Rettkowski Aquifer Test

Lincoln County, Washington

July, 1985

State of Washington
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Governor

WDOE 85-4

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RETTKOWSKI AQUIFER TEST, LINCOLN COUNTY, WASHINGTON

WDOE REPORT 85-4

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May 1985

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ABSTRACT

This report presents the results of an aquifer test involving an irrigation well penetrating 850 feet into a thick basalt sequence in Eastern Washington. Pumping the well at 2,800 gpm for two days induced measurable water level changes 4½ miles away. Water level changes recorded in 16 observation wells indicate a complex ground water flow system with aquifer properties influenced by fracture distribution in the basalt. The basalt includes at least two potentiometric head zones and several discontinuous aquifers.

Water level changes during the test also suggest the presence of a vertical fault approximately 2½ miles east of the pumped well. This fault may explain why two springs are severely depleted by irrigation pumping.

Aquifer transmissivity and storage coefficient vary with distance and direction from the pumped well. An average transmissivity of 3,500 ft^2/day (26,000 gpd/ft.) and storage coefficient of 2×10^{-4} were used to estimate water level drawdown several miles north and south of the pumped well.

A proposed 35 percent increase in yearly withdrawal by the pumped well would cause at least 15 feet of additional, seasonal drawdown in some nearby wells. Increased seasonal water level declines in the aquifers would further diminish flow from springs supplying base flow to nearby Sinking Creek. The rate of permanent water level decline (ground water storage depletion) in the area would increase by one or two feet per year.

Key words: aquifer test, basalt, ground water, wells

INTRODUCTION

An aquifer test was conducted on an irrigation well (local number 25N/33E - 27A2) owned by Craig and Gail Rettkowski and located near Wilbur in Lincoln County. Test data was needed to predict both the seasonal and long-term effects of pumping on nearby wells and on spring discharge to a nearby stream. Water resources managers within the Washington Department of Ecology requested this information to aid their evaluation of a proposed 35 percent increase in yearly withdrawal from the well.

This report presents the aquifer test results, data analysis, interpretations of the local ground water flow system, and predictions regarding the ground water/surface water response to seasonal pumping from the Rettkowski irrigation well.

AQUIFER TEST

Location

The pumped well is located approximately eight miles south and three miles east of Wilbur, Washington (Figures 1 and 2). The well site lies on a ridge forming the topographic divide between the Sinking Creek watershed to the north and the Cannawai Creek watershed to the south.

Well Construction

Table 1 lists pertinent facts about most of the wells located within a five mile radius of the Rettkowski well, including all the wells monitored during the test. The data are from driller's logs, owner's reports, U. S. Geological Survey field records, borehole camera observations, and Washington Department of Ecology (WDOE) measurements of well depths and water levels. Well 25N/34E - 29J is the only multiple-piezometer well in the area. Water levels in these piezometers are believed to represent the true potentiometric heads at each screened interval in the well. Water levels in most of the other wells are composite (intermediate) heads resulting from the absence of casing and the commingling of water from several aquifers with differing heads.

Distances to the Rettkowski well and land surface elevations shown in Table 1 are U. S. Geological Survey 7.5 minute topographic quadrangle maps. These maps include the Goven, Wagner Lake, Creston Butte, and Draper Lake quadrangles.

Water levels reported in Table 1 are primarily those measured just prior to the testing. Water levels for currently inaccessible wells are from various sources. In most cases these water levels represent late winter or early spring conditions preceding the irrigation pumping season.

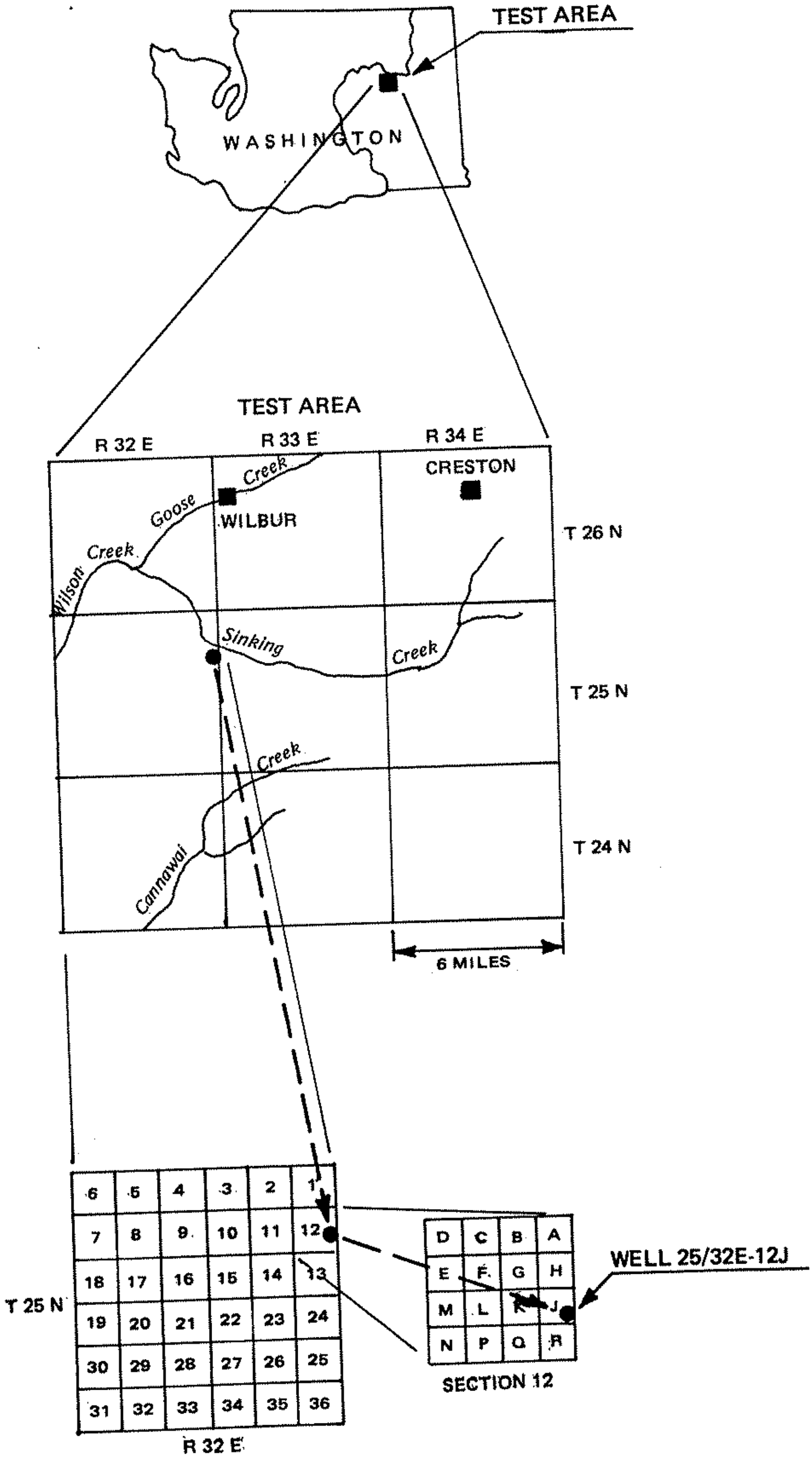
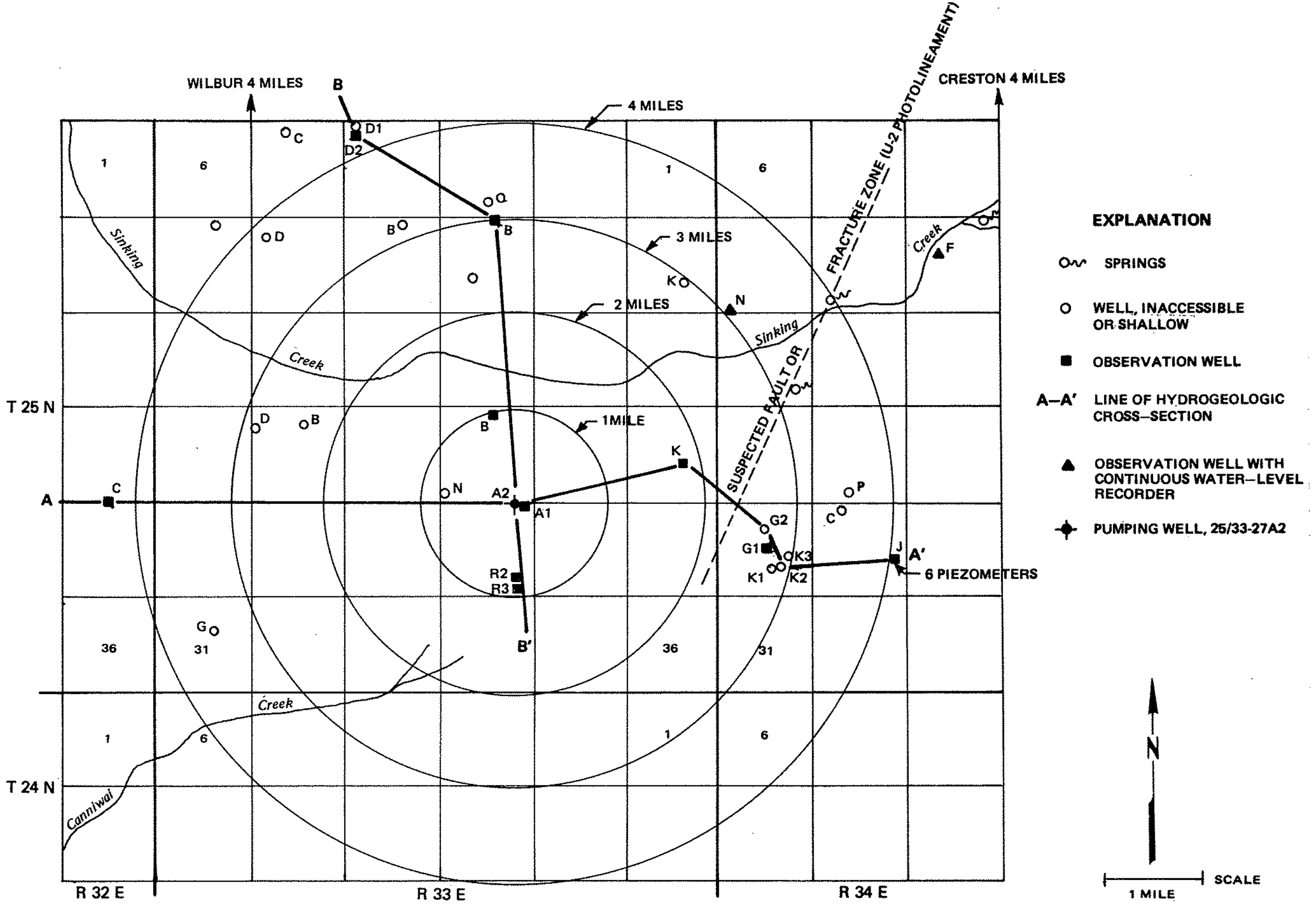


Figure 1. INDEX MAP OF TEST AREA AND DIAGRAM SHOWING WELL NUMBERING SYSTE



WILBUR 4 MILES
CRESTON 4 MILES
4 MILES
3 MILES
2 MILES
1 MILE
FRACTURE ZONE (U-2 PHOTOLINEAMENT)
SUSPECTED FAULT OR
Sinking
Creek
Sinking
Creek
Canniwai
Creek
A
A'
B
B'
C
D1
D2
Q
B
D
K
N
F
A1
A2
R2
R3
K1
K2
K3
G1
G2
J
P
G
6 PIEZOMETERS
T 25 N
T 24 N
R 32 E
R 33 E
R 34 E
1
6
36
31
EXPLANATION
SPRINGS
WELL, INACCESSIBLE OR SHALLOW
OBSERVATION WELL
A—A' LINE OF HYDROGEOLOGIC CROSS—SECTION
OBSERVATION WELL WITH CONTINUOUS WATER—LEVEL RECORDER
PUMPING WELL, 25/33-27A2
N
1 MILE
SCALE

Table 1. WELL DATA 1/

Well Number	Owner	Well or Screened Depth	Depth of Casings, Liners, Plugs	Depth to Water	Distance to Pumped Well	Land Surface Elevation	Comments
25/32-25C1	R. Quirk	635	0-350	378	22,500	2280	Irrigation well
25/33-4D1	W. Dreger	928	0-75	260		2305	Irrigation, no access
25/33-4D2	W. Dreger	505	0-62	260	23,000	2305	Irrigation, open casing
25/33-10B1	R. Rosman	362	0-12	90	16,300	2355	Domestic
25/33-22B1	J. Rodriguez	300	?	160	5,300	2265	Domestic, no log
25/33-22N1	B. Rosman	400	?	?		2360	Domestic, no log, no access
25/33-24K1	Rich. Dreger	308	?	107	10,200	2270	Abandoned, no log
25/33-27A1	Rettkowski	850	0-18 452-480	289	168	2320	Abandoned, collapsed at 524 ft.
25/33-27A2	Rettkowski	865	0-27 389-572	289	0	2320	Irrigation well
25/33-27R2	Rettkowski	200	?	20	4,100	2195	Abandoned, no log
25/33-27R3	Rettkowski	650	0-55	234	4,600	2235	Domestic
25/34-7N1	Randy Dreger	200	0-30	31	16,700	2270	Abandoned, no log
25/34-9F1	M. Houger	211	0-20	15	28,500	2240	Abandoned, no log
25/34-9F1	Rich. Dreger		Casing 0-23 Liner 480-700 Cement Plugs		22,600	2285	USGS piezometer installation. Piezometers 1-6 depths are open borehole intervals monitored by each piezometer. Partial lithologic log. Full suite of geophysical logs.
Piezometer 6		0-259	259-269	42			
Piezometer 5		269-352	352-364	62			
Piezometer 4		364-463	463-478 666-673	62			
Piezometer 3		673-747	747-758 899-910	548			
Piezometer 2		910-996	996-1006 1080-1090	548			
Piezometer 1		1090-1225		548			
25/34-30G2	Rich. Dreger	596	0-304 317-399	470	15,300	2280	Abandoned, cascading water
25/34-30K2	Rich. Dreger	705	0-96	34	15,600	2280	Irrigation, no access

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1/ All units in feet.

Hydrogeology

Loess deposits consisting of windblown silt and fine sand form rich agricultural soils throughout the upland areas. Erosion by present day streams and catastrophic flooding during the last glacial epoch have removed the loess on floodplains, stream terraces, and valley bottoms. In these areas are found thin stream deposits of silt, sand, and gravel and pockets of catastrophic flood deposits up to 50 feet thick, consisting of coarse gravel and sand (Wildrick, 1982, Plate 1). Outcrops of basalt bedrock are common along the valleys. Basalt underlies all the other surface deposits and extends to unknown depths, probably exceeding 2000 feet.

In the test area ground water is pumped almost exclusively from layered, fractured basalt of the Columbia River Basalt Group. The movement and storage of ground water in basalts is poorly understood but is probably controlled by the extent of primary (lava cooling) and secondary (regional tectonic folding) fractures. Likewise, the three-dimensional distribution of fractures is poorly known and nearly impossible to document with current techniques.

Previous hydrologic studies in the Columbia River basalts of Washington and Oregon, the Snake River Plain basalts of Idaho, and the Deccan basalts of India, have produced the following general concepts of ground water occurrence and flow and related fracturing in basalts.

Water bearing zones in the basalt are relatively thin and are found principally in fractured or rubbly contact cooling zones between flows. These contact zones are often called interflow zones. Aquifer test data from the basalts of the Snake River Plain and near the present study area (Loo, personal communication) provide strong evidence that the horizontal permeability is anisotropic. Walton and Stewart (1961) suggest that the highest permeability parallels the direction of original dip of the basalt flow and lowest values lie along the strike.

Vertical and horizontal permeability of the relatively thick, less fractured, flow centers is much lower than in water-bearing interflow zones, as inferred from the lack of significant water production and confirmed by packer testing in the Pasco Basin basalts of Washington. Occasional clay-bearing interflow zones, probably the result of prolonged surface weathering, are also present in the test area but may be discontinuous. These are also presumed to have lower vertical and horizontal permeability compared to water-bearing zones. Average vertical permeability of both the flow centers and clay-bearing interflow zones is many times lower than the average horizontal permeability of water-bearing interflow zones.

The cross-section diagrams in Figures 3 and 4 depict a simplified interpretation of the geohydrology of the test area. The interpretations are based on lithology from driller's logs and on water levels measured for this test. Locations of the two cross-sections are shown in Figure 2.

There appear to be at least two, and possibly three, distinct potentiometric head zones. The head throughout each zone is relatively constant with depth and then declines significantly over a small vertical interval between head zones. A previous study in the area (Wildrick, 1982) interpreted the presence of three head zones, and recent data, especially the piezometer water levels from well 25N/34E - 29J, are also indicative of three zones. A thin clay-bearing interflow zone noted by several drillers is thought to be the principal cause of the head drop between the middle and lower head zones in the test area. Nonetheless, the delineation of head zones is open to interpretation and additional piezometer data are needed to improve the interpretation. For the purpose of test data analysis the two or three head zones are treated as one.

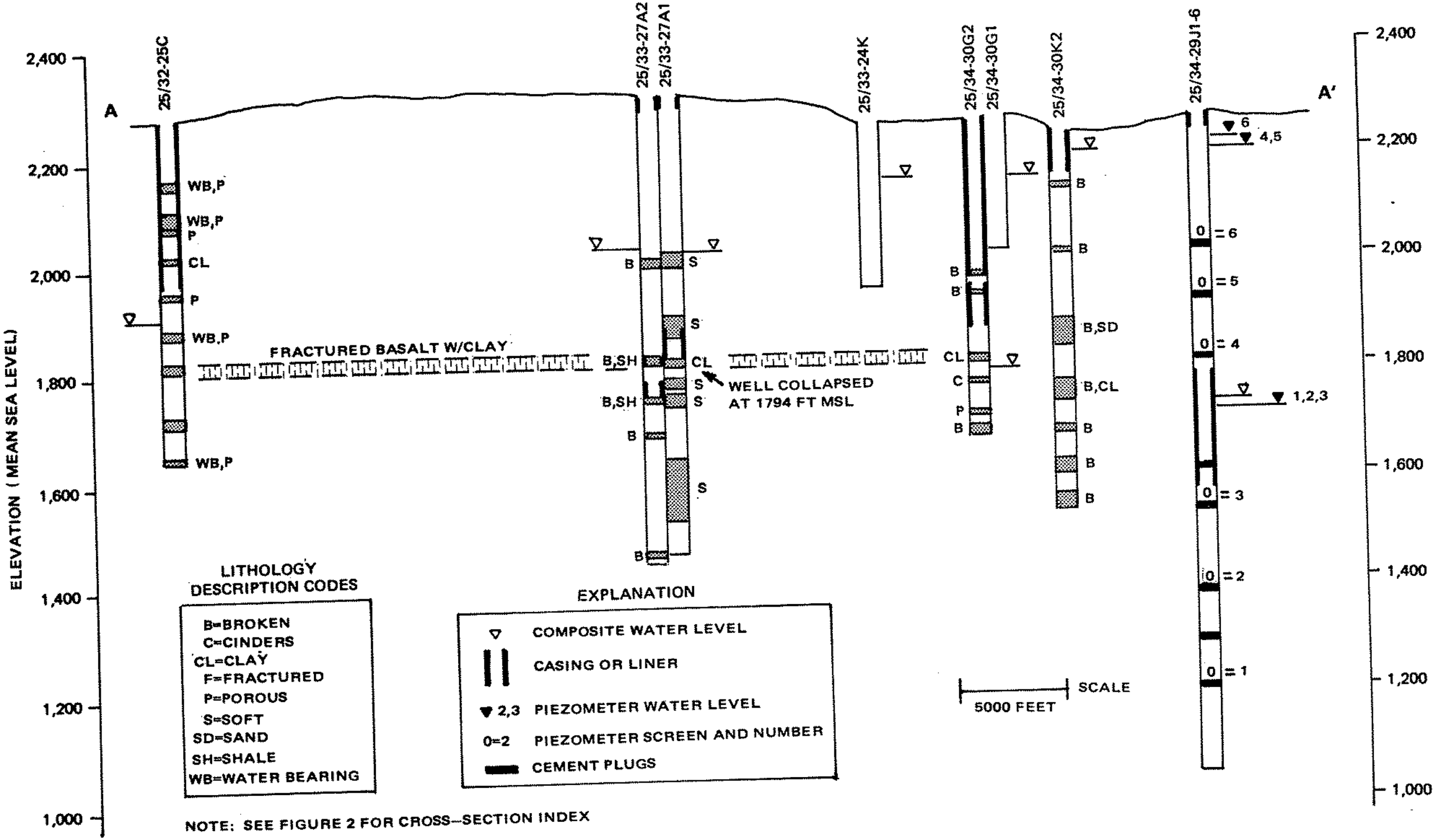
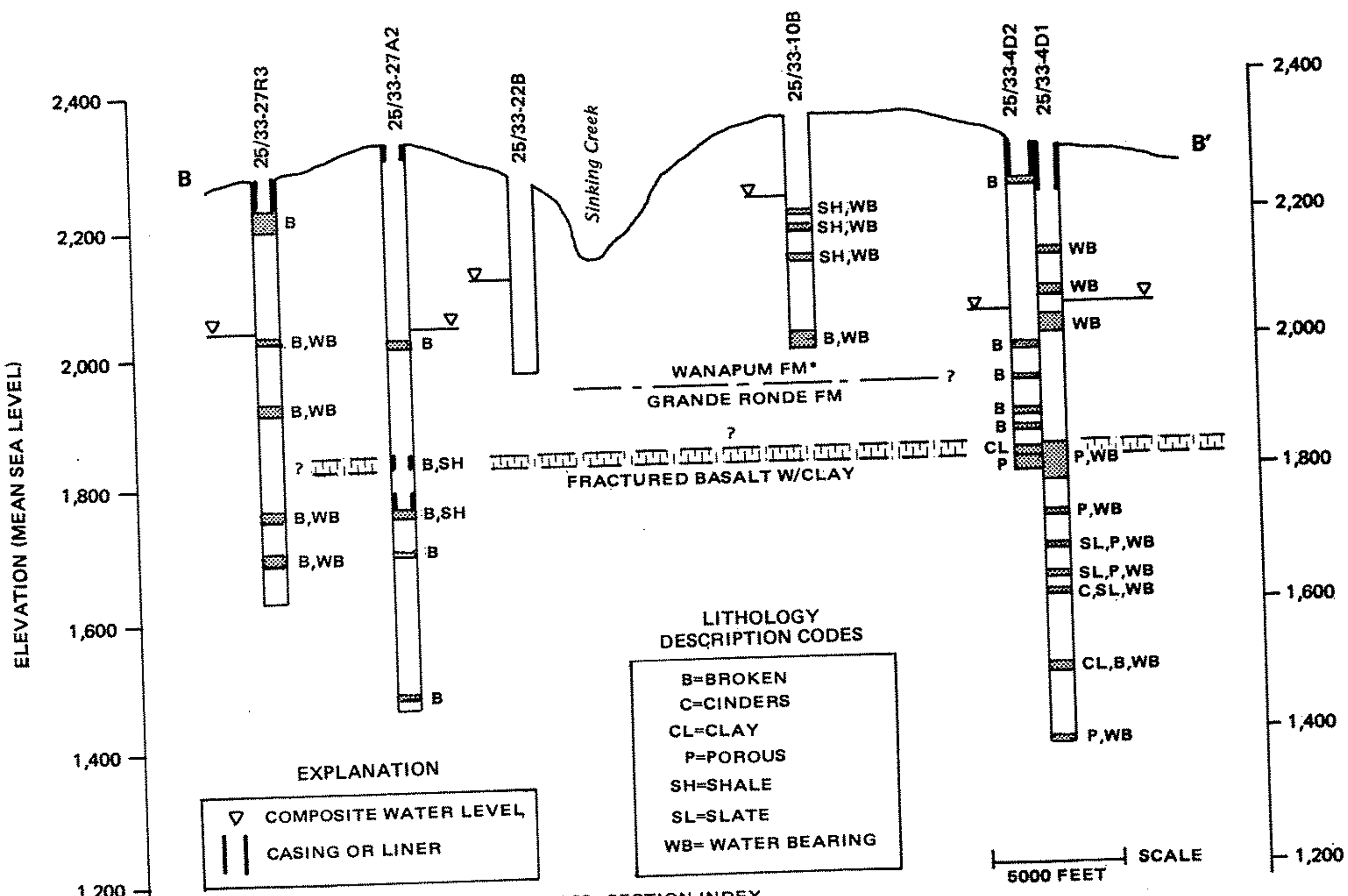


Figure 3. EAST–WEST HYDROGEOLOGIC CROSS–SECTION A–A'



NOTE: SEE FIGURE 2 FOR CROSS–SECTION INDEX

* STRATIGRAPHIC CONTACT INTERPRETED FROM GEOPHYSICAL LOGS FOR WELL 25N/33E-7B1, BY JEFFREY C. BROWN, WASHINGTON STATE UNIV.

Figure 4 NORTH–SOUTH HYDROGEOLOGIC CROSS–SECTION B–B'

Pumping Rate Measurement

To assure accurate pumping rate measurements the Rettkowski well was temporarily equipped with a calibrated, propellor-type flowmeter. The manufacturer specifications claim ± three per cent accuracy for up to 3500 gpm and calibration for a 12 inch I.D. pipe. The pipe in which the meter was mounted was only 11 9/16 inches I.D. Therefore, the actual test pumping rate was only 96% of the rate indicated by the meter. A gate valve in the mainline near the well controlled the pumping rate. This valve was adjusted periodically during the test to maintain a steady pumping rate. Pumping commenced on April 17, 1984 and continued for 49.5 hours. A (corrected) pumping rate of 2800 gpm (±50 gpm) was maintained throughout the test except for the initial 10 minutes of pumping.

Observation Wells

Observation wells were chosen on the basis of depth (greater than 200 feet), location relative to the Rettkowski well, and access for water level measurements with electric probes. Access for measurements could not be achieved in nearby wells 25/33-20B, 25/33-22N, or 25/33-31G. Altogether 16 wells were monitored during the pumping phase of the test (Figure 2). These included 25/32-25C, 25/33-4D2, 25/33-10B, 25/33-22B, 25/33-24K, 25/33-27A1, 25/33-27A2 (pumping well), 25/33-27R2, 25/33-27R3, 25/34-7N (continuous recorder), 25/34-9F (continuous recorder), 25/34-30G2, and piezometer well 25/34-29N (piezometers 1, 3, 4 and 6). Locations and pertinent data for these wells are shown in Figure 2 and Table 1, respectively.

TEST RESULTS

Observation well drawdown responses, distances to the pumped well, drawdown after 49.5 hours of pumping, and comments on problems and accuracy of measurements are listed in Table 2. Figure 5 depicts the log-log drawdown versus time curves, and Figure 6 depicts the semi-log drawdown versus time curves for the five wells.

The response or lack of response to pumping in the observation wells, according to direction and distance from the pumped well, reveals a very complex pattern of pressure decline and, hence, of the hydraulic continuity, within and between aquifers. For instance, well 25/33-4D2, located four miles north of the pumped well, responded while wells 25/32-25C and 25/34-29J (piezometers 1 and 3), four miles west and east, respectively, did not respond. Preliminary interpretation indicated that these three wells are all open to the lower head zone, and therefore, should show some response to pumping. In another example of the complex pattern of response, well 25/33-24K, 1.8 miles northeast of the pumped well, responded to the pumping while well 25/33-30G1, 2.8 miles east, did not respond. The wells penetrate to similar elevations and both were expected to respond to pumping.

Table 2. OBSERVATION WELL RESPONSE TO PUMPING

Observation Well No.	Distance to Pumped Well (feet)	Measurable Drawdown Response	Drawdown During Pumping (feet)	Comments on Response
25/32-25C1	22,500	No	None	E-tape through ¼" airline, static water level (SWL) 380' - poor precision.
25/33-4D2	23,100	Yes	0.8	Open casing, SWL = 261'.
25/33-10B1	16,300	No	None (2.7 rise)	Water level rose throughout test. Pumped the day before test, very slow recovery.
25/33-22B1	5,300	No	None (2.9 rise)	Same as above, SWL = 160'.
25/33-24K1	10,200	Yes	2.9	Open casing, precision excellent.
25/33-27A1	165	Yes	6.9	E-tape through airline. SWL = 289', precision ± 0.05'.
25/33-27A2	Pumping Well	Yes	139	Airline with calibrated gage. Precision ± 0.5 psi or ± 1.2' water.
25/33-27R2	4,100	No	None	Equipment problems, operator error.
25/33-27R3	4,600	Yes	4.4	E-tape through airline, SWL = 234'.
25/34-7N1	16,700	Probably	? less than 1.0'	Continuous recorder, bumped by cattle, record indecipherable.
25/34-9F1	25,500	No	None	Continuous recorder.
25/34-29J Piezometers 1, 3, 4, & 6	22,600	No	None	Deep piezometers (1 and 3) difficult to measure, SWL = 548", E-tape through 2" I.D. steel pipes.
25/34-30G1	15,300	No	None	Open casing.

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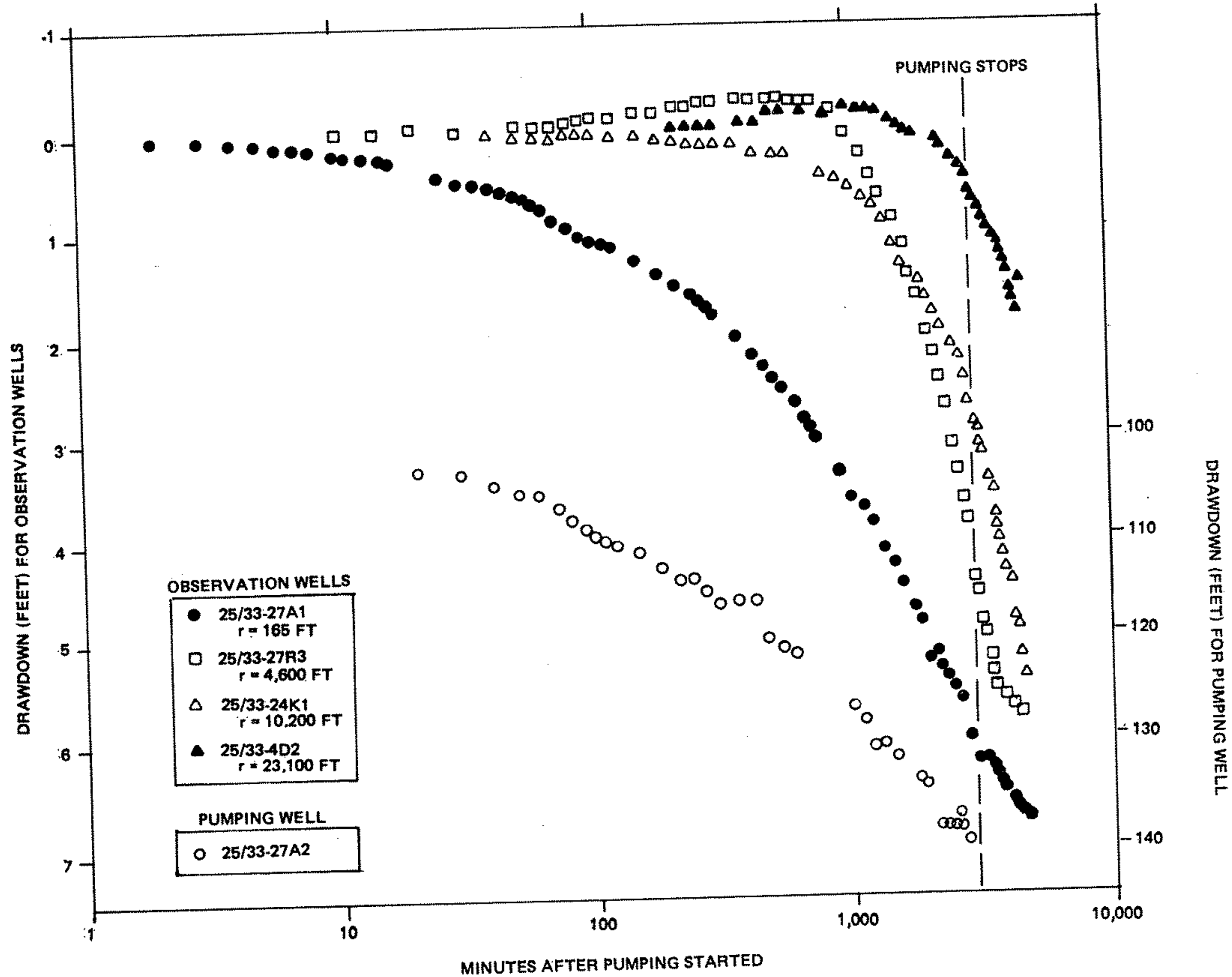

Figure 6. DRAWDOWN IN PUMPING AND OBSERVATION WELLS

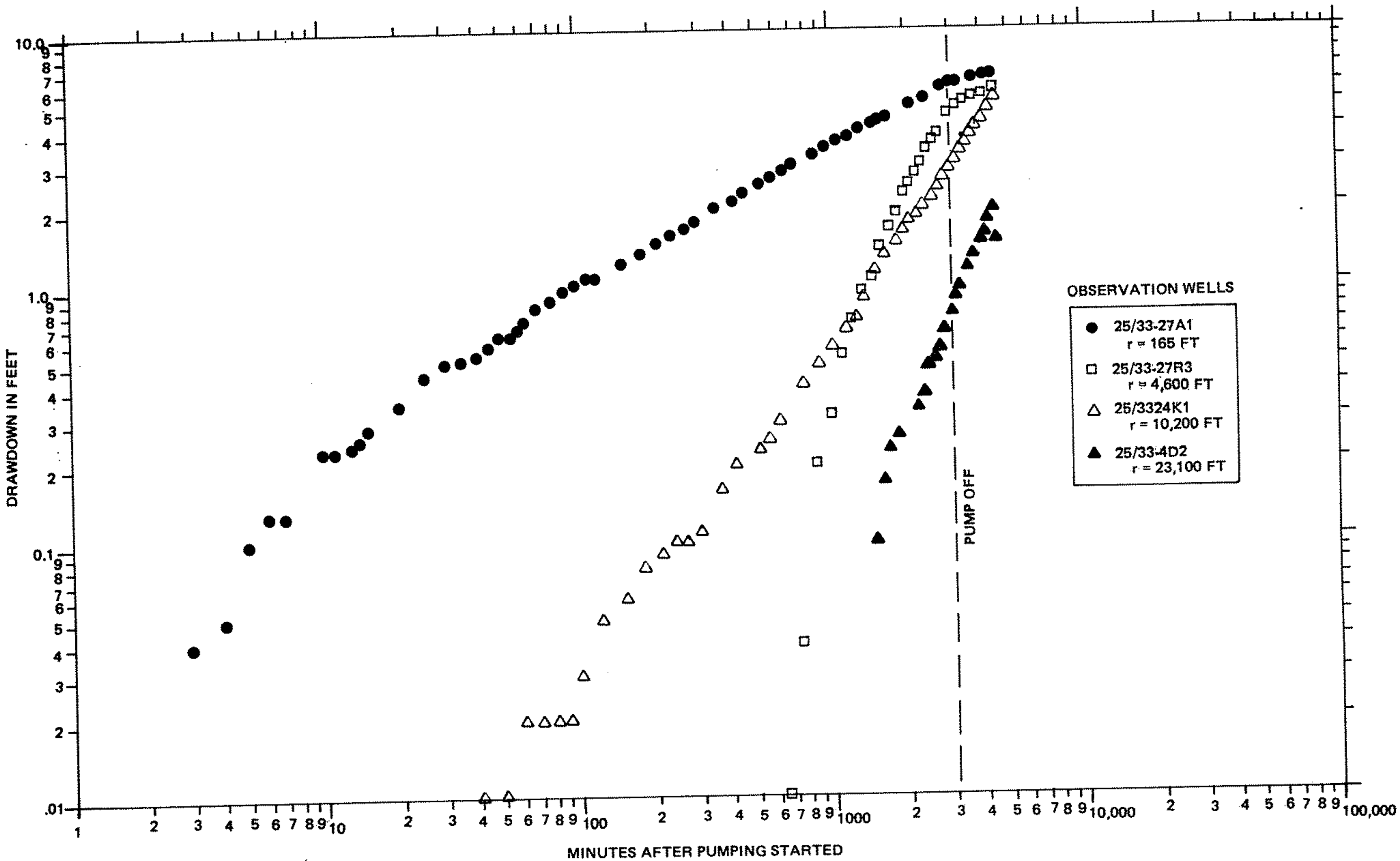

Figure 5. DRAWDOWN IN OBSERVATION WELLS, LOG—LOG PLOT.

Analysis

Drawdown data from the pumped well and the four responding observation wells were analyzed using Theis curve matching (Lohman, 1979), automated least squares Theis curve matching (Paschetto and McElwee, 1982) and Jacob's approximation (Lohman, ibid.) techniques. (Use of more sophisticated analytical models for leaky aquifer or double-porosity fracture flow was not warranted because of uncertainties in flow system geometry and fracture distribution).

The Theis and Jacobs methodologies are based on mathematical models of idealized, confined aquifers comprised of granular, porous materials with a reasonable degree of homogeneity, such as sands and gravels, and constant permeability in all directions. Applicability of the analytical methods to fractured basalt aquifers with little primary porosity, nonhomogeneous fracturing, and irregular permeability distribution depends upon the geometric similarity to the sand and gravel aquifer analogy. On a local scale of a few hundred feet the similarity probably does not hold, but on a larger scale of thousands of feet the comparison improves. Irregularities in porosity, permeability and geometry are averaged during the propagation of pressure changes through the aquifers from a pumping well to distant observation wells. This averaging process often results in observed pressure response similar to that observed for intergranular flow.

The pumped well produced water from several aquifers in both the middle and lower head zones. Regretably, the proportion of yield coming from each zone or individual aquifer could not be measured or estimated. Even if this were possible, the simplified analytical methods cannot provide separate transmissivity and storage coefficient estimates for multiple aquifers. Therefore, we were limited to using the three methods related to the Theis interpretation for confined aquifers. Despite the uncertainties in application, the Theis analytical model is useful for making rough estimates of the average aquifer transmissivity and storage coefficient. These estimates may then be used to roughly predict the drawdowns which would occur over the course of a 5-month pumping season in the responding wells.

Transmissivity and Storage Coefficient Estimates

Table 3 lists the transmissivity and storage coefficient estimates obtained by various methods for the responding observation wells and the pumped well. In all but one analysis the Jacob's approximation method was determined to be invalid and not appropriate (see "Comments" column in Table 3). Estimates of aquifer characteristics for the pumped well and for nearby observation well 25/33-27A1 are probably not representative of the composite aquifer. Estimates derived for observation wells 25/33-4D2, 25/33-24K1, and 25/33-27R3 are judged to be reasonably representative. Taking the logarithmic average (log-mean) of the transmissivities and storage coefficients for the latter three wells yields a log-mean transmissivity of 3,500 ft^2/day (26,000 gpd/ft) and a log-mean storage coefficient of 2×10^{-4}. These estimated properties may be used to estimate water level drawdown several miles north and south of the Rettkowski well.

Assuming the well is pumped at 2,900 gpm for 150 days each year under the present permit, a 35 percent increase in irrigated acreage would require 3,900 gpm for 150 days. Drawdown estimates (Theis method) after 150 days at these pumping rates are as follows:

Present Pumping	Proposed Pumping	Distance From Pumped Well
68 feet	91 feet	1 mile
50 feet	67 feet	2 miles
33 feet	48 feet	4 miles

Table 3. ESTIMATES OF TRANSMISSIVITY AND STORAGE COEFFICIENT
RETTKOWSKI AQUIFER TEST

Well Number	Distance from Pumped Well (feet)	Interpreted Data Interval (minutes)	Analysis Method	Transmissivity (ft^2/d)	Storage Coefficient	Comments
25/33-27A2	0	35-440 470-2880	Jacobs Jacobs	7,600 3,800	None None	Apparent no-flow hydrologic boundary.
25/33-27A1	165	55-210	Jacobs	72,000	1.0×10^{-2}	U = 0.01 at 139 min., method invalid.
		500-1400	Jacobs	26,000	2.4×10^{-2}	U = 0.01 at 395 min., method invalid.
		1200-3000	Jacobs	17,000	3.5×10^{-2}	U = 0.01 at 1950 min., method valid.
		2-60	Least Squares Theis*	138,000	5.4×10^{-2}	Good fit to field data, but early data only represents aquifer near well.
		720-2960	Least Squares Theis	17,000	0.24	Good fit to field data. No distinct boundaries. Storge coefficients questionable.
25/33-27R3	4,600	1000-1600	Jacobs	19,000	1.6×10^{-4}	U = 0.01 at 4.6 days, method invalid.
		2000-3000	Jacobs	7,500	1.0×10^{-4}	U = 0.01 at 7 days, method invalid.
		1000-3000	Least Squares Theis	2,800	8.7×10^{-4}	Good fit to field data.
25/33-24K1	10,200	1200-2600	Jacobs	22,000	2.7×10^{-4}	U = 0.01 at 32 days, method invalid.
		2700-4000	Jacobs	9,400	2.2×10^{-4}	U = 0.01 at 61 days, method invalid.
		1200-3400	Least Squares Theis	7,000	3.2×10^{-4}	Good fit to field data.
25/33-4D2	23,000	2500-4500	Jacobs	17,000	1.4×10^{-4}	U = 0.01 at 11.5 days, method invalid.
		2200-4500	Least Squares Theis	2,200	3.0×10^{-5}	Excellent fit to field data.

* Method of Paschetto and McElwee (1982).

CONCLUSIONS AND PREDICTIONS

1. The most serious effect of increased ground water pumping in the vicinity of Sinking Creek will be the further seasonal depletion of springs supplying baseflow to the creeks. The Rettkowski well already is causing a significant (greater than 10 percent) proportion of this depletion, judging from its location and pumping rate relative to other irrigation wells. Therefore, pumping more water for additional acreage will add to an already serious problem.

2. Although the pumping season drawdown due to current pumpage amounts to several tens of feet throughout the test area, it has not been a problem in nearby wells except as noted below. A 35 percent increase in the irrigated acreage (for the new water right application) will increase the drawdown by the same percentage. This increase in yearly withdrawal can also be expected to exascerbate, by a few percent, the long-term water level decline rate in the middle and lower head zones.

3. The pumped well or its nearby predecessor, well 25A/33E-27A1, has been in use for over ten years. Observation well, 25N/33E-24K1, has been abandoned for stock water supply due to seasonal drawdown interference. Based on our test results most of this drawdown is caused by the Rettkowski well. Domestic well 25/33-22D1 (Burt Rosman, owner) is also reported to be significantly affected by the Rettkowski well, but this could not be confirmed.

4. A vertical fault may be present east of the Rettkowski well. The fault extends from the surface through several basalt layers to depths of hundreds of feet. The fault serves as a partial barrier to the horizontal flow of ground water across the zone and, simultaneously as a highly transmissive conduit for ground water flow between adjacent head zones giving rise to springs in sections 8 and 18 of Township 25 North, Range 34 East. The barrier effect appeared as an indistinct hydrologic boundary in drawdown data for observation wells 25/33E-27A1 and 25N/33E-24K1 together with the lack of drawdown in observation wells east of the fracture zone (wells 25N/34E-29J and 25N/34E-30G1). A previous study (Wildrick, ibid.) found indications for the fault zone in a photolineament map based on U-2 high altitude photographs and in local head data.

5. Preliminary analysis of the geology of the test area indicated a geometrically simple, "layer-cake" sequence of (nearly) horizontal basalt flows. On the other hand, the aquifer testing revealed a very complex subsurface geometry with ground water flow controlled by indeterminate fracture patterns.

   The uncertainty about the flow system geometry limits our ability to accurately predict water level changes beyond a single season.

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APPENDIX

Data Analysis Details

Transmissivity estimates from the pumped well data are only order-of-magnitude in accuracy for several reasons. First, the drawdown measurements were relatively inaccurate (airline compared to electrical probes). Second, well losses always create greater drawdown in the wellbore compared to the aquifer immediately adjacent. Third, the drawdown response seems to indicate the effects of a no-flow or negative hydrologic boundary but this effect was not found in the data from observation wells. Except for the suspected fault, 2.5 miles east, there is no known physical limit to the aquifers within the area significantly affected by the two days of pumping. Relatively impermeable metamorphic and granitic rocks located approximately seven miles to the northeast are too distant to have caused a measurable boundary effect.

Interpretation of the data of observation well 25/33-27A1 yields estimates of uncertain reliability. The Jacob's approximation and least squares Theis methods applied to late-time data indicate a transmissivity of 17,000 ft^2/day. This is a reasonable value for basalt aquifers but is suspect for three reasons. First, the observation well is very close to the pumped well; and, thus, the transmissivity is applicable only to a small portion of the aquifer. Second, this observation well has collapsed in its lower portion and may have a delayed response to the pressure change in the deeper aquifers. Third, the compound-curve shape of the log-log drawdown plot (Figure 4) does not resemble the Theis analytical model curve. The curve shape more closely resembles the type curves derived by Boulton and Streltsova (Sauveplane, 1984) for a double-porosity, fractured rock model. Unfortunately, no information on fracture distribution and size is available to allow interpretation with this analytical model. Storage coefficients estimated from the data for the well are suspect for the same reasons.

The log-log drawdown plot for observation well 25/33-24K1 also is a compound curve making interpretation difficult. The least squares Theis analysis yields a good fit to the late drawdown data and reasonable values for the transmissivity and storage coefficient. On the other hand, the water level in this well continued to decline for at least 10 days after pumping ceased, casting suspicion on any simplified analysis of the drawdown data. The continued decline cannot be explained by leakage from the middle to lower head zone because the leakage should have ceased after a few days of water level recovery in the lower head zone. The nearness of the suspected fault zone may affect the drawdown/recovery response in this well but no logical explanation for the relationship is apparent.

The drawdown responses for observation wells 25/33-4D2 and 25/33-27R3 more closely fit the Theis model type curves. Using the Least Squares Theis method, the transmissivity estimates for these two wells of 2,200 and 2,800 ft^2/day, respectively, are in close agreement. Estimated storage coefficients for the two wells vary by more than an order of magnitude. This latter difference cannot be explained with available data.