G R O U N D W A T E R

O P E N F I L E R E P O R T

A HYDROGEOLOGIC INVESTIGATION OF THE HAY CREEK AREA NEAR MADRAS, OREGON

By

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DEFINITIONS OF TERMS

Acre-Foot (AF): The volume required to cover 1.0 acre to a depth of 1.0 foot. This is equal to 43,560 cubic feet or 325,851 gallons.

Alluvium: Deposits of clay, silt, sand and gravel resulting from the deposition by modern rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.

Anticline: A fold that is convex upward, in which strata dip away in opposite direction from a common ridge or axis and whose core contains stratigraphically older rocks.

Aquifer: A body of saturated rock, alluvium, or other naturally occurring material having sufficient permeability to store, transmit, and yield sufficient quantities of water to wells or springs so that they can serve as a practical supply of water.

Artesian Aquifer: Artesian is synonymous with confined. A geologic unit that contains water under sufficient hydrostatic pressure to cause the water level in a well to stand above the bottom of the overlying confining layer. When the pressure is sufficient to raise the water level above land surface, a properly constructed well penetrating an artesian aquifer will flow.

Cone of Depression: The conical depression in a potentiometric surface or water table that forms around a well as a result of pumping.

Ground Water Reservoir: A designated body of standing or moving ground water having exterior boundaries which may be ascertained or reasonably inferred (ORS 537.515(4)).

Fault: A fracture or series of fractures in rock accompanied by a displacement of one side with respect to the other in a direction parallel to the fracture.

Hydraulic Conductivity: A measure of the volume of ground water flowing in unit time through a face of unit cross sectional area perpendicular to the direction of flow under a unit hydraulic gradient. It can be expressed as gallons per day per square foot or feet per day.

Interference: The lowering of the water level in a well or spring due to pumping of neighboring well(s).

Permeability: The ability of a rock or soil to transmit fluid such as water under a hydraulic gradient.

Potentiometric Head: The level to which water in an aquifer will rise by hydrostatic pressure, usually expressed as an elevation above sea level.

Specific Yield: The ratio of the volume of water which a saturated rock or soil will yield by gravity to the total volume of rock or soil.

Storage Coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Syncline: A fold in rocks that is concave upward in which strata dip inward from both sides toward the axis and whose core contains stratigraphically younger rocks.

Total Head: The total head of a liquid at a given point is the sum of three components: (1) elevation head, which is the elevation of a point above a datum, (2) pressure head, which is the height of a column of static water that can be supported by the static pressure at the point, and (3) velocity head, which is the height the kinetic energy of the liquid is capable of lifting the liquid. In most ground water situations, velocity head is nil.

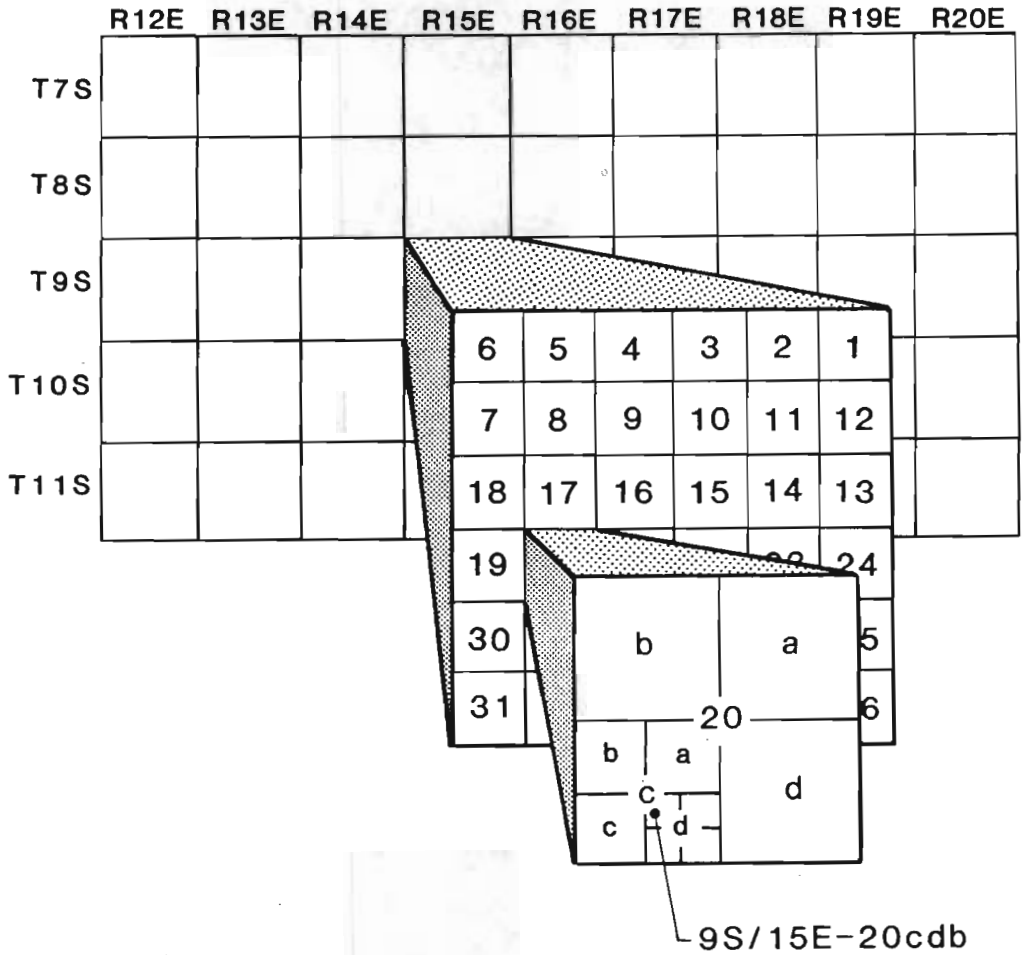
Transmissivity: The rate of flow at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the saturated thickness of the aquifer. It is usually expressed as gallons per day per foot, or square feet per day. In simple terms, the ability of an aquifer to transmit water.

Water Level: The distance from land surface to the top of the water column in a well. When the well is pumping, it is called a pumping water level. It is referred to as a static water level in a well that has recovered from any pumping.

Water Table Aquifer: Water table is synonymous with unconfined. A water-bearing geologic unit in which the hydrostatic pressure at the upper surface of the water body is atmospheric.

WELL NUMBERING SYSTEM

The well and spring numbering system used in Oregon is based on the rectangular system used for subdivision of public lands. Each well number indicates the geographic location of the well and describes the township, range, and section. For example, the well number 9S/15E-20cdb indicates a well located within Township 9 South, Range 15 East, and section 20. The letters following the section number indicate the well location within the section as shown below. The first letter (c) represents the quarter section (160 acres), the second letter (d) the quarter-quarter section (40 acres), and the third letter (b) the 10.0 acre tract. A series number is added following the third letter to distinguish two or more wells within a 10.0 acre tract.



EXECUTIVE SUMMARY

On September 14, 1987, Bob Main, the Watermaster in District 11, was notified of a potential ground water interference problem. The owner of an irrigation well northeast of Madras was unable to pump his normal quantity of water. The Geology/Hydrology Section was requested to conduct an aquifer test to determine if there was interference between the ground water users.

A preliminary round of water level measurements was made on October 7, 1987. A 24-hour constant rate aquifer test was conducted on October 14-15, 1987. Water levels were measured in the pumping well and in five observation wells and one spring. Analysis of the aquifer test data indicated that at least two barriers to ground water flow affected the water levels. Storage coefficient values were calculated ranging from 1.09×10^{-4} to 6.75×10^{-5} indicating a confined aquifer. The transmissivity values calculated range from 4,100 to 26,400 gallons per day per foot.

There was 8.53 feet of drawdown at the Ochs irrigation well after pumping the Rueter irrigation well for 24 hours at 200 gallons per minute. Using the aquifer characteristics determined from the test, drawdown at the Ochs irrigation well was estimated to be 24 feet after after 30 days.

Because Mr. Ochs has the older ground water right and is unable to pump his duty of water, any interference is significant. A gentleman's agreement should be worked out between the users on how to distribute the ground water resource. If no agreement can be reached, regulatory action may be required to protect the older water right.

INTRODUCTION

Location

Hay Creek is located 15 miles northeast of Madras in Jefferson County. The wells in the investigation are located on both sides of Hay Creek. Hay Creek flows into Trout Creek, a tributary of the Deschutes River.

Purpose

On September 14, 1987, Bob Main, the Watermaster in District 11, was notified of a potential ground water interference problem. Ron Ochs, a farmer in the Hay Creek area northeast of Madras (Figure 1) indicated that his irrigation well was not producing its normal quantity of water. He felt that the use of a new well in the valley was interfering with his well. Bob Main requested the Geology/Hydrology Section to look into the problem and conduct an aquifer test to determine: 1) if there was interference between the two wells and 2) if the interference was significant.

On October 7, 1987, Marc Norton, a hydrogeologist from the Salem office accompanied Bob Main to Hay Creek. A preliminary round of water level measurements was made at the wells. An aquifer test was conducted the following week.

Previous Studies

In 1964, Peck conducted an investigation of the geology in the Antelope-Ashwood area and described the stratigraphy of the John Day Formation in detail. Robinson (1974) also mapped the geology in the area as part of a larger study.

In September 1980, the Water Resources Department conducted an investigation to determine if interference was occurring between the Ochs irrigation well and a spring owned by Mr. Bauer. The investigation included a 2 day recovery test when the Ochs pump was shut down after pumping most of July and August. A 24-hour drawdown test was run when the pump was turned back on. The Bauer spring was dry during both tests, but data collected during the test and at the end of the irrigation season confirmed the connection between the Ochs irrigation well and the Bauer spring. It was noted that the discharge from the Ochs irrigation well dropped during the summer. The pump was drawing air prior to shut down indicating that the ground water level was at the intake section of the pump. An agreement was reached between the parties settling the issue concerning the ground water supply at that time in the area.

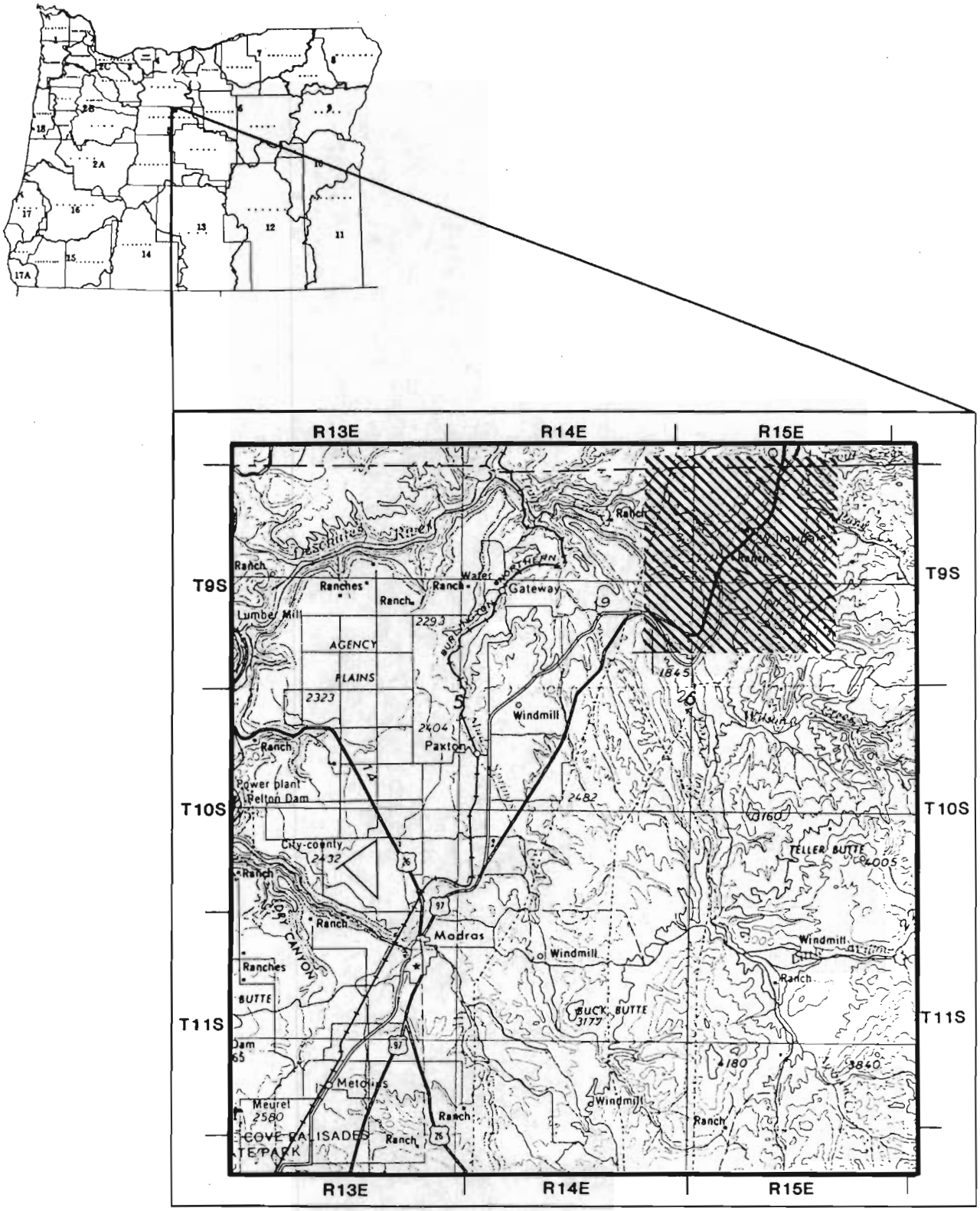


Figure 1. LOCATION OF STUDY AREA

Ground Water Development

Listed in Table 1 are the ground water rights in the Hay Creek area. There are four ground water rights not included in the list because they appropriate water from the shallow alluvial material. Mr. Ochs has the largest and oldest ground water permit. Mr. Rueter has the smallest and newest ground water permit. Certificates have not been issued on any of the permits.

Table 1. List of ground water rights in the Hay Creek area (not including shallow alluvial wells).

OWNER	APPLICATION NUMBER	PERMIT NUMBER	PRIORITY DATE	PERMITTED DIVERSION (CFS)	ACREAGE *
OCHS	G-8956	G-9178	10/ 4/78	2.83	226.5 (P)
BAUER	G-9511	G-9179	8/28/80	2.69	215.15 (S)
RUETER	G-11083	G-10253	9/14/83 11/14/83	0.56 0.34	71.6 (S)

* (P) Primary irrigation acres (S) Supplemental irrigation acres

Acknowledgments

Mr. Ochs, Mr. Rueter, and Mr. Bauer greatly facilitated this investigation by providing access to their wells. Mr. Ochs removed the tops of his unused wells so that recorders could be installed. I would like to thank Central Electric Cooperative, Inc. in Redmond for information concerning the Rueter irrigation well and for donating the electricity used during the aquifer test.

I greatly appreciate the assistance I received from the following department personnel: Susan Hartford, data collection and report review; Mike Zwart, Ken Lite, Jerry Grondin, Marshall Gannett and Donn Miller, report review, Bob Main, Watermaster, report review and data collection during the aquifer test, and Duane Clark, Assistant Watermaster, data collection during the aquifer test.

GEOGRAPHIC SETTING

The climate is semi-arid. Most of the hills are barren except for sagebrush and juniper. The valley bottom is farmed using water from Hay Creek and wells. The average annual precipitation at Madras is nearly 10 inches. The precipitation at Hay Creek is close to 10.7 inches annually. Temperatures can exceed 100 Fahrenheit (^{o}F) in the summer and drop below 0 F in the winter. The only discharge measurements for Hay Creek on record were in 1915-1916. Discharge ranged from .5 cubic feet per second (cfs) to 9.16 cfs. Flooding can cover most of the valley floor.

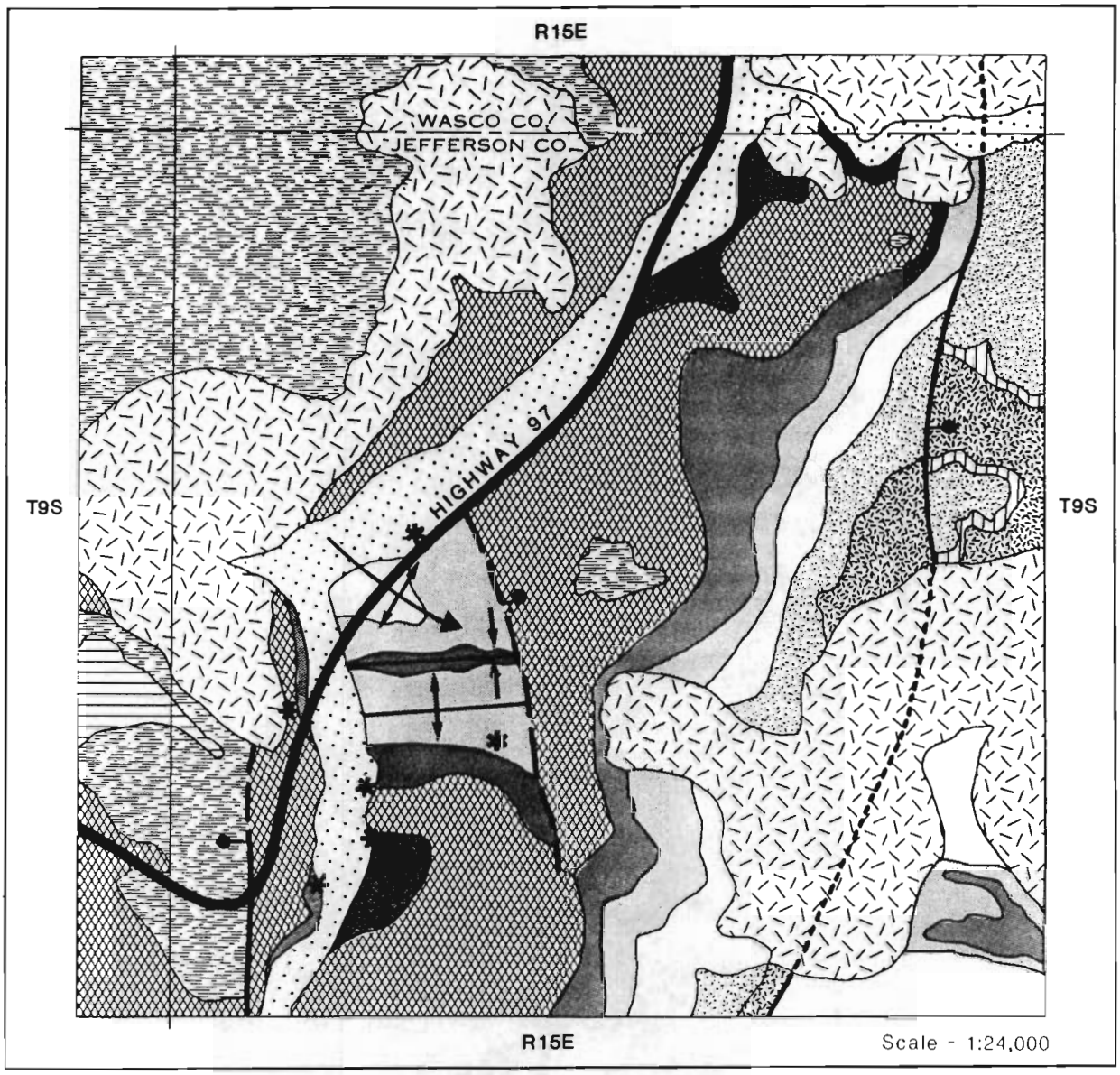
HYDROGEOLOGIC SETTING

Geology

A thin layer of alluvial material consisting of silt, sand, and gravel has been deposited in the stream valleys. The sediments are a minor source of water. Wells penetrating the alluvium can obtain sufficient water for year round domestic use and small irrigation use during the spring and early summer.

The John Day Formation is the source of ground water for the wells monitored in the aquifer test. The John Day Formation consists of about 4000 feet of tuff and is divided into nine members (Peck, 1964). Tuff consists of very small fragments that form as a result of volcanic eruption. Seven members of the John Day Formation are exposed near Hay Creek due to faulting, folding, and erosion (Figure 2). Several north-south trending faults have been mapped in the area. The wells are located between two faults, one located on each side of Hay Creek. The area between the faults has been uplifted. The amount of displacement is unknown. An east-west trending u-shaped fold (syncline) is flanked by arched shaped folds (anticlines) on the north and south.

Geologic structures such as faults and folds can affect the movement of ground water in a flow system. If the ability of the rocks to transmit water is reduced, a barrier to ground water flow is created. Faulting and folding can increase the ability of ground water to move vertically. Recharge to the ground water flow system can occur along faults or folds. Ground water can also move upward from greater depths along faults or folds in to an upper aquifer. The presence of barriers or recharge areas can sometimes affect the aquifer test results.



EXPLANATION

- Qa ALLUVIAL DEPOSITS
- Qls LANDSLIDE DEPOSITS
- Td DALLES FORMATION - Sedimentary Rocks
- Tcr BASALT OF COLUMBIA RIVER FLOW - Basalt Flows
- Fault - Dashed where approximately located, dotted where concealed. Ball on downthrown side
- Contact - Approximately Located
- Anticline - Arrow indicates direction of plunge
- Syncline

JOHN DAY FORMATION:
- Tji Member i
- Tjh Member h
- Tjg Member g
- Tjf Member f
- Tje Member e
- Tjd Member d
- Tjc Member c

- Well Location

Figure 2. GEOLOGIC MAP
From Robinson, 1975

The Hydrologic Cycle

The hydrologic cycle is the movement of water over, on and in the earth's crust (Figure 3). Water evaporates from bodies of water and the land surface to form clouds. Precipitation in the form of rain or snow returns the water to earth. Much of the precipitation is returned to the atmosphere by evaporation or by plants.

Water that reaches the ground, infiltrates into the soil or runs off to streams. Once in the soil, water is used by plants or percolates downward to be temporarily stored as ground water. The part stored as ground water then moves laterally, eventually discharging as springs or seeps into streams. Man intercepts ground water by developing springs and constructing wells. Water reaching streams, returns to the oceans where it is again evaporated to continue the cycle.

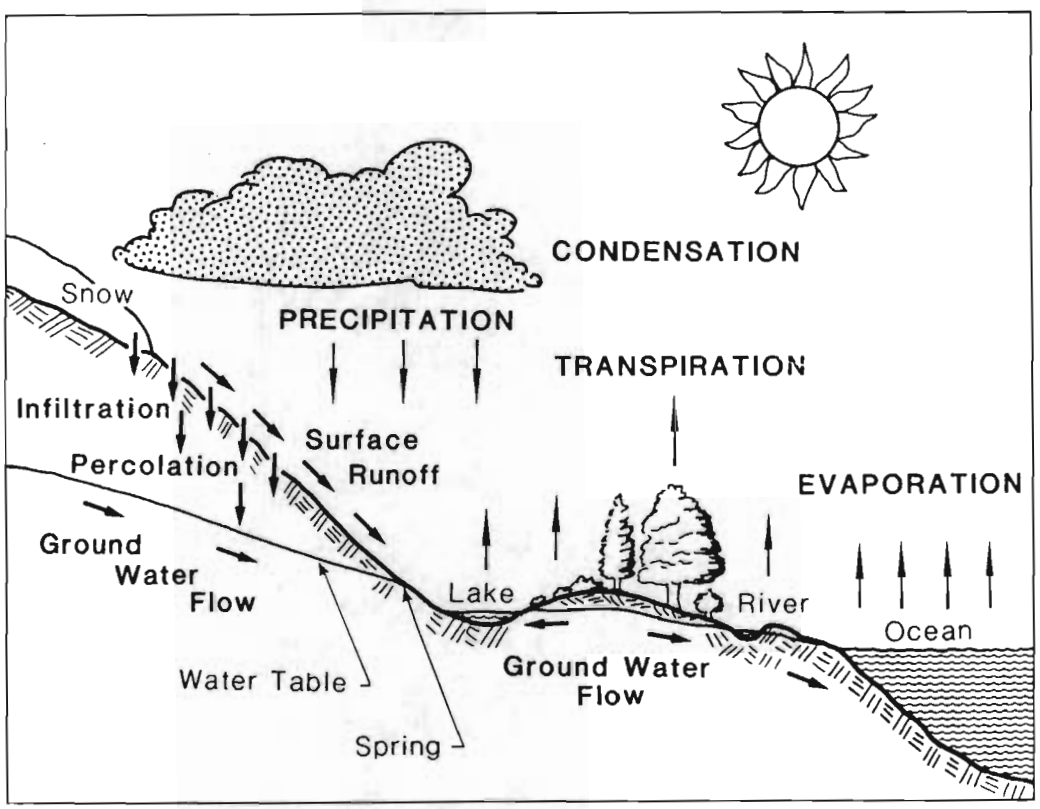


Figure 3. THE HYDROLOGIC CYCLE
From Todd, 1959

Ground Water

An aquifer is a body of saturated rock, alluvium, or other naturally occurring material that contains sufficient permeability to store, transmit, and yield quantities of water to wells or springs so that the source can serve as a practical supply of water. Aquifers are classified as unconfined (water table) or confined (artesian), depending on the absence or presence of a confining stratum (Figure 4). An unconfined aquifer is a water-bearing geologic unit where the hydrostatic pressure at the upper surface of the water body equals the atmospheric pressure. A confined aquifer is a geologic unit that contains water under sufficient hydrostatic pressure to cause the water level in a well to stand above the bottom of the overlying confining stratum.

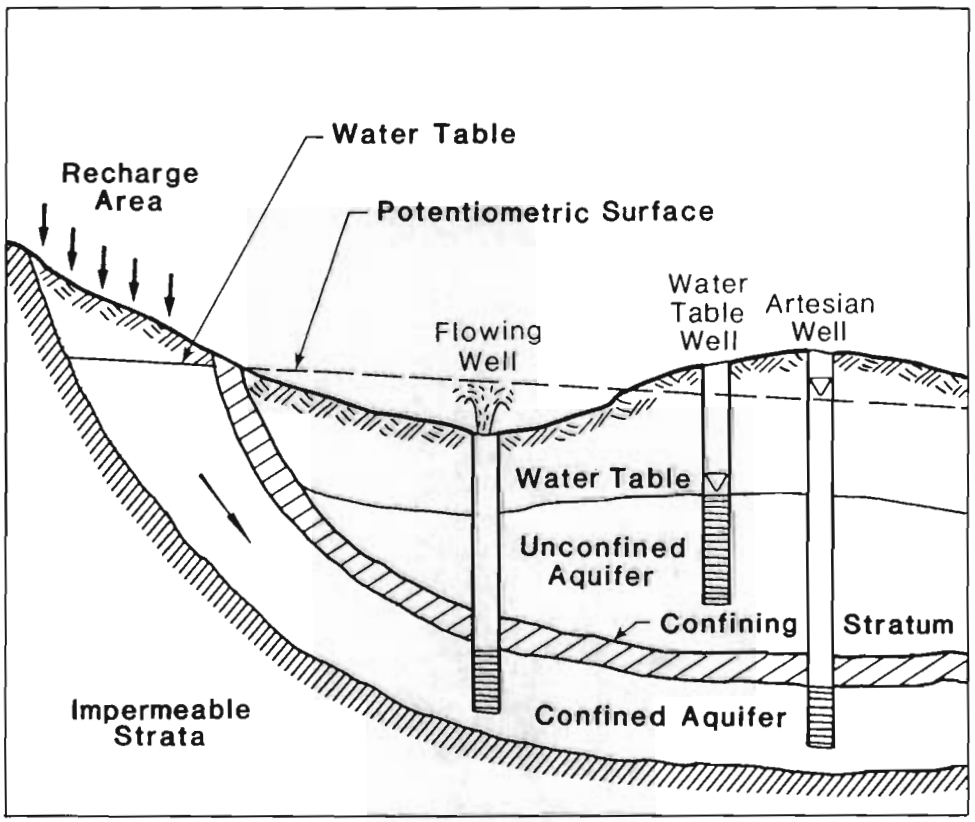


Figure 4. UNCONFINED AND CONFINED AQUIFERS
From Todd, 1959

DESCRIPTION OF THE AQUIFER TEST

Aquifer Test Methods

On October 7, 1987, ground water levels were measured in 6 wells and at the Bauer spring (Figure 5). Table 2 lists the wells and spring measured during the test. On October 13, 1987, a second round of measurements was taken to determine ground water level trends prior to the aquifer test. Type F water level recorders were installed on two unused wells located nearby. A microbarograph was placed at the Ochs' farm to monitor changes in atmospheric pressure during the test.

The Rueter irrigation well was the pumping well for this test. It was equipped with a 25 horsepower submersible pump. A gate valve at the well head was used to maintain the discharge at a constant rate. Discharge was measured by flowing the water into a ditch, then over a rectangular weir. The water then flowed into Hay Creek. Water temperature was measured periodically throughout the test. The electric meter was read before and after the test. The rate of demand for electricity was checked periodically during the test. Water levels were measured with calibrated electric tape. Each well was measured with the same sounder throughout the test to maintain data integrity.

An aquifer test consists of pumping one well at a known constant rate and observing the effects in the pumping well and in nearby observation wells. The test includes drawdown and recovery phases.

Table 2. Wells and springs measured during the Ochs/Rueter aquifer test.

Well	Well depth, (Feet)	Elevation at well head, (Feet)	Distance to pumped well, (Feet)
RUETER IRRIGATION	225	1,770	--
RUETER DOMESTIC	272	1,760	2,150
OCHS IRRIGATION	210	1,755	3,370
BAUER IRRIGATION	350	1,740	5,520
BAUER SPRING	--	1,730	5,520
OCHS TEST 17	780	1,710	11,155
OCHS TEST 21	800	1,840	6,800

For this test, the pump was turned on at 10:00 AM on October 14, 1987 and drawdown was measured for 24 hours. Recovery was measured for 4 hours immediately after the pumping period. Bob Main measured the water levels in the wells approximately 26 hours after the pump was shut off. An additional round of measurements was made on November 16, 1987.

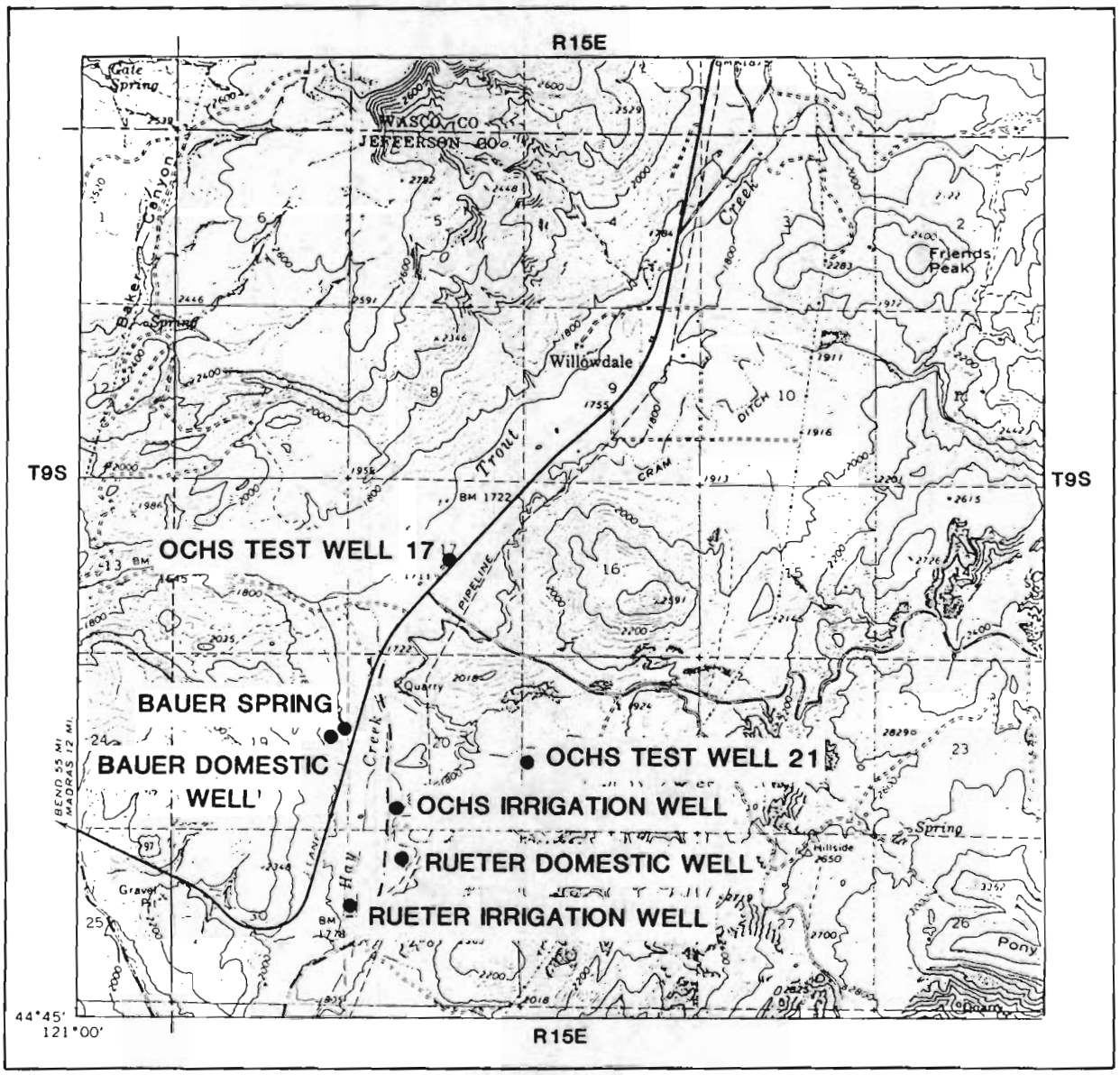


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Figure 5. LOCATION OF WELLS MEASURED DURING AQUIFER TEST

When a well is pumped, ground water is removed from the aquifer in the vicinity of the well. Because the aquifer is artesian, the water level measured in the well represents the pressure in the aquifer. The water level in the pumping well drops, lowering the pressure head in the surrounding aquifer. Water moves from areas of higher pressure toward the well, resulting in the formation of a cone of depression. When the cone of depression reaches another well, the water level in that well will begin to drop. The aquifer response to stress (pumping) is observed by measuring the water level changes with time.

Drawdown data is plotted versus time since pumping began. Recovery data is plotted against the ratio of time since pumping ended divided by the time since pumping started. The graphs are used to solve equations which describe the hydraulic properties of the aquifer. These properties include the transmissivity and storage coefficient.

Transmissivity (T) is the capacity of an aquifer to transmit water and is expressed in units of gallons per day per foot (gpd/ft). The higher the transmissivity value, the easier water moves through the aquifer.

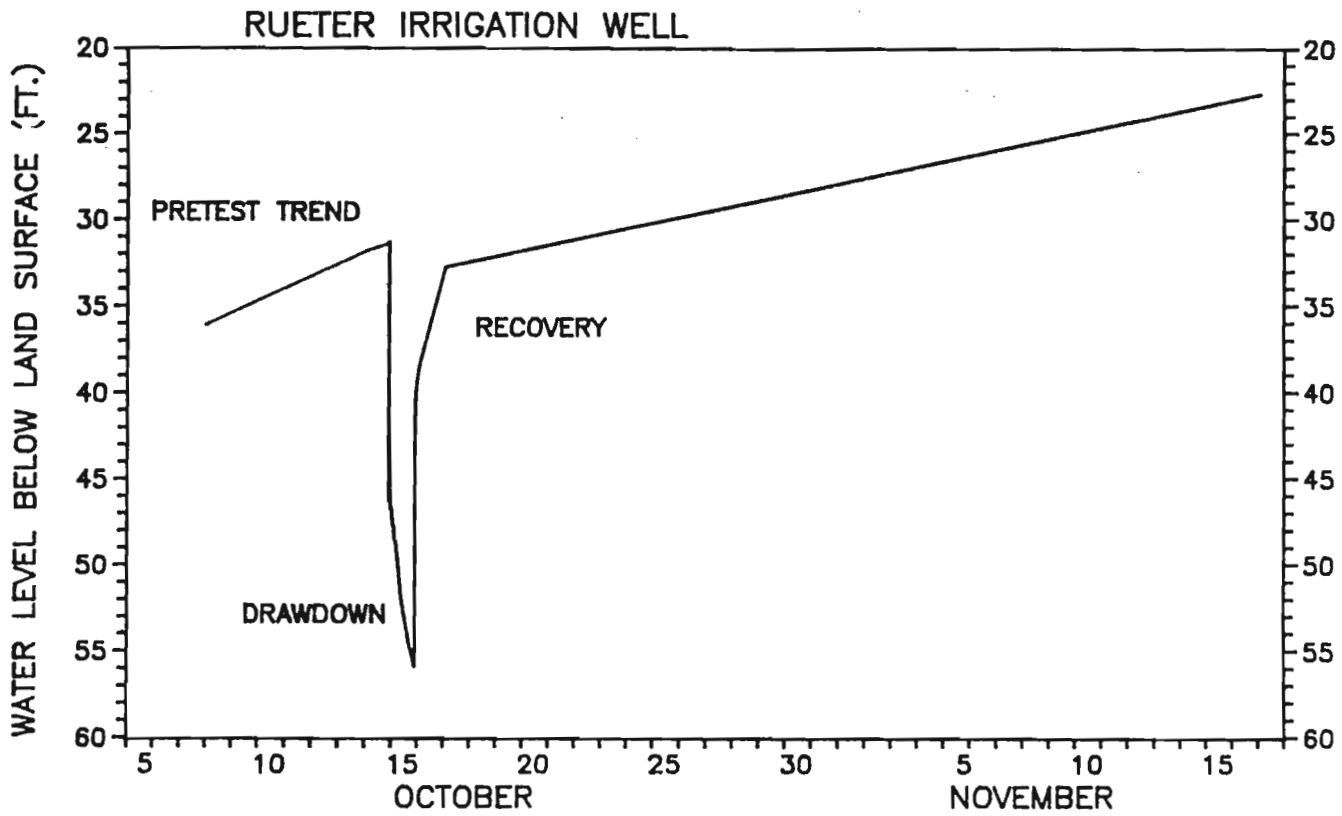
Storage coefficient (S) is the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head and is dimensionless. The storage coefficient of most confined aquifers ranges from about $1x10^{-3}$ to 10^{-5}. For unconfined aquifers, the storage coefficient ranges from 0.01 to 0.3 (Freeze and Cherry, 1979, p. 61).

The data collected during the aquifer test are listed in Appendix II. The observed data were adjusted for the pretest water level trend. The data were not adjusted for effects of atmospheric pressure because only minor changes were recorded. There was very little difference noted between the observed water levels and the water levels adjusted for the pretest water level trend. Therefore, all the calculations are based on the observed data.

Two basic methods for calculating aquifer characteristics from aquifer test data were used in this test: the Theis Non-equilibrium Well Equation and the Jacob Modified Non-equilibrium Well Equation. An explanation of both methods is presented in Appendix III (Heath, 1983). The Theis Equation requires the drawdown versus time data to be plotted on log-log graph paper. The Jacob Equation requires the drawdown versus time data to be plotted on semi-log graph paper. Additional conditions must be met for the Jacob method to yield satisfactory results. These conditions were only met at the pumping well. See Appendix III for further explanation.

Aquifer Characteristics

Water level data collected during the aquifer test were plotted on arithmetic, semi-log, and log-log graph paper. Drawdown and recovery from pumping the Rueter well can be seen in Figures 6 and 7 (arithmetic plots). The rise in water levels prior to the aquifer test indicates that the wells were recovering from pumping during the irrigation season. The total drawdown at the Rueter irrigation well was 24.66 feet. The effects of pumping the Rueter irrigation well were noted at the Rueter domestic well and at the Ochs irrigation well within 15 minutes after



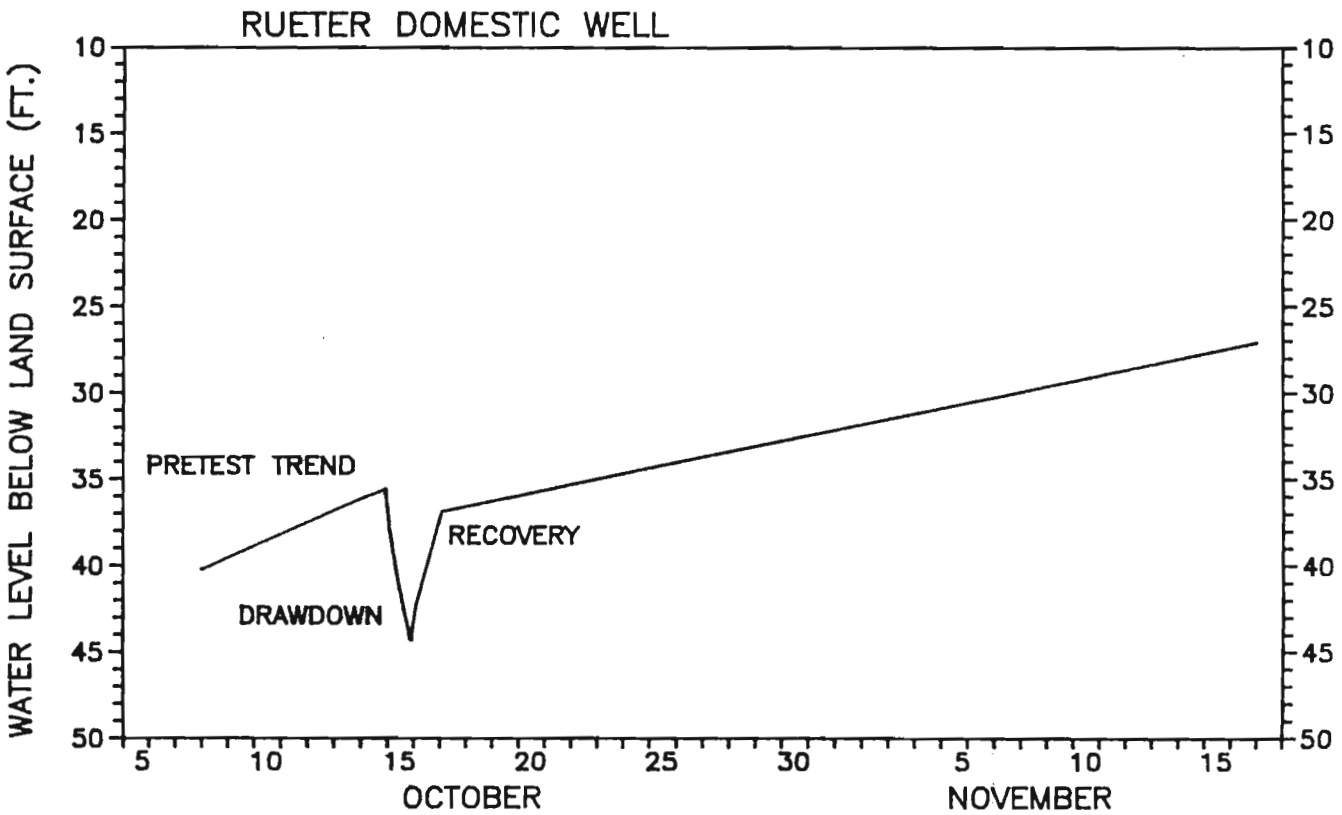


FIGURE 6. ARITHMETIC PLOT OF GROUND WATER LEVEL DATA FROM THE RUETER IRRIGATION WELL AND DOMESTIC WELL.

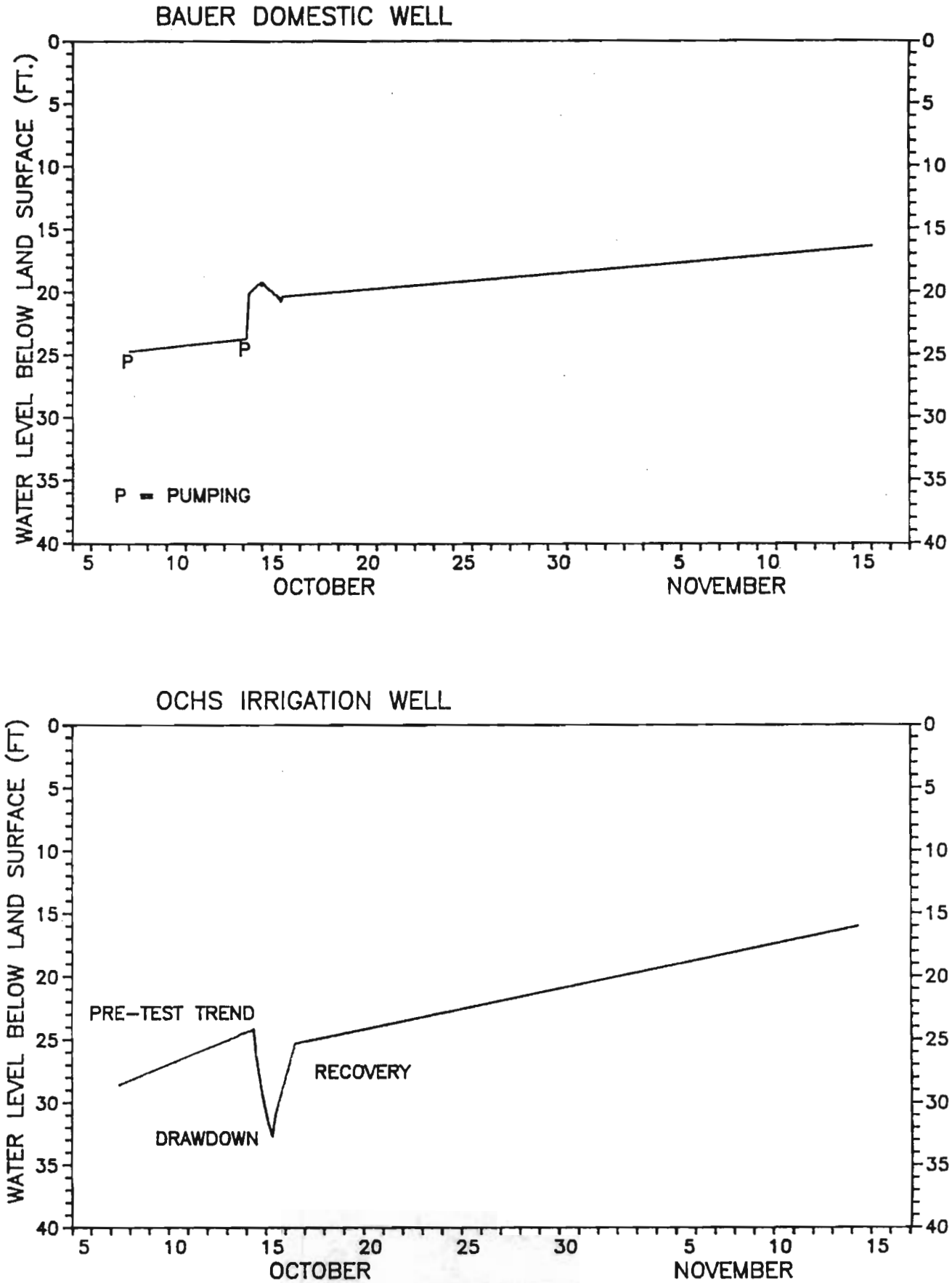


FIGURE 7. ARITHMETIC PLOT OF GROUND WATER LEVEL DATA FROM THE BAUER DOMESTIC WELL AND THE OCHS IRRIGATION WELL.

the pump was started. After pumping the Rueter irrigation well for 24 hours, the drawdown at the Rueter domestic well was 8.78 feet. The drawdown at the Ochs irrigation well after 24 hours was 8.53 feet. The effect of pumping the Rueter irrigation well was noted at the Bauer well after 5 hours. Total drawdown at the Bauer well was 1.45 feet. The pump was on at the Bauer well which affected the pretest water level data.

Ground water levels in the Ochs unused wells did not respond to pumpage from the Rueter irrigation well during the test. The ground water levels remained unchanged through November 16, 1987 (Figure 8).

Tables 3, 4, and 5 list the aquifer characteristics calculated from the data collected during the aquifer test. The storage coefficient calculations were very consistent, ranging from 1.09×10^{-4} to 6.75×10^{-5} indicating a confined aquifer. The transmissivity values range from 3,900 to 26,400 gpd/ft. The higher transmissivity values were calculated from early time drawdown data and are representative of the aquifer near the well. The lower transmissivity values were calculated from late time drawdown data that represents the regional nature of the aquifer. Aquifer characteristics were not calculated from the recovery data because the log-log plots were too flat for curve matching (Theis Method) and requirements of the Jacob Method (semi-log) were not met.

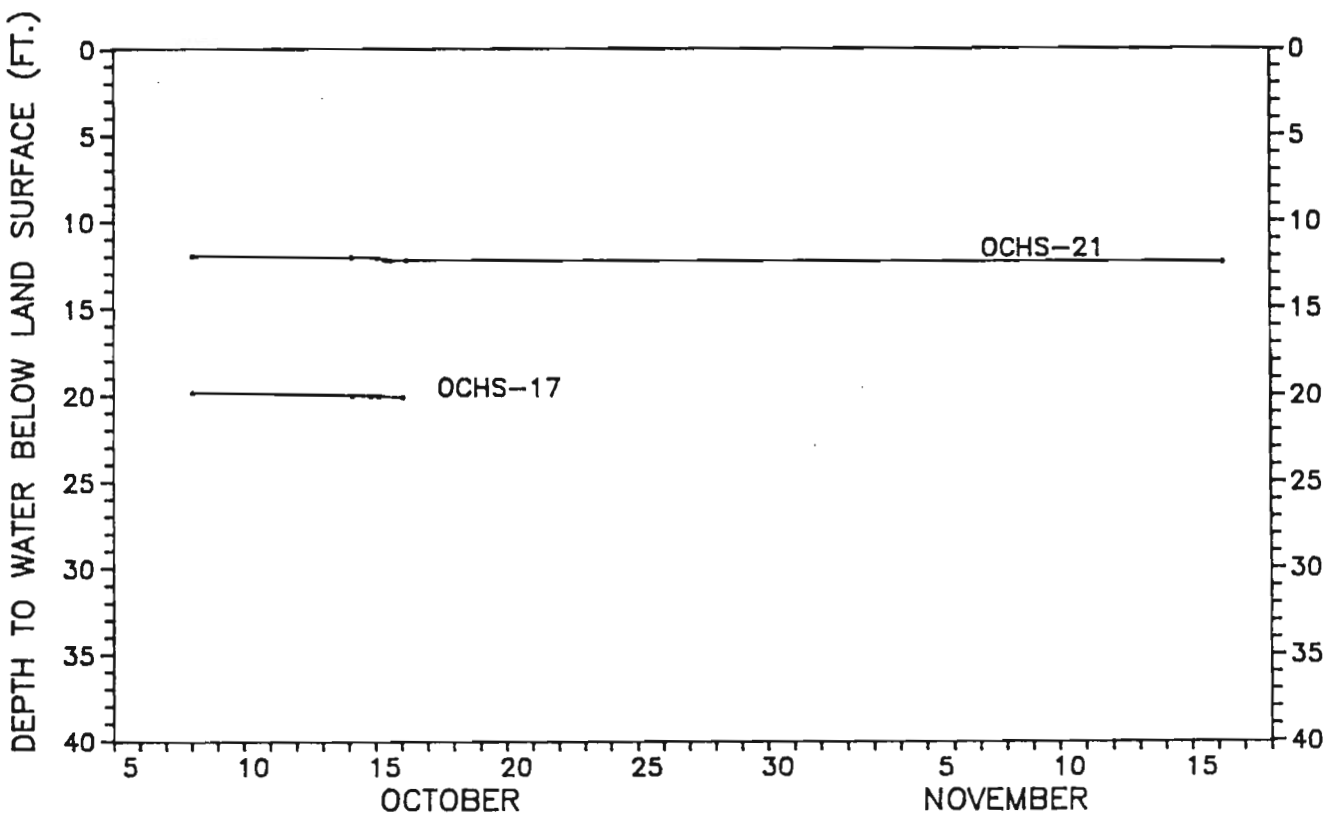


FIGURE 8. ARITHMETIC PLOT OF GROUND WATER LEVEL DATA FROM THE OCHS TEST WELLS IN SECTIONS 17 AND 21.

Table 3. Summary of early time aquifer characteristics.

WELL	Distance from pumping well (feet)	T (gpd/ft)	S (10^{-5})	Method
Rueter Irr.	0	22,700		Theis Drawdown
	0	26,400		Jacob Drawdown
Rueter Dom.	2150	20,800	5.01	Theis Drawdown
Ochs Irr.	3370	20,800	2.79	Theis Drawdown
Bauer Dom.	5520	17,600	0.11	Theis Drawdown

Table 4. Summary of middle time aquifer characteristics.

WELL	Distance from pumping well (feet)	T (gpd/ft)	S (10^{-5})	Method
Rueter Irr.	0	13,200		Jacob Drawdown
	0	7,900		Theis Drawdown

Table 5. Summary of late time aquifer characteristics.

Well	Distance from pumping well (feet)	T (gpd/ft)	S (10^{-5})	Method
Rueter Irr.	0	3,900		Theis Drawdown
	0	4,100		Jacob Drawdown
Rueter Dom.	2150	4,200	6.75	Theis Drawdown
Ochs Irr.	3370	4,200	2.88	Theis Drawdown

Figure 9 is a semi-log plot of drawdown data from the pumping well (Jacob Method). Because the distance between wells is large and the transmissivity values are low, the Jacob Method could only be used on the data from the pumping well. Under ideal conditions, the data should plot along a straight line. If the data departs from the straight line, a boundary condition probably exists. The type of boundary present, whether a recharge or no-flow barrier, is indicated by the direction of deviation from the straight line. If the data plot below the straight line, a barrier to ground water flow was intercepted by the cone of depression as it expanded. Two breaks in the slope were noted for data from the Rueter irrigation well (Figure 9). Straight lines were drawn through the data at each break in slope to determine the amount of drawdown per log cycle. Values of transmissivity were calculated for each portion of the data represented by a straight line. The transmissivity values are 26,400 gpd/ft for early "t" or time, 13,200 gpd/ft for middle "t" and 4,100 gpd/ft for late "t". The changes in transmissivity values indicates at least two barriers to ground water flow were encountered.

Figure 10 is a log-log plot of drawdown from the Rueter irrigation well. In the Theis method, the drawdown data is matched to an idealized aquifer response. If the data depart from the "Type Curve", a boundary condition probably exists. The type of boundary present, whether a recharge or no-flow barrier, is indicated by the direction of deviation from the type curve. If the data plot shows increasing drawdown by plotting above the "Type Curve", it indicates that a barrier to ground water flow was intercepted by the cone of depression as it expanded. The data deviates upward from the Type Curve twice, indicating at least two barriers to ground water flow were encountered.

Plots from the Rueter domestic well and the Ochs irrigation well also indicate barriers to ground water flow (Figures 11 and 12). Five Type Curves were fitted to the data. The three additional curves drawn through the data are probably reflections of the boundary conditions and do not indicate more boundaries.

The plot from the Bauer well did not show any boundary conditions (Figure 13). If the test had run for a longer period of time, the influence of the boundaries would probably have been observed. With three observation wells and a longer test, location of the boundaries may have been estimated.

Aquifer characteristics calculated from the data collected in September 1980 when the Ochs irrigation well was shut down are similar to those calculated from the Ochs/Rueter aquifer test. Early time transmissivities range from 19,000 to 26,000 gpd/ft. Late time transmissivities was calculated to be 5000 gpd/ft. A storage coefficient of 2.54×10^{-4} was calculated.

The transmissivity values, calculated from the data collected when the Ochs irrigation well recommenced pumping, range from 29,000 to 31,200 gpd/ft (early time) and 16,700 gpd/ft (middle time). These are in the same range as the early and middle time values calculated from the more recent aquifer test.

The normal temperature for shallow ground water (30 - 60 feet deep) is approximately 2F above the average annual air temperature. Below these shallow depths, the temperature increases approximately 0.5^{F} for each 100 feet of depth (Todd, 1959). The average annual air temperature at Madras is 48F. The temperature of the ground water being pumped from the Rueter irrigation well should be around 51-53F. The temperature of the ground water pumped from the

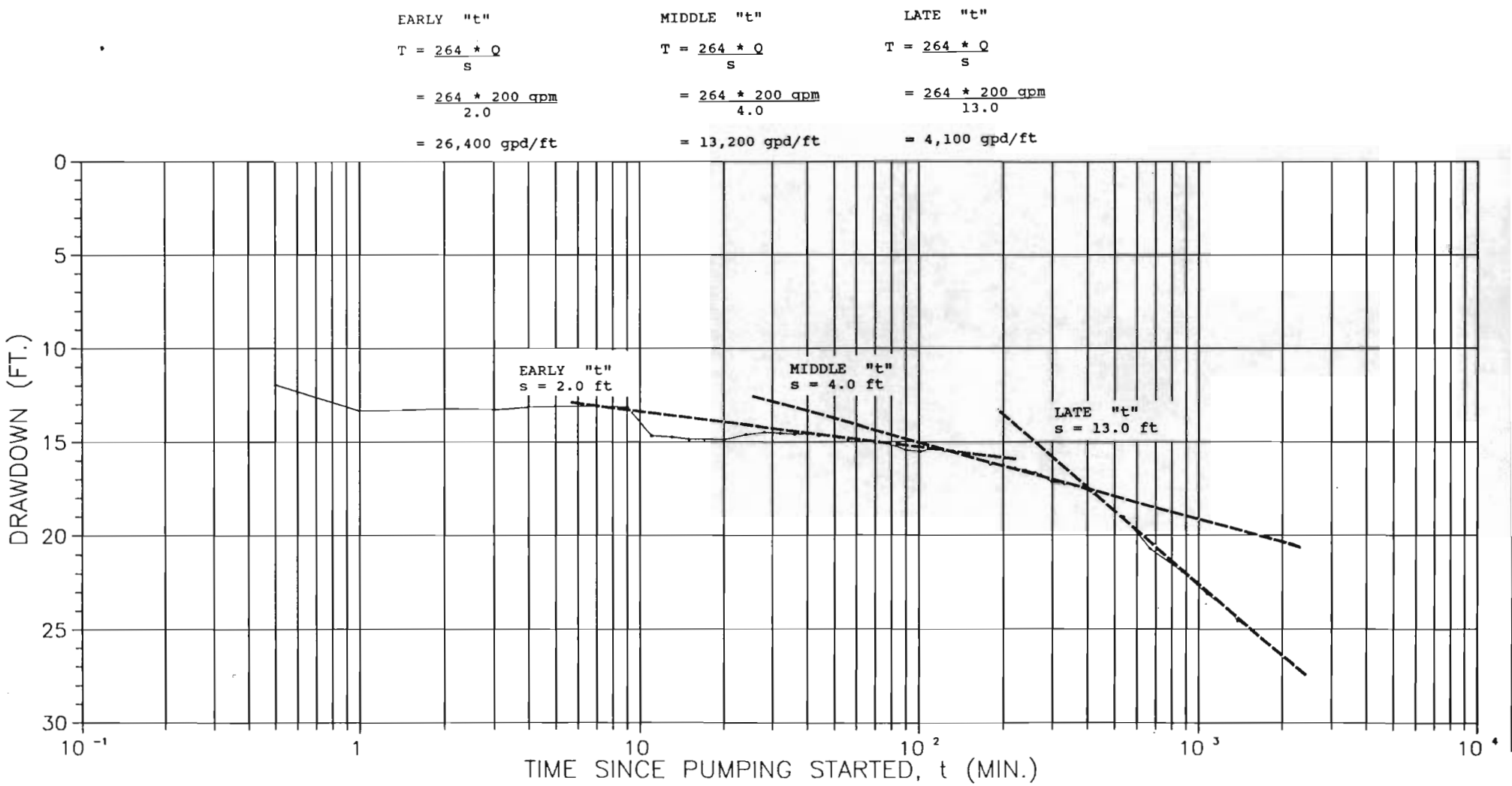


FIGURE 9. SEMI-LOG PLOT OF DRAWDOWN DATA AT THE RUETER IRRIGATION WELL.

EARLY "t"	MIDDLE "t"	LATE "t"
$T = \frac{114.6 * Q}{s} * W(u)$	$T = \frac{114.6 * Q}{s} * W(u)$	$T = \frac{114.6 * Q}{s} * W(u)$
$= \frac{114.6 * 200 \text{ gpm}}{10.1 \text{ ft.}} * 10$	$= \frac{114.6 * 200 \text{ gpm}}{2.9 \text{ ft.}} * 1$	$= \frac{114.6 * 200 \text{ gpm}}{5.9 \text{ ft.}} * 1$
= 22,700 gpd/ft	= 7,900 gpd/ft	= 3,900 gpd/ft

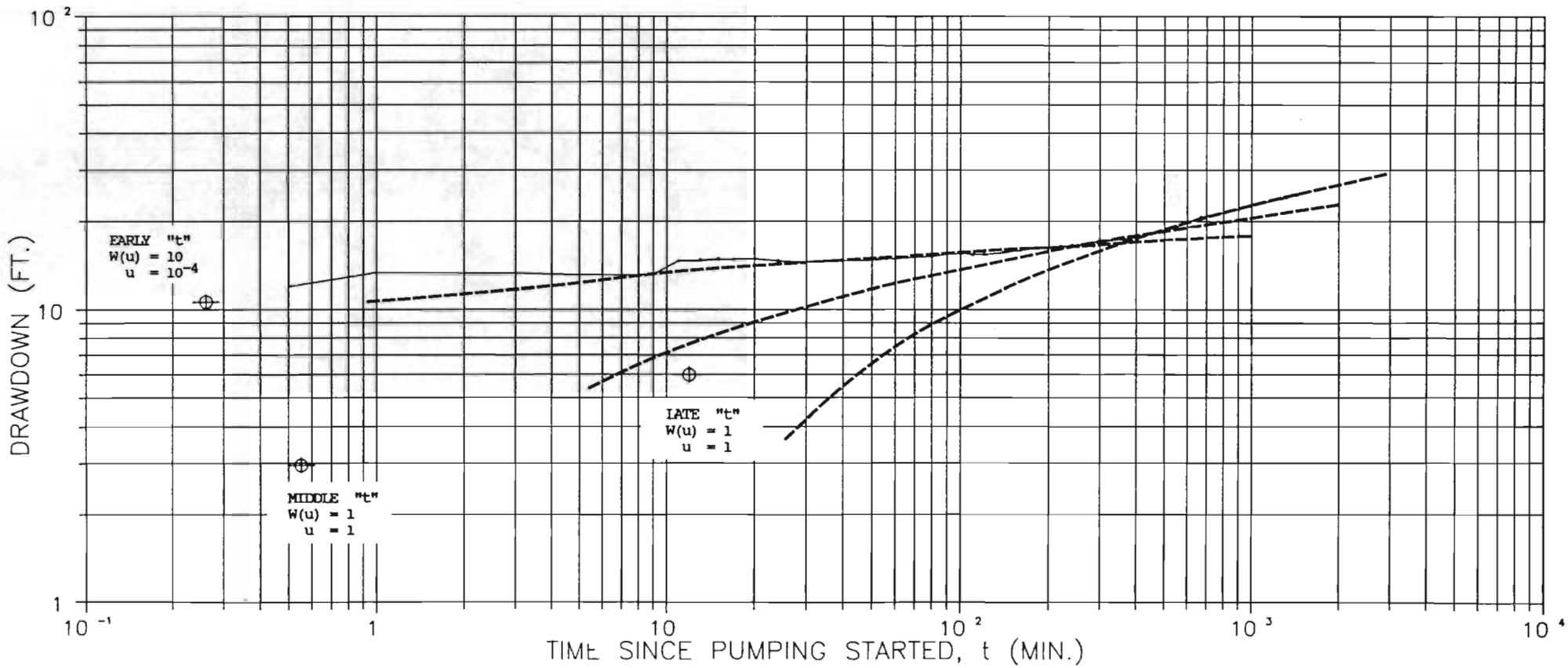


FIGURE 10. LOG–LOG PLOT OF DRAWDOWN DATA AT THE RUETER IRRIGATION WELL.

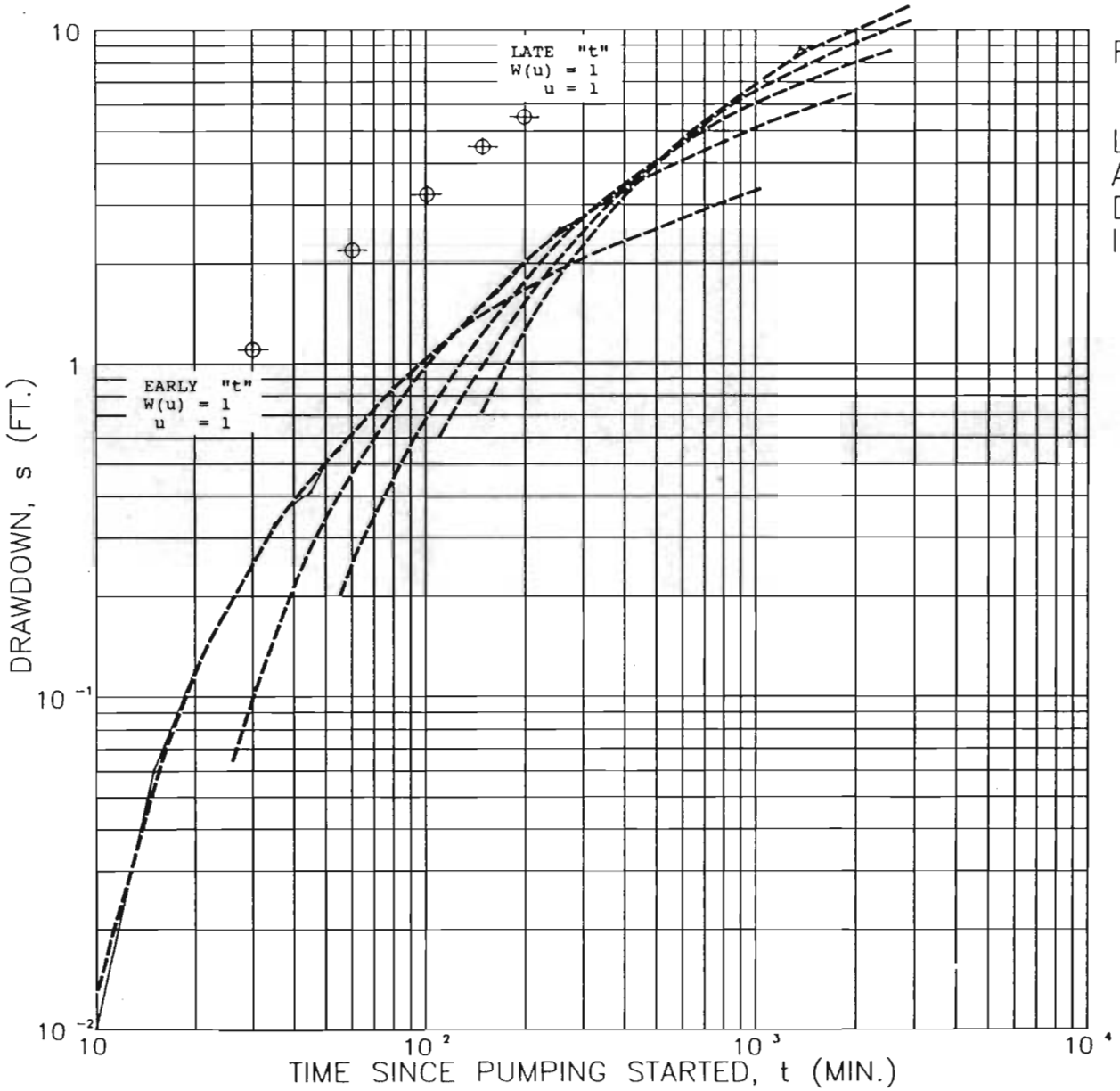


FIGURE 11.

LOG–LOG PLOT OF DRAWDOWN DATA AT THE RUETER DOMESTIC WELL DUE TO PUMPING THE RUETER IRRIGATION WELL.

EARLY "t"

$$T = \frac{114.6 * Q}{s} * W(u)$$

$$= \frac{114.6 * 200 \text{ gpm}}{1.1 \text{ ft.}} * 1$$

$$= 20{,}800 \text{ gpd/ft}$$

$$S = \frac{T * t}{(r)^2 * 2693} * u$$

$$= \frac{20{,}800 \text{ gpd/ft} * 30 \text{ min.}}{(2150)^2 * 2693} * 1$$

$$= 5.01 \times 10^{-5}$$

LATE "t"

$$T = \frac{114.6 * Q}{s} * W(u)$$

$$= \frac{114.6 * 200 \text{ gpm}}{5.5 \text{ ft.}} * 1$$

$$= 4{,}200 \text{ gpd/ft}$$

$$S = \frac{T * t}{(r)^2 * 2693} * u$$

$$= \frac{4{,}200 \text{ gpd/ft} * 200 \text{ min.}}{(2150)^2 * 2693} * 1$$

$$= 6.75 \times 10^{-5}$$

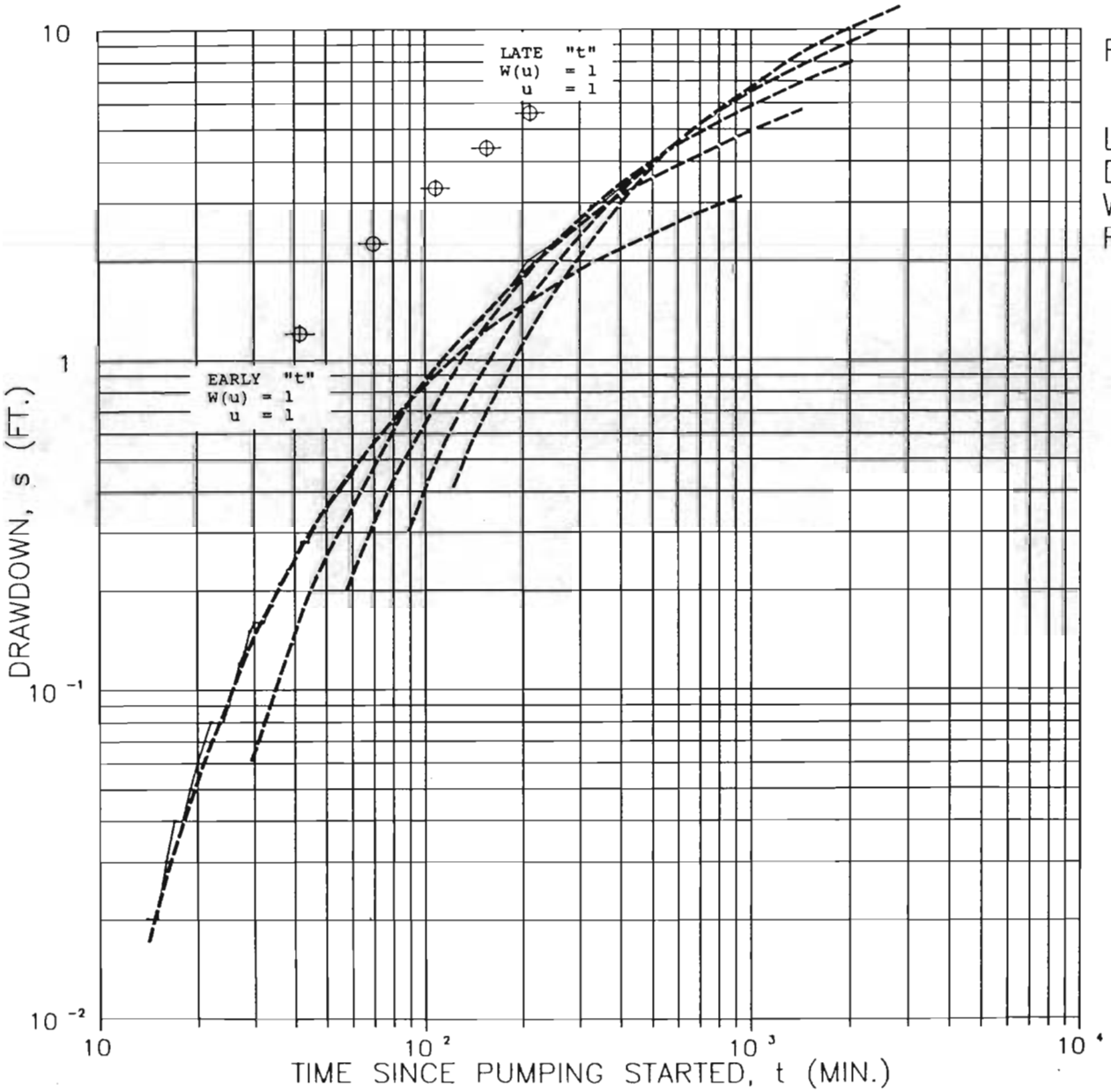


FIGURE 12.

LOG–LOG PLOT OF DRAWDOWN DATA AT THE OCHS IRRIGATION WELL DUE TO PUMPING THE RUETER IRRIGATION WELL.

EARLY "t"

$$T = \frac{114.6 \times Q}{s} \times W(u)$$

$$= \frac{114.6 \times 200 \text{ gpm}}{1.1 \text{ ft.}} \times 1$$

$$= 20{,}800 \text{ gpd/ft}$$

$$S = \frac{T \times t}{(r)^2 \times 2693} \times u$$

$$= \frac{20{,}800 \text{ gpd/ft} \times 41 \text{ min.}}{(3370)^2 \times 2693} \times 1$$

$$= 2.79 \times 10^{-5}$$

LATE "t"

$$T = \frac{114.6 \times Q}{s} \times W(u)$$

$$= \frac{114.6 \times 200 \text{ gpm}}{5.5 \text{ ft.}} \times 1$$

$$= 4{,}200 \text{ gpd/ft}$$

$$S = \frac{T \times t}{(r)^2 \times 2693} \times u$$

$$= \frac{4{,}200 \text{ gpd/ft} \times 210 \text{ min.}}{(3370)^2 \times 2693} \times 1$$

$$= 2.88 \times 10^{-5}$$

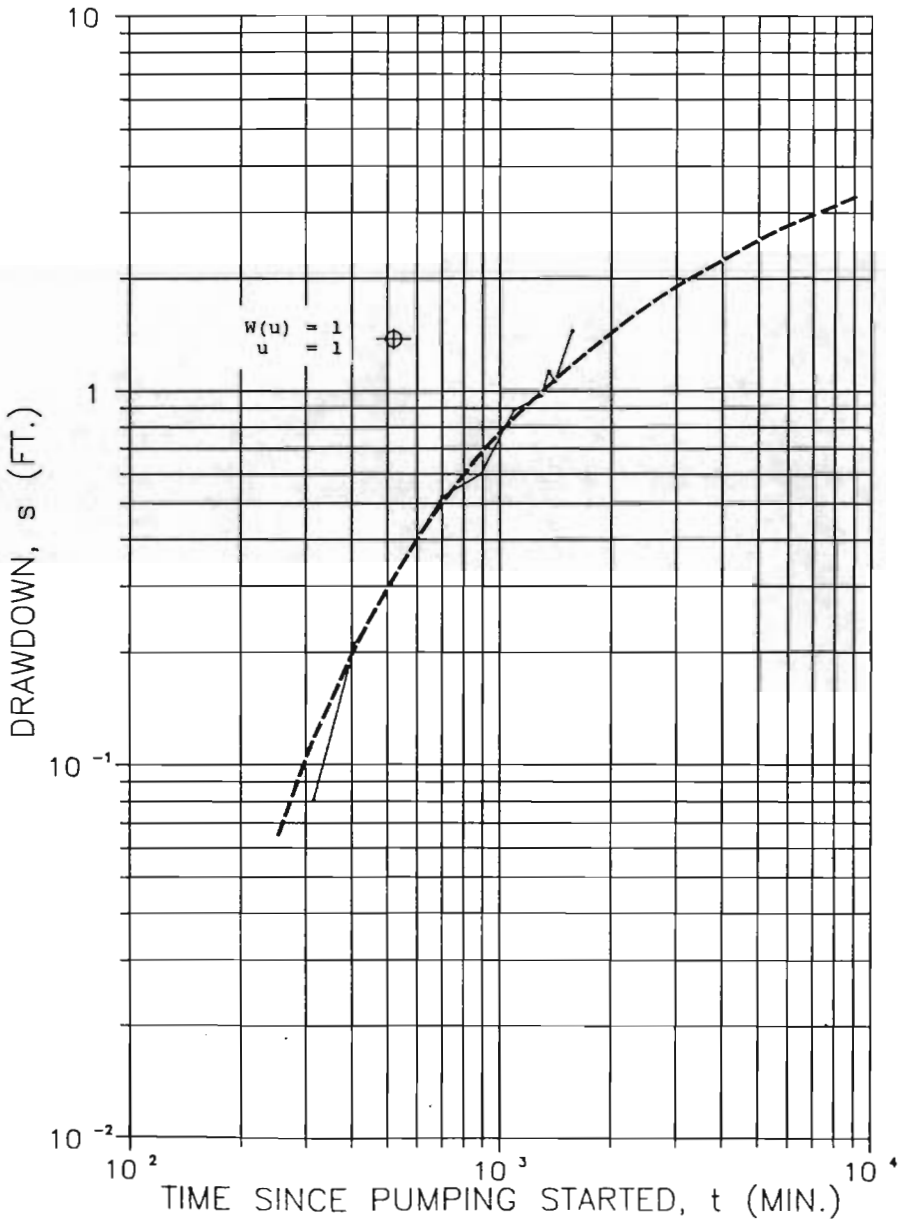


FIGURE 13.

LOG–LOG PLOT OF DRAWDOWN DATA AT THE BAUER DOMESTIC WELL DUE TO PUMPING THE RUETER IRRIGATION WELL.

$$T = \frac{114.6 * Q}{s} * W(u)$$

$$= \frac{114.6 * 200 \text{ gpm}}{1.3 \text{ ft.}} * 1$$

$$= 17{,}600 \text{ gpd/ft}$$

$$S = \frac{T * t}{(r)^2 * 2693} * u$$

$$= \frac{17{,}600 \text{ gpd/ft} * 510 \text{ min.}}{(5520 \text{ ft.})^2 * 2693} * 1$$

$$= 1.09 * 10^{-4}$$

Rueter irrigation well was 72F throughout the test. A ground water temperature of 67.1F was measured during the 1980 aquifer test at the Ochs irrigation well. One possible explanation for the warmer water would be that ground water is moving up one or more of the nearby faults. Because the temperature at the Rueter irrigation well stayed the same during the test, most of the water being pumped could be coming from greater depth. This also indicates that recharge, at least in part, is not occurring locally.

Long Term Projections

After 24 hours of pumping the Rueter irrigation well at 200 gpm, there were 8.53 feet of drawdown (interference) measured at the Ochs irrigation well, 3370 feet away. Using a late time transmissivity of 5000 gpd/ft and a storage coefficient of 3.0×10^{-5}, the drawdown at the Ochs irrigation well after 15 days of pumping the Rueter irrigation well at 200 gpm is calculated to be about 21 feet. The drawdown was calculated to be about 24 feet after 30 days and about 28 feet after 60 days. These predictions assume that the aquifer characteristics will remain the same during the time period. This amount of drawdown (interference) would substantially reduce the pumping capacity of the Ochs irrigation well.

An estimate of annual recharge was made from the data collected during the study. A given volume of water was removed from the aquifer resulting in a known amount of water level decline. This value is multiplied by the pretest water level trend to determine the rate of recharge. Approximately 85 acre feet per year is recharged to the aquifer. If the recharge estimate is off on the low side by 50 percent, the annual recharge would be approximately 130 acre feet. The recharge estimate assumes that the pretest water level trend is constant throughout the year which is unlikely. Ground water levels continued to rise after the test but at a reduced rate. The estimate of recharge indicates that the ground water resource is very limited in this system.

More water can be pumped annually than is being recharged, but it comes from storage with a resulting water level decline. When the Ochs' irrigation well was drilled in 1978, the well flowed at a rate of 200 gallons per minute at land surface. The well no longer flows, indicating that there maybe an overdraft on the ground water flow system.

Pump Efficiency

Water horsepower (Whp) is the power required to pump water at a given rate and against a given head. Total dynamic head (TDH) is essentially the lift (pumping water level to ground surface) plus the pressure against which the pump is working.

$$Whp = \frac{Q(gpm) * TDH(ft)}{3960} = \frac{200\ gpm * 200\ ft}{3960} = 10.1$$

The pump efficiency is the Whp divided by the Brake Horsepower (Bhp). The submersible pump in the Rueter Irrigation well is rated at 25 Bhp. The pump efficiency is equal to:

$$\frac{\text{Whp}}{\text{Bhp}} = \frac{10.1}{25} = 40\ \%.$$

The irrigation system was inspected by FloSonics, Inc., Umatilla, on April 15, 1987. Pump efficiency was calculated to be only 30 %. FloSonics indicated that by installing a pump with a lower Bhp rating, the efficiency could be raised.

Power use for the 24 hour test was 610 kilowatt-hours. Discharge during the test was 200 gpm or 288,000 gallons. The irrigation system would use approximately 690 kilowatt-hours per acre-foot of water pumped.

RESOURCE MANAGEMENT

Conclusions

1. The aquifer supplying water to the Ochs, Rueter, and Bauer wells is limited by hydrogeologic barriers. Geologic structures (faults and folds) control the ground water flow system.

2. Aquifer characteristics indicate that the aquifer has a limited capability to supply the quantity of water needed to meet the valid ground water rights.

3. There is a hydrologic connection between the Rueter irrigation well, the Ochs irrigation well, and the Bauer domestic well. Interference was calculated to be 24 feet at the Ochs irrigation well after 30 days of pumping the Rueter irrigation well.

4. The Ochs test wells in sections 17 and 20 did not respond to pumping the Rueter well. The test wells may be an alternate source of water if they can produce a sufficient quantity of water

5. The Ochs irrigation well was breaking suction prior to use of the Rueter irrigation well. Mr. Ochs indicated that the discharge from his well has dropped off over the last several years.

6. There is a possibility of a long term water level decline in the aquifer supplying water to the wells.

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APPENDIX I

WELL LOGS

RUETER IRRIGATION WELL LOG

WATER WELL REPORT
STATE OF OREGON

RECEIVED
APR 22 1983
WATER RESOURCES DEPT.
SALEM, OREGON

State Well No. 9S/15E-29

State Permit No.

PLEASE TYPE OR PRINT

(1) OWNER:
Name William Rueter
Address 25106 116th Avenue S.E.
City Kent State Wash. 98031

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary Air ☒ Driven ☐
Rotary Mud ☐ Dug ☐
(☒ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☒ Test Well ☐ Other ☐
Thermal Withdrawal ☐ Reinjection ☐

(5) CASING INSTALLED:
Steel ☒ Threaded ☐ Plastic ☐ Welded ☒
10" Diam. from +1 ft. to 196 ft Gauge .250
" Diam. from ft. to ft. Gauge

LINER INSTALLED: -----
" Diam. from ft. to ft. Gauge

(6) PERFORATIONS:
Perforated? ☐ Yes ☒ No
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS:
Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot Size Set from ft. to ft.
Diam. Slot Size Set from ft. to ft.

(8) WELL TESTS:
Drawdown is amount water level is lowered below static level

Was a pump test made? ☒ Yes ☐ No If yes, by whom? Contractor
Yield: 250 gal./min. with 20 ft. drawdown after 72 hrs.
" " " "
Air test gal./min. with drill stem at ft. hrs.
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water 54* Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Special standards: Yes ☐ No ☒
Well seal—Material used Cement
Well sealed from land surface to 20 ft.
Diameter of well bore to bottom of seal 14 in.
Diameter of well bore below seal 10" in.
Number of sacks of cement used in well seal 16 sacks
How was cement grout placed? Pressure Grouted

Was pump installed? yes Type subm. HP 25 Depth 200 ft.
Was a drive shoe used? ☒ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☒ No
Type of Water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☒ No Size of gravel:
Gravel placed from ft. to ft.

(10) LOCATION OF WELL:
County Jefferson Driller's well number
¼ ¼ Section 29 T. 9S R. 15E W.M.
Tax Lot # Lot Blk Subdivision
Address at well location none assigned

(11) WATER LEVEL: Completed well.
Depth at which water was first found 200 ft.
Static level 42 ft. below land surface. Date 3-28-83
Artesian pressure lbs. per square inch. Date

(12) WELL LOG:
Diameter of well below casing 10"
Depth drilled 225 ft. Depth of completed well 225 ft.
Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
Conglomerate, Clay	0	22	
Sand & Gravel	22	50	
Blue Clay	50	163	
Yellow Clay	163	192	
Red Sand & Gravels, Water-Bear	192	225	42

Work started 8-25 19 82 Completed 3-28 19 83
Date well drilling machine moved off of well 3-28 19 83

(unbonded) Water Well Constructor Certification (if applicable):
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] [signature] Date 4-6 , 19 83

Bonded Water Well Constructor Certification:
Bond 630130021279 (number) Issued by: U.S. Fidelity & Guaranty (Surety Company Name)
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name Orvail Buckner Well Drilling, Inc. (Person, firm or corporation) (Type or print)
Address 1686 N.E. Negus Way, Redmond, Oreg. 97756
[Signed] [signature] Water Well Constructor
Date 4-6 , 19 83

RECONSTRUCTION OF RUETER IRRIGATION WELL

SEP 23 1985 9S/15E-2

WATER RESOURCES DEPT. Record
SALEM, OREGON (for official use only)

STATE OF OREGON

WATER WELL REPORT

(as required by ORS 537.765)

PLEASE TYPE or PRINT IN INK

(1) OWNER:

Name William Rueter

Address Gateway Star Rte, Box 443

City Madras State Oreg. 97741

(2) TYPE OF WORK (check):

New Well ☐ Deepening ☐ Reconditioning ☒ Abandon ☐

If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:

Rotary Air ☐ Driven ☐

Rotary Mud ☐ Dug ☐

Cable ☒ Bored ☐

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☐

Irrigation ☒ Thermal: Withdrawal ☐ Reinjection ☐

Other: Piezometric ☐ Grounding ☐ Test ☐

(5) CASING INSTALLED:

Steel ☒ Plastic ☐

Threaded ☐ Welded ☒

10 " Diam. from +1 ft. to 196 ft. Gauge .250

" Diam. from ft. to ft. Gauge

LINER INSTALLED:

Steel ☐ Plastic ☐

Threaded ☐ Welded ☐

" Diam. from ft. to ft. Gauge

(6) PERFORATIONS:

Perforated? ☐ Yes ☒ No

Size of perforations in. by in.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

(7) SCREENS:

Well screen installed? ☐ Yes ☒ No

Manufacturer's Name

Type Model No.

Diam. Slot Size Set from ft. to ft.

Diam. Slot Size Set from ft. to ft.

(8) WELL TESTS:

Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☒ No If yes, by whom?

Yield: gal./min. with ft. drawdown after hrs.

Air test gal./min. with drill stem at ft. hrs.

Bailer test 2x 30 gal./min. with 0 ft. drawdown after 1 hrs.

Artesian flow g.p.m.

Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:

Special standards: Yes ☒ No ☐

Well seal—Material used Cement Grout

Well sealed from land surface to 60' ft.

Diameter of well bore to bottom of seal 16 in.

Diameter of well bore below seal 10 in.

Amount of sealing material 240 sacks cement-21 sacks bentonit sacks ☐ pounds ☐

How was cement grout placed? Pumped

Was pump installed? yes Type subm. HP 25 Depth 195 ft.

Was a drive shoe used? ☒ Yes ☐ No Plugs Size: location ft.

Did any strata contain unusable water? ☐ Yes ☒ No

Type of Water? depth of strata

Method of sealing strata off

Was well gravel packed? ☐ Yes ☒ No Size of gravel:

Gravel placed from ft. to ft.

(10) LOCATION OF WELL by legal description:

County Jefferson ¼ ¼ of Section 29

Township 9S (Township is North or South), Range 15E (Range is East or West) WM

Tax Lot Lot Block Subdivision

MAILING ADDRESS OF WELL (or nearest address) same as #1

(11) WATER LEVEL of COMPLETED WELL:

Depth at which water was first found 30

Static level 55 ft. below land surface. Date 9-11-

Artesian pressure lbs. per square inch. Date

(12) WELL LOG:

Diameter of well below casing 10"

Depth drilled 222 ft. Depth of completed well 222

Formation: Describe color, texture, grain size and structure of materials; and show thickne and nature of each stratum and aquifer penetrated, with at least one entry for each change formation. Report each change in position of Static Water Level and indicate princip water-bearing strata.

MATERIAL	From	To	SWL
unchanged..See original well log			
Everything approved by Dick Nimrod			
and Bend Watermaster....			

Date work started July 10 /completed 9-11-85

Date well drilling machine moved off of well 9-11 19 8

(unbonded) Water Well Constructor Certification (if applicable):

This well was constructed under my direct supervision. Materials used an information reported above are true to my best knowledge and belief.

(Signed) Earl Salisbury Date 9-13, 19 85

(bonded) Water Well Constructor Certification:

Bond 10596951 (number) Issued by: AMWEST (Surety Company Name)

On behalf of Buckner Pump Service for Orvail Buckr (type or print name of Water Well Constructor)

This well was drilled under my jurisdiction and this report is true to th best of my knowledge and belief.

(Signed) Robert Buckner (Water Well Constructor)

(Dated) Sept. 17, 1985

NOTICE TO WATER WELL CONSTRUCTOR

WATER RESOURCES DEPARTMENT, SALEM, OREGON

SP*46866-69

RUETER DOMESTIC WELL LOG

WATER WELL REPORT
STATE OF OREGON

SEP 8 1982
WATER RESOURCES DEPT.
SALEM, OREGON

State Well No. 9S/15E-29

State Permit No

(1) OWNER:
Name Bill Rueter
Address 25106 116th Ave, S.E.
City Kent State Wash. 98031

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary Air ☒ Driven ☐
Rotary Mud ☐ Dug ☐
Cable ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☒ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐
Thermal Withdrawal ☐ Reinjection ☐

(5) CASING INSTALLED:
Steel ☒ Plastic ☐
Threaded ☐ Welded ☒
8 " Diam. from +2 ft. to 30 ft Gauge .250
" Diam. from ft. to ft. Gauge

LINER INSTALLED:
5 " Diam. from -1½ ft. to 273 ft. Gauge .188

(6) PERFORATIONS:
Perforated? ☒ Yes ☐ No
Type of perforator used Factory
Size of perforations 1 in. by 3 in.
576 perforations from 193 ft. to 273 ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS:
Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot Size Set from ft. to ft.
Diam. Slot Size Set from ft. to ft.

(8) WELL TESTS:
Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☒ No If yes, by whom?
gal./min. with ft. drawdown after hrs.
" " " "
Air test 25 gal./min. with drill stem at 267 ft. 1 hrs.
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water 54* Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Special standards: Yes ☐ No ☒
Well seal—Material used Cement
Well sealed from land surface to 30 ft.
Diameter of well bore to bottom of seal 12 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal 11 sacks
How was cement grout placed? Pressure Grouted

Was pump installed? no Type HP Depth ft.
Was a drive shoe used? ☐ Yes ☒ No Plugs Size: location ft.
Did any strata contain unusable water? ☒ Yes ☐ No
Type of Water? surface w. depth of strata trace
Method of sealing strata off cased out
Was well gravel packed? ☐ Yes ☒ No Size of gravel:
Gravel placed from ft. to ft.

(10) LOCATION OF WELL:
County Jefferson Driller's well number
¼ ¼ Section 29 T. 9S R. 15E W.M.
Tax Lot # Lot Blk Subdivision
Address at well location: none

(11) WATER LEVEL: Completed well.
Depth at which water was first found 248 ft.
Static level 25 ft. below land surface. Date 9-1-82
Artesian pressure lbs. per square inch. Date

(12) WELL LOG:
Diameter of well below casing -0-
Depth drilled 273 ft. Depth of completed well 273 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
Brown Clay (some surface water)	0	20	
Brown Clay	20	31	
Blue Clay	31	215	90'
Red Clay	215	248	
Pink Claystone, Water-Bear.	248	255	
Mild Brown Lava	255	272	

Work started 8-23 1982 Completed 9-1 1982
Date well drilling machine moved off of well 9-1 1982

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Earl Salisbury (Drilling Machine Operator) Date 9-1, 1982
Drilling Machine Operator's License No. 162

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name Orvail Buckner Well Drilling, Inc. (Person, firm or corporation) (Type or print)
Address 1686 N.E. Negus Way, Redmond, Oreg. 97756
[Signed] Orvail Buckner (Water Well Contractor)
Contractor's License No. 608 Date 9-1-82 19

NOTICE TO WATER WELL CONTRACTOR WATER RESOURCES DEPARTMENT, SP*12658-690

OCHS IRRIGATION WELL LOG

The original and first copy are to be filed with the WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

FEB 9 1979
WATER RESOURCES DEPT.
SALEM, OREGON

State Well No. 9s/15E-20

State Permit No.

(1) OWNER:
Name RON OCHS
Address RT 1 Box (GATEWAY RT.)
MADRAS ORE. 97741

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☒ Driven ☐
Cable ☒ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☒ Test Well ☐ Other ☐

CASING INSTALLED: Threaded ☐ Welded ☐
12" Diam. from +2 ft. to 96 ft. Gage .250
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

PERFORATIONS: Perforated? ☐ Yes ☒ No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☒ No If yes, by whom?
Yield: gal./min. with ft. drawdown after hrs.
" " "
" (FLOWING) " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow 200 g.p.m.
Temperature of water 60° Depth artesian flow encountered 200 ft.

(9) CONSTRUCTION:
Well seal—Material used CEMENT
Well sealed from land surface to 40 ft.
Diameter of well bore to bottom of seal 16 in.
Diameter of well bore below seal 12 in.
Number of sacks of cement used in well seal 27 sacks
How was cement grout placed? PRESSURE GROUT

Was a drive shoe used? ☐ Yes ☒ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☒ No Size of gravel:

(10) LOCATION OF WELL:
County JEFFERSON Driller's well number
S.E. ¼ S.W. ¼ Section 20 T. 9S R. 15E. W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 200 ft.
Static level FLOWING ft. below land surface. Date 2-6-7
Artesian pressure 1 lbs. per square inch. Date 10-6-

(12) WELL LOG: Diameter of well below casing 12"
Depth drilled 210 ft. Depth of completed well 210 ft.

Formation: Describe color, texture, grain size and structure of materials and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
TOP-SOIL	0	1	
BROKEN LAVA & BROWN CLAY	1	36	
BLUE GREY CLAY CLOSE	36	180	
BROWN CLAYSTONE CONGLOM	180	190	
WATER-BEARING RED ROCK	190	210	

Work started 9-27 1978 Completed 1-20 1979
Date well drilling machine moved off of well 2-6 1979

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] William D. Sikes Date 2-6, 1979
(Drilling Machine Operator)
Drilling Machine Operator's License No. 803

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name DERRIL BUCKNER WELL DRILLING INC
(Person, firm or corporation) (Type or print)
Address 1680 N.E. NEGHS WAY REDMOND, ORE. 97
[Signed] Derril Buckner
(Water Well Contractor)
Date 2-6 1979

BAUER DOMESTIC WELL LOG

The original and first copy of this report are to be filed with the WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

RECEIVED WATER RESOURCES DEPT SALEM, OREGON

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

State Well No. 9s/15E-19da

State Permit No.

(1) OWNER:
Name FLOYD BAUER
Address GATEWAY ROUTE BOX 48E MADRAS, ORE 97741

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☒ Jetted ☐
Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☒ Test Well ☐ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☒
10" Diam. from 0 ft. to 39 ft. Gage 250 WALL
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☒ No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☒ Yes ☐ No If yes, by whom? JACK ABRAS
Yield: 160 gal./min. with 190 ft. drawdown after 1 hrs.
" " " "
" " " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water 60° Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used CEMENT
Well sealed from land surface to 20 ft.
Diameter of well bore to bottom of seal 16 in.
Diameter of well bore below seal 10 in.
Number of sacks of cement used in well seal 23 sacks
How was cement grout placed? WITH GROUT PUMP
Was a drive shoe used? ☐ Yes ☒ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☒ No Size of gravel:

(10) LOCATION OF WELL:
County JEFF. Driller's well number
NE ¼ SE ¼ Section 19 T. 9 R. 15 E W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 42 ft.
Static level 20 ft. below land surface. Date FEB 16, 1980
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing 10 in.
Depth drilled 350 ft. Depth of completed well 350 ft.
Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
SANDY SOIL	0	3	
BOULDERS IN CLAY	3	8	
HARD YELLOW CLAYSTONE	8	37	
" BLUE "	37	58	
" TAN "	58	74	
" BLUE "	74	81	
" TAN "	81	112	
" BLUE-GREEN "	112	120	
" GREEN "	120	134	
" BLUE-GREEN "	134	143	
SOFT YELLOW RHYOLITE	143	164	
HARD YELLOW CLAYSTONE	164	166	
" RHYOLITE	166	179	
HARD BLUE GREEN CLAYSTONE	179	218	
" BROWN "	218	222	
" BLUE GREEN "	222	234	
BLUE GREEN RHYOLITE	234	253	
TAN CLAY	253	256	
RED RHYOLITE	256	258	

Work started NOV 21 1979 Completed FEB 16 1980
Date well drilling machine moved off of well MARCH 3 1980

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Lawrence Kowalski Date MAR 6, 1980
(Drilling Machine Operator)
Drilling Machine Operator's License No. 1

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name LAWRENCE KOWALESKI (Person, firm or corporation) (Type or print)
Address 741-4 MADRAS, ORE 97741
[Signed] Lawrence Kowaleski
(Water Well Contractor)
Date 19 , 19 80

BAUER DOMESTIC WELL LOG (CONT.)

The original and first copy of this report are to be filed with the WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

WATER WELL REPORT
STATE OF OREGON
(Please type or print)

(Do not write above this line)

State Well No. 9s/15E-19da

State Permit No

(1) OWNER:
Name FLOYD BAUER
Address CONTINUED

(2) TYPE OF WORK (check):
New Well ☐ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☐ Jetted ☐
☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☐
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☐ No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☐ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom?
Yield: gal./min. with ft. drawdown after hrs.
" " " "
" " " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used
Well sealed from land surface to ft.
Diameter of well bore to bottom of seal in.
Diameter of well bore below seal in.
Number of sacks of cement used in well seal sacks
How was cement grout placed?
Was a drive shoe used? ☐ Yes ☐ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☐ No Size of gravel:

(10) LOCATION OF WELL:
County JEFF Driller's well number
¼ ¼ Section T. R. W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found ft.
Static level ft. below land surface. Date
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing
Depth drilled ft. Depth of completed well ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
HARD BROWN CLAY	258	265	
HARD GREY CLAYSTONE	265	271	
BLUE GREEN RHYOLITE	271	274	
TAN "	274	285	
RED "	285	288	
TAN "	288	293	
RED "	293	341	
TAN "	341	350	

RECEIVED
WATER RESOURCES DEPT
SALEM, OREGON

Work started 19 Completed 19
Date well drilling machine moved off of well 19

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Date 19
(Drilling Machine Operator)
Drilling Machine Operator's License No.

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name
(Person, firm or corporation) (Type or print)
Address
[Signed]
(Water Well Contractor)

OCHS TEST WELL LOG -- SEC. 17

The original and first copy of this report are to be filed with the WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

RECEIVED APR 27 1979 WATER RESOURCES DEPT. SALEM, OREGON

State Well No. 9s/15E -17

State Permit No.

(1) OWNER:
Name Ronald B. Ochs
Address Gateway Rt. Box 481
Madras, Oregon 97741

(2) TYPE OF WORK (check):
New Well [X] Deepening [ ] Reconditioning [ ] Abandon [ ]
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary [X] Driven [ ]
Cable [ ] Jetted [ ]
Dug [ ] Bored [ ]

(4) PROPOSED USE (check):
Domestic [ ] Industrial [ ] Municipal [ ]
Irrigation [X] Test Well [X] Other [ ]

CASING INSTALLED: Threaded [ ] Welded [X]
8 " Diam. from 0 ft. to 35 ft. Gage .250
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

PERFORATIONS: Perforated? [ ] Yes [X] No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? [ ] Yes [X] No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? [ ] Yes [X] No If yes, by whom?
Yield: 100 gal./min. with 250 ft. drawdown after 1 hrs.
AIR ROTARY - TOTAL " "
" " " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used Cement
Well sealed from land surface to 35 ft.
Diameter of well bore to bottom of seal 12 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal 35 sacks
How was cement grout placed? pressure grouted
Was a drive shoe used? [X] Yes [ ] No Plugs Size: location ft.
Did any strata contain unusable water? [ ] Yes [X] No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? [ ] Yes [X] No Size of gravel:

(10) LOCATION OF WELL:
County Jefferson Driller's well number D-219-79
¼ ¼ Section 17 T. 9s R. 15e W.M.
Bearing and distance from section or subdivision corner
Willow Dale area

(11) WATER LEVEL: Completed well.
Depth at which water was first found 12 ft.
Static level 20 ft. below land surface. Date 4-19-1979
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing 8"
Depth drilled 780 ft. Depth of completed well 780 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
clay brown	0	12	
gravel	12	30	
claystone brown	30	80	
claystone gray water	80	100	20
clay broken rock decoposed	100	145	
clay blue	145	280	
~~[illegible]~~	~~280~~	~~310~~	
diorite green hard	280	310	
diorite fracture, water	310	318	20
diorite green	318	400	
claystone blue	400	509	
claystone brown	509	587	
claystone blue	587	655	
clay red	655	780	

Work started 4-16- 1979 Completed 4-19 1979
Date well drilling machine moved off of well 4-19- 1979

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] [signature] (Drilling Machine Operator) Date 4-24, 1979
Drilling Machine Operator's License No. 883

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name S & M DRILLING & SUPPLY, INC. (Person, firm or corporation) (Type or print)
Address 399 SE Walnute St. Canby, Or. 97013
[Signed] [signature] (Water Well Contractor)

OCHS TEST WELL LOG --SEC. 21

The original and first copy of this report are to be filed with the WATER RESOURCES DEPARTMENT, SALEM, OREGON 97310 within 30 days from the date of well completion.

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

State Well No. 9S/15E-20

State Permit No.

(1) OWNER:
Name Ron Ochs
Address Gateway Star Route
Madras, Oregon 97741

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☒ Driven ☐
Cable ☐ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☒ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☐
5" Diam. from +1 ft. to 19 ft. Gage .258
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☒ No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☒ No If yes, by whom?
gal./min. with ft. drawdown after hrs.
Blow Test- 50 GPM " "
" " " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m.
Temperature of water 60 Depth artesian flow encountered ft.

(9) CONSTRUCTION:
Well seal—Material used cement
Well sealed from land surface to 19 ft.
Diameter of well bore to bottom of seal 8 in.
Diameter of well bore below seal 8 in.
Number of sacks of cement used in well seal 8 sacks
How was cement grout placed? pressure grout
Was a drive shoe used? ☐ Yes ☒ No Plugs Size: location ft.
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? depth of strata
Method of sealing strata off

(10) LOCATION OF WELL:
County Jefferson Driller's well number
¼ ¼ Section 20 T. 9S R. 15E W.M.
Bearing and distance from section or subdivision corner

(11) WATER LEVEL: Completed well.
Depth at which water was first found 250 ft.
Static level 20 ft. below land surface. Date 8-6-79
Artesian pressure lbs. per square inch. Date

(12) WELL LOG: Diameter of well below casing 8"
Depth drilled 800 ft. Depth of completed well 800 ft.
Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level and indicate principal water-bearing strata.

MATERIAL	From	To	SWL
Brown Clay Stone	0	3	
Lt. Tan Sediment Rock	3	43	
White Cleachy	43	47	
Brown Sandstone Conglomerate	47	51	
Sediment Rock-Brown	51	210	
Dk. Brown Sandstone Conglomer.	210	250	
Black Sandstone	250	350	
Brown Claystone Conglomerate	350	390	
Sediment Rock, Tan & Hard	390	460	
Hard Brwn Clay with Grn Congl.	460	640	
Brown Hard Clay	640	800	

RECEIVED
AUG 16 1979
WATER RESOURCES DEPT
SALEM, OREGON

Work started 3-22 19 79 Completed 8-6 19 79
Date well drilling machine moved off of well 8-6 19 79

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] William R. [illegible] (Drilling Machine Operator) Date 8-8, 19 79
Drilling Machine Operator's License No. 803

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Name Orvail Buckner Well Drilling, Inc. (Person, firm or corporation) (Type or print)
Address 1686 N.E. Negus Way, Redmond, Ore. 97741
[Signed] Orvail Buckner

APPENDIX II

TEST DATA

DATA FOR OCHS/RUETER AQUIFER TEST

RUETER IRRIGATION WELL PUMPING WELL DRAWDOWN DATA

PUMP IS A 25 HP SUBMERSIBLE AND DISCHARGE WAS MEASURED BY FLOWING THE WATER OVER A 24" RECTANGULAR WEIR

t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	REMARKS
10/ 7/87	1200		36.00	-4.76	PRE-TEST DATA
10/13/87	1250		31.78	-.54	PRE-TEST DATA
	1252		31.77	-.53	PRE-TEST DATA
	2001		31.60	-.36	PRE-TEST DATA
10/14/87	808		31.35	-.11	PRE-TEST DATA
	849		31.30	-.06	PRE-TEST DATA
	927		31.29	-.05	PRE-TEST DATA
	955		31.26	-.02	PRE-TEST DATA
	1000	0	31.24	.00	PUMP ON!
	1000.5	.5	43.18	11.94	
	1001	1	44.60	13.36	
	1002	2	44.46	13.22	
	1003	3	44.52	13.28	
	1004	4	44.38	13.14	
	1005	5	44.34	13.10	
	1007	7	44.31	13.07	
	1009	9	44.39	13.15	
	1011	11	45.90	14.66	
	1013	13	45.97	14.73	
	1015	15	46.10	14.86	
	1017	17	46.08	14.84	
	1020	20	46.12	14.88	
	1024	24	45.84	14.60	
	1028	28	45.71	14.47	
	1032	32	45.77	14.53	
	1036	36	45.83	14.59	
	1040	40	45.81	14.57	
	1044	44	45.91	14.67	
	1048	48	45.90	14.66	
	1052	52	46.01	14.77	
	1056	56	46.12	14.88	
	1100	60	46.12	14.88	
	1110	70	46.29	15.05	
	1120	80	46.40	15.16	
	1130	90	46.69	15.45	
	1141	101	46.77	15.53	
	1150	110	46.61	15.37	
	1200	120	46.65	15.41	
	1220	140	46.86	15.62	
	1240	160	47.12	15.88	
	1300	180	47.43	16.19	
	1320	200	47.51	16.27	
	1340	220	47.66	16.42	
	1400	240	47.77	16.53	
	1420	260	47.90	16.66	

DATA FOR OCHS/RUETER AQUIFER TEST

RUETER IRRIGATION WELL PUMPING WELL DRAWDOWN DATA

PUMP IS A 25 HP SUBMERSIBLE AND DISCHARGE WAS MEASURED BY FLOWING THE WATER OVER A 24" RECTANGULAR WEIR

t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	REMARKS
10/14/87	1433	273	48.01	16.77	
	1500	300	48.42	17.18	
	1530	330	48.49	17.25	
	1600	360	48.59	17.35	
	1700	420	49.01	17.77	
	1800	480	49.72	18.48	
	1857	537	50.25	19.01	
	2108	668	51.92	20.68	
10/15/87	30	870	53.14	21.90	
	350	1070	54.34	23.10	
	712	1272	55.17	23.93	
	800	1320	55.38	24.14	
	900	1380	55.80	24.56	
	946	1426	55.84	24.60	
	959	1439	55.90	24.66	
	1000	1440			PUMP OFF!

DATA FOR OCHS/RUETER AQUIFER TEST

RUETER IRRIGATION WELL PUMPING WELL RECOVERY DATA

PUMP IS A 25 HP SUBMERSIBLE AND DISCHARGE WAS MEASURED BY FLOWING WATER OVER A 24" RECTANGULAR WIER

t = TIME SINCE PUMPING STARTED t' = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	t' (MIN.)	t/t'	WL BELOW MP (FT.)	RESIDUAL DRAWDOWN (FT.)	REMARKS
10/15/87	1000	1440	0				PUMP OFF!
	1001	1441	.5	2881	42.50	11.26	
	1001	1441	1	1441	41.71	10.47	
	1002	1442	2	721	41.25	10.01	
	1003	1443	3	481	41.06	9.82	
	1004	1444	4	361	40.95	9.71	
	1005	1445	5	289	40.88	9.64	
	1006	1446	6	241	40.80	9.56	
	1007	1447	7	207	40.75	9.51	
	1008	1448	8	181	40.70	9.46	
	1009	1449	9	161	40.65	9.41	
	1010	1450	10	145	40.61	9.37	
	1012	1452	12	121	40.54	9.30	
	1014	1454	14	104	40.48	9.24	
	1016	1456	16	91	40.42	9.18	
	1018	1458	18	81	40.38	9.14	
	1020	1460	20	73	40.33	9.09	
	1023	1463	23	64	40.27	9.03	
	1026	1466	26	56	40.21	8.97	
	1029	1469	29	51	40.16	8.92	
	1032	1472	32	46	40.10	8.86	
	1035	1475	35	42	40.06	8.82	
	1040	1480	40	37	39.98	8.74	
	1045	1485	45	33	39.90	8.66	
	1050	1490	50	30	39.85	8.61	
	1055	1495	55	27	39.78	8.54	
	1100	1500	60	25	39.71	8.47	
	1110	1510	70	22	39.61	8.37	
	1120	1520	80	19	39.50	8.26	
	1137	1537	97	16	39.33	8.09	
	1153	1553	113	14	39.21	7.97	
	1230	1590	150	11	38.89	7.65	
	1333	1653	213	8	38.46	7.22	
	1400	1680	240	7	38.31	7.07	
10/16/87	1351	3111	1671	2	32.68	1.44	
11/16/87					24.01		

DATA FOR OCHS/RUETER AQUIFER TEST

RUETER DOMESTIC WELL OBSERVATION WELL DRAWDOWN DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 2150 FT.
t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	REMARKS
10/ 7/87	1200		40.15	-4.66	PRE-TEST DATA
10/13/87	1409		36.00	-.51	PRE-TEST DATA
	1949		49.95	-14.46	DOMESTIC USE
10/14/87	800		35.55	-.06	PRE-TEST DATA
	955		35.53	-.04	PRE-TEST DATA
	1000	0	35.49	.00	PUMP ON
	1005	5	35.48	-.01	
	1010	10	35.50	.01	
	1015	15	35.55	.06	
	1020	20	35.61	.12	
	1025	25	35.67	.18	
	1030	30	35.74	.25	
	1035	35	35.82	.33	
	1040	40	35.87	.38	
	1045	45	35.90	.41	
	1050	50	35.99	.50	
	1055	55	36.04	.55	
	1100	60	36.10	.61	
	1110	70	36.21	.72	
	1120	80	36.34	.85	
	1130	90	36.41	.92	
	1140	100	36.52	1.03	
	1150	110	36.62	1.13	
	1200	120	36.71	1.22	
	1215	135	36.86	1.37	
	1230	150	36.99	1.50	
	1245	165	37.12	1.63	DOMESTIC USE
	1253	173	42.90	7.41	@ 1251 HOURS
	1256	176	47.90	12.41	DOMESTIC USE
	1309	189	52.90	17.41	DOMESTIC USE
	1329	209	54.74	19.25	DOMESTIC USE
	1332	212	42.90	7.41	DOMESTIC USE
	1345	225	38.32	2.83	DOMESTIC USE
	1415	255	38.03	2.54	
	1447	287	38.18	2.69	
	1519	319	38.38	2.89	
	1600	360	38.63	3.14	
	1706	426	39.01	3.52	
	1813	493	39.49	4.00	
	1913	553	39.87	4.38	
	2117	677	40.65	5.16	
10/15/87	40	880	41.75	6.26	
	358	1078	42.75	7.26	
	719	1279	43.59	8.10	
	822	1342	46.88	11.39	DOMESTIC USE
	840	1360	44.28	8.79	DOMESTIC USE
	917	1397	44.17	8.68	
	1000	1440	44.27	8.78	PUMP OFF

DATA FOR OCHS/RUETER AQUIFER TEST

RUETER DOMESTIC WELL OBSERVATION WELL RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 2150 FT.
t = TIME SINCE PUMPING STARTED t' = TIME SINCE PUMPING STOPPED

DATE	TIME	t (MIN.)	t' (MIN.)	t/t'	WL BELOW MP (FT.)	RESIDUAL DRAWDOWN (FT.)	REMARKS
10/15/87	1000	1440	0				PUMP OFF!
	1010	1450	10	145	44.26	8.77	
	1020	1460	20	73	44.15	8.66	
	1025	1465	25	59	44.10	8.61	
	1030	1470	30	49	44.02	8.53	
	1045	1485	45	33	43.89	8.40	
	1055	1495	55	27	43.77	8.28	
	1100	1500	60	25	43.72	8.23	
	1110	1510	70	22	43.62	8.13	
	1120	1520	80	19	43.53	8.04	
	1130	1530	90	17	43.44	7.95	
	1140	1540	100	15	43.35	7.86	
	1237	1597	157	10	42.87	7.38	
	1409	1689	249	7	42.32	6.83	
10/16/87	1402	3122	1682	2	36.78	1.29	
11/16/87					29.12		

DATA FOR OCHS/RUETER AQUIFER TEST

OCHS IRRIGATION WELL OBSERVATION WELL DRAWDOWN DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 3370 FT.
t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	REMARKS
10/ 7/87	1200		28.54	4.41	PRE-TEST DATA
10/13/87	1415		24.68	.55	PRE-TEST DATA
	1943		24.48	.35	PRE-TEST DATA
10/14/87	752		24.22	.09	PRE-TEST DATA
	1000	0	24.13	.00	PUMP ON!
	1005	5	24.13	.00	
	1010	10	24.13	.00	
	1012	12	24.13	.00	
	1014	14	24.15	.02	
	1015	15	24.15	.02	
	1016	16	24.16	.03	
	1017	17	24.17	.04	
	1018	18	24.17	.04	
	1019	19	24.18	.05	
	1020	20	24.19	.06	
	1022	22	24.21	.08	
	1024	24	24.21	.08	
	1025	25	24.22	.09	
	1027	27	24.25	.12	
	1028	28	24.26	.13	
	1029	29	24.28	.15	
	1030	30	24.29	.16	
	1032	32	24.29	.16	
	1034	34	24.31	.18	
	1036	36	24.34	.21	
	1038	38	24.36	.23	
	1040	40	24.38	.25	
	1042	42	24.41	.28	
	1044	44	24.41	.28	
	1046	46	24.44	.31	
	1048	48	24.47	.34	
	1050	50	24.48	.35	
	1055	55	24.53	.40	
	1100	60	24.58	.45	
	1105	65	24.64	.51	
	1110	70	24.70	.57	
	1115	75	24.74	.61	
	1120	80	24.78	.65	
	1130	90	24.88	.75	
	1135	95	24.94	.81	
	1140	100	24.99	.86	
	1150	110	25.09	.96	
	1200	120	25.20	1.07	
	1210	130	25.30	1.17	
	1220	140	25.37	1.24	
	1230	150	25.46	1.33	
	1240	160	25.56	1.43	

DATA FOR OCHS/RUETER AQUIFER TEST

OCHS IRRIGATION WELL OBSERVATION WELL DRAWDOWN DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 3370 FT.
t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	REMARKS
10/14/87	1250	170	25.65	1.52	
	1300	180	25.77	1.64	
	1328	208	26.13	2.00	
	1410	250	26.40	2.27	
	1444	284	26.65	2.52	
	1515	315	26.88	2.75	
	1525	325	27.05	2.92	
	1557	357	27.15	3.02	
	1702	422	27.61	3.48	
	1808	488	27.99	3.86	
	1917	557	28.44	4.31	
	2122	682	29.20	5.07	
10/15/87	45	885	30.30	6.17	
	403	1083	31.25	7.12	
	723	1283	32.07	7.94	
	921	1401	32.54	8.41	
	956	1436	32.65	8.52	
	1000	1440	32.66	8.53	PUMP OFF!

DATA FOR OCHS/RUETER AQUIFER TEST

OCHS IRRIGATION WELL OBSERVATION WELL RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 3370 FT.
t = TIME SINCE PUMPING STARTED t' = TIME SINCE PUMPING STOPPED

DATE	TIME	t (MIN.)	t' (MIN.)	t/t'	WL BELOW MP (FT.)	RESIDUAL DRAWDOWN (FT.)	REMARKS
10/15/87	1000	1440	0		32.66	8.53	PUMP OFF!
	1001	1441	1	1441	32.66	8.53	
	1002	1442	2	721	32.66	8.53	
	1003	1443	3	481	32.66	8.53	
	1004	1444	4	361	32.67	8.54	
	1005	1445	5	289	32.67	8.54	
	1006	1446	6	241	32.68	8.55	
	1007	1447	7	207	32.68	8.55	
	1008	1448	8	181	32.68	8.55	
	1009	1449	9	161	32.68	8.55	
	1010	1450	10	145	32.68	8.55	
	1012	1452	12	121	32.68	8.55	
	1013	1453	13	112	32.67	8.54	
	1014	1454	14	104	32.67	8.54	
	1015	1455	15	97	32.66	8.53	
	1016	1456	16	91	32.66	8.53	
	1017	1457	17	86	32.65	8.52	
	1018	1458	18	81	32.65	8.52	
	1019	1459	19	77	32.64	8.51	
	1020	1460	20	73	32.64	8.51	
	1021	1461	21	70	32.63	8.50	
	1022	1462	22	66	32.63	8.50	
	1023	1463	23	64	32.62	8.49	
	1024	1464	24	61	32.60	8.47	
	1025	1465	25	59	32.59	8.46	
	1026	1466	26	56	32.59	8.46	
	1027	1467	27	54	32.58	8.45	
	1028	1468	28	52	32.58	8.45	
	1029	1469	29	51	32.56	8.43	
	1030	1470	30	49	32.56	8.43	
	1032	1472	32	46	32.55	8.42	
	1034	1474	34	43	32.53	8.40	
	1036	1476	36	41	32.51	8.38	
	1038	1478	38	39	32.49	8.36	
	1040	1480	40	37	32.48	8.35	
	1045	1485	45	33	32.44	8.31	
	1050	1490	50	30	32.39	8.26	
	1055	1495	55	27	32.36	8.23	
	1100	1500	60	25	32.32	8.19	
	1105	1505	65	23	32.26	8.13	
	1110	1510	70	22	32.22	8.09	
	1115	1515	75	20	32.17	8.04	
	1120	1520	80	19	32.13	8.00	
	1130	1530	90	17	32.04	7.91	
	1148	1548	108	14	31.89	7.76	

DATA FOR OCHS/RUETER AQUIFER TEST

OCHS IRRIGATION WELL OBSERVATION WELL RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 3370 FT.
t = TIME SINCE PUMPING STARTED t' = TIME SINCE PUMPING STOPPED

DATE	TIME	t (MIN.)	t' (MIN.)	t/t'	WL BELOW MP (FT.)	RESIDUAL DRAWDOWN (FT.)	REMARKS
10/15/87	1243	1603	163	10	31.47	7.34	
	1327	1647	207	8	31.14	7.01	
	1413	1693	253	7	30.88	6.75	
10/16/87	1410	3130	1690	2	25.25	1.12	
11/16/87					18.47		

DATA FOR OCHS/RUETER AQUIFER TEST

OCHS IRRIGATION WELL OBSERVATION WELL RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 3370 FT.
t = TIME SINCE PUMPING STARTED t' = TIME SINCE PUMPING STOPPED

DATE	TIME	t (MIN.)	t' (MIN.)	t/t'	WL BELOW MP (FT.)	RESIDUAL DRAWDOWN (FT.)	REMARKS
10/15/87	1000	1440	0		32.66	8.53	PUMP OFF!
	1001	1441	1	1441	32.66	8.53	
	1002	1442	2	721	32.66	8.53	
	1003	1443	3	481	32.66	8.53	
	1004	1444	4	361	32.67	8.54	
	1005	1445	5	289	32.67	8.54	
	1006	1446	6	241	32.68	8.55	
	1007	1447	7	207	32.68	8.55	
	1008	1448	8	181	32.68	8.55	
	1009	1449	9	161	32.68	8.55	
	1010	1450	10	145	32.68	8.55	
	1012	1452	12	121	32.68	8.55	
	1013	1453	13	112	32.67	8.54	
	1014	1454	14	104	32.67	8.54	
	1015	1455	15	97	32.66	8.53	
	1016	1456	16	91	32.66	8.53	
	1017	1457	17	86	32.65	8.52	
	1018	1458	18	81	32.65	8.52	
	1019	1459	19	77	32.64	8.51	
	1020	1460	20	73	32.64	8.51	
	1021	1461	21	70	32.63	8.50	
	1022	1462	22	66	32.63	8.50	
	1023	1463	23	64	32.62	8.49	
	1024	1464	24	61	32.60	8.47	
	1025	1465	25	59	32.59	8.46	
	1026	1466	26	56	32.59	8.46	
	1027	1467	27	54	32.58	8.45	
	1028	1468	28	52	32.58	8.45	
	1029	1469	29	51	32.56	8.43	
	1030	1470	30	49	32.56	8.43	
	1032	1472	32	46	32.55	8.42	
	1034	1474	34	43	32.53	8.40	
	1036	1476	36	41	32.51	8.38	
	1038	1478	38	39	32.49	8.36	
	1040	1480	40	37	32.48	8.35	
	1045	1485	45	33	32.44	8.31	
	1050	1490	50	30	32.39	8.26	
	1055	1495	55	27	32.36	8.23	
	1100	1500	60	25	32.32	8.19	
	1105	1505	65	23	32.26	8.13	
	1110	1510	70	22	32.22	8.09	
	1115	1515	75	20	32.17	8.04	
	1120	1520	80	19	32.13	8.00	
	1130	1530	90	17	32.04	7.91	
	1148	1548	108	14	31.89	7.76	

DATA FOR OCHS/RUETER AQUIFER TEST

OCHS IRRIGATION WELL OBSERVATION WELL RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 3370 FT.
t = TIME SINCE PUMPING STARTED t' = TIME SINCE PUMPING STOPPED

DATE	TIME	t (MIN.)	t' (MIN.)	t/t'	WL BELOW MP (FT.)	RESIDUAL DRAWDOWN (FT.)	REMARKS
10/15/87	1243	1603	163	10	31.47	7.34	
	1327	1647	207	8	31.14	7.01	
	1413	1693	253	7	30.88	6.75	
10/16/87	1410	3130	1690	2	25.25	1.12	
11/16/87					18.47		

DATA FOR OCHS-RUETER AQUIFER TEST

BAUER DOMESTIC WELL OBSERVATION WELL DRAWDOWN AND RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 5520 FT.
t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	SPRING LEVEL (FT.)	REMARKS
10/ 7/87	1200		26.08	-5.38	-3.00	DOMESTIC USE
10/13/87	1615		25.07	-4.37	-2.45	DOMESTIC USE
	1928		21.46	-.76		PRE-TEST DATA
10/14/87	719		20.72	-.02	-2.40	PRE-TEST DATA
	1000	0	20.70	.00		PUMP ON / EST. W.L.
	1035	35	20.68	-.02		
	1038	38			-2.38	
	1040	40	20.69	-.01		
	1043	43	20.65	-.05		
	1044	44	20.64	-.06		
	1048	48	20.63	-.07		DOMESTIC USE
	1049	49	20.83	.13		
	1051	51			-2.38	
	1053	53	20.65	-.05		
	1055	43	20.63	-.07		
	1058	58	20.62	-.08		
	1101	61	20.61	-.09		
	1105	65	20.61	-.09		
	1106	66	20.77	.07		DOMESTIC USE
	1109	69			-2.38	
	1111	71	20.63	-.07		
	1116	76	20.62	-.08		
	1122	82	20.60	-.10		
	1125	85	20.78	.08		DOMESTIC USE
	1130	90	20.62	-.08		
	1135	95	20.61	-.09		
	1138	98	20.61	-.09		
	1144	104	20.85	.15		
	1148	108	20.63	-.07		
	1151	111	20.62	-.08		
	1159	119	20.60	-.10		
	1202	122	20.86	.16		DOMESTIC USE
	1207	127	20.64	-.06		
	1209	129			-2.38	
	1215	135	20.61	-.09		
	1229	149	20.62	-.08		
	1239	159	20.72	.02		
	1245	165	20.65	-.05		
	1300	180	20.68	-.02		
	1301	181			-2.37	
	1515	315	20.78	.08		
	1649	409	20.91	.21		
	2139	699	21.22	.52		

DATA FOR OCHS-RUETER AQUIFER TEST

BAUER DOMESTIC WELL OBSERVATION WELL DRAWDOWN AND RECOVERY DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 5520 FT.
t = TIME SINCE PUMPING STARTED

DATE	TIME	t (MIN.)	WL BELOW MP (FT.)	DRAWDOWN s (FT.)	SPRING LEVEL (FT.)	REMARKS
10/15/87	51	891	21.30	.60		
	411	1091	21.59	.89		
	730	1290	21.67	.97	-2.37	
	832	1352	21.83	1.13		
	928	1408	21.76	1.06		
	1206	1566	22.15	1.45	-2.37	
	1423	1703	21.69	.99		
10/16/87	1435	3155	19.55		-2.25	
11/16/87			17.73		-1.74	SPRING FLOWING

DATA FOR OCHS-RUETER AQUIFER TEST

OCHS-17 TEST WELL OBSERVATION WELL WATER LEVEL DATA

DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 11155 FT.
ADDITIONAL DATA COLLECTED WITH A CONTINUOUS WATER LEVEL RECORDER

DATE	TIME	HOLD (FT.)	CUT (FT.)	WL BELOW MP (FT.)	WATER LEVEL BELOW LAND SURFACE (FT.)
10/ 7/87		10.00	4.64	14.64	11.94
10/13/87	1428	15.00	-.67	14.33	12.03
10/14/87	730	15.00	-.65	14.35	12.05
	1442	15.00	-.53	14.47	12.17
	1642	15.00	-.54	14.46	12.16
	2130	15.00	-.49	14.51	12.21
10/15/87	1215	15.00	-.50	14.50	12.20
11/16/87		15.00	-.35	14.65	12.35

DATA FOR OCHS-RUETER AQUIFER TEST

OCHS-21 TEST WELL OBSERVATION WELL WATER LEVEL DATA

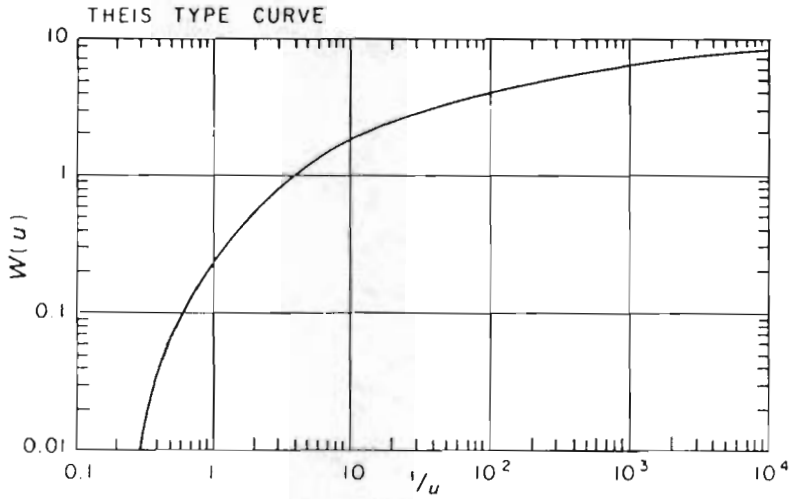
DISCHARGE = 200 GPM DISTANCE TO PUMPING WELL (r) = 6800 FT.
ADDITIONAL DATA COLLECTED WITH A CONTINUOUS WATER LEVEL RECORDER

DATE	TIME	HOLD (FT.)	CUT (FT.)	WL BELOW MP (FT.)	WATER LEVEL BELOW LAND SURFACE (FT.)
10/ 7/87		20.00	1.32	21.32	19.82
10/13/87	1451	20.00	.95	20.95	20.00
10/14/87	740	20.00	.98	20.98	20.03
	1500	20.00	.98	20.98	20.03
10/15/87	1257	20.00	1.05	21.05	20.10

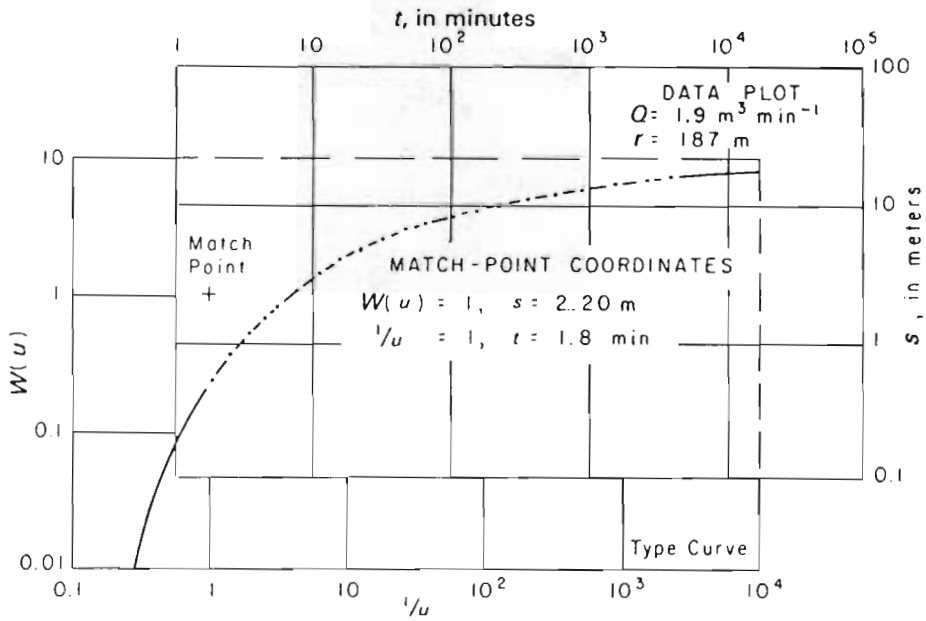
APPENDIX III

DESCRIPTION OF AQUIFER TEST ANALYSIS METHODS

ANALYSIS OF AQUIFER-TEST DATA



(1)

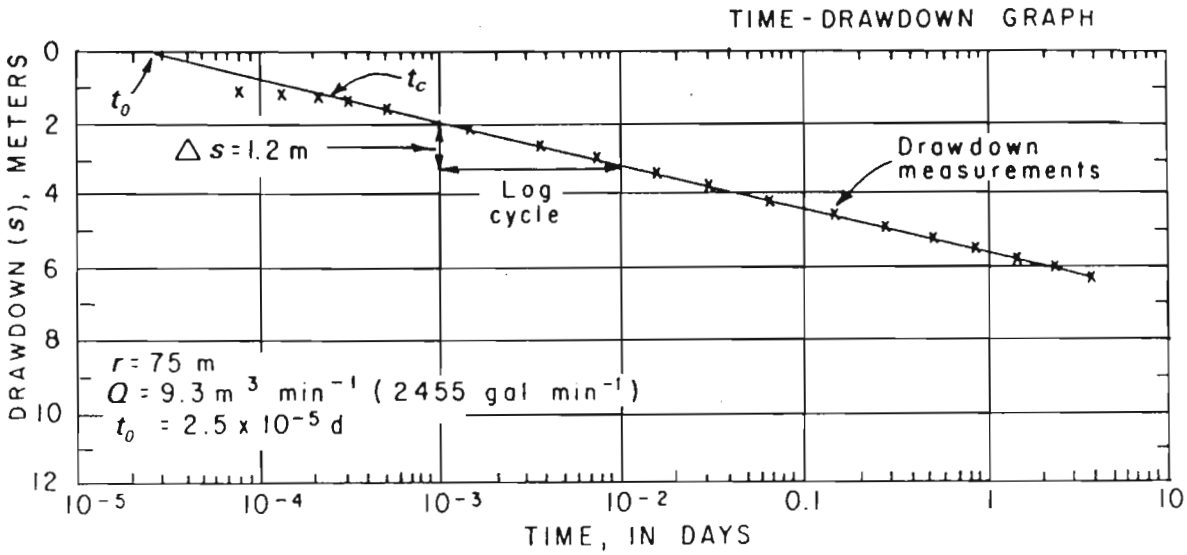


(2)

In 1935, C. V. Theis of the New Mexico Water Resources District of the U.S. Geological Survey developed the first equation to include time of pumping as a factor that could be used to analyze the effect of withdrawals from a well. Thus, the *Theis equation* permitted, for the first time, determination of the hydraulic characteristics of an aquifer before the development of new steady-state conditions resulting from pumping. The importance of this capability may be realized from the fact that, under most conditions, a new steady state cannot be developed or that, if it can, many months or years may be required.

Theis assumed in the development of the equation that:

1. The transmissivity of the aquifer tapped by the pumping well is constant during the test to the limits of the cone of depression.
2. The water withdrawn from the aquifer is derived entirely from storage and is discharged instantaneously with the decline in head.
3. The discharging well penetrates the entire thickness of the aquifer, and its diameter is small in comparison with the pumping rate, so that storage in the well is negligible.



(4)

Equations 2 and 3 are in consistent units. Thus, if Q is in cubic meters per day and s is in meters, T is in square meters per day. S is dimensionless, so that, in equation 3, if T is in square meters per day, then r must be in meters and t_0 must be in days.

It is still common practice in the United States to express Q in gallons per minute, s in feet, t in minutes, r in feet, and T in square feet per day. We can modify equations 2 and 3 for direct substitution of these units as follows:

$$T = \frac{2.3\,Q}{4\pi\Delta s} = \frac{2.3}{4\pi} \times \frac{\text{gal}}{\text{min}} \times \frac{1{,}440\ \text{min}}{\text{d}} \times \frac{\text{ft}^3}{7.48\ \text{gal}} \times \frac{1}{\text{ft}}$$

$$T = \frac{35\,Q}{\Delta s} \tag{4}$$

(where T is in square feet per day, Q is in gallons per minute, and Δs is in feet) and

$$S = \frac{2.25\,Tt_0}{r^2} = \frac{2.25}{1} \times \frac{\text{ft}^2}{\text{d}} \times \frac{\text{min}}{\text{ft}^2} \times \frac{\text{d}}{1{,}440\ \text{min}}$$

$$S = \frac{Tt_0}{640\,r^2} \tag{5}$$

(where T is in square feet per day, t_0 is in minutes, and r is in feet).

TIME-DRAWDOWN ANALYSIS

The Theis equation is only one of several methods that have been developed for the analysis of aquifer-test data. (See "Analysis of Aquifer-Test Data.") Another method, and one that is somewhat more convenient to use, was developed by C. E. Jacob from the Theis equation. The greater convenience of the Jacob method derives partly from its use of semilogarithmic graph paper instead of the logarithmic paper used in the Theis method and from the fact that, under ideal conditions, the data plot along a straight line rather than along a curve.

However, it is essential to note that, whereas the Theis equation applies at all times and places (if the assumptions are met), Jacob's method applies only under certain additional conditions. These conditions must also be satisfied in order to obtain reliable answers.

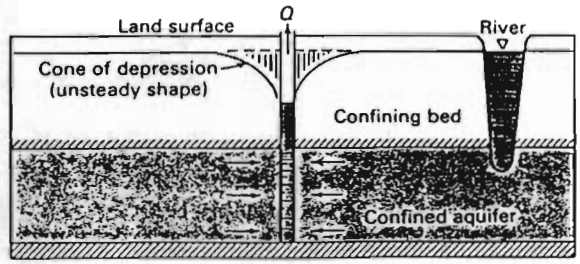
To understand the limitations of Jacob's method, we must consider the changes that occur in the cone of depression during an aquifer test. The changes that are of concern involve both the *shape of the cone* and the *rate of drawdown*. As the cone of depression migrates outward from a pumping well, its shape (and, therefore, the hydraulic gradient at different points in the cone) changes. We can refer to this condition as *unsteady shape*. At the start of withdrawals, the entire cone of depression has an unsteady shape (1). After a test has been underway for some time, the cone of depression begins to assume a relatively *steady shape*, first at the pumping well and then gradually to greater and greater distances (2). If withdrawals continue long enough for increases in recharge and (or) reductions in discharge to balance the rate of withdrawal, drawdowns cease, and the cone of depression is said to be in a *steady state* (3).

The Jacob method is applicable only to the zone in which steady-shape conditions prevail or to the entire cone only after steady-state conditions have developed. For practical purposes, this condition is met when $u = (r^2S)/(4Tt)$ is equal to or less than about 0.05. Substituting this value in the equation for u and solving for t, we can determine the time at which steady-shape conditions develop at the outermost observation well. Thus,

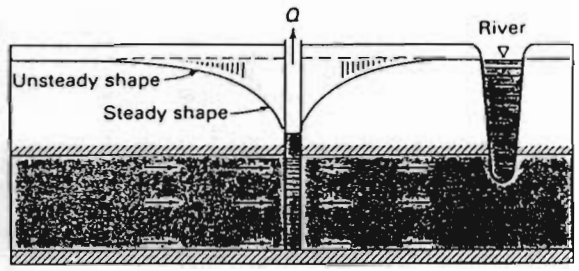
$$t_c = \frac{7{,}200\, r^2 S}{T} \qquad (1)$$

where t_c is the time, in minutes, at which steady-shape conditions develop, r is the distance from the pumping well, in feet (or meters), S is the estimated storage coefficient (dimensionless), and T is the estimated transmissivity, in square feet per day (or square meters per day).

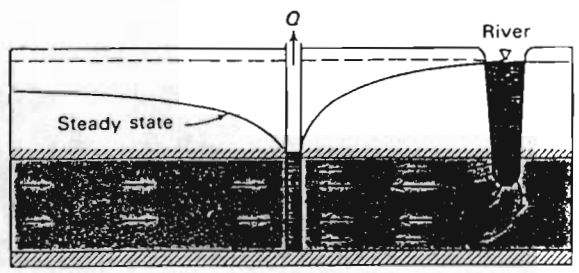
After steady-shape conditions have developed, the drawdowns at an observation well begin to fall along a straight line on semilogarithmic graph paper, as sketch 4 shows. Before that time, the drawdowns plot below the extension of the straight line. When a time-drawdown graph is prepared, drawdowns are plotted on the vertical (arithmetic) axis versus time on the horizontal (logarithmic) axis.



(1)



(2)



(3)

The slope of the straight line is proportional to the pumping rate and to the transmissivity. Jacob derived the following equations for determination of transmissivity and storage coefficient from the time-drawdown graphs:

$$T = \frac{2.3\, Q}{4\pi \Delta s} \qquad (2)$$

$$S = \frac{2.25\, T t_0}{r^2} \qquad (3)$$

where Q is the pumping rate, Δs is the drawdown across one log cycle, t_0 is the time at the point where the straight line intersects the zero-drawdown line, and r is the distance from the pumping well to the observation well.

These assumptions are most nearly met by confined aquifers at sites remote from their boundaries. However, if certain precautions are observed, the equation can also be used to analyze tests of unconfined aquifers.

The forms of the Theis equation used to determine the transmissivity and storage coefficient are

$$T = \frac{Q\,W(u)}{4\pi s} \qquad (1)$$

$$S = \frac{4Ttu}{r^2} \qquad (2)$$

where T is transmissivity, S is the storage coefficient, Q is the pumping rate, s is drawdown, t is time, r is the distance from the pumping well to the observation well, $W(u)$ is the well function of u, which equals

$$-0.577216 - \log_e u + u - \frac{u^2}{2\times 2!} + \frac{u^3}{3\times 3!} - \frac{u^4}{4\times 4!} + \ldots$$

and $u = (r^2S)/(4Tt)$.

The form of the Theis equation is such that it cannot be solved directly. To overcome this problem, Theis devised a convenient graphic method of solution that involves the use of a type curve (1). To apply this method, a data plot of drawdown versus time (or drawdown versus t/r^2) is matched to the type curve of $W(u)$ versus $1/u$ (2). At some convenient point on the overlapping part of the sheets containing the data plot and type curve, values of s, t (or t/r^2), $W(u)$, and $1/u$ are noted (2). These values are then substituted in equations 1 and 2, which are solved for T and S, respectively.

A Theis type curve of $W(u)$ versus $1/u$ can be prepared from the values given in the table contained in the preceding section, "Aquifer Tests." The data points are plotted on logarithmic graph paper—that is, graph paper having logarithmic divisions in both the x and y directions.

The dimensional units of transmissivity (T) are L^2t^{-1}, where L is length and t is time in days. Thus, if Q in equation 1 is in cubic meters per day and s is in meters, T will be in square meters per day. Similarly, if, in equation 2, T is in square meters per day, t is in days, and r is in meters, S will be dimensionless.

Traditionally, in the United States, T has been expressed in units of gallons per day per foot. The common practice now is to report transmissivity in units of square meters per day or square feet per day. If Q is measured in gallons per minute, as is still normally the case, and drawdown is measured in feet, as is also normally the case, equation 1 is modified to obtain T in square feet per day as follows:

$$T = \frac{Q\,W(u)}{4\pi s} = \frac{\text{gal}}{\text{min}} \times \frac{1{,}440\ \text{min}}{\text{d}} \times \frac{\text{ft}^3}{7.48\ \text{gal}} \times \frac{1}{\text{ft}} \times \frac{W(u)}{4\pi}$$

or

$$T(\text{in ft}^2\ \text{d}^{-1}) = \frac{15.3Q\,W(u)}{s}$$

(when Q is in gallons per minute and s is in feet). To convert square feet per day to square meters per day, divide by 10.76.

The storage coefficient is dimensionless. Therefore, if T is in square feet per day, t is in minutes, and r is in feet, then, by equation 2,

$$S = \frac{4Ttu}{r^2} = \frac{4}{1} \times \frac{\text{ft}^2}{\text{d}} \times \frac{\text{min}}{\text{ft}^2} \times \frac{\text{d}}{1{,}440\ \text{min}}$$

or

$$S = \frac{Ttu}{360\,r^2}$$

(when T is in square feet per day, t is in minutes, and r is in feet).

Analysis of aquifer-test data using the Theis equation involves plotting both the type curve and the test data on logarithmic graph paper. If the aquifer and the conditions of the test satisfy Theis's assumptions, the type curve has the same shape as the cone of depression along any line radiating away from the pumping well and the drawdown graph at any point in the cone of depression.

Use of the Theis equation for unconfined aquifers involves two considerations. First, if the aquifer is relatively fine grained, water is released slowly over a period of hours or days, not instantaneously with the decline in head. Therefore, the value of S determined from a short-period test may be too small.

Second, if the pumping rate is large and the observation well is near the pumping well, dewatering of the aquifer may be significant, and the assumption that the transmissivity of the aquifer is constant is not satisfied. The effect of dewatering of the aquifer can be eliminated with the following equation:

$$s' = s - \left(\frac{s^2}{2b}\right) \qquad (3)$$

where s is the observed drawdown in the unconfined aquifer, b is the aquifer thickness, and s' is the drawdown that would have occurred if the aquifer had been confined (that is, if no dewatering had occurred).

To determine the transmissivity and storage coefficient of an unconfined aquifer, a data plot consisting of s' versus t (or t/r^2) is matched with the Theis type curve of $W(u)$ versus $1/u$. Both s and b in equation 3 must be in the same units, either feet or meters.

As noted above, Theis assumed in the development of his equation that the discharging well penetrates the entire thickness of the aquifer. However, because it is not always possible, or necessarily desirable, to design a well that fully penetrates the aquifer under development, most discharging wells are open to only a part of the aquifer that they draw from. Such *partial penetration* creates vertical flow in the vicinity of the discharging well that may affect drawdowns in observation wells located relatively close to the discharging well. Drawdowns in observation wells that are open to the same zone as the discharging well will be larger than the drawdowns in wells at the same distance from the discharging well but open to other zones. The possible effect of partial penetration on drawdowns must be considered in the analysis of aquifer-test data. If aquifer-boundary and other conditions permit, the problem can be avoided by locating observation wells beyond the zone in which vertical flow exists.