well S12D2 during January 1 through December 31, 1993 and January 1 through December 31, 1991.

# LONG-TERM HYDROGRAPH FOR WELL INEL-S

JANUARY 1, THROUGH DECEMBER 31, 1993

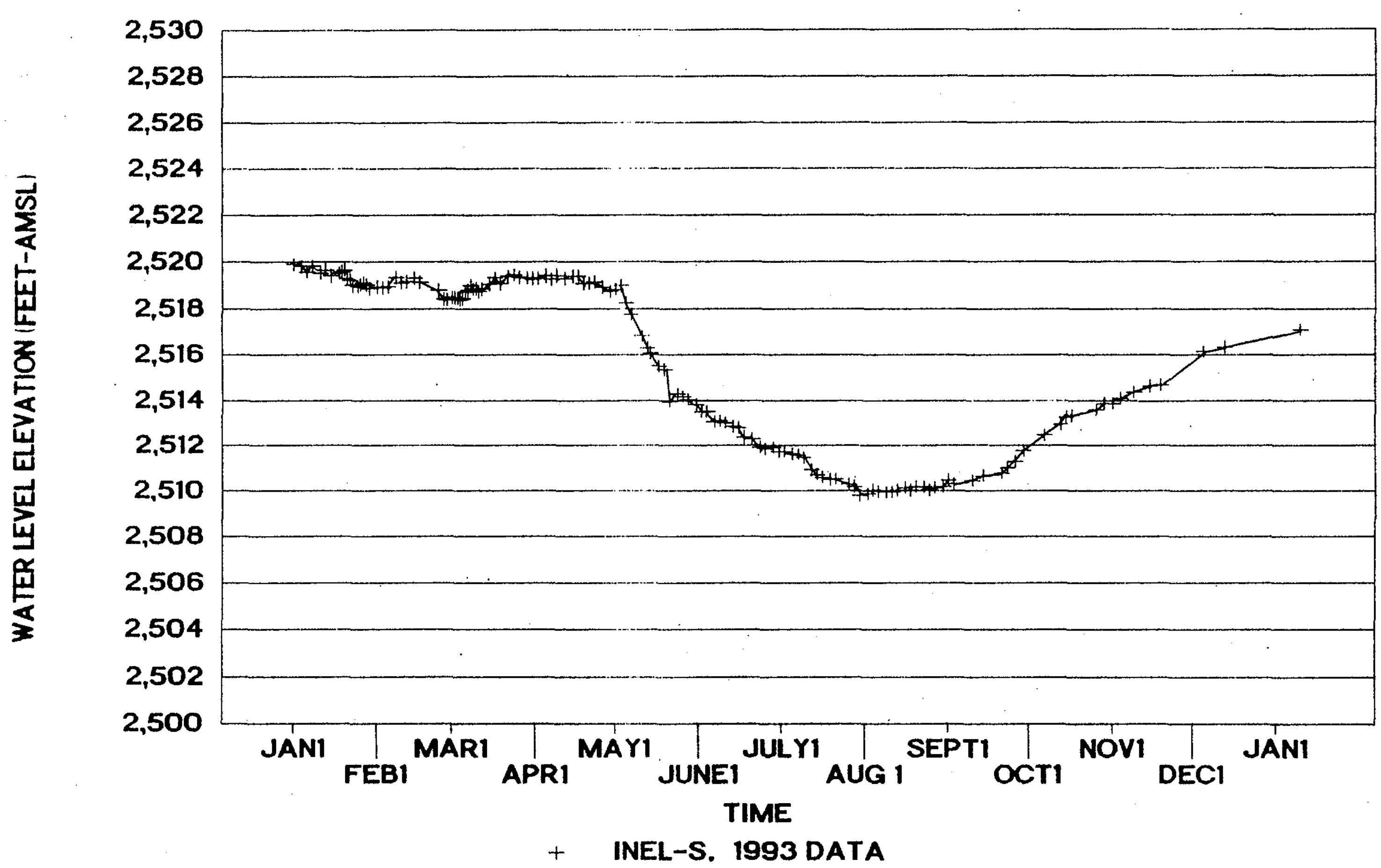



Figure 4.8 Long-term hydrograph showing water level elevations in well INEL-S during January 1 through December 31, 1993.

# LONG-TERM HYDROGRAPH FOR WELL V16D

JANUARY 1 THROUGH DECEMBER 31, 1993

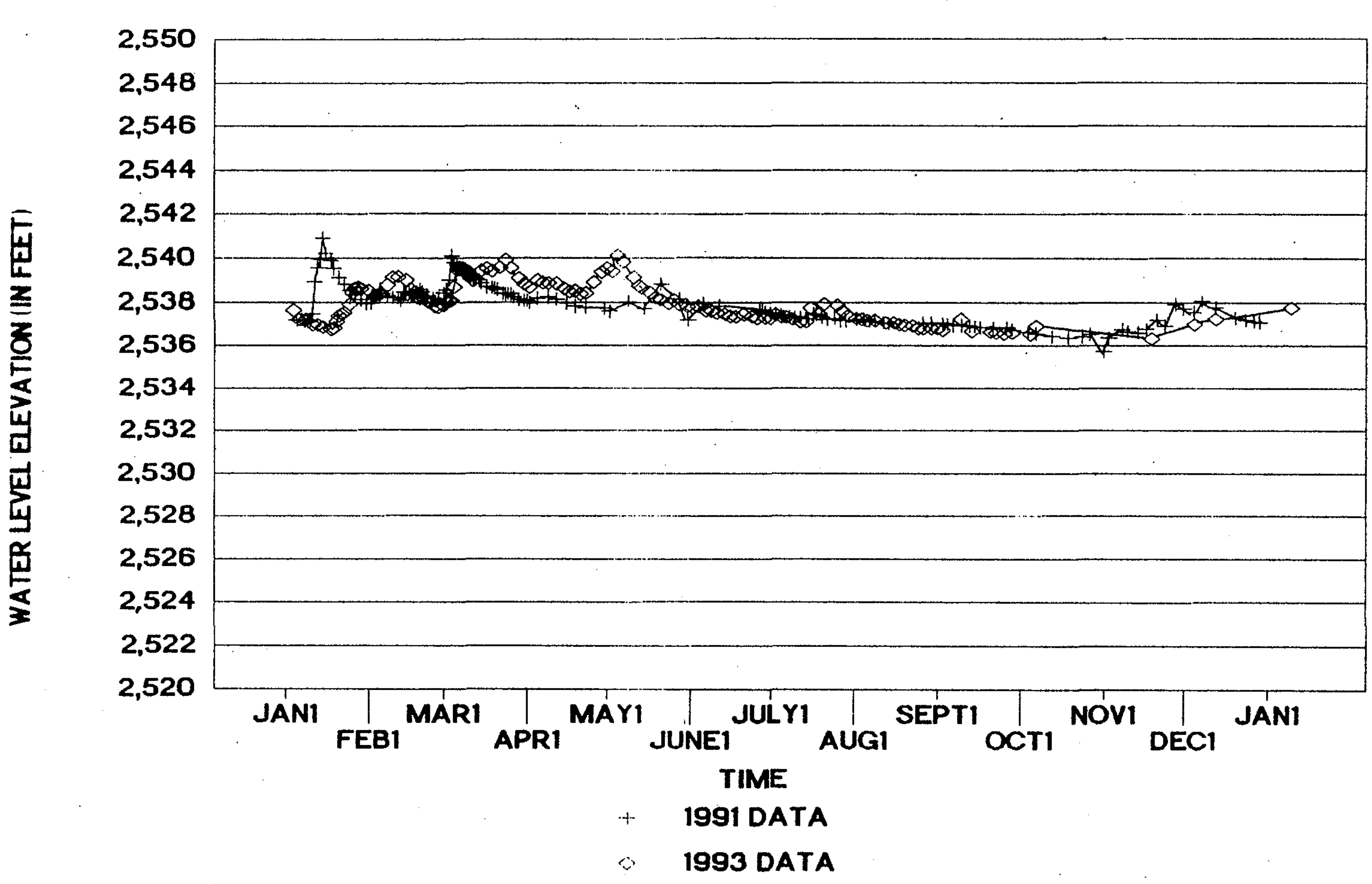



Figure 4.9 Long-term hydrograph showing water level elevations in well V16D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

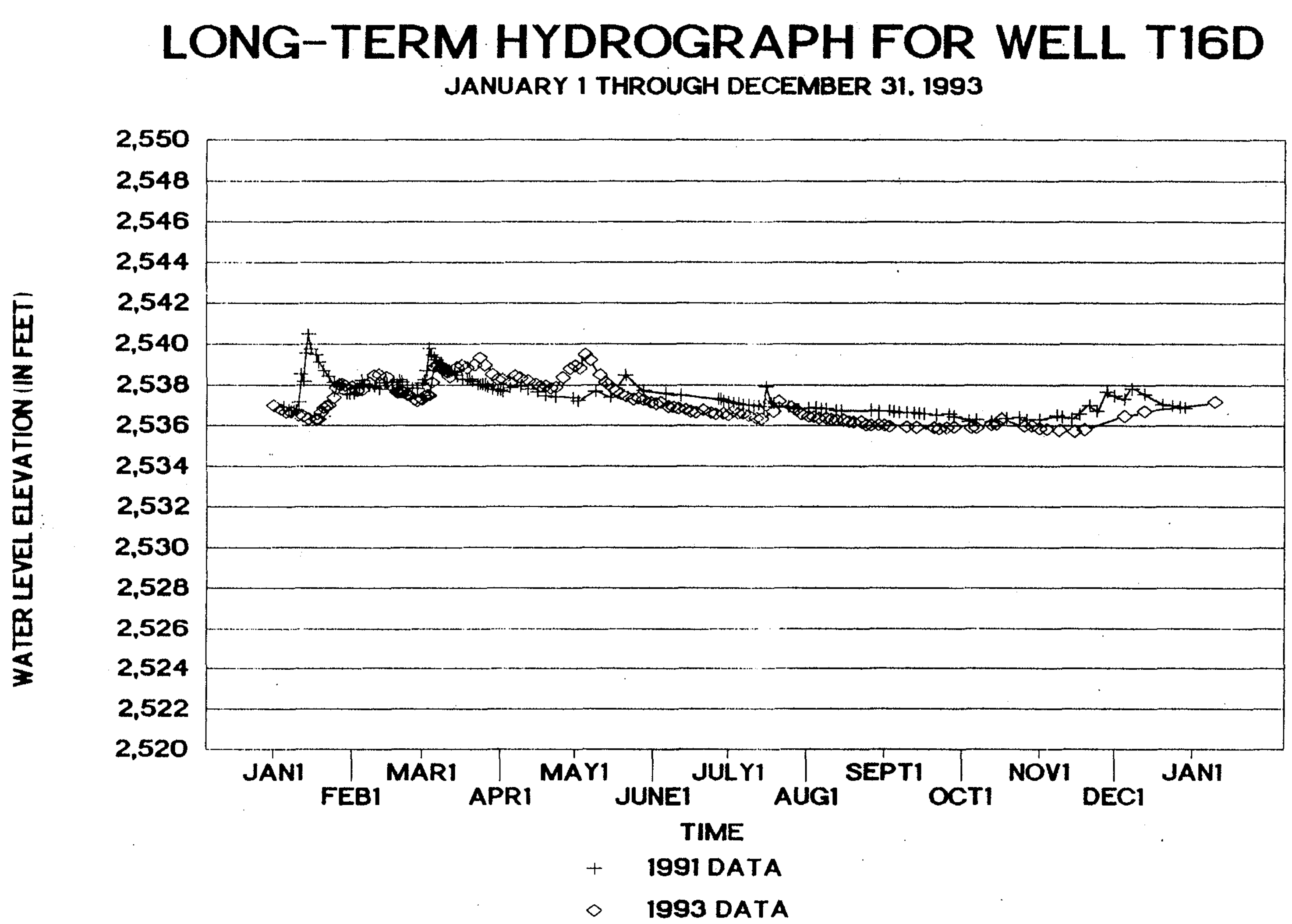



Figure 4.10 Long-term hydrograph showing water level elevations in well T16D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

## LONG-TERM HYDROGRAPH FOR WELL Q16D

JANUARY 1 THROUGH DECEMBER 31, 1993

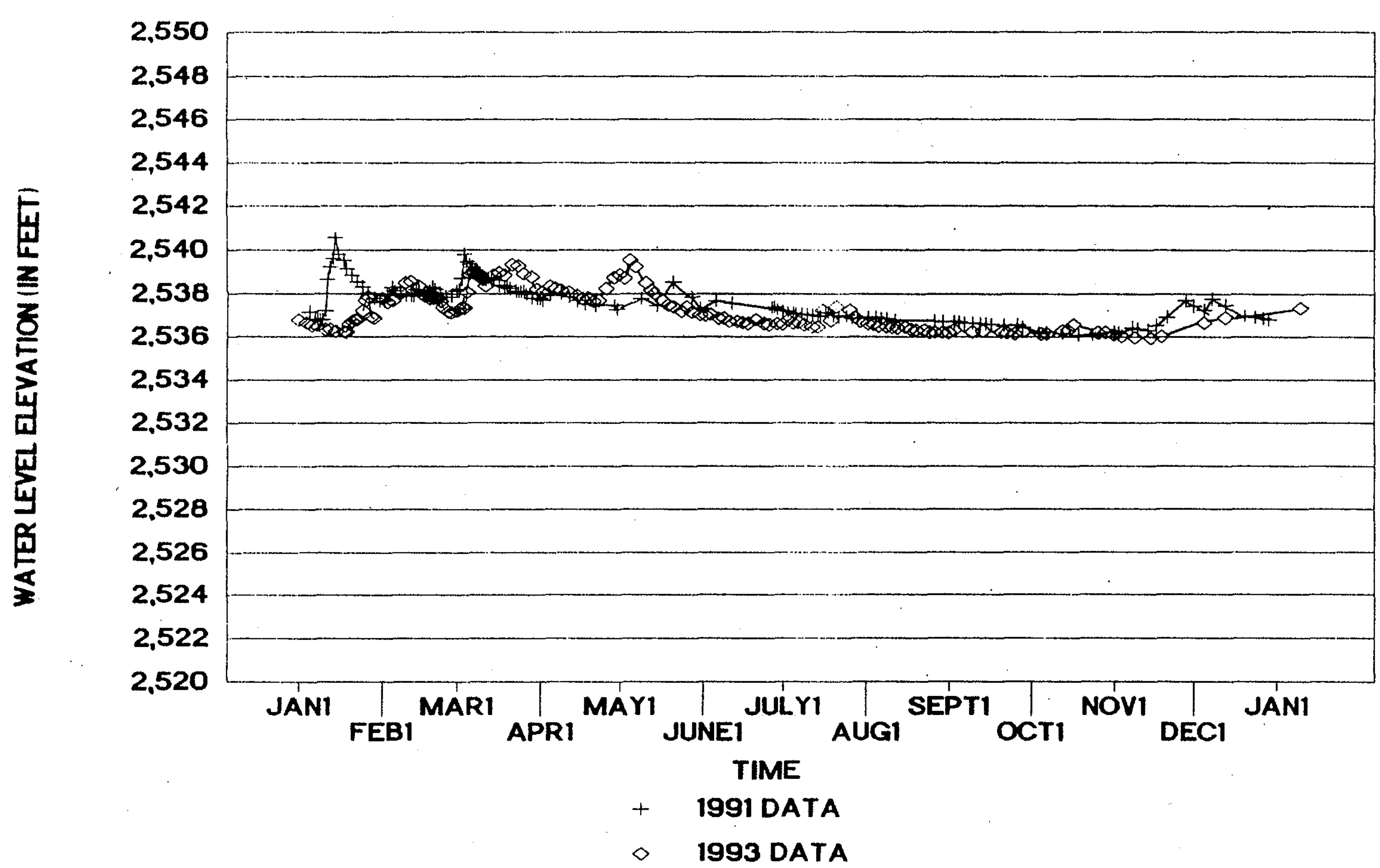



Figure 4.11 Long-term hydrograph showing water level elevations in well Q16D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

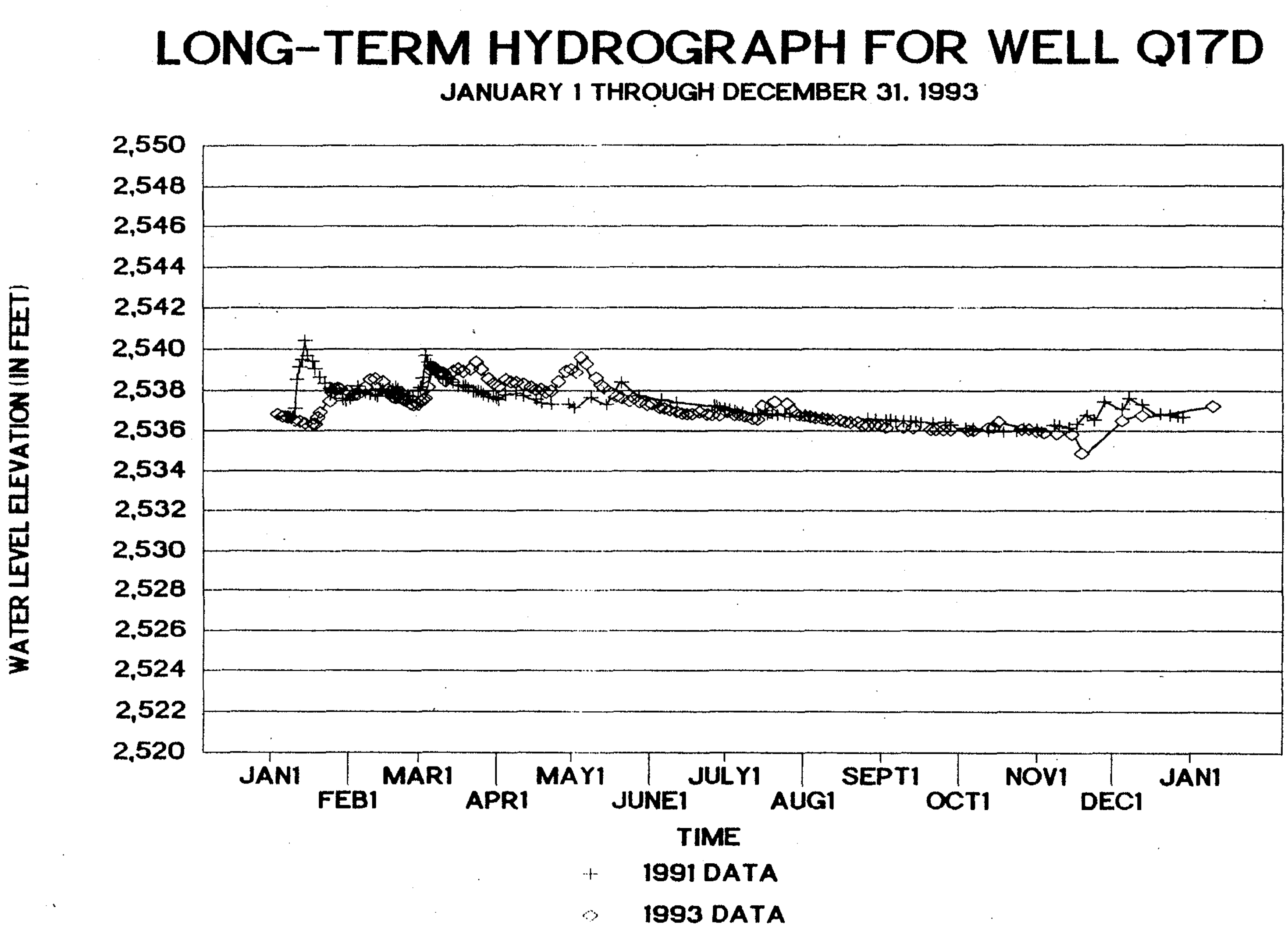



Figure 4.12 Long-term hydrograph showing water level elevations in well Q17D during January 1 through December 31, 1993 and January 1 through December 31, 1991.

# LONG-TERM HYDROGRAPH FOR WELL J16S

JANUARY 1 THROUGH DECEMBER 31, 1993

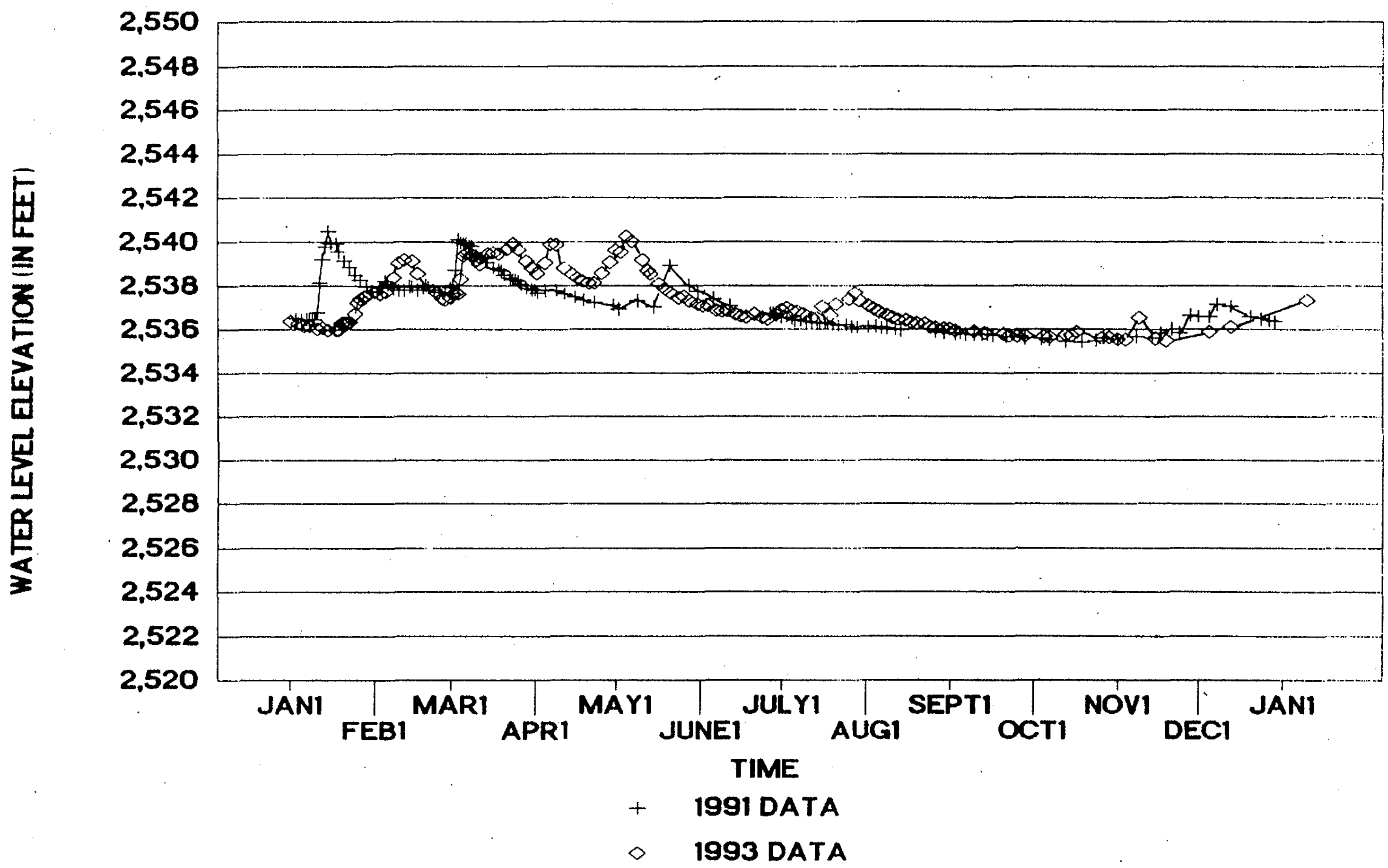



Figure 4.13 Long-term hydrograph showing water level elevations in well J16S during January 1 through December 31, 1993 and January 1 through December 31, 1991.

## LONG-TERM HYDROGRAPH FOR WELL Q16S

JANUARY 1 THROUGH DECEMBER 31, 1993

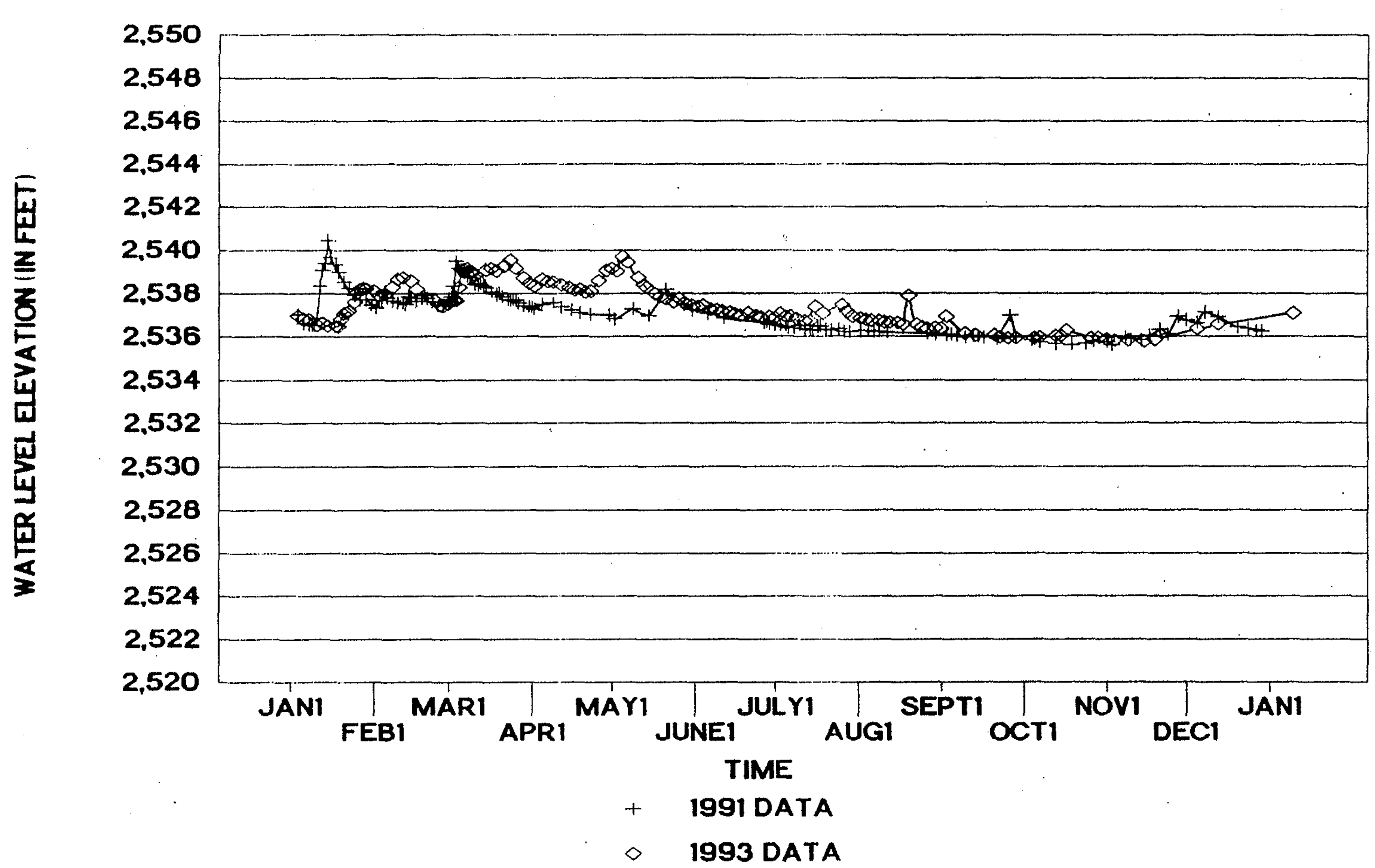



Figure 4.14 Long-term hydrograph showing water level elevations in well Q16S during January 1 through December 31, 1993 and January 1 through December 31, 1991.

Fractured wells and in the shallow alluvial aquifer wells are very similar. None of these wells show a definite response to long-term pumping in well UI No. 6. Comparison of the 1991 data and 1993 data indicate that the slight decline in water levels observed during June through October are attributable to seasonal decline, and are not a response to pumping of well UI No. 6.

OTHER UIGRS WELLS

Two wells at the UIGRS, wells S12D1 and U3S, are completed in unclassified fractures in the basalt. The long-term hydrographs for these wells are shown in figures 4.15 and 4.16.

Water levels in well S12D1 respond in a pattern similar to that recorded in the W-Fractured wells, but show a longer lag-time before response is observed. Response to some recharge events that were observed in E-Fractured wells are also reflected in this well. The aquifer in well S12D1 is hydraulically connected to some degree with both the E-Fractured and W-Fractured aquifers. Comparison of the data from 1991 with the 1993 data indicates that water levels in this well are declining annually at a rate of from 2 to 5 feet per year. This decline is also reflected in the partial data available for 1992. The reasons for this decline have not been determined.

The long-term hydrograph for well U3S shows some similarity to water level pattern observed in the E-Fractured

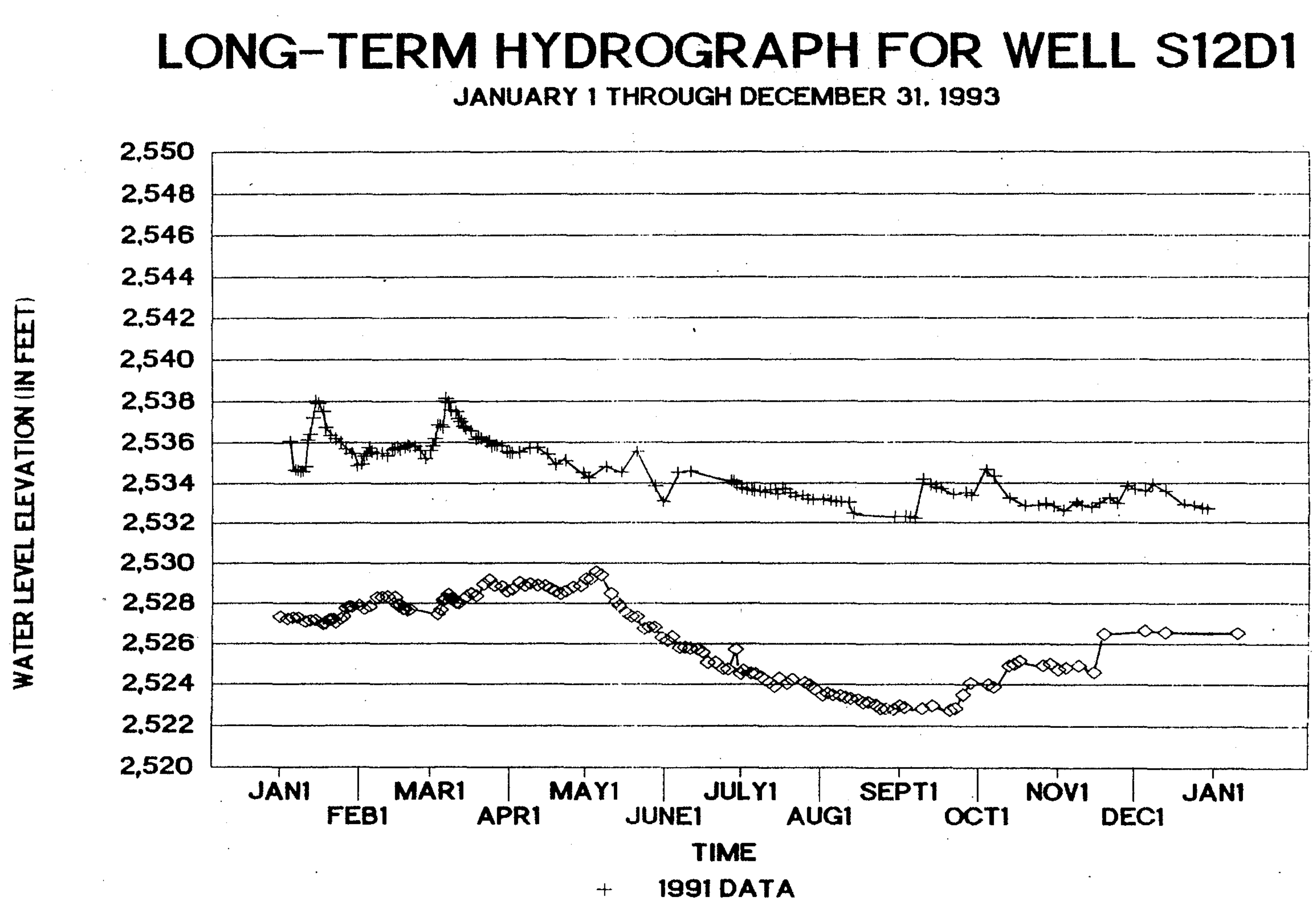



Figure 4.15 Long-term hydrograph showing water level elevations in well S12D1 during January 1 through December 31, 1993 and January 1 through December 31, 1991.

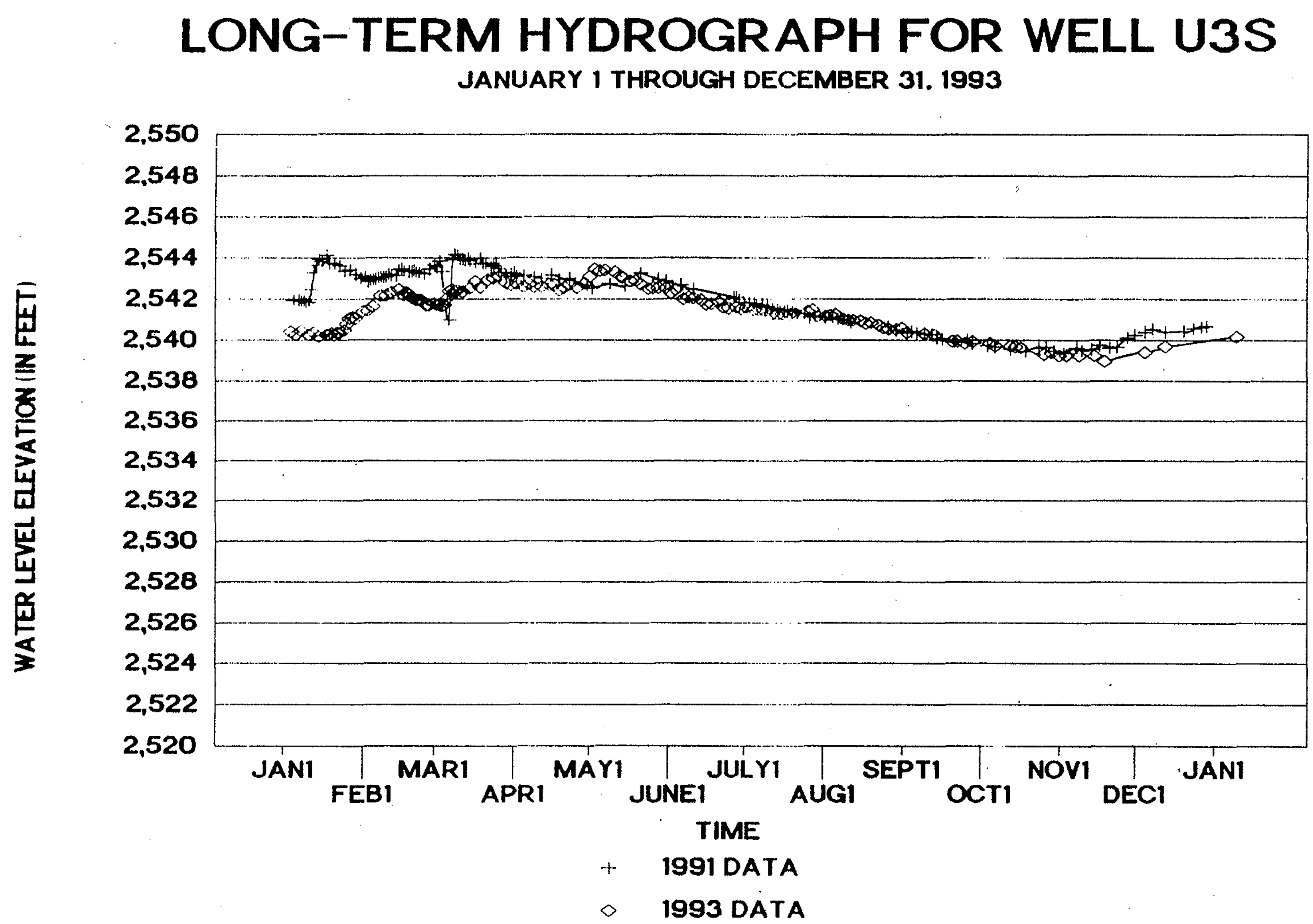



Figure 4.16 Long-term hydrograph showing water level elevations in well U3S during January 1 through December 31, 1993 and January 1 through December 31, 1991.

wells and shallow alluvial aquifer wells. No response to the pumping of well UI No. 6 is reflected in this hydrograph. The fracture in well U3S is not hydraulically connected with the W-fractured zone or the aquifers in the sediment interbed.

# CHAPTER 5

## CONCEPTUAL HYDROGEOLOGICAL MODEL

The upper aquifer at the Aquaculture site is conceptualized as a sub-horizontal multilayered system. Water-bearing zones are present both in the Wanapum Basalt and in the underlying sediment interbed of the Latah formation. Ground water development at the site and in deeper wells at the adjoining UIGRS is confined to the basalt flow and to the upper one-third of the sediment interbed. The conceptual model for the upper aquifer at the Aquaculture site and adjacent UIGRS is illustrated in figure 5.1.

### AQUIFERS IN THE BASALT

Aquifers in the basalt are formed from interconnecting fractures at several horizons within the Lolo flow. Important water-bearing zones include a section with multiple fractures located from 60 to 120 feet below the top of the flow, and a vesicular and fractured section near the base of the flow. Horizontal to sub-horizontal fractures are the principal water-bearing structures. Near-vertical columnar joints and high-angle faults may locally be ae important as recharge avenues.

Li (1991) described two primary water-bearing fracture sets at the UIGRS which he named the W- and E-Fractured aquifers. The E-Fractured aquifer is restricted to the

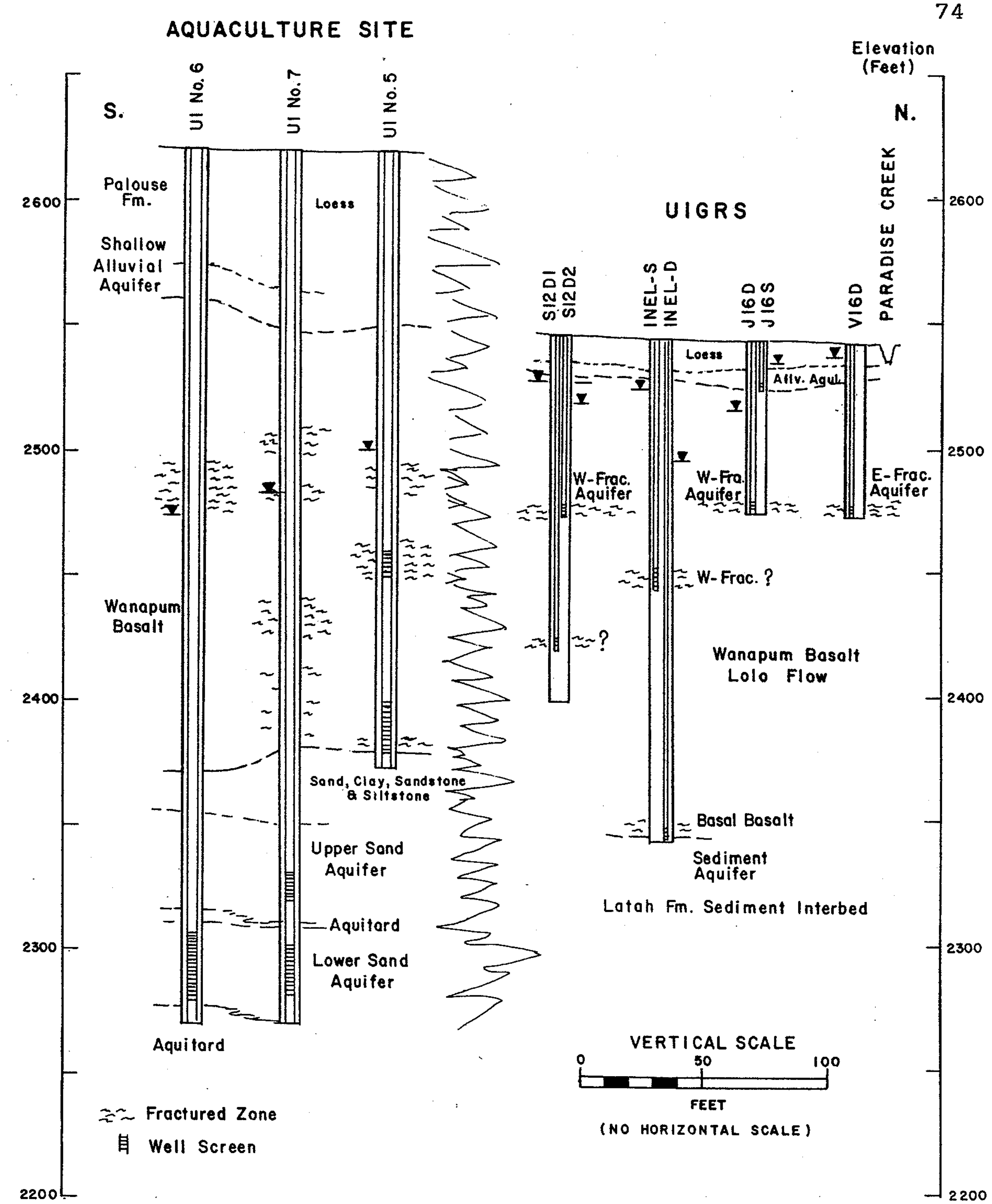



Figure 5.1 Conceptual hydrogeologic model for the upper aquifer at the Aquaculture site and adjacent UIGRS.

northeast corner of the UIGRS, and has not been identified in wells at the Aquaculture site. Li (1991) described the W-Fractured aquifer as occurring at the contact of an entablature and colonnade structure near the middle of the Lolo flow. The W-Fractured aquifer appears to be more widespread. Drawdown, noted in the W-Fractured wells during drilling and development of wells UI No. 6 and UI No. 7, indicates that a hydraulic connection exists between the zone of multiple fractures near the middle of the basalt in these wells and the W-Fractured wells at the UIGRS. Water-bearing fractures are apparent in the logs from wells UI No. 5 and INEL-D near the base of the Lolo flow. Little is known regarding the lateral extent or the water yield from this basal zone.

A poor hydraulic connection exists at the UIGRS between wells completed in the E-Fractured aquifer and wells in the W-Fractured aquifer (Li, 1991). No hydraulic connection has been observed between the W-Fractured aquifer and the shallow alluvial aquifer overlying the basalt.

AQUIFERS IN THE SEDIMENT INTERBED

Water-bearing zones within unconsolidated sand layers in the upper 110 feet of the interbed are the most prolific aquifers in the upper aquifer system. Geologic logs from water wells located several thousands of feet to the north, south and east of the Aquaculture wells, show a similar thick sequence of sands in the upper section of the sediment interbed. Although the sand layer is laterally extensive, facies changes within this formation may limit the extent of individual aquifers.

Two distinct aquifers are present in this sediment sequence at the Aquaculture site: the upper sand aquifer and the lower sand aquifer. Well UI No. 6 penetrates both aquifers but is completed in only the lower sand aquifer. Well UI No. 7 is completed in both the upper and lower sand aquifers. Separating the two aquifers is a thin aquitard layer consisting of poor to well consolidated, thinly laminated siltstone and sandstone. Well INEL-D is completed at the very top of the sediment interbed, and is not located in the same aquifer as well UI No. 6. Significant lateral changes in facies in this aquitard are present between wells UI No. 6 and UI No. 7; a distance of only 122 feet. The long lag-time observed in well INEL-D in response to pumping of well UI No. 6, indicates that this aquitard extends out laterally at least as far as the UIGRS.

The upper sand aquifer is overlain gradationally by a section of poorly consolidated sandstone and siltstone that extends up to the base of the basalt. Well INEL-D is completed at the upper contact of this sediment layer at the base of the Lolo basalt. Interstitial cementation of the mineral grains results in a slightly lower hydraulic conductivity for this layer compared to the unconsolidated sand aquifers. Logs from wells located 3500 to 5000 feet to the south show a thickening and a gradation of this layer to predominantly clay. A similar, but more highly consolidated sandstone layer underlies the lower sand aquifer, and in well UI No. 6 forms an aquitard below the sand.

GROUND WATER MOVEMENT

The cone of depression around well UI No. 6 has a large horizontal component and a significant vertical component. Leakage occurs between the lower sand aquifer and both the overlying upper sand aquifer and the W-Fractured aquifer. When pumping well UI No. 6, no leakage is observed in the wells at the UIGRS completed in the E-Fractured or shallow alluvial aquifers. A downward vertical gradient is observed between wells completed in the W-Fractured and basal basalt aquifers and wells completed in the underlying sediments. A similar downward vertical gradient is observed between aquifers in the upper aquifer in the Lennard Chin well, approximately 3600 feet south of the Aquaculture site. Static water level measurements taken in wells UI No. 6 and UI No. 7 show that the water level is approximately 9 feet higher in Well UI No. 7. This indicates that a vertical downward gradient exists between the upper and lower sand aquifers in well UI No. 7.

Recovery data measured in wells UI No. 6 and UI No.7 show that water levels in the lower and upper sand aquifers recover rapidly following periods of short-term and long-term pumping. Water levels in wells completed in the W-Fractured aquifer and the INEL-D well show a significant delay in recovery from pump tests conducted in well UI No 6. Measurements made in these wells on January 10, 1994, 116 days after the pump in well UI No. 6 was turned off, show water levels well below pre-pumping static levels. Recharge to the W-Fractured aquifer and the aquifer in well INEL-D is slow, and long-term pumping of the underlying sand aquifers might seriously affect water levels in these minor aquifers.

On the bases of hydraulic interconnection, the upper aquifer is divided into two separate systems. The upper system, which extends from surface to approximately 45 feet below the top of the Lolo basalt, includes the shallow alluvial aquifer and E-Fractured aquifer. The lower system extends from approximately 50 feet below the top of this flow, down at least through the upper one-third of the sediment interbed. This system includes the W-Fractured aquifer and the two sand aquifers in the sediment interbed. A hydraulic barrier, probably a basalt aquiclude with poor interconnecting fractures, segregates these two systems.

# CHAPTER 6

# DESCRIPTION AND ANALYSIS OF HYDRAULIC TESTING

## DESCRIPTION OF FEBRUARY,1993 AQUIFER TEST-WELL UI NO. 6

A seven-day aquifer test was conducted in well UI No. 6 during the period February 18-25, 1993. The pumping rate during the test was controlled through a gate valve installed at the collar of the well. The flow rate was monitored using a flowmeter with a totalizer gage mounted adjacent to the gate valve. Flow rates measured at the gage ranged between 116 and 148 gallons per minute, and averaged very close to the target rate of 125 gallons per minute during most of the test. Figure 6.1 is a graph illustrating the variations in the pumping rate recorded with the totalizer gage. Discharge water from the well was diverted away from the site through a shallow ditch into a small valley located northwest of the Aquaculture laboratory. Total volume of water pumped from the well during this seven-day period is estimated at 1.26 million gallons (Ralston, personal communications, 1993).

Fifteen observation wells, including UI No. 5, UI No.2, and 13 wells at the UIGRS, were monitored for water level elevation during this test. A list of the wells included in this and subsequent aquifer tests conducted in 1993 at the

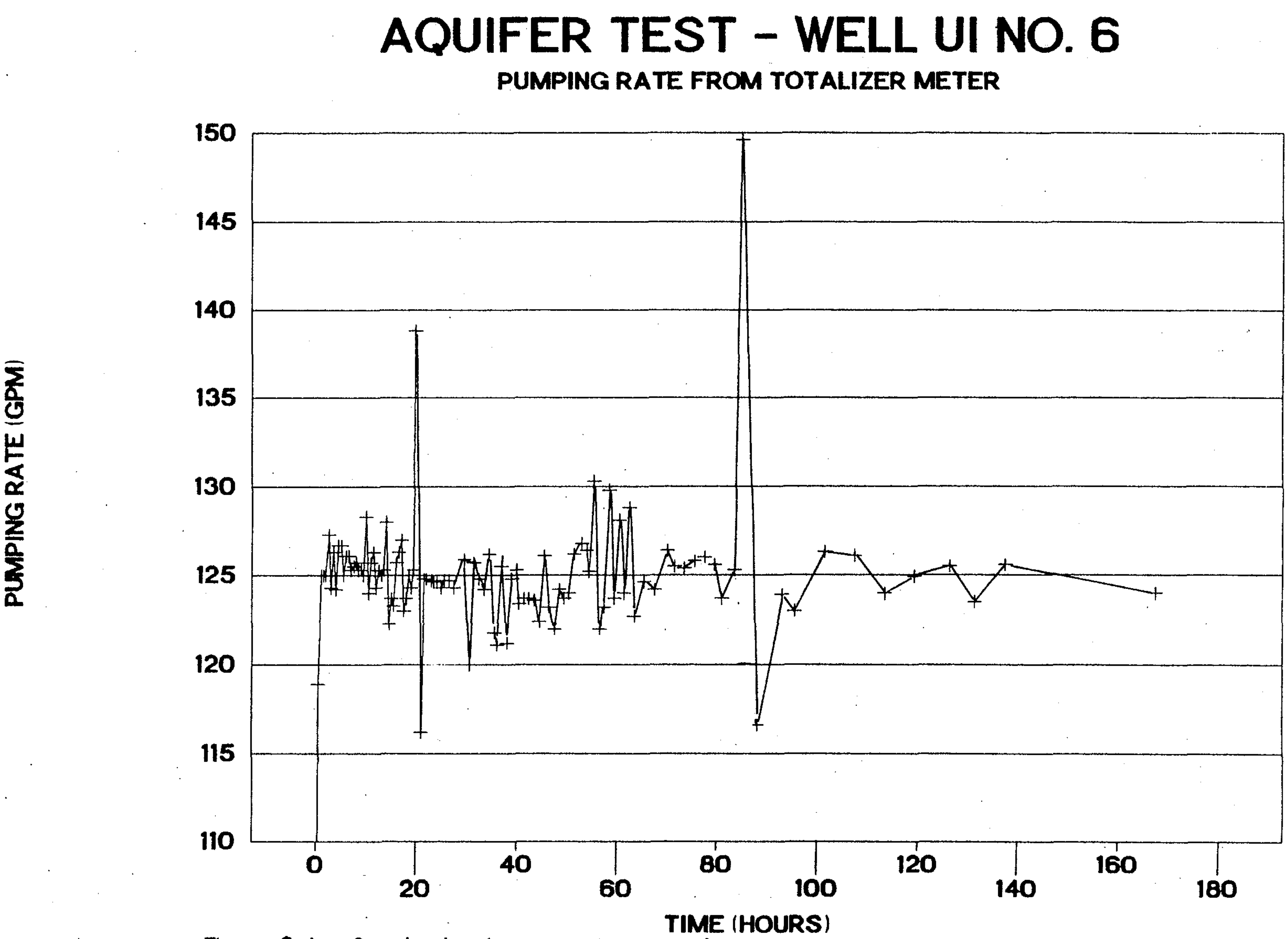



Figure 6.1 Graph showing pumping rate from totalizer meter at well UI No. 6 during February, 1993 aquifer test.

Aquaculture site, is presented in table 6.1. Table 6.2 is a list of wells included in the February, 1993 aquifer test, and shows water level drawdown data for each well. Recovery data were measured in these wells for approximately 10 days following shut-off of the pump. Additional long-term recovery data were obtained for wells at the UIGRS from the ongoing well monitoring program at this site. Well response and recovery data for each well are shown in table 6.3.

Depth to water was measured in well UI No. 6 using an electrical tape. Water levels were also monitored during part of the recovery period using a Campbell Scientific Model 21X datalogger. Measurements in the observations wells were taken using either a steel tape, an electrical tape or a datalogger. Static water level elevations were measured periodically during an eight-day period prior to the start of the test in all wells except UI No. 2 and UI No. 5. All water level depth measurements are referenced to measuring points at the top of the casing or piezometer.

The pumping test was started at 12:15 pm on February 18. The pump was turned off at 12:45 pm on February 25, after 168.48 hours of continuous pumping. Depth to water measurements were taken in the pumping well as frequently as possible, or at approximate 15-second intervals, during the first 10 minutes of the test. The time intervals between measurements were gradually increased to one minute after 30 minutes, every hour after 24 hours, and every six hours from

TABLE 6.1 LIST OF WELLS INCLUDED IN 1993 AQUIFER TESTS AT AQUACULTURE SITE

| WELL NO. | LOCATION | YEAR CONSTRUCTED | DEPTH (FEET) | GROUND ELEV. (FEET AMSL) | DATUM ELEV. (FEET AMSL) |
|---|---|---|---|---|---|
| UI NO. 7 | AQUA SITE | 1993 | 350 | 2617 | 2619 |
| UI NO. 6 | AQUA SITE | 1993 | 351 | 2618.5 | 2620.5 |
| UI NO. 5 | AQUA SITE | 1991 | 247 | 2617 | 2619 |
| UI NO. 2 | CAMPUS | 1951 | 354 | 2553 | 2557.8 |
| INELD&S | UIGRS | 1992 | 205 | 2544 | 2545.1 |
| J16D | UIGRS | 1990 | 68 | *2545.6 | *2546.68 |
| U3D | UIGRS | 1990 | 83 | *2547.65 | *2548.62 |
| S12D2 | UIGRS | 1989 | 146 | *2545.95 | *2546.93 |
| D19D | UIGRS | 1987 | 140 | *2542.74 | *2543.76 |
| V16D | UIGRS | 1987 | 70 | *2543.46 | *2544.41 |
| T16D | UIGRS | 1988 | 80 | *2543.61 | *2545.24 |
| Q17D | UIGRS | 1987 | 100 | *2544.98 | *2545.95 |
| Q16D | UIGRS | 1990 | 80 | *2545.1 | *2546.96 |
| U3S | UIGRS | 1990 | 83 | *2547.65 | *2548.62 |
| S12D1 | UIGRS | 1989 | 146 | *2545.95 | *2546.93 |
| J16S | UIGRS | 1990 | 68 | *2545.6 | *2546.68 |
| Q16S | UIGRS | 1990 | 80 | *2545.1 | *2546.96 |

* GROUND AND DATUM ELEVATIONS FROM LI (1991)

TABLE 6.2 LIST OF WELLS INCLUDED IN FEBRUARY, 1993 AQUIFER TEST IN WELL UI NO. 6
SHOWING WELL DRAWDOWN DATA

FEBRUARY 18, THROUGH 25, 1993

| | | UNCORRECTED VALUES | | | CORRECTED VALUES | | | | |
|---|---|---|---|---|---|---|---|---|---|
| WELL NO. | AQUIFER | STATIC DTW (FT) | MAX. DTW (FT) | DRAWDOWN (FT) | STATIC DTW (FT) | MAX DTW (FT) | DRAWDOWN (FT) | B. E. PERCENT | WELL SCREEN (FT) |
| UI NO. 6 | SAND | -143.88 | -189.09 | 45.21 | -143.88 | -188.97 | 45.09 | 60 | 315.75 TO 342 |
| UI NO. 5 | BASALT | -120.91 | -121.55 | 0.64 | -120.92 | -121.51 | 0.59 | 65 | 220-240&305-350 |
| UI NO. 2 | SAND | -40.35 | -40.63 | 0.28 | -40.36 | -40.65 | 0.29 | 85 | 190 TO 275 |
| INEL-D | SAND | -49.15 | -51.15 | 2.00 | -49.16 | -51.04 | 1.88 | 60 | 203 TO 205 |
| J16D | W FRAC. | -27.32 | -27.85 | 0.53 | -27.33 | -27.76 | 0.43 | 65 | 65 TO 67 |
| U3D | W FRAC. | -29.26 | -29.80 | 0.54 | -29.26 | -29.82 | 0.56 | 70 | 80 TO 82.5 |
| S12D2 | W FRAC. | -27.56 | -28.18 | 0.62 | -27.57 | -28.24 | 0.70 | 55 | 64 TO 73 |
| D19D | W FRAC. | -27.52 | -28.48 | 0.96 | N/A | N/A | N/A | N/A | 135 TO 140 |
| V16D | E FRAC | -5.94 | -6.41 | 0.47 | -5.95 | -6.44 | 0.49 | 35 | 64 TO 66.5 |
| T16D | E FRAC. | -7.36 | -7.76 | 0.40 | -7.37 | -7.81 | 0.44 | 40 | 65 TO 69 |
| Q17D | E FRAC. | -8.03 | -8.44 | 0.41 | -8.04 | -8.49 | 0.45 | 40 | 76 TO 79 |
| Q16D | E FRAC. | -8.90 | -9.30 | 0.40 | -8.91 | -9.38 | 0.47 | 40 | 70.5 TO 73 |
| U3S | ? FRAC. | -6.29 | -6.73 | 0.44 | -6.29 | -6.67 | 0.38 | 54 | 33.5 TO 34.5 |
| S12D1 | ? FRAC. | -18.98 | -19.33 | 0.35 | -18.99 | -19.35 | 0.36 | 54 | 118 TO 126 |
| J16S | SHALLOW | -8.25 | -9.02 | 0.77 | -8.25 | -9.06 | 0.81 | N/A | 19 TO 20 |
| Q16S | SHALLOW | -9.18 | -9.60 | 0.42 | N/A | N/A | N/A | N/A | 26.5 TO 28.5 |

UNCORRECTED = AS MEASURED DATA

CORRECTED = MEASURED DATA ADJUSTED FOR B.E. AND/OR STREAM RECHARGE

TABLE 6.3 LIST OF WELLS INCLUDED IN FEBRUARY, 1993 AQUIFER TEST IN WELL UI NO. 6

SHOWING DRAWDOWN RESPONSE AND WELL RECOVERY DATA

| WELL NO. | AQUIFER | RESPONSE TO TEST? | UNCORRECTED DELAY IN RESPONSE IN HOURS | *CORRECTED DELAY IN RESPONSE IN HOURS | REMARKS |
|---|---|---|---|---|---|
| UI NO. 6 | SAND | YES | IMMEDIATE | IMMEDIATE | NOT FULLY RECOVERED AT 407 HRS.(SHORT 5.68 FT.) |
| UI NO. 5 | BASALT | YES | 41.76 | 4.00 | NOT FULLY RECOVERED AT 335 HRS.(SHORT 0.58 FT.) |
| UI NO. 2 | SAND | YES? | 42.40 | 127.16 | NOT FULLY RECOVERED AT 241 HRS.(SHORT 0.82 FT.) |
| INEL-D | SAND | YES | 42.34 | 1.91 | NOT FULLY RECOVERED AT 1205 HRS.(SHORT 0.27 FT.) |
| J16D | W FRAC. | YES | 42.25 | 8.08 | FULL RECOVERY AT 815 HRS. |
| U3D | W FRAC. | YES | 42.35 | 4.17 | FULL RECOVERY AT 815 HRS. |
| S12D2 | W FRAC. | YES | 42.31 | 6.82 | FULL RECOVERY AT 935 HRS. |
| D19D | W FRAC. | YES | N/A | N/A | FULL RECOVERY AT 460 HRS. |
| V16D | E FRAC. | ? | 40.29 | 6.00 | DID NOT RESPOND TO TEST |
| T16D | E FRAC | ? | 40.32 | 5.92 | DID NOT RESPOND TO TEST |
| Q17D | E FRAC | ? | 40.38 | 6.24 | DID NOT RESPOND TO TEST |
| Q16D | E FRAC. | ? | 42.21 | 1.81 | DID NOT RESPOND TO TEST |
| U3S | ? FRAC. | NO | N/A | N/A | N/A |
| S12D1 | ? FRAC. | YES | 44.21 | 10.22 | FULL RECOVERY AT 530 HRS. |
| J16S | SHALLOW | NO | N/A | N/A | N/A |
| Q16S | SHALLOW | NO | N/A | N/A | N/A |

*NOTE: DRAWDOWN DATA CORRECTED FOR BAROMETRIC EFFICIENCY AND STREAMFLOW RECHARGE.

96 hours until the end of the pumping period.

During recovery, water level data were measured in the pumping well on a frequency of 15- to 25-seconds during the first 20 minutes of the recovery period. The intervals were increased to approximately every two minutes during the second hour of well recovery. After the initial two-hour period, measurements were taken about daily through the 7th of March. Datalogger readings were recorded from 290.28 to 426.61 hours into the aquifer test. A reading was taken each time a change in water level of 0.1 foot or more occurred or every 20 minutes, whichever occurred first. The data logger measurements show an erratic pattern with many sharp fluctuations and are difficult to interpret. This erratic pattern may result from changes in air temperature and/or sunlight affecting the long coil of transducer cable laying exposed on the ground.

Water level information was collected during the pumping period in observation wells UI No. 5, UI No. 2 and the INEL-D on a frequency similar to that described for well UI No. 6. Other observation wells used in this test were measured on a less frequent schedule. In these wells measurements were taken every hour during the first several hours, decreasing to six hours during the final day of the pumping period. Measurements were made using a steel or electrical tape. A Campbell Scientific datalogger was also used to monitor water levels on the INEL-D well from 2 to 196 hours into the test.

Water level in well D19D, near the west end of the UIGRS, was monitored during the pumping period with a Stevens data recorder. Cattle grazing in the UIGRS pasture during the test repeatedly knocked the recorder over interrupting the data record, and rendered this record uninterpretable.

All water level elevation data obtained during this aquifer test from the sediment aquifer and the W- and E-Fractured aquifers were corrected for barometric efficiency. Barometric efficiency was estimated using the Bureau of Reclamation method described in the Ground Water Manual (1985). Atmospheric data used in this analysis were obtained from the University of Idaho Agricultural Engineering office weather station located on the University campus. A graph showing the barometric data for the test period is presented in figure 6.2. A correction factor was applied to drawdown data obtained from E-Fractured and shallow alluvial aquifer wells to adjust for variations in stream flow recharge to these aquifers. Stage levels for Paradise Creek were obtained for this period from the U.S. Geological Survey gage station located 100 feet east-northeast of the UIGRS.

## DESCRIPTION OF STEP-DRAWDOWN TEST - WELL UI NO. 7

A step-drawdown pump test was performed in well UI No. 7 on May 21, 1993. Dominico and Schwartz (1990) describe a step-drawdown test as one in which a well is pumped during

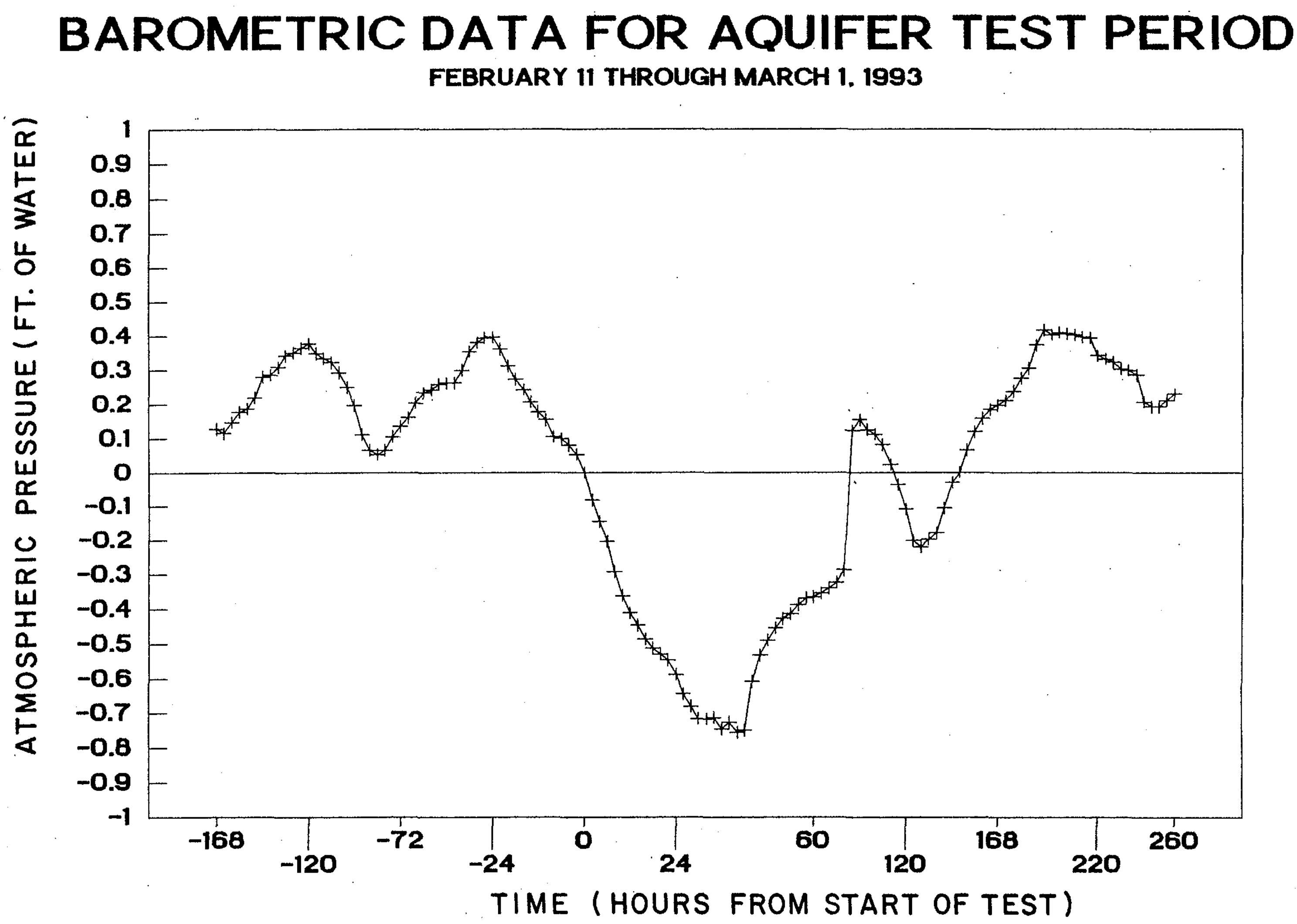



Figure 6.2 Graph showing barometric data during the period February 11 - March 1, 1993. Recorded at the University of Idaho Agricultural Engineering office building.

successive periods at increasing rates, each representing a constant fraction of the wells full capacity. The pumping steps can be successive or each step can be followed by an intermediate period where the well is permitted to fully recover (Ralston, personal communication, 1993). Step-drawdown tests are useful in estimating the yield of a well and to establish a safe rate of pumping. Transmissivity of the aquifer can be estimated from a semi-log plot of the drawdown versus time data, and then applying these data to a Jacob solution. Storativity can not be determined from a step-drawdown test.

A temporary submersible pump was set in well UI No. 7 at a depth of approximately 220 feet prior to conducting the test. The well was pumped in a series of continuous 30-minute steps at rates of 100, 200, 300, 400 and 450 gallons per minute. Upon completion of the last 30-minute period, the pumping rate was reduced to 400 gallons per minute. The well was pumped for three hours at this new rate. The pumped water was transferred approximately 150 feet away from the well in a four-inch PVC pipe, and discharged into an adjoining valley south of the site.

The depth to water was monitored in wells UI No. 6 and UI No. 7 using electrical tapes. No other observation wells were monitored during this test. Well UI No. 6 was pumped concurrently during the test by the Aquaculture laboratory at a rate of 140 to 145 gallons per minute. Measurements were taken every 30-seconds during the first ten minutes of each step, and every minute during each ensuing 20-minute segment. Water level measurements were taken on a less frequent schedule during the final three-hour pumping period. Recovery data ~~was~~ were not collected in either well following shut-off of the pump in well UI No. 7.

DESCRIPTION OF OCTOBER 4, 1993 AQUIFER TEST - WELL UI NO. 6

The pumping season at the Aquaculture Research Laboratory terminated on September 16, 1993. Except for a brief period of pumping on September 25, well UI No. 6 remained idle for several weeks following shut-off of the pump.

A two-hour-long aquifer test was performed in well UI No. 6 on October 4, 1993. During this test, the well was pumped at a steady rate of about 126 gallons per minute for a period of two hours. Water level measurements were made using electrical tapes in the pumping well and in observation well UI No. 7. Measurements were taken at 15-second intervals at the start of the test, decreasing to five-minute intervals near the termination of the period. Recovery data were collected at close-spaced time intervals for 100 minutes following the pumping period, and periodically during the ensuing 20 hours.

# ANALYSIS OF DATA FROM AQUIFER TESTS

## AQUACULTURE WELLS

Data obtained from the three pumping tests performed during 1993 in the Aquaculture wells provide information about: 1) water level drawdown, 2) estimation of aquifer parameters, and 3) boundary conditions. An estimate of the maximum yield for wells UI No. 6 and UI No. 7 is also made from these data.

## WELL UI NO. 6

The static water level elevation measured in well UI No. 6 just prior to the start of the February, 1993 pumping test was 2476.62 feet (AMSL). Maximum drawdown in this well recorded at the end of this test was 45.09 feet, with the water level elevation located at 2431.53 feet (AMSL). Figure 6.3 is a hydrograph showing the corrected water level elevation curve for well UI No. 6 during the pumping and recovery periods. All water level elevation data from this test were corrected for barometric efficiency using a factor of 60 percent. Recovery of the water level following shut-off of the pump was rapid during the first two hours, then slowed notably. Full recovery to the prior static level did not occur during the 10 days that recovery data ~~was~~ were monitored.

The static water level elevation in well UI No. 6 at the start of the October 4, 1993 aquifer test was 2472.2 feet (AMSL). Drawdown of the water level during the two-hour test

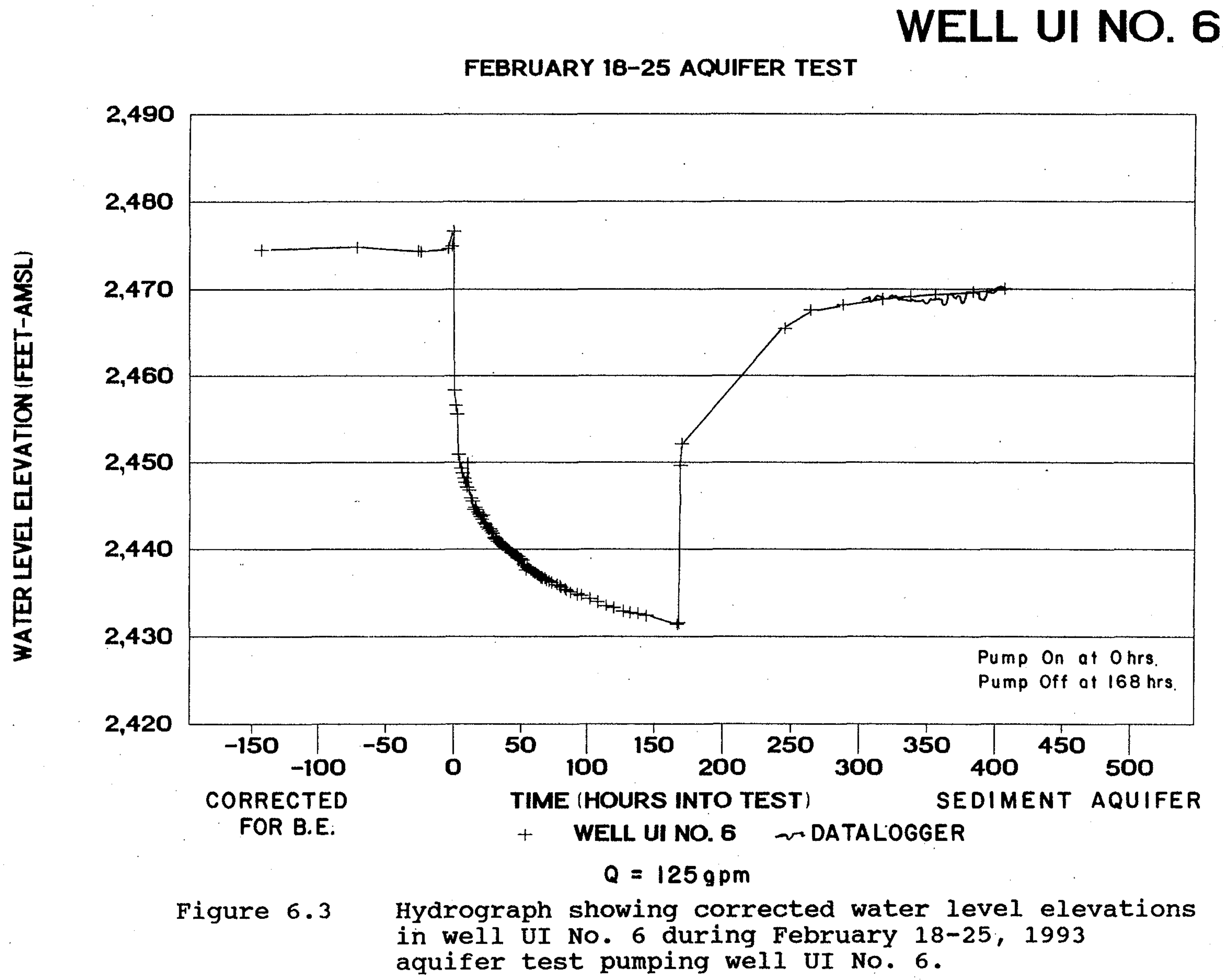



Figure 6.3 Hydrograph showing corrected water level elevations in well UI No. 6 during February 18-25, 1993 aquifer test pumping well UI No. 6.

was 21.82 feet to an elevation of 2450.38 feet (AMSL). Recovery in the well was rapid, and full recovery occurred 20 hours after the pump was turned off.

Well UI No. 6 was used as an observation well during the step-drawdown test conducted in well UI No. 7 on May 21, 1993. Well UI No. 6 was pumped by the Aquaculture laboratory concurrent with the testing of well UI No. 7. The pumping water level elevation in well UI No. 6 at the start of this test was 2438.55 feet (AMSL). Total drawdown in this well, caused by the pumping in well UI No. 7, was 15.61 feet, with the new water level elevation at 2422.94 feet (AMSL).

Applications of analytical models to time-drawdown data obtained from a pumping well include semi-logarithmic plots and a solution using the Jacob equations. Semi-log plots were constructed for well UI No. 6 using data collected during both the February and October pumping tests. A log-log solution yielded aquifer parameter for well UI No. 6 from step 1 of the step-drawdown test pumping well UI No. 7.

Figure 6.4 is a semi-log plot of the data from the February, 1993 aquifer test. The plot shows two general slopes with a sharp increase in drawdown observed between 2.5 and 4 hours into the test. This abrupt change could be caused by either an impermeable boundary or interference from pumping another well located in the same aquifer. The slope flattens again after about 4 hours, and retains this new slope to the end of the pumping test. The new slope is steeper

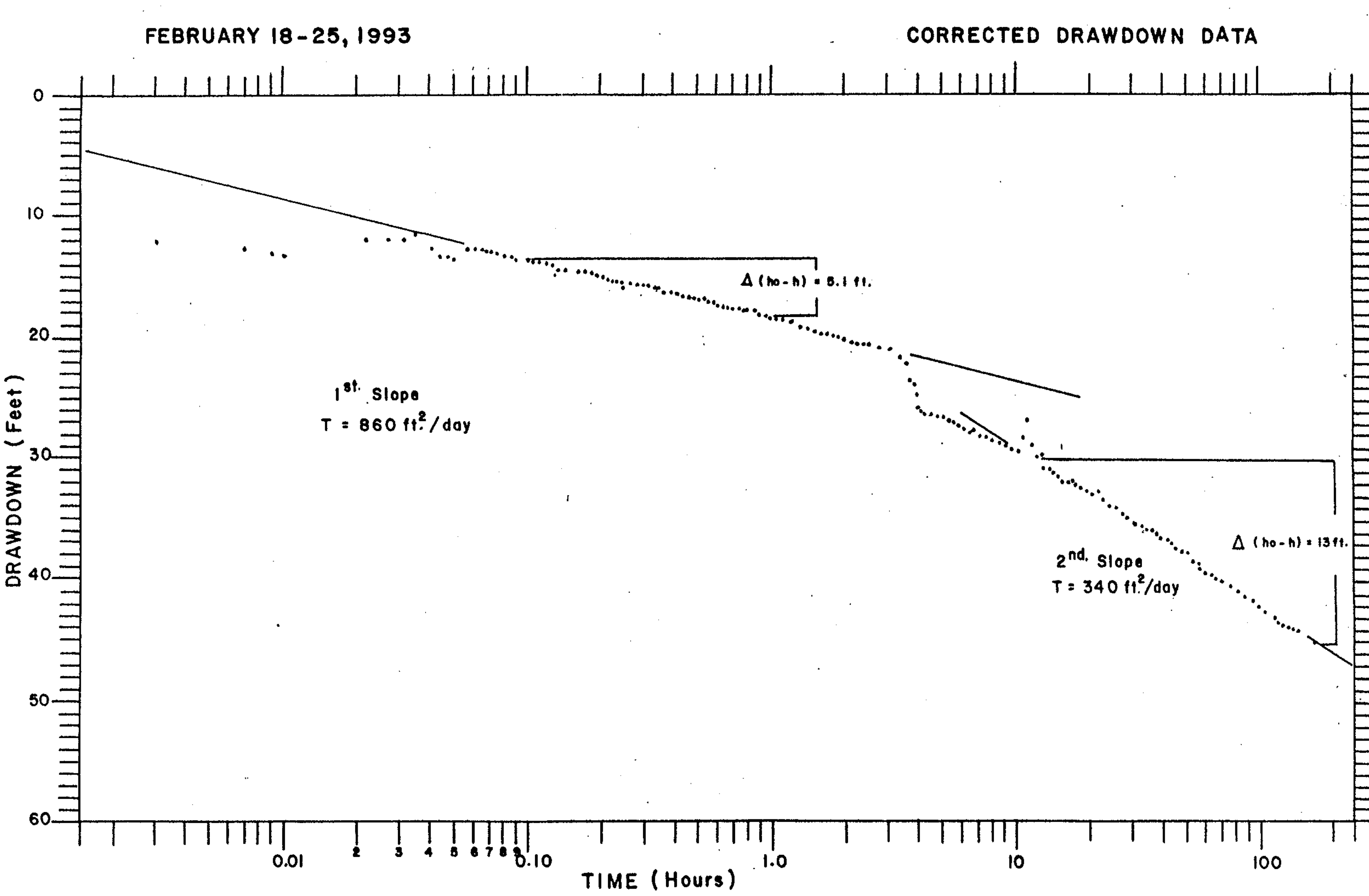



Figure 6.4 Semi-log plot of drawdown versus time for well UI No. 6 during February, 1993 aquifer test in well UI No. 6.

than that obtained for early-time data, and may reflect boundary conditions as well as leakage from another unpumped aquifer. The early time solution of this plot results in a transmissivity value of 860 $ft^2$/sec. A semi-log plot was also constructed for well UI No. 6 using recovery data from this test. This solution yields a transmissivity of 770 $ft^2$/day. Figure 6.5 shows a plot of these data.

A log-log plot of drawdown versus time data for well UI No. 6 was constructed for step 1 from the step-drawdown test conducted in pumping well UI No. 7. The plot of these data is shown in figure 6.6. The Theis equation gives a transmissivity of 1600 $ft^2$/day and storativity of $2X10^{-4}$. This transmissivity value probably is high because only a portion of the water pumped from well UI No. 7 was obtained from the lower sand aquifer that is penetrated by well UI No. 6. Fluctuations in the pumping rate at the start of the test probably cause the deviations in the early-time data from the type curve.

Semi-log plots were constructed for well UI No. 6 from both pumping and recovery data obtained during the October 4, 1993 aquifer test. A plot of the drawdown versus time data for the pumping period is shown in figure 6.7. The plot yields a transmissivity of 1110 $ft^2$/day. The plot shows no effect from any boundary conditions. Figure 6.8, a plot of the recovery data from this test, yields a transmissivity of 1050 $ft^2$/day. A summary of the transmissivity and

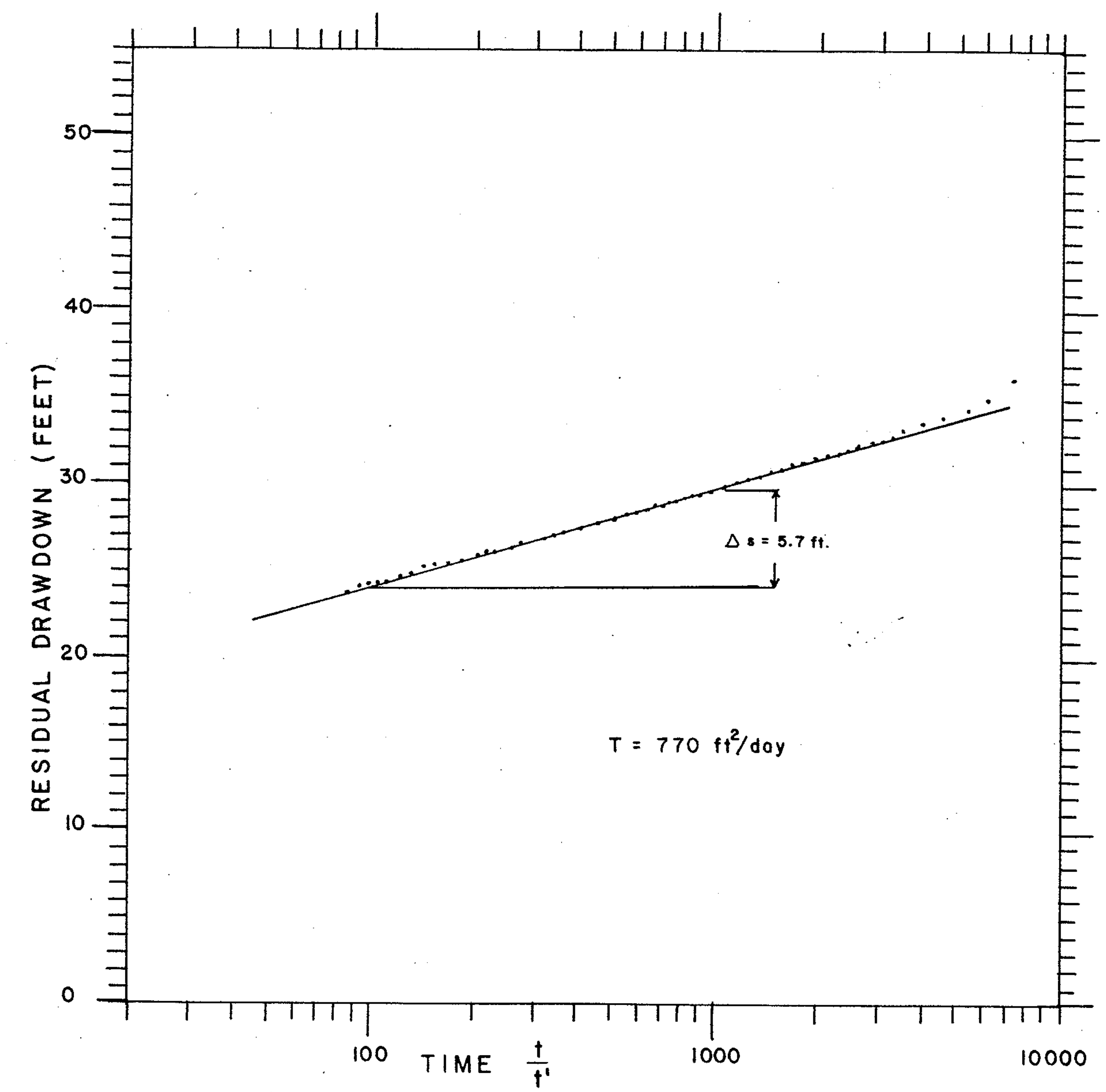



Figure 6.5 Semi-log plot of residual drawdown versus time ( t/t') for recovery data from well UI No. 6 during February, 1993 aquifer test in well UI No. 6.

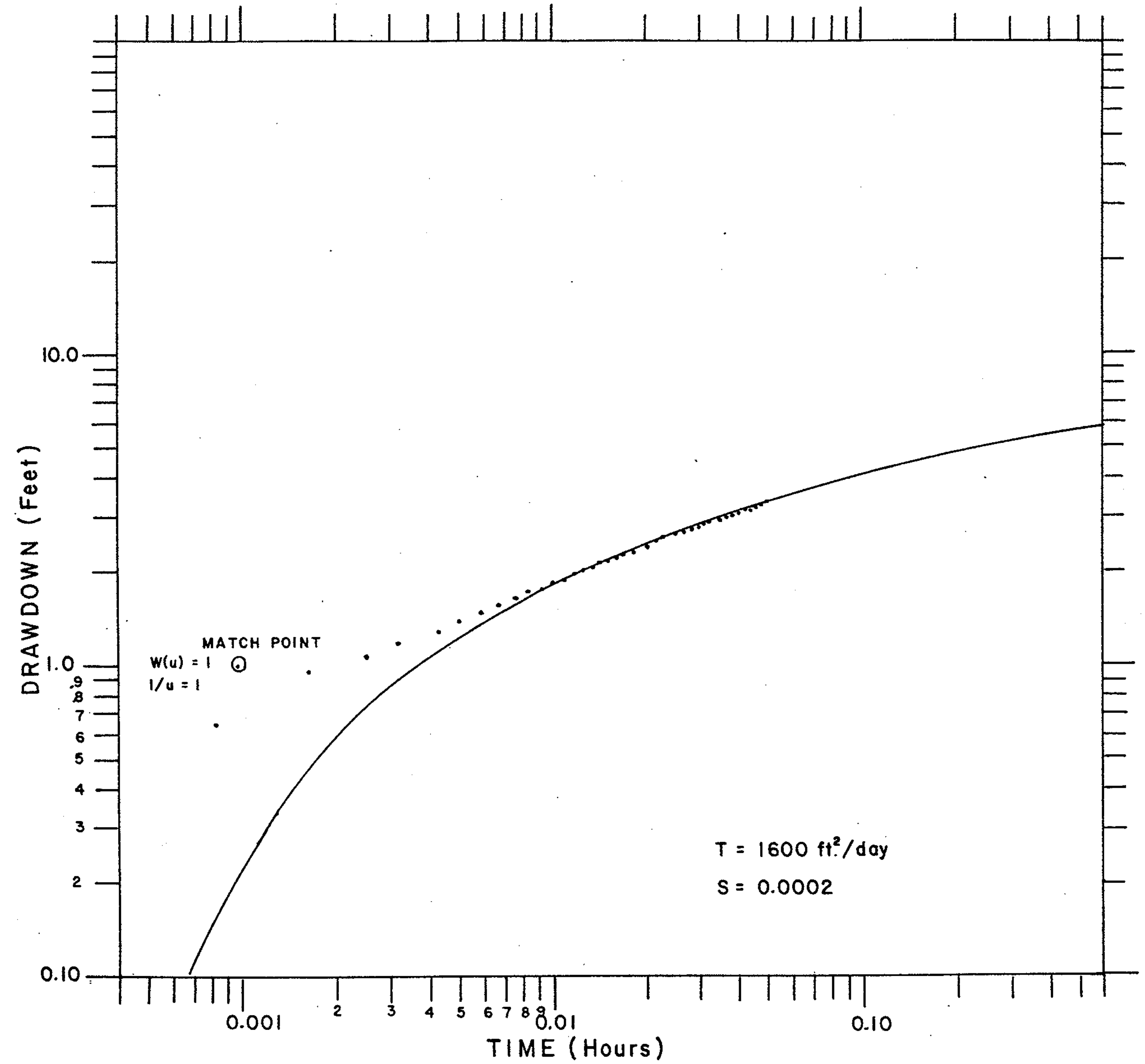



Figure 6.6 Log-log plot of drawdown versus time for well UI No. 6 from May, 1993 step drawdown test in well UI No. 7 for step 1.

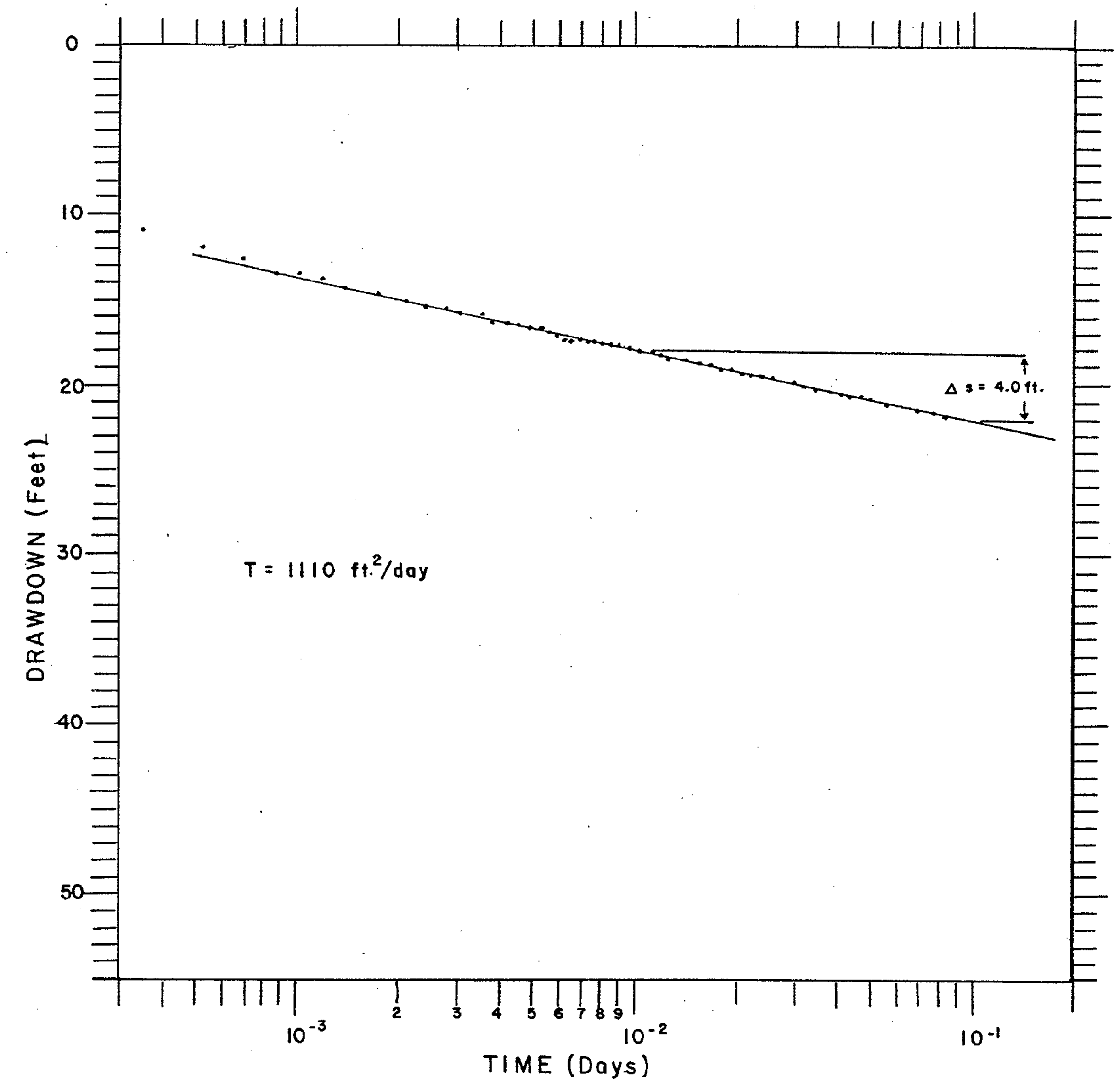



Figure 6.7 Semi-log plot of drawdown versus time for well UI No. 6 during October, 1993 aquifer test in well UI No. 6.

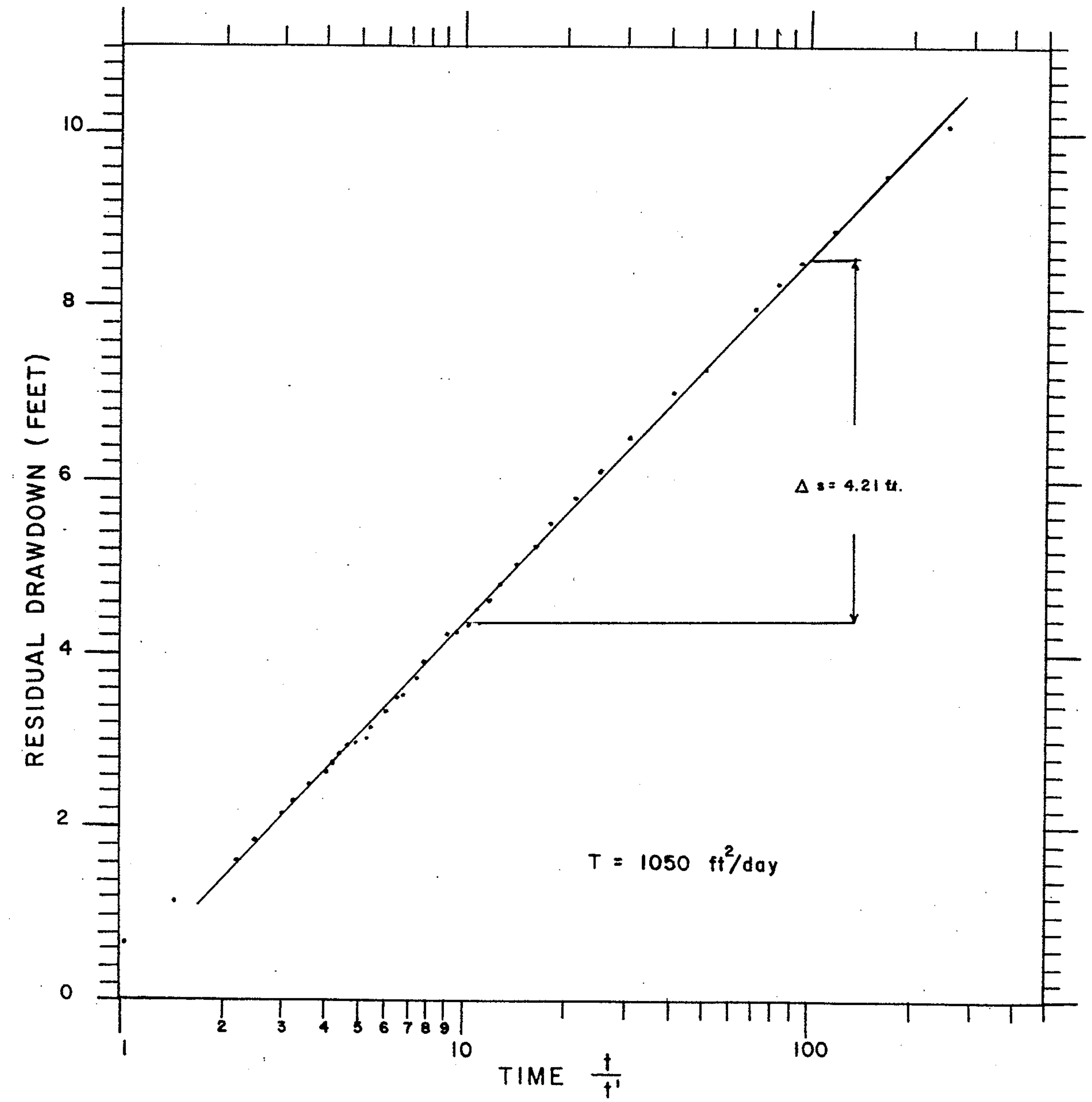



Figure 6.8 Semi-log plot of residual drawdown versus time (t/t') for recovery data from well UI No.6 during October, 1993 aquifer test in well UI No. 6.

storativity values obtained from the three aquifer tests is presented in table 6.4.

WELL UI NO. 7

Drawdown in well UI No. 7 during the step-drawdown test conducted on May 21, 1993 totaled 56.08 feet. Water level elevations ranged from a pre-pumping static level at 2471.33 feet (AMSL) to a minimum elevation of 2415.25 feet (AMSL) at the end of step 6.

The static water level elevation in well UI No. 7 at the start of the October 4, 1993 pump test in well UI No. 6 was 2481.67 feet. This elevation is approximately 10 feet higher than the static level measured in this well prior to the May 21, 1993 step-drawdown test. This occurred because well UI No. 6 was pumping in May but not in October. Drawdown in well UI No. 7 during the two-hour-long October test was 3.22 feet. An initial lag in time of about 20 seconds preceded any drawdown response in the observation well. Water levels recovered rapidly after the pump was turned off, and full recovery occurred within 20 hours.

An estimate of the transmissivity for well UI No. 7 using a semi-log plot of drawdown versus time data from the May 21, 1993 step-drawdown test was made using the Jacob equation. Figure 6.9 is a plot of these data. A transmissivity of 540 $ft^2$/day was estimated for step 1. Negative values obtained for well loss constants from this test data indicate that the well was developing during the aquifer test (Ralston, personal

Table 6.4 Summary of Aquifer Test Results

February 18-25, 1993 Aquifer Test - Pumping Well UI No. 6

| ANALYTICAL METHOD | WELL UI NO. 6 | WELL UI NO. 7 |
|---|---|---|
| Jacob * | T=860 $ft^2$/day | N/A |
| Jacob * (Recovery) | T=770 $ft^2$/day | N/A |

May 21, 1993 Step-Drawdown Test - Pumping Well UI No. 7

| ANALYTICAL METHOD | WELL UI NO. 6 | WELL UI NO. 7 |
|---|---|---|
| Jacob (Step 1) | T=1770 $ft^2$/day | N/A |
| Theis (Step 1) | T=1600 $ft^2$/day S=$2X10^{-4}$ | N/A |

October 4, 1993 Aquifer Test - Pumping Well UI No. 6

| ANALYTICAL METHOD | WELL UI NO. 6 | WELL UI NO. 7 |
|---|---|---|
| Theis | N/A | T=1930 $ft^2$/day S=$6X10^{-4}$ |
| Jacob | T=1110 $ft^2$/day | T=2360 $ft^2$/day S=$4X10^{-4}$ |
| Jacob (Recovery) | T=1050 $ft^2$/day | T=2780 $ft^2$/day S=$4X10^{-4}$ |

* Drawdown corrected for Barometric Efficiency

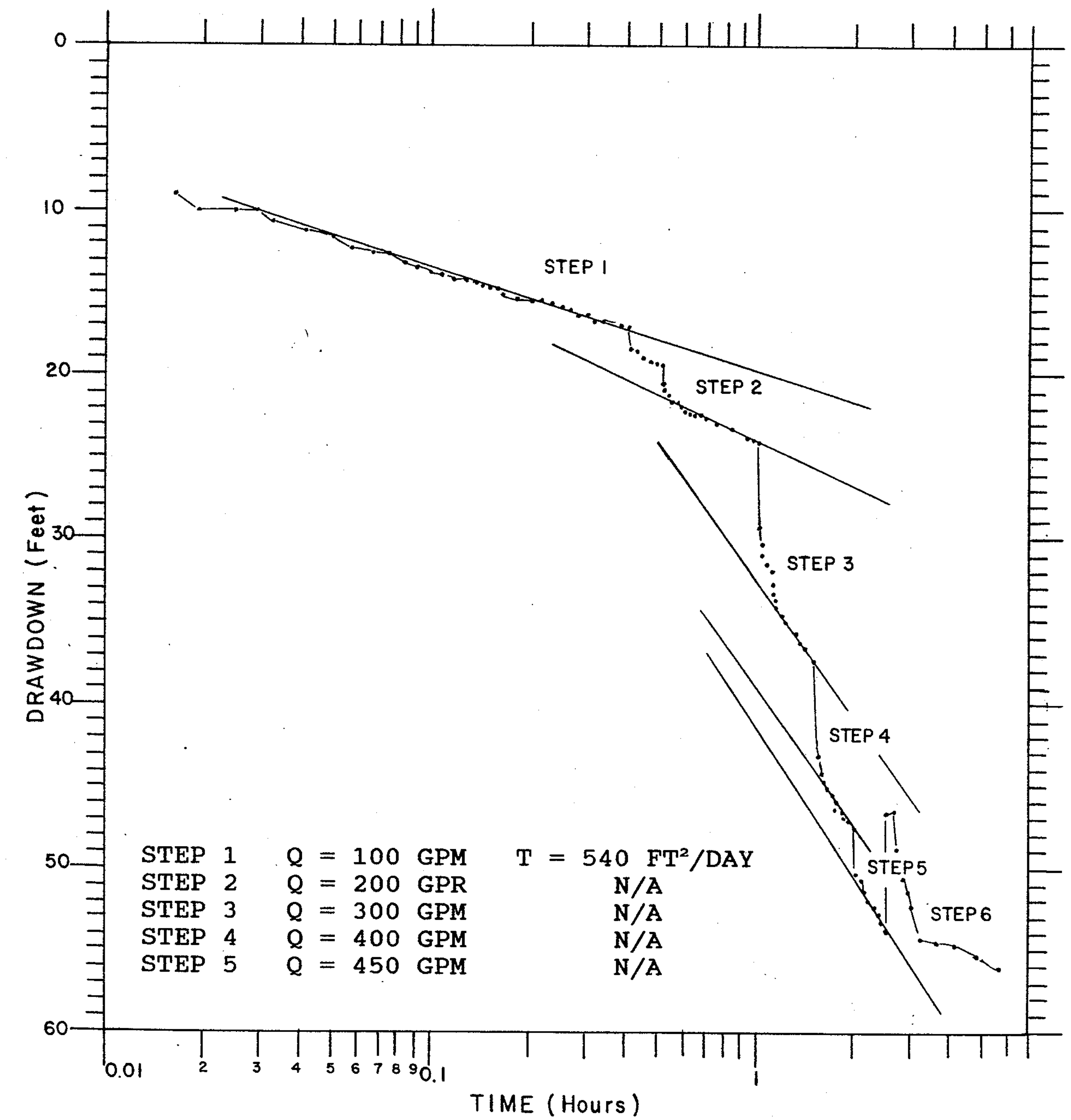



Figure 6.9 Semi-log plot of drawdown versus time for well UI No. 7 from May, 1993 step-drawdown test in well UI No. 7.

communications, 1993). If a well is developing, then the values estimated for transmissivity are invalid, and the test should be rerun after well development is complete (Birsoy and Summers, 1980). Transmissivity and storativity for an observation well are not affected by the well loss in the pumping well, and analytical model solutions for these wells are still valid. A summary of the data obtained from the step-drawdown test is presented in table 6.5.

The October 4, 1993 aquifer test data allows estimation of aquifer parameters for well UI No. 7, using both log-log and semi-log solutions for pumping data and the semi-log solution for recovery data. Plots for these solutions are shown in figures 6.10 through 6.12. The Theis equation gives a transmissivity of 1930 $ft^2$/day and a storativity of $6X10^{-4}$. Data points for time greater than 35 minutes show a smaller drawdown than that predicted by the type curve. This indicates that the cone of depression intersected a positive boundary or more probably leakage from an unpumped aquifer. Well UI No. 7 taps both the upper and lower sand aquifers while only the lower sand aquifer was being pumped by well UI No. 6. This will cause an overestimation of the transmissivity (Ralston, personal communication, 1993). The semi-log solution for the pumping data gives a transmissivity of 2360 $ft^2$/day and a storativity of $4X10^{-4}$. The straight line plot shows a positive boundary effect, probably a result of leakage from an unpumped aquifer. The semi-log solution

## TABLE 6.5 SUMMARY OF STEP-DRAWDOWN TEST IN WELL UI NO. 7

WELL UI NO. 7

| STEP | DRAWDOWN (FEET) | PUMPING RATE (GPM) | TIME (MINUTES) | SPECIFIC CAPACITY (GPM/FT) | WELL LOSS CONSTANT (FT/(GPM)) | TRANSMISSIVITY (FT/DAY) | STORATIVITY | CUMULATIVE DDN. (FEET) |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.33 | 100 | 30 | 5.17 | −7.29E−04 | 541 | N/A | 19.33 |
| 2 | 4.75 | 200 | 30 | 8.31 | 4.25E−04 | 764 | N/A | 24.08 |
| 3 | 13.25 | 300 | 30 | 8.04 | −1.50E−04 | 377 | N/A | 37.33 |
| 4 | 10.25 | 400 | 30 | 8.41 | 1.55E−04 | 504 | N/A | 47.58 |
| 5 | 6.29 | 450 | 30 | 8.35 | N/A | 529 | N/A | 53.87 |
| AVERAGE | N/A | N/A | N/A | N/A | −7.50E−05 | 543 | N/A | N/A |
| 6 | 2.21 | 400 | 180 | 7.13 | N/A | N/A | N/A | 56.08 |

WELL UI NO. 6

| STEP | DRAWDOWN (FEET) | PUMPING RATE (GPM) | TIME (MINUTES) | SPECIFIC CAPACITY (GPM/FT) | WELL LOSS CONSTANT(FT/(GPM)) | TRANSMISSIVITY (FT/DAY) | STORATIVITY | CUMULATIVE DDN. (FEET) |
|---|---|---|---|---|---|---|---|---|
| 1 | 3.42 | N/A | 30 | N/A | N/A | *1600 | 2.00E−04 | 3.42 |
| 1−6 | 15.61 | 330 [AVE.] | 330 | N/A | N/A | N/A | | 15.61 |

Note: UI No. 6 pumped during test at 140−145 gpm.

*THEIS METHOD

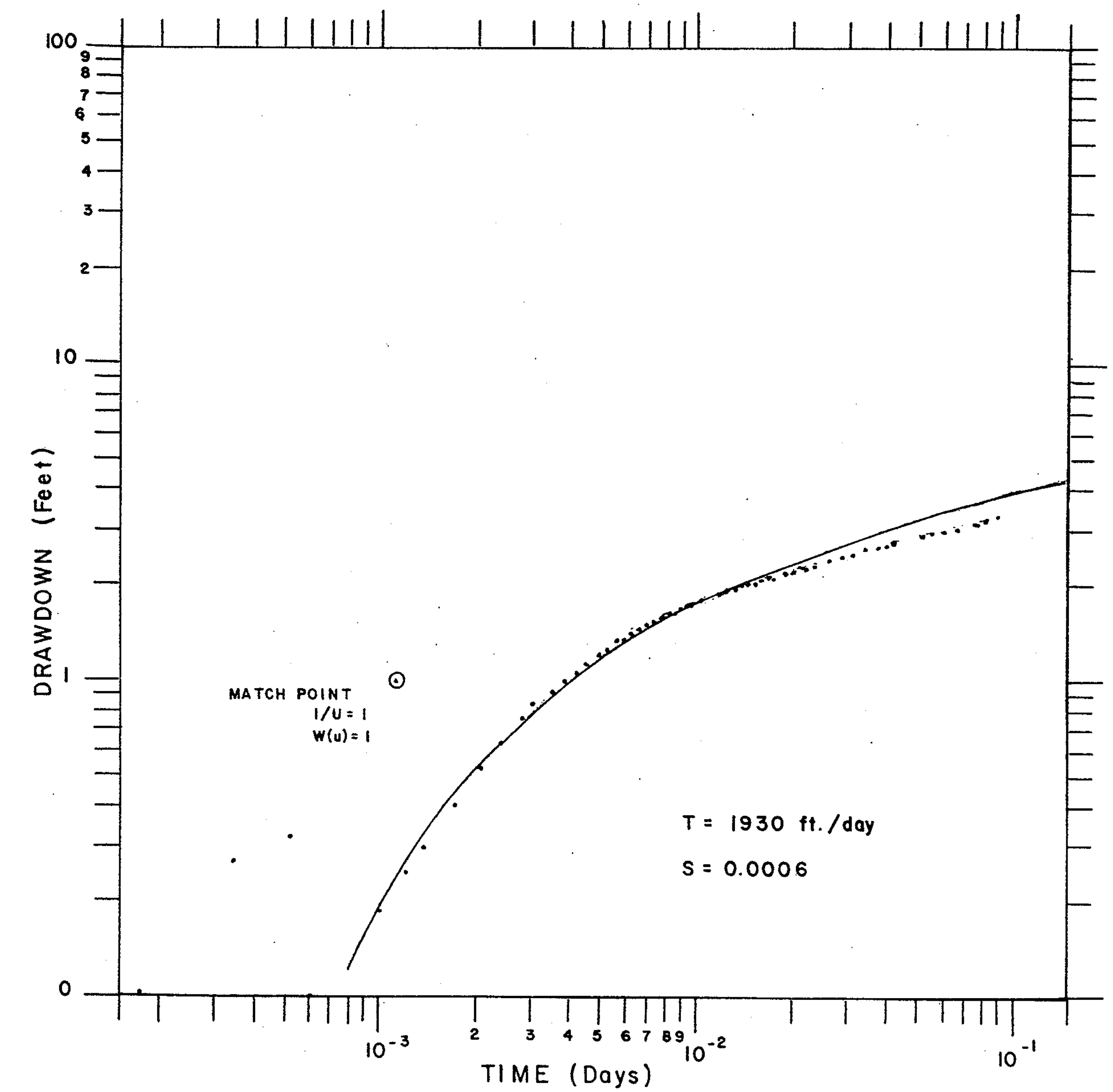



Figure 6.10 Log-log plot of drawdown versus time for observation well UI No. 7 during October, 1993 aquifer test in well UI No. 6.

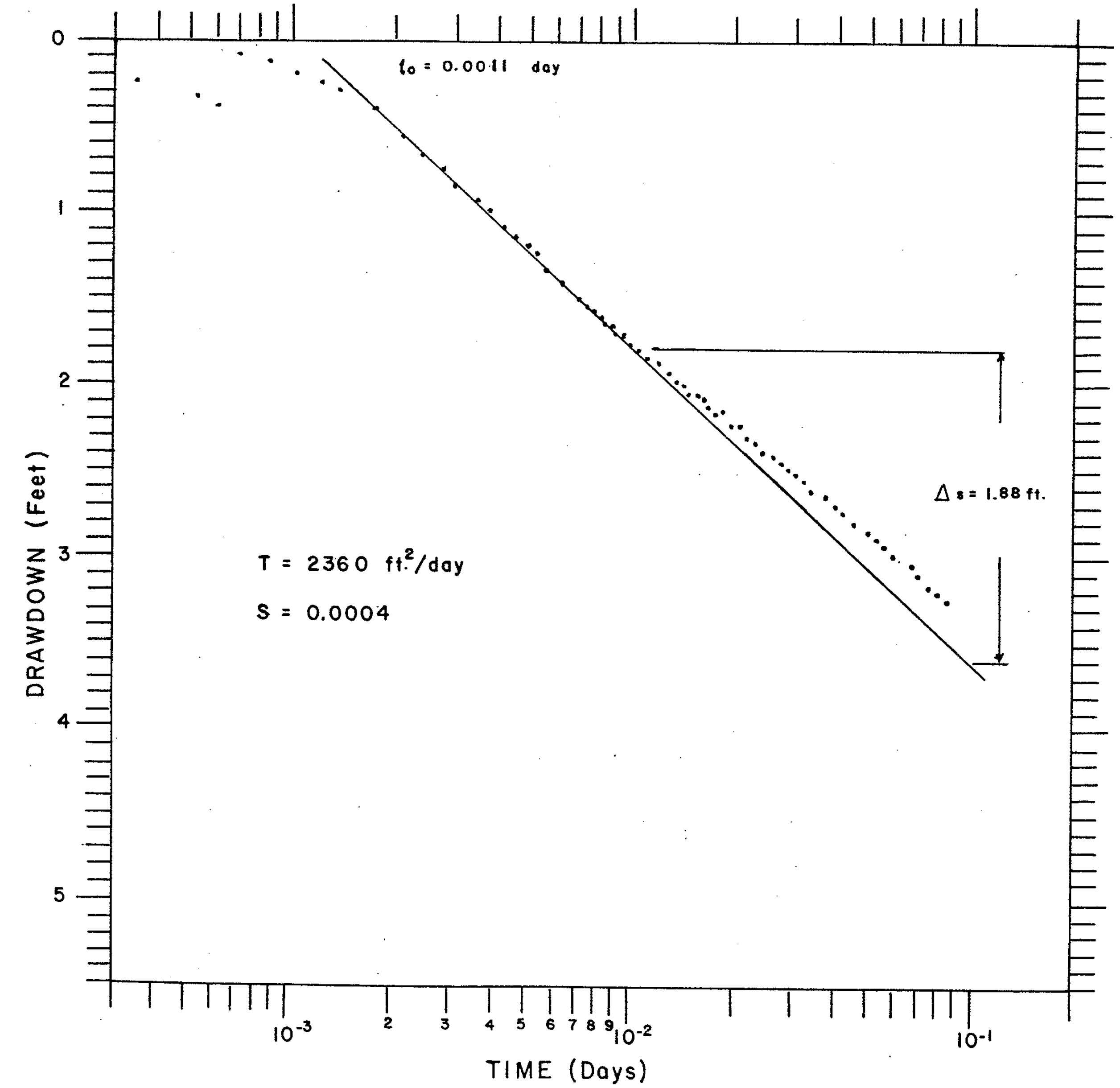



Figure 6.11 Semi-log plot of drawdown versus time for observation well UI No.7 during October, 1993 aquifer test in well UI No. 6.

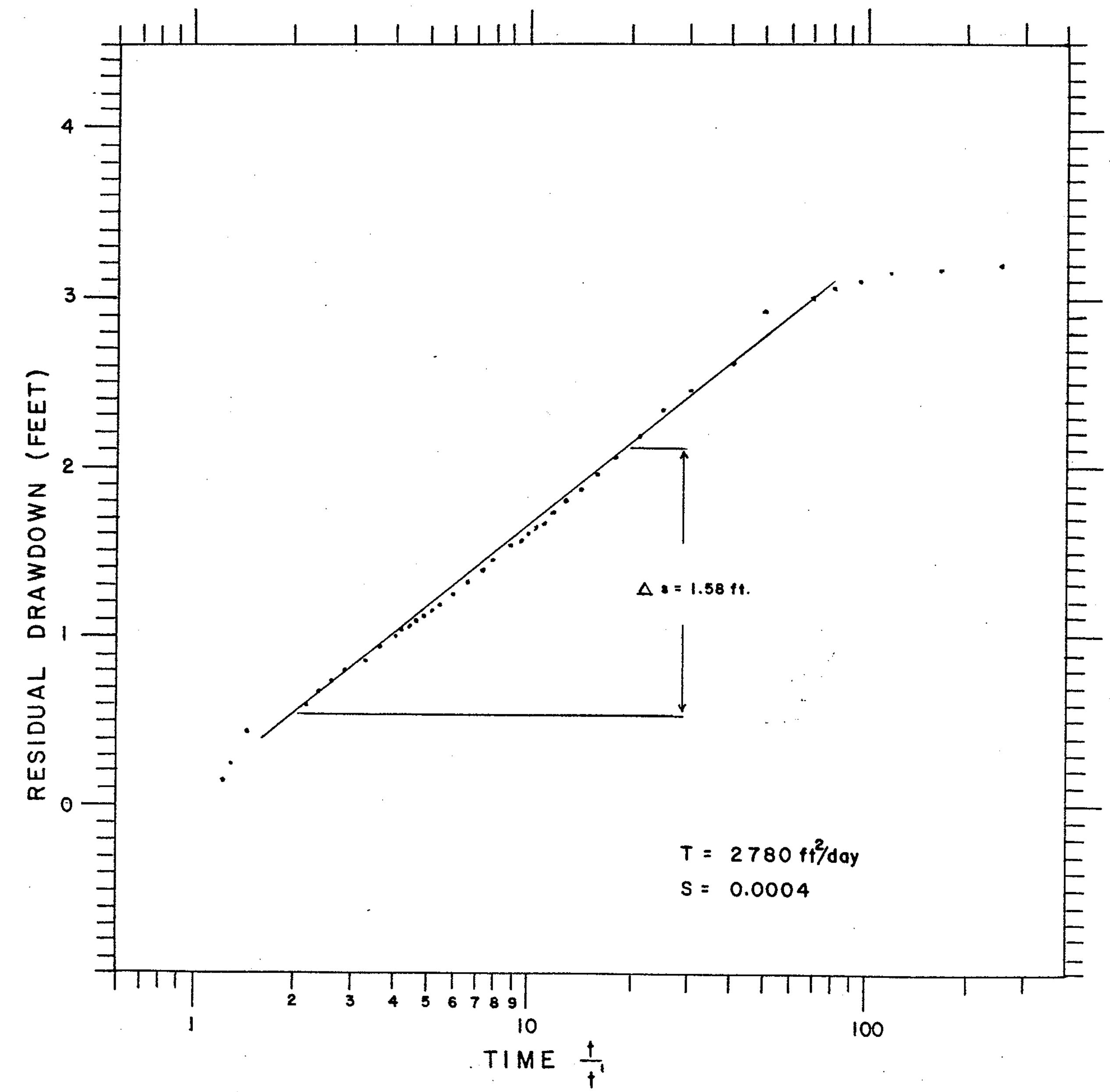



Figure 6.12 Semi-log plot of residual drawdown versus time (t/t') for recovery data from well UI No. 7 during October, 1993 aquifer test in well UI No. 6.

for recovery data gives an estimate for transmissivity of 2780 ft²/day.

WELL UI NO. 5

No aquifer tests were performed on well UI No. 5 during this study; however, this well was an observation well in the February pumping test in well UI No. 6. The static water level elevation in this well just prior to the test was 2578.64 feet. Corrected total drawdown during the pump test was 0.59 feet. Figure 6.13, a hydrograph of well UI No. 5, shows the water level elevations recorded in this well during this aquifer test. A lag-time of about 127 hours preceded any observable response. No recovery of the water level occurred during the seven-day period of monitoring that followed shut-off of the pump. These results indicate that a low hydraulic conductivity aquitard exists between the pumped lower sand aquifer in well UI No. 6 and the basalt aquifers in which well UI No. 5 is completed.

UIGRS WELLS

Thirteen wells at the UIGRS were monitored during the February, 1993 pumping test conducted in well UI No. 6. Hydrographs for these wells, with corrected drawdown data, are presented in figures 6.14 through 6.25. Drawdown response occurred in: 1) well INEL-D at the very top of the sediment, 2) in all W-Fractured wells and 3) in well S12D1 which is completed in a separate fracture, hydraulically connected to the W- and E-Fractured zones.

## WELL UI NO. 5

FEBRUARY 18-25, 1993 AQUIFER TEST

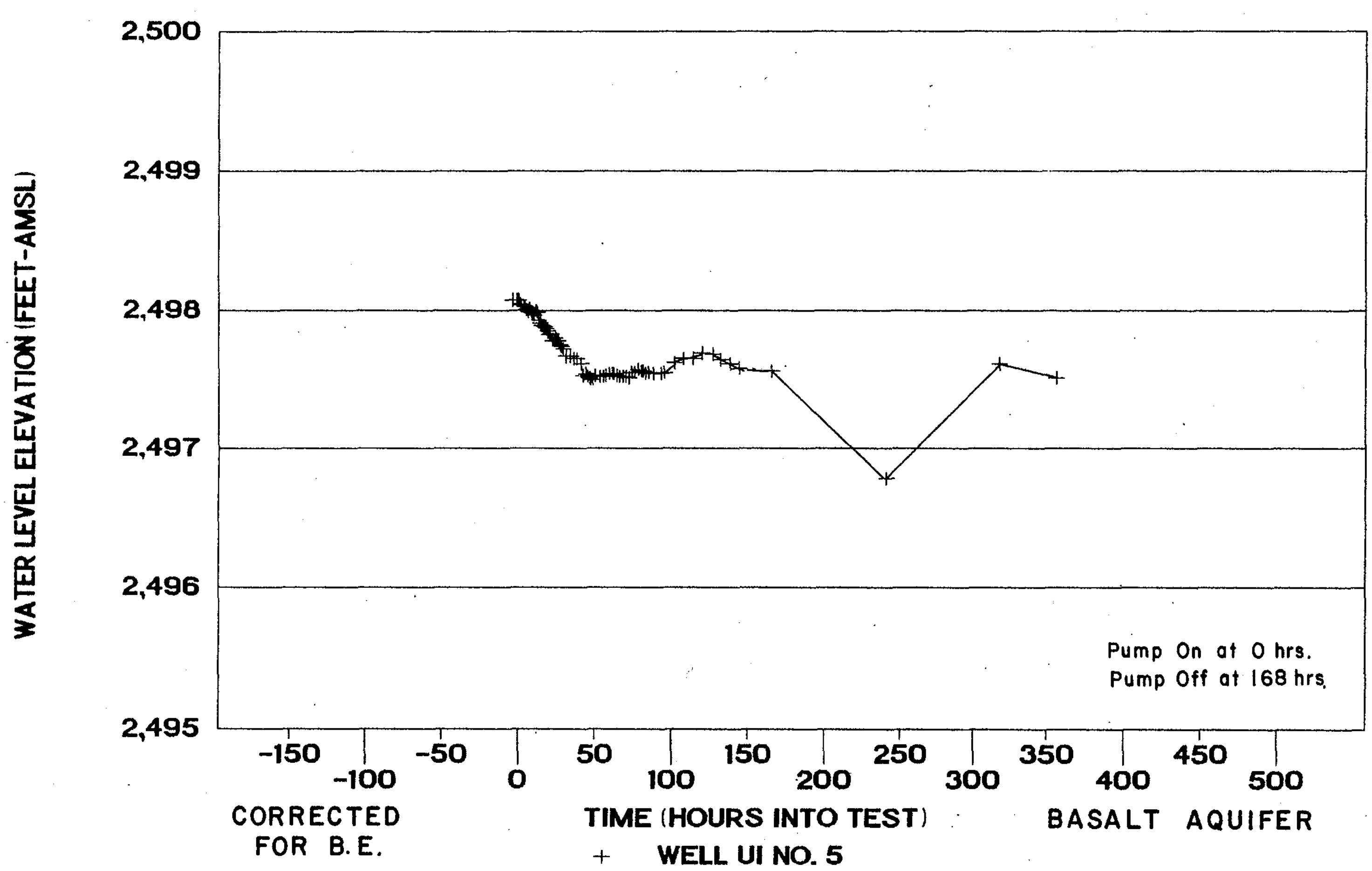



Figure 6.13 Hydrograph showing corrected water level elevations in well UI No. 5 during February 18-25, 1993 aquifer test in well UI No. 6.

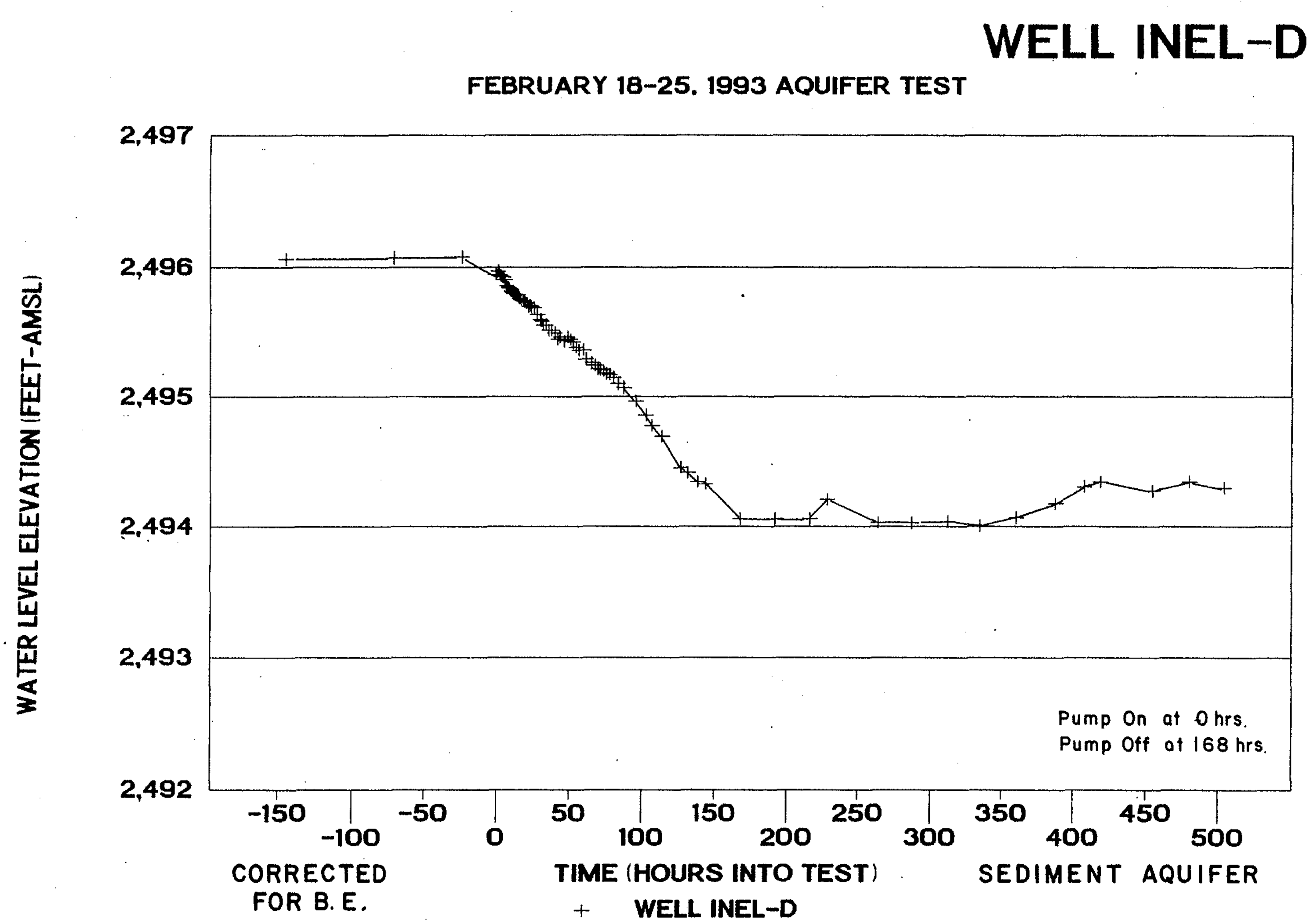



Figure 6.14 Hydrograph showing corrected water level elevations in well INEL-D during February 18-25, 1993 aquifer test in well UI No. 6.

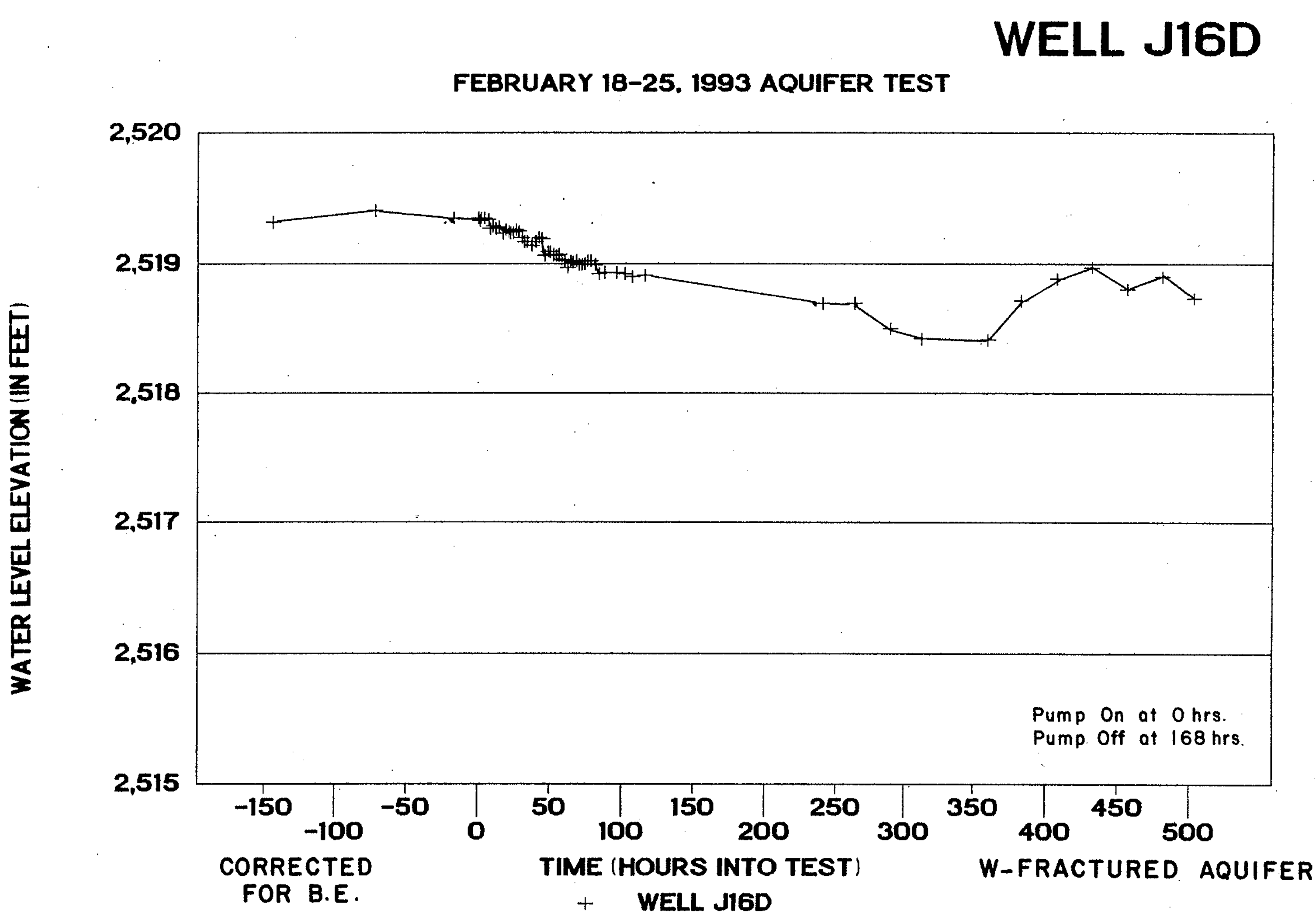



Figure 6.15 Hydrograph showing corrected water level elevations in well J16D during February 18-25, 1993 aquifer test in well UI No. 6.

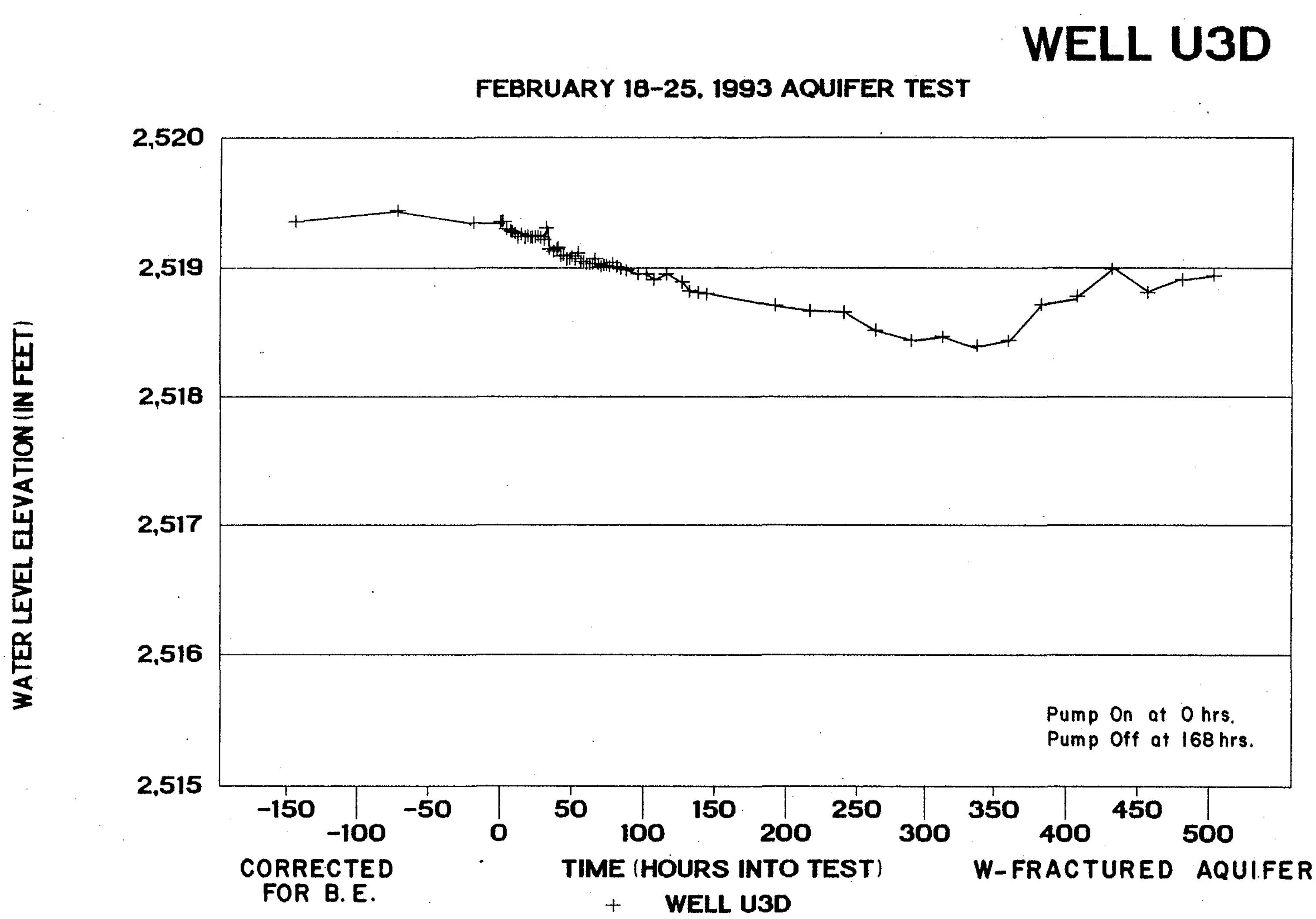



Figure 6.16 Hydrograph showing corrected water level elevations in well U3D during February 18-25, 1993 aquifer test in well UI No. 6.

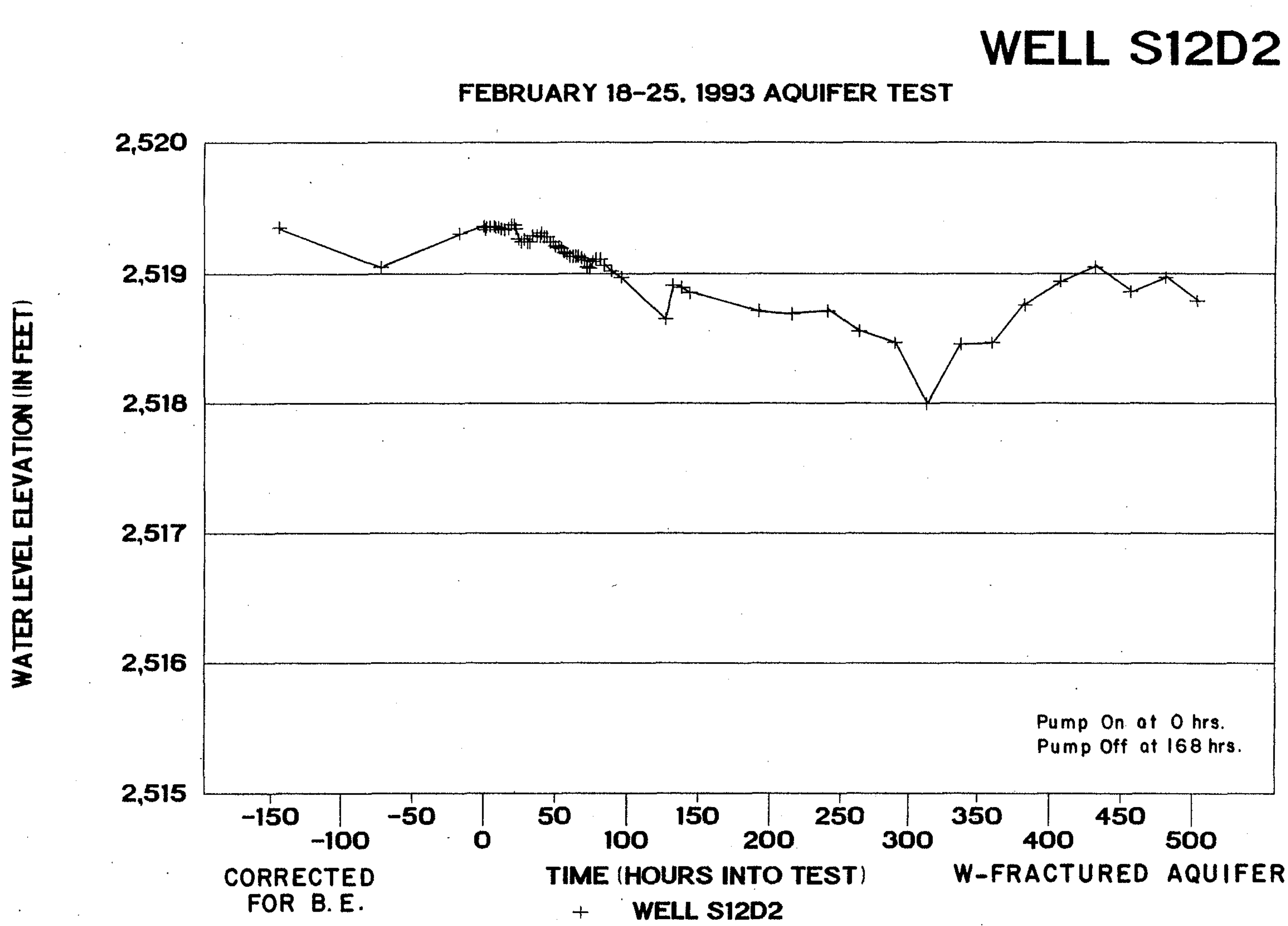



Figure 6.17 Hydrograph showing corrected water level elevations in well S12D2 during February 18-25, 1993 aquifer test in well UI No. 6.

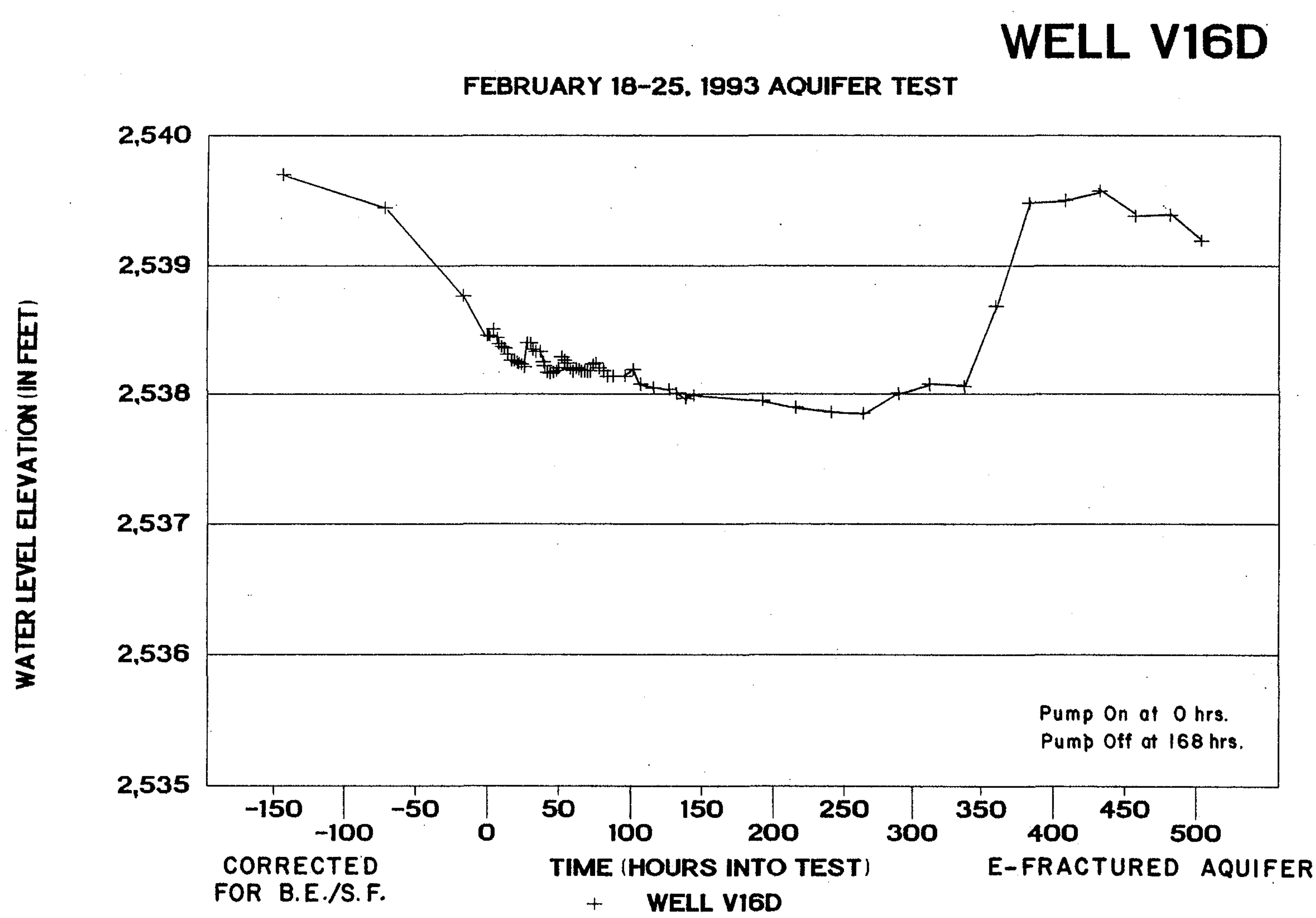



Figure 6.18 Hydrograph showing corrected water level elevations in well V16D during February 18-25, 1993 aquifer test in well UI No. 6.

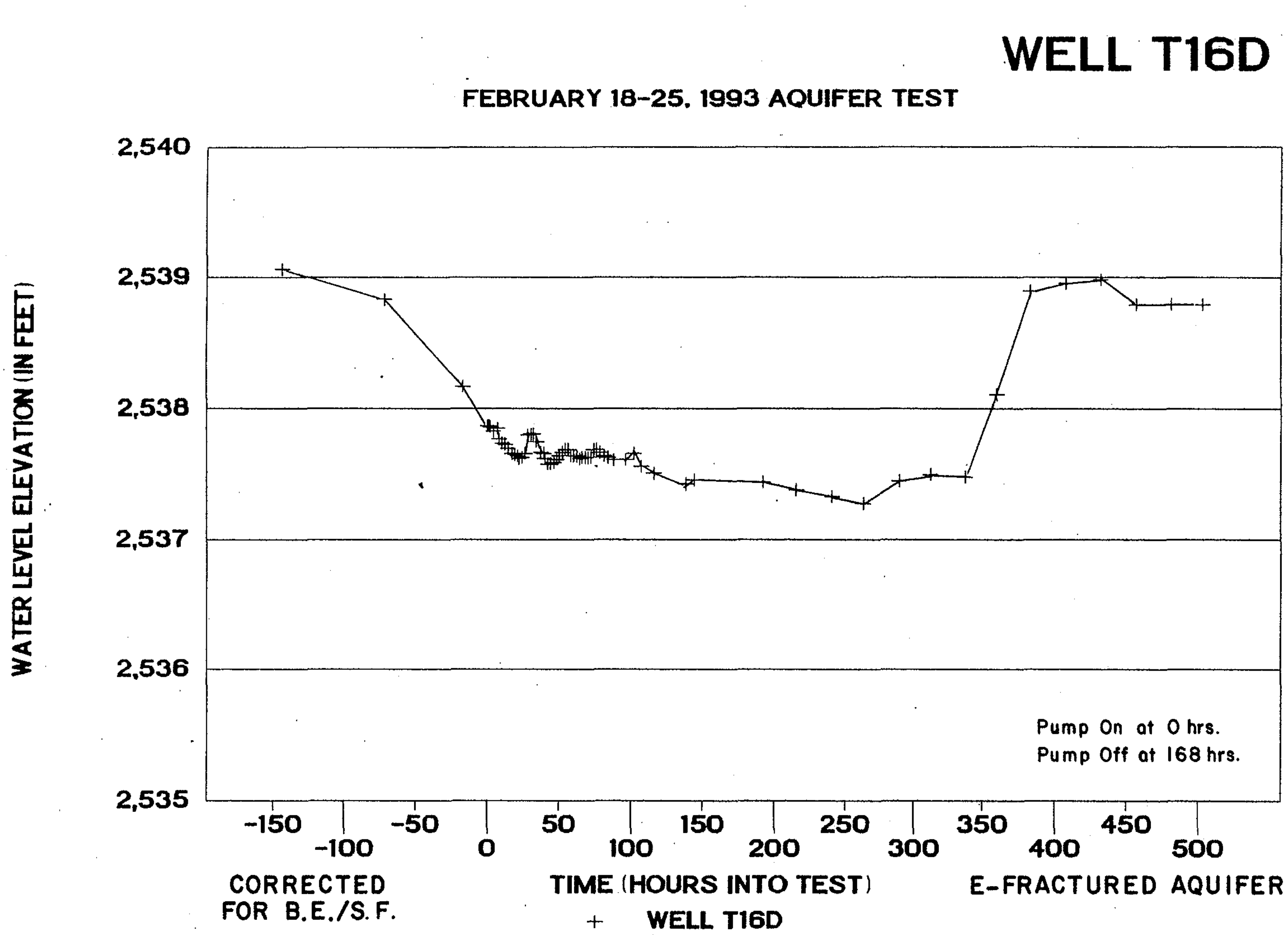



Figure 6.19 Hydrograph showing corrected water level elevations in well T16D during February 18-25, 1993 aquifer test in well UI No. 6.

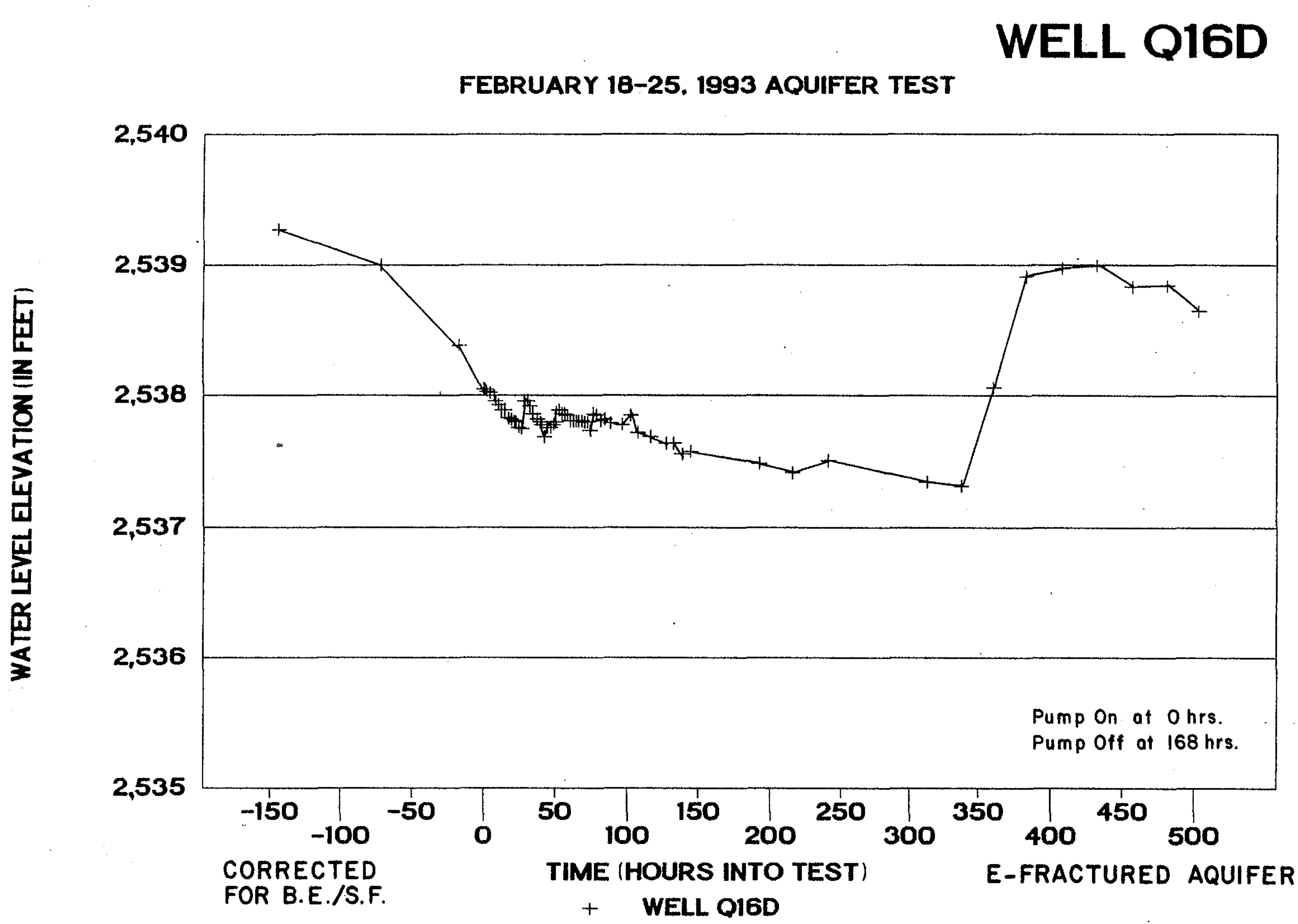



Figure 6.20 Hydrograph showing corrected water level elevations in well Q16D during February 18-25, 1993 aquifer test in well UI No. 6.

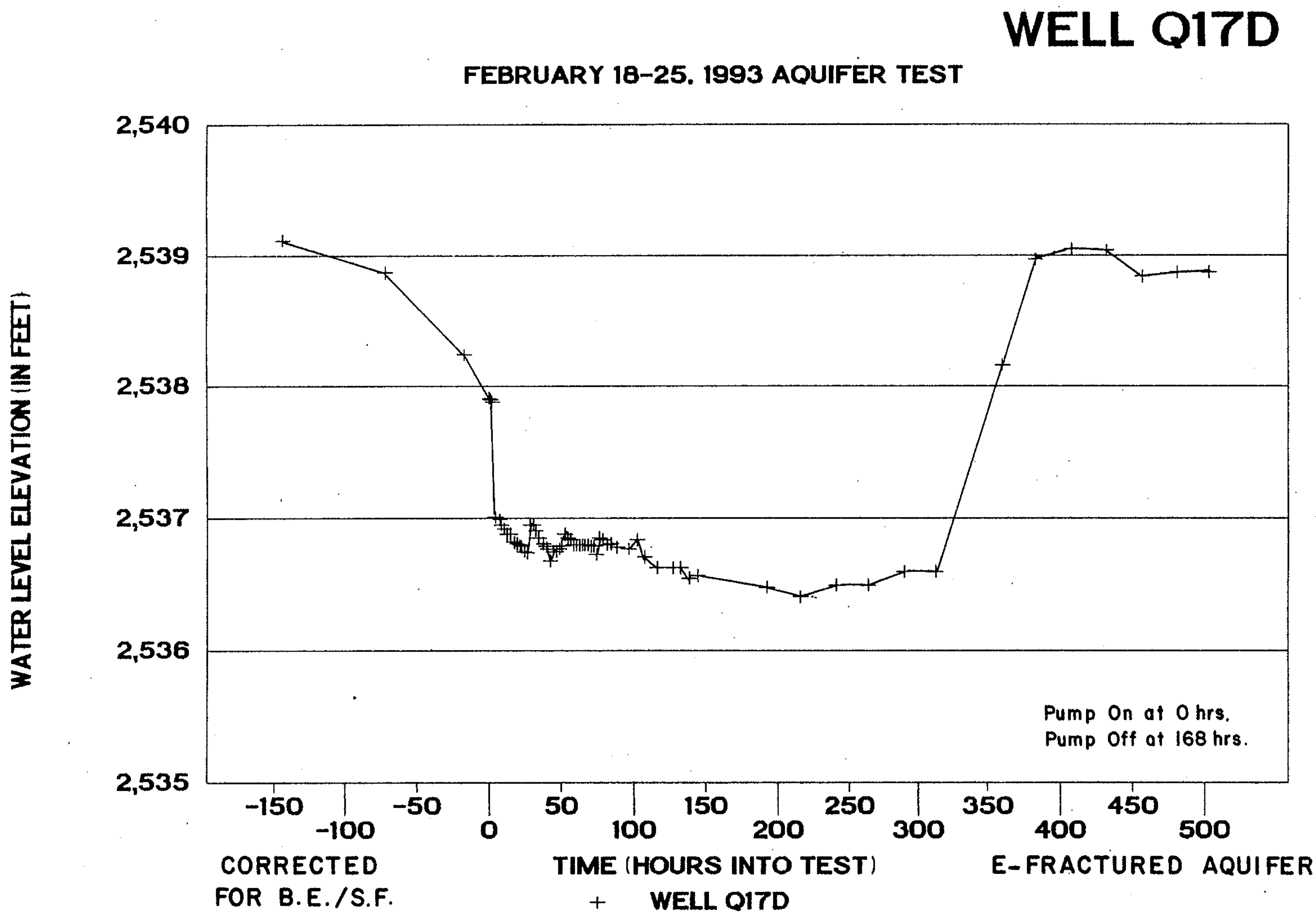



Figure 6.21 Hydrograph showing corrected water level elevations in well Q17D during February 18-25, 1993 aquifer test in well UI No. 6.

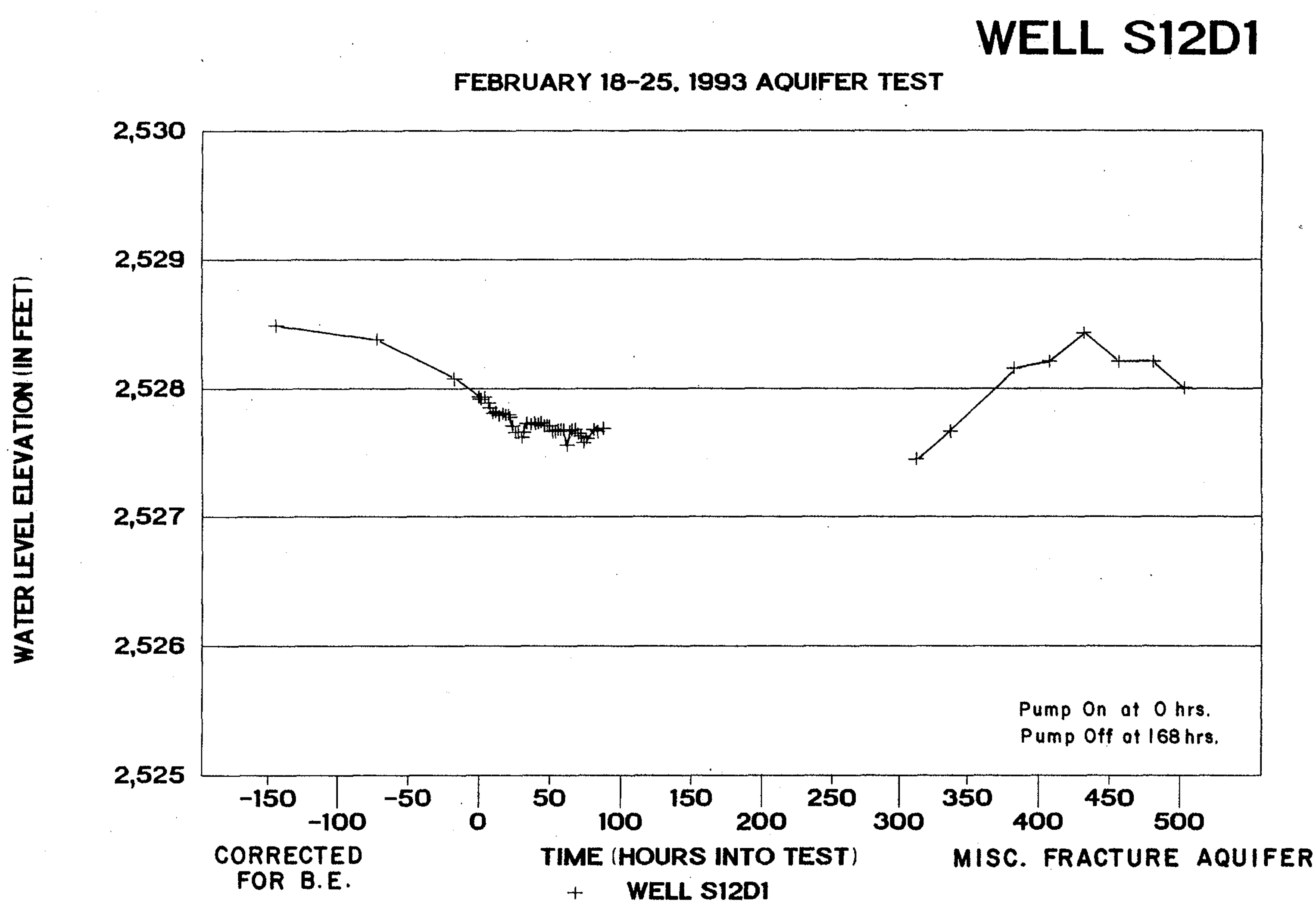



Figure 6.22 Hydrograph showing corrected water level elevations in well S12D1 during February 18-25, 1993 aquifer test in well UI No. 6.

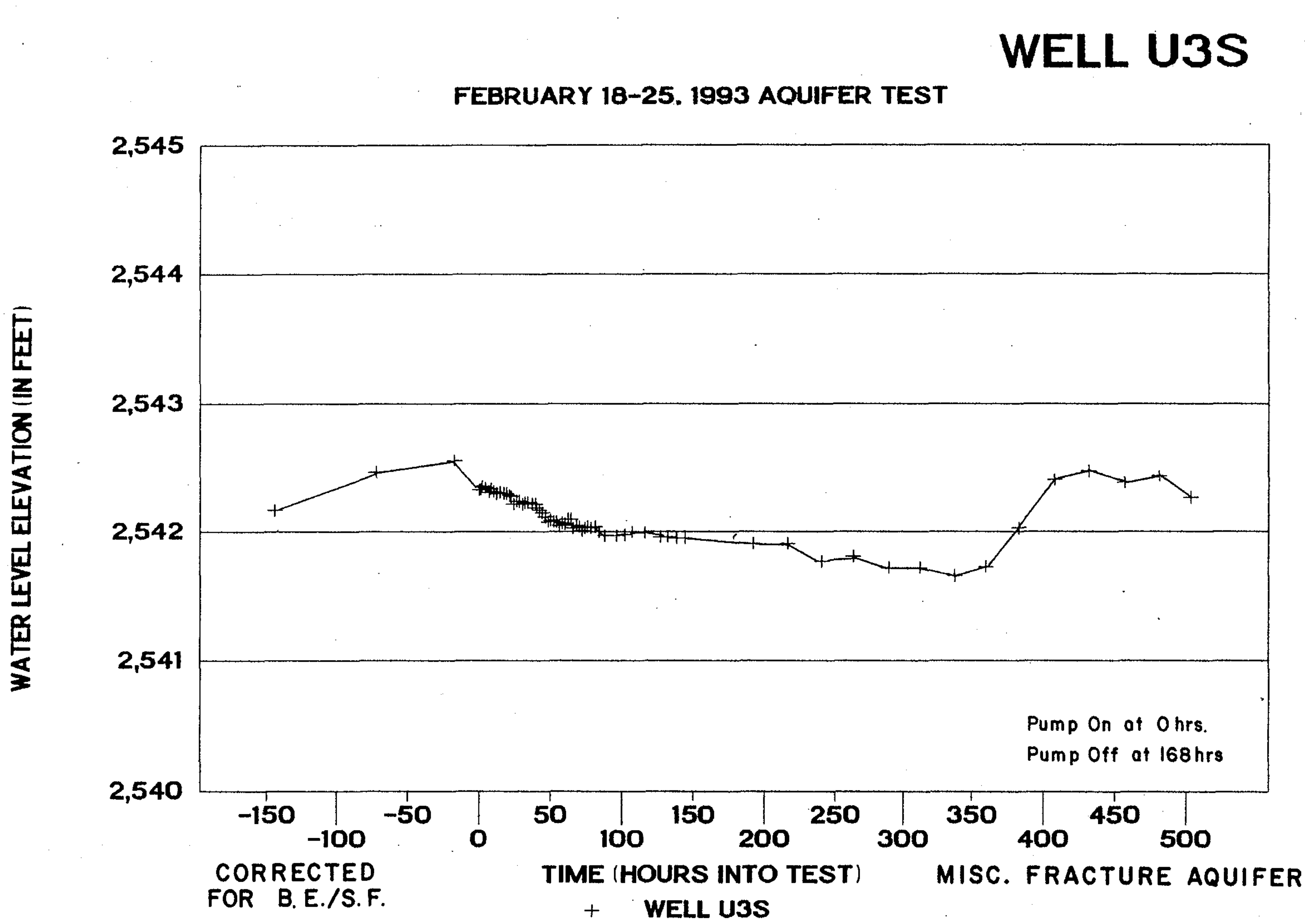



Figure 6.23 Hydrograph showing corrected water level elevations in well U3S during February 18-25, 1993 aquifer test in well UI No. 6.

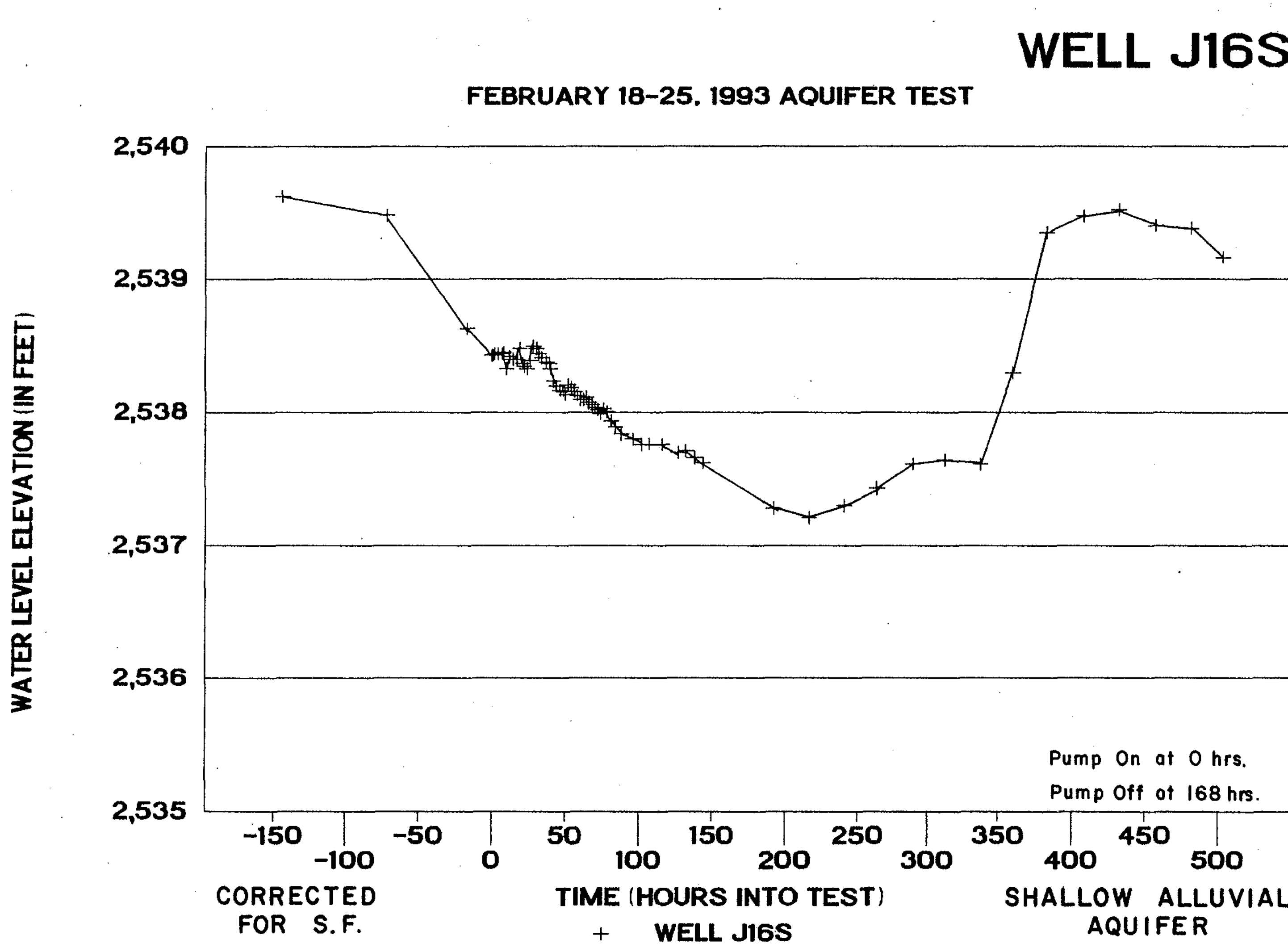



Figure 6.24 Hydrograph showing corrected water level elevations in well J16S during February 18-25, 1993 aquifer test in well UI No. 6.

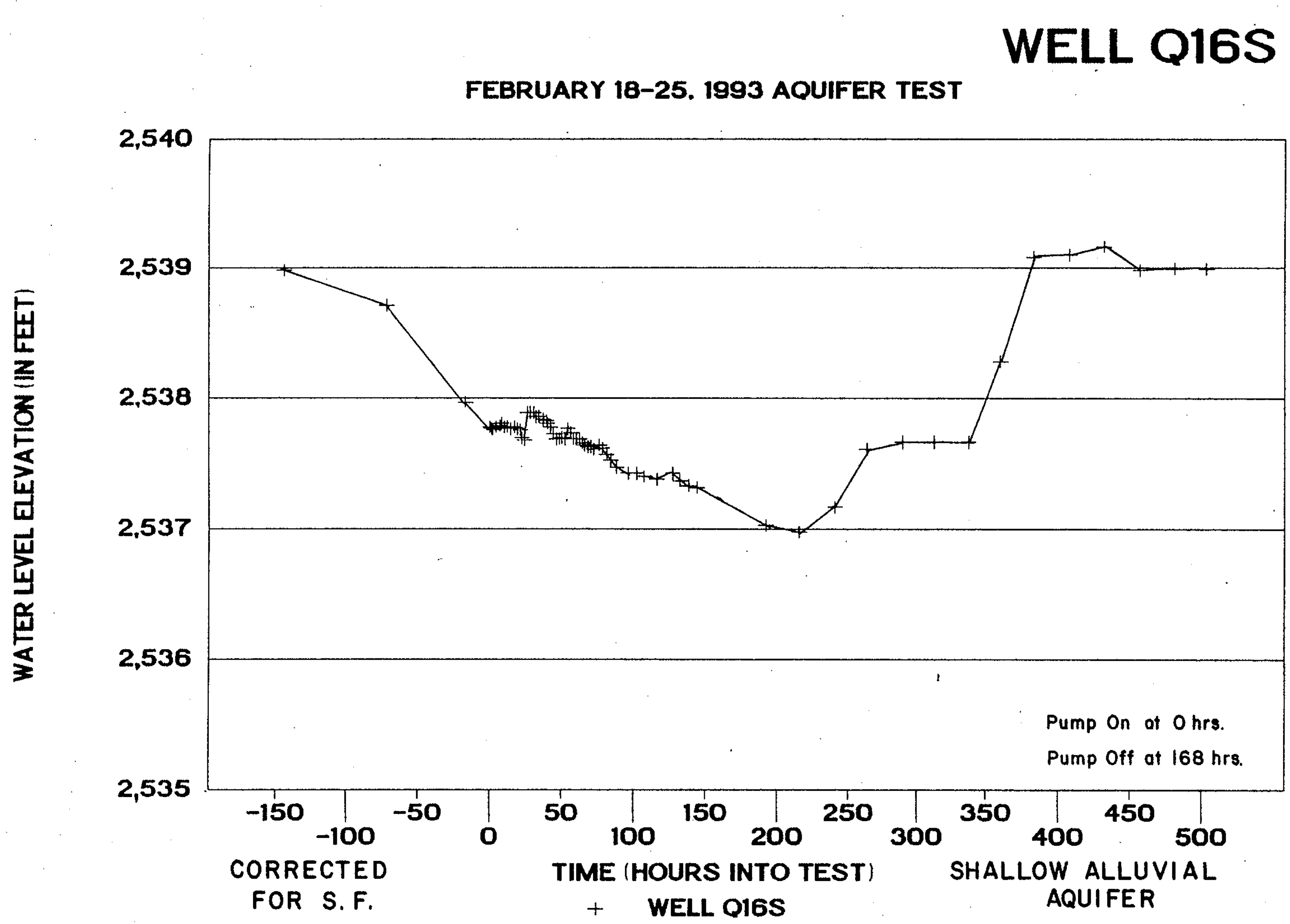



Figure 6.25 Hydrograph showing corrected water level elevations in well Q16S during February 18-25, 1993 aquifer test in well UI No. 6.

The largest drawdown in any of these wells was 1.88 feet recorded in well INEL-D. Drawdown response began in this well about 1.91 hours after the start of the test. Water level recovery in this well was very slow, with no significant increase during the first 200 hours of the recovery period. Maximum recovery occurred 1205 hours from the start of the test, when the water level rose to within 0.29 feet of the pre-test static level.

The three wells in the W-Fractured aquifer monitored during this aquifer test, had similar drawdown and recovery responses. Recorded drawdown during the pumping period in these wells were 0.43 feet in well J16D, 0.56 feet in well U3D and 0.70 feet in well S12D2. Water levels continued to drop after the pump was turned off for approximately 172 hours. Full recovery did not occur in these wells until 815 to 935 hours after the start of the aquifer test.

Water levels elevations in the E-Fractured wells declined between 0.44 to 0.49 feet during the February aquifer test in well UI No. 6. Water levels in the E-Fractured wells were at high seasonal levels prior to and at the start of the pumping test. Cold, dry weather, with a resultant drop in the rate of infiltration and recharge from Paradise Creek, occurred during the pumping period. This weather-related decrease in recharge probably caused the water level drop in the E-Fractured wells. A period of warm, wet weather occurred about 265 hours after the start of the test, and continued through the recovery period. This would produce the rise in water levels that occurred in these wells, coincident with the test recovery period. Water levels in the E-Fractured wells did not respond to the long-term pumping of well UI No. 6 during April to September, 1993.

Water level elevation data for well S12D1 was incomplete due to a problem with a frozen well cap during part of the test. The well did appear to respond to the test; however, a maximum drawdown was not recorded. The water level recovery was similar to that of the E-Fractured wells, with full recovery approximately 430 hours after the start of the test.

Analytical models such as Theis and Jacob do not apply to the drawdown data collected in the UIGRS wells during the February, 1993 aquifer test, because none of the observation wells are completed in the pumped aquifer. Other aquifer tests of the Aquaculture wells during 1993 did not include observation wells at the UIGRS.

The Neuman and Witherspoon (1972) ratio method allows estimation of the hydraulic properties of an aquitard in a leaky aquifer system from aquifer test results. In the ratio method, the drawdown in an observation well completed in the aquitard is compared with the drawdown in a second observation well completed in the pumped aquifer. The two observation wells must be at approximately the same radial distance from the pumping well. This ratio gives an estimate for the vertical hydraulic conductivity and specific storage of the aquitard.

The ratio method can not be used directly with data from the February, 1993 aquifer test, because none of the UIGRS wells are completed in the pumped aquifer. An exercise was conducted using an imaginary well along with data from the INEL-D well as representing the aquitard. Drawdown (s) and time (t) values were estimated for an imaginary fully penetrating well located at the site of the INEL-D well. The pumping rate from the February, 1993 aquifer test was used along with transmissivity and storativity values estimated from the October 4, 1993 pump test. The drawdown value estimated for 1/u = 1 and W(u) = 1 was then plotted on log-log paper. A Theis type curve was aligned with this match point, and traced onto the log-log paper.

A values of s for the imaginary well was scaled off the log-log plot at time $t_o$. A value for drawdown (s′) in well INEL-D was obtained from data measured in this well during the February aquifer test. These drawdown values were then used to estimate an s′/s ratio at a time $t_o$. The value used for $t_o$ was taken at the earliest time at which actual drawdown was observed in well INEL-D. The ratio s′/s was then used to estimate the vertical hydraulic conductivity ($K'_v$) of the aquitard located between the pumped lower sand aquifer and the upper contact of the sediment interbed. Estimation of a $K'_v$ value requires that a specific storage value for the aquitard be known or estimated. A range of values for a compacted sand material were selected from various literature and were used in estimating this parameter. The $K'_v$ values obtained from this estimate ranged from $5X10^{-2}$ ft/day to $5X10^{-4}$ft/day for specific storage values of $1.5X10^{-5}$ to $1.5X10^{-7}$.

A second set of calculations were made using estimated drawdown for the imaginary well and measured test data from well S12D2, completed in the W-Fractured aquifer. The aquitard in this example is a composite sequence consisting of both sediment and basalt layers. Again, a range of values were selected for the specific storage parameter used in estimating the $K'_v$. The $K'_v$ values represent only a crude estimate of a range of values for this heterogeneous anisotropic sequence. The estimated values for $K'_v$ range from $4X10^{-4}$ ft/day to $4X10^{-6}$ft/day for specific storage values of $5X10^{-7}$ to $5X10^{-7}$.

WELL UI NO. 2

Well UI No. 2 is reported to be completed in two sand layers in the sediment interbed that are at approximately the same stratigraphic position as the sand layer screened in well UI No.6. A water level measurement taken in this well on January 9, 1958 showed a static water level elevation of 2478 feet (AMSL). This elevation is very close to the static water level elevation of 2481.1 feet (AMSL) measured in well UI No. 6 on January 12, 1993. A static water level measurement taken in well UI No. 2 on February 18, 1993 gave an elevation of 2512.4 feet (AMSL). This extremely shallow water level elevation makes data from UI No. 2 of questionable value.

All measurements on well UI No. 2 during the aquifer test were taken down the pump column. Access down the well casing was not possible. Measurement taken in this well during the aquifer test are highly suspect, and are not believed to be representative of water levels in the pumped sand aquifer. The extremely high water level elevations may be caused by: 1) collapse of the well, 2) plugging of the well screen by sand or precipitates, or 3) by measuring the well down the pump column.

A hydrograph showing water level elevations in this well is presented in figure 6.26. No conclusions can be drawn from these data.

## MAXIMUM YIELD ANALYSIS

The maximum yield is a useful measure in determining a pumping rate for a well and the size of pump for a well. The maximum yield is the product of the estimated long-term specific capacity and the usable drawdown in the well. Because the specific capacity will decline with time when a well is pumped continuously at a constant rate, adjustments in the specific capacity value should be made to account for this decline (Heath, 1989).

Maximum yield estimates were made for wells UI No. 6 and

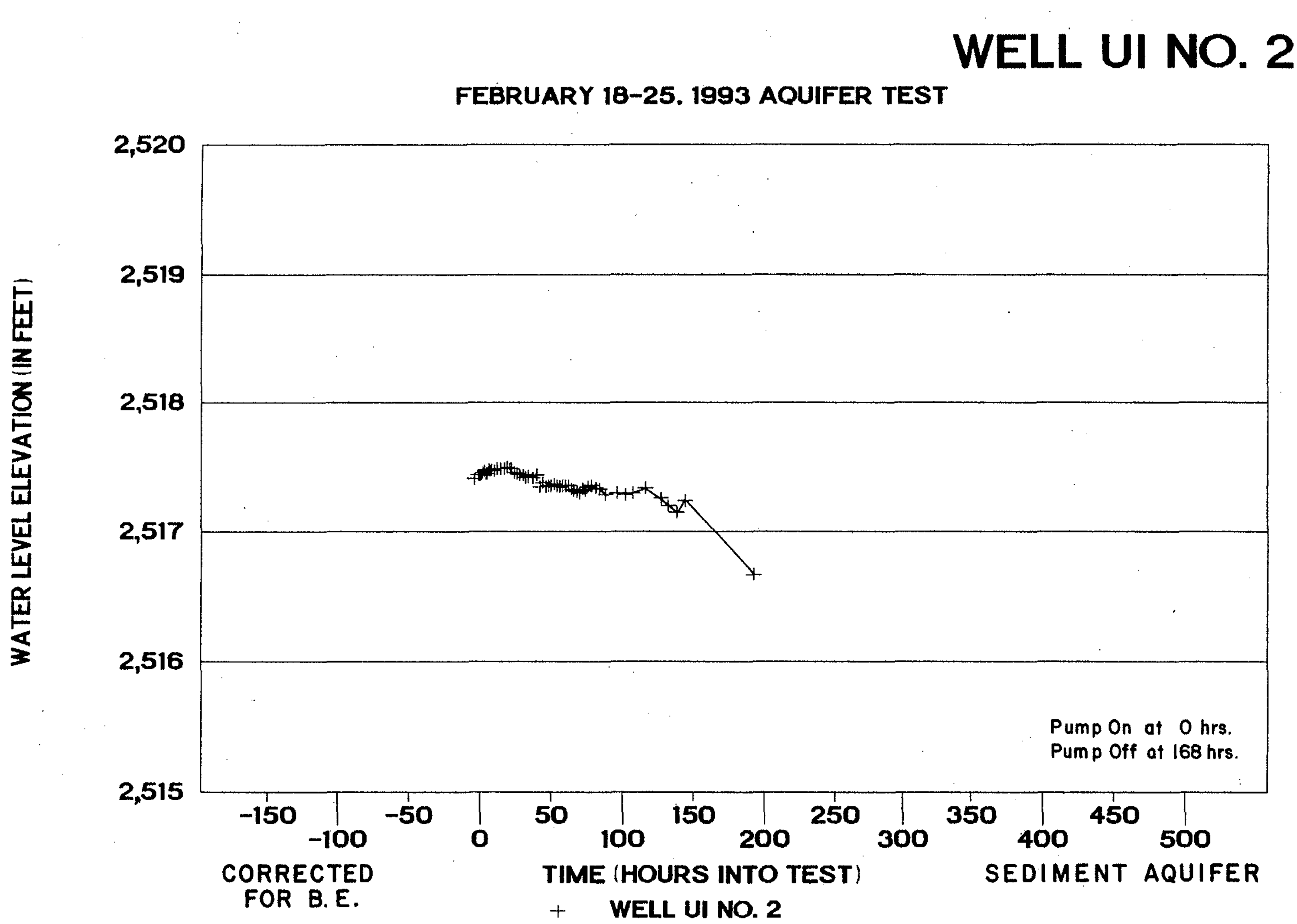



Figure 6.26 Hydrograph showing corrected water level elevations in well UI No. 2 during February 18-25, 1993 aquifer test in well UI No. 6.

UI No. 7 on the basis of information from the aquifer tests conducted in 1993. Calculations for the maximum yield estimates are shown in figure 6.27 and 6.28. A long-term maximum yield for well UI No. 6 was estimated from the February aquifer test data. A value of about 240 gallons per minute is estimated for this well. An maximum long-term yield of about 450 gallons per minute is estimated for well UI No. 7 using data obtained from the May step-drawdown test performed on this well.

**WELL UI NO. 6**

**MAXIMUM YIELD ESTIMATE**

DATA FROM AQUIFER PUMP TEST - FEBRUARY 18-25, 1993:

MID-TERM SPECIFIC CAPACITY = 125 GPM/45 FT. OF DRAWDOWN (7-DAY PERIOD)
= 2.78 GPM/FT.

LONG-TERM SPECIFIC CAPACITY = 125 GPM/65 FT OF DRAWDOWN (EST.) (20 YEARS)
= 1.92 GPM/FT.

| | | |
|---|---|---|
| TOTAL AVAILABLE DRAWDOWN: | | |
| MAX. PUMP SETTING | 305 FT. | (BELOW SURFACE) |
| STATIC WATER LEVEL | 144 FT. | (BELOW SURFACE) |
| TOTAL AVAILABLE DDN. | 161 FT. | |
| ALLOWANCES (ESTIMATED) | | |
| PUMP SUBMERGENCE | 15 FT. | |
| INTERFERENCE | 4 FT. | |
| SAFTY FACTOR | 15 FT. | |
| BAROMETRIC | 1 FT. | |
| TOTAL ALLOWANCES | 35 FT. | |

USABLE DRAWDOWN = 161 FT. MINUS 35 FT. = 126 FT.

**MAXIMUM YIELD** = 126 FT. X 1.92 GPM/FT.

= **240 GPM (ESTIMATED)**

Figure 6.27 Estimated long-term maximum yield for well UI No. 6.

# WELL UI NO. 7

## MAXIMUM YIELD ESTIMATE

DATA FROM AQUIFER STEP-DRAWDOWN TEST - MAY 21, 1993:

SHORT-TERM SPECIFIC CAPACITY = 400 GPM/56.08 FT OF DRAWDOWN (330 MIN.)
= 7.13 GPM/FT.

LONG-TERM SPECIFIC CAPACITY = 400 GPM/86 FT. OF EST. DRAWDOWN (20 YEARS)
= 4.65 GPM/FT.

TOTAL AVAILABLE DRAWDOWN:

| | |
|---|---|
| MAX. PUMP SETTING | 280 FT. (BELOW SURFACE) |
| STATIC WATER LEVEL | 147 FT. (BELOW SURFACE) |
| TOTAL AVAILABLE DDN. | 133 FT. |

ALLOWANCES (ESTIMATED)

| | |
|---|---|
| PUMP SUBMERGENCE | 15 FT. |
| INTERFERENCE | 4 FT. |
| SAFTY FACTOR | 15 FT. |
| BAROMETRIC | 1 FT. |
| TOTAL ALLOWANCES | 30 FT. |

USABLE DRAWDOWN = 133 FT. MINUS 35 FT. = 98 FT.

**MAXIMUM YIELD** = 98 FT. X 4.65 GPM/FT.
= **450 GPM (ESTIMATED)**

Figure 6.28 Estimated long-term maximum yield for well UI No. 7.

# CHAPTER 7

# CONCLUSIONS AND RECOMMENDATIONS

## GENERAL CONCLUSIONS

The upper aquifer system at the Aquaculture Research Laboratory site is composed of a number of aquifers occurring within two major lithologic formations. Aquifers in the Lolo member of the Wanapum Basalt are capable of supplying water for low-yield wells, with sustained yields of less than 50 gallons per minute. The underlying sediment interbed contains two important water-bearing zones within thick layers of sand and silt in the upper section of this unit. A basalt aquiclude between the E-Fractured zone and the W-Fractured zone segregates the upper aquifer into two hydraulically separate systems.

Wells completed in the two sand aquifers in the sediment interbed are capable of producing sustained yields of several hundreds of gallons of water per minute. Wells UI No. 6 and UI No. 7, located at the Aquaculture facility, are completed in these sand aquifers. Each well is capable of supplying the required needs of this facility of about 150 gallons per minute.

Full recovery of the water level in the Aquaculture wells appears to occur within a period of several months after termination of periods of long-term pumping. Water levels in wells completed in the W-Fractured aquifer and in the aquifer at the very top of the sediments interbed, are slow to recover. Long-term pumping of the Aquaculture wells may significantly lower the water level elevation in these minor aquifers.

## SPECIFIC CONCLUSIONS

The following specific conclusions are made from this study:

1) The upper aquifer system, on the bases of stratigraphic and hydrogeologic criteria, consists of both the Lolo flow member of the Wanapum Basalt and the underlying Latah formation sediment interbed.

2) The shallow alluvial aquifer and the E-Fractured aquifer in the basalt are hydraulically connected, and receive recharge mostly from infiltration of precipitation and flow from Paradise Creek. Aquifers in the sediment interbed and the W-Fractured and basal zones in the basalt, are hydraulically separate from these near-surface zones. Recharge to the deeper aquifers is mostly from distal lateral flow with infiltration of surface waters occurring at the basin margins. A basalt aquiclude, approximately 40 to 50 below the top of the Lolo flow, most likely segregates the two hydraulic systems.

3) Development of the ground water potential within the sediment interbed at the Aquaculture facility is limited to the upper 110-foot section of this unit at the study site.

Total thickness of this unit is between 220 and 300 feet. The potential for development of other deeper aquifers in the lower part of the sediment interbed is unknown.

4) The lithology of the upper section of the sediment interbed consists of in decreasing order: 1) a poorly consolidated sandstone-siltstone layer from 15 to 30 feet thick; 2) an unconsolidated sand-silt layer 35 to 40 feet thick; 3) a thin consolidated sandstone-siltstone layer from 2 to 6 feet thick; 4) a second unconsolidated sand-silt layer from 30 to 40 feet thick; and 5) a poorly to moderately consolidated sandstone-siltstone layer of unknown thickness. All of these layers contain varying amounts of clays. The two unconsolidated sand layers form the principal aquifers in this formation. The consolidated layers form aquitards, but may have a permeability of only one to three orders of magnitude lower than the aquifers they segregate. Lateral continuity of any of the layers is poorly known.

5) Well UI No. 6 is screened in a 26-foot section in the lower sand aquifer. Well UI No. 7 is screened over a 10.5-foot interval in the upper sand aquifer and in a second 21-foot interval in the lower sand aquifer. Static water levels in wells UI No. 6 and UI No. 7 measured on January 12, 1994 were at elevations of 2481.1 feet (AMSL) and 2488.5 feet (AMSL), respectively. This seven-foot difference in water level elevations indicates that the two sand aquifers do not react hydraulically as a single unit. A downward vertical

gradient is present between the two aquifers in well UI No. 7.

6) Estimate of transmissivity for the lower sand aquifer on the bases of results from the October aquifer test is 1110 $ft^2$/day. Transmissivity of the combined lower and upper sand aquifers in well UI No. 7 is estimated at 1930 to 2780 $ft^2$/day. A combined storativity for the two sand aquifers is estimated at $4X10^{-4}$.

7) Leaky conditions occur between the two sand aquifers in the upper section of the sediment interbed, and between the sediment aquifers and the W-Fractured aquifer in the overlying basalt. During the seven-day aquifer test in well UI No. 6, drawdown occurred in the INEL-D well (1.88 ft.) and in the W-Fractured aquifer wells (0.43 to 0.70 ft.). Long-term pumping of well UI No. 6 during April to September, 1993 produced similar but greater drawdown responses in these wells. Maximum drawdown during this period was 15.85 feet in well INEL-D. Drawdown in the W-Fractured wells ranged from 9.21 to 10.94 feet. Water levels did not fully recover in the INEL-D and W-Fractured wells during the period monitored from September, 1993 through January 10, 1994.

8) Water levels in the observation wells in the E-Fractured aquifer and the shallow alluvial aquifer did not respond to pumping of well UI No. 6. No hydraulic connection between the E-Fractured and shallow alluvial aquifers and the aquifers in the sediment interbed was apparent in this study.

9) Long-term maximum yield estimates made from the

aquifer test data produced values of about 240 gallons per minute for well UI No. 6 and about 450 gallons per minute for well UI No. 7.

10) By using proper well construction design, wells completed in the sand aquifer are capable of producing long-term yields up to several hundreds of gallons per minute with no significant deterioration due to plugging of the well screen by sand. Water pumped from well UI No. 6 by the Aquaculture laboratory during 1993 was reportedly free of sand.

## RECOMMENDATIONS

1) An aquifer test should be performed on well UI No. 7 to obtain additional and more accurate values for aquifer and aquitard parameters. The long-term aquifer test made in February, 1993 did not include an observation in the pumped aquifer. This precluded the use of leaky aquifer analytical solutions for these parameters. The well should be pumped for approximately one week, and recovery data collected for an additional three week period. Observation wells should include the INEL and W-Fractured wells at the UIGRS, UI No. 6, and at least one other well in the area completed in the pumped aquifer.

2) Water quality data should be monitored periodically in the Aquaculture wells during both pumping and idle periods.

This data is needed to determine if water quality continues to meet the specifications required by the Aquaculture laboratory.

3) Monitoring of wells at the UIGRS should continue with measurements taken on alternate days (or three times a week). A daily monitoring schedule should be followed during periods of high recharge. This data is useful in monitoring the effects of pumping in the Aquaculture wells on the upper aquifer system.

4) Monitoring of water levels in the Aquaculture wells should be added to the program of well monitoring currently active at the UIGRS. This data will help to identify annual fluctuations in the water level, the amount of drawdown resulting from future pumping of these wells, and provide post-pumping recovery information.

5) A new monitor well should be drilled at the UIGRS to a depth of about 300 feet, and piezometers installed in the two sand aquifers. This well would be used to monitor long-term effects on this aquifer system resulting from future pumping at the Aquaculture facility.

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