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TEST-OBSERVATION WELL NEAR ALMIRA, WASHINGTON: DESCRIPTION AND PRELIMINARY RESULTS

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ABSTRACT

A 750-foot test-observation well drilled near Almira, Wash., is one of several drilled to date (1971) in selected areas of the State. The test wells provide information on ground-water conditions where large-scale pumping from wells is rapidly increasing or is expected to increase, but where data available from existing wells are incomplete and fail to provide adequate guidance for management of the area's ground-water resources.

The upper 60 feet of the Almira well has a 10-inch casing; below this depth the well is uncased in basalt. Four major aquifer zones are penetrated by the well. Geophysical logging during drilling provided data on hole diameter, water resistivity (mineralization) and temperature, and natural radiation of the rock units. These data supplemented the driller's log as a basis for final selection of the aquifers to be monitored. Two pumping tests showed that (1) when the well was 546 feet

deep, and was pumped at a rate of about 510 gpm (gallons per minute) for 9½ hours, the specific capacity was 92 gpm per foot of drawdown; and (2) at the final 750-foot depth, with all four aquifers contributing water and the well being pumped at a rate of 525 gpm for 24 hours, the specific capacity was 96 gpm per foot of drawdown. Water from the well when drilled to its final depth of 750 feet is slightly warmer and somewhat more mineralized than when the well was only 546 feet deep.

Four piezometer pipes were installed in the well so that each reflected the head in a specific aquifer zone that is hydraulically isolated from the other aquifer zones by cement seals. The maximum difference in water levels between the uppermost and lowermost aquifers after the zones were isolated was 180 feet; the difference may increase somewhat as the heads in the aquifers continue to adjust after isolation. An access pipe also was provided for an instrument to measure the geothermal gradient.

The data that have been obtained from the test-observation well and that which will be available from it in the future are expected to provide invaluable guidance for management of the ground-water resources.

INTRODUCTION

The test-observation well described in this report was designed to yield key ground-water information for a highly productive agricultural area of Washington State in which irrigation from ground-water sources is rapidly increasing. The information obtained during the drilling and testing of this well adds considerably to the hydrologic knowledge of the area. Furthermore, information to be collected from the well in coming years, as more ground-water development occurs, will be of far greater value and will include data of a type that cannot be obtained from water-supply wells, especially those for which construction data are incomplete.

Construction of this well is part of a project for drilling, testing, and periodically collecting data from test-observation wells in selected areas of the State. These wells are being drilled where there is a need for ground-water data for water-management purposes and where the data cannot be obtained by other means. The project, part of a continuing cooperative program of water-resources investigations in Washington, is financed jointly by the U.S. Geological Survey and the State of Washington Department of Ecology. The data from this well will facilitate other cooperative investigations of the relationship between pumpage and decline of ground-water levels.

The locations of this and other test-observation wells drilled in eastern Washington as part of this project are shown in figure 1.

GROUND-WATER PROBLEMS IN THE AREA

The soil, topography, and climate of the Almira area are well suited to the growing of wheat and other crops common to eastern Washington, and much of the area is favorable for sprinkler irrigation, similar to other areas that have been under irrigation since before 1960. The area is underlain by the thick sequence of basalt flows which contain aquifers (water-bearing zones) that provide ground water for irrigation in much of eastern Washington. However, because the depth to water in the upland parts of the area is greater than in many other parts of eastern Washington, irrigation from ground-water sources has until recently been limited to coulee floors. Improvements in pumping and sprinkling equipment, and the successful irrigation of wheat by ground water in other areas, have led to the construction recently of several deep irrigation wells in the Almira area.

Irrigation from ground-water sources in the Almira area is presently (1971) at about the same stage of development as it was in 1960 in the Odessa area (fig. 1), about 25 miles to

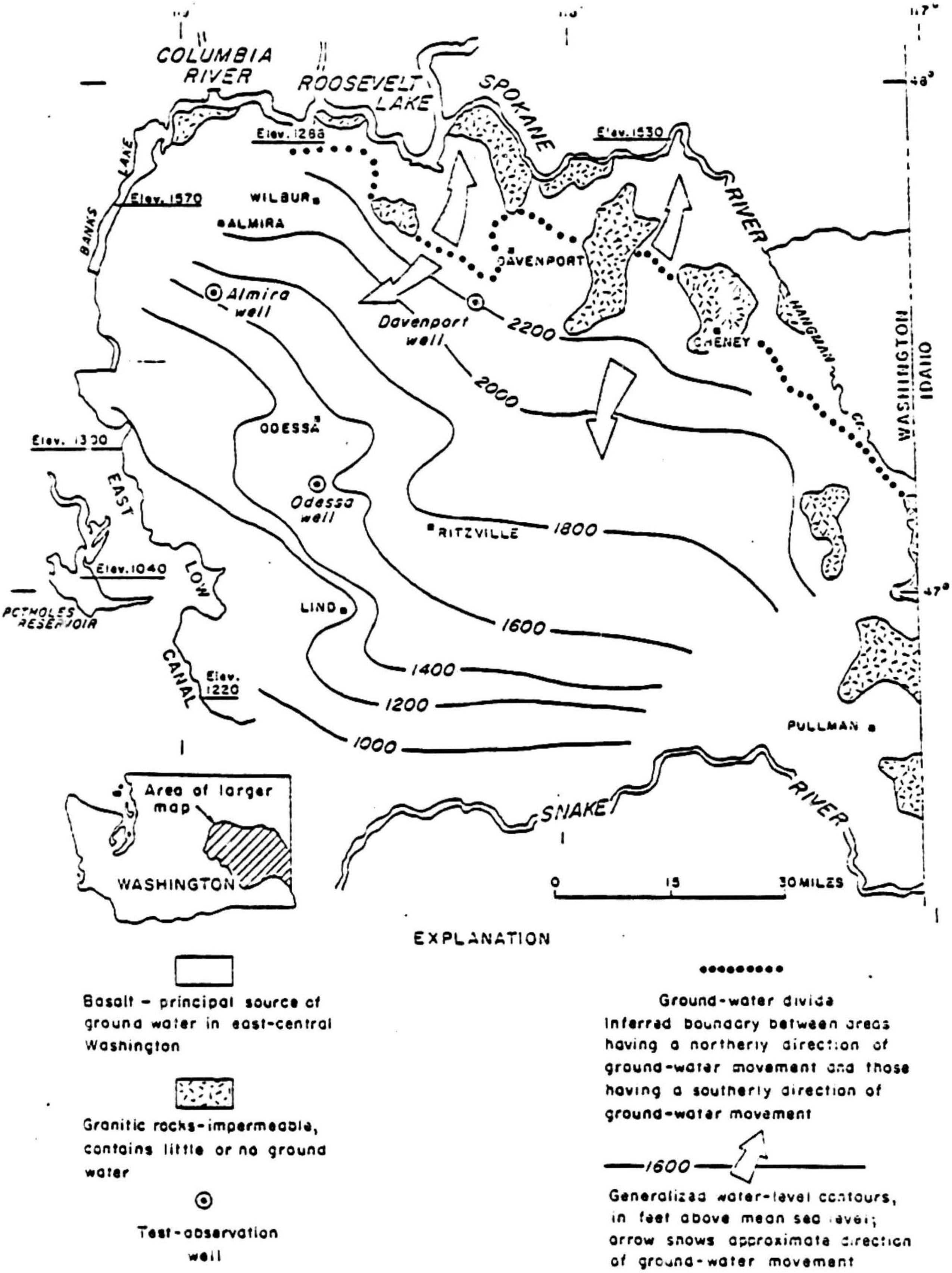

FIGURE 1.--Regional movement of ground water and locations of test-observation wells in east-central Washington.

the southeast. Ground-water pumpage in the Odessa area increased from about 13,000 acre-feet in 1963 (the earliest year for which pumpage figures are available) to about 70,000 acre-feet in 1970. Localized areas of water-level decline and well interference in the Odessa area were detected as early as 1964, and by 1971 areas of major water-level decline had enlarged and coalesced to involve several hundred square miles. Declining water levels have resulted in increased pumping costs to irrigators and the deepening of some domestic and stock wells and shallow irrigation wells.

The decline in water levels that may occur in the Almira area depends almost entirely on the rate of ground-water withdrawal--in adjacent areas as well as in the Almira area itself--which depends in turn on economic factors and water-management decisions. Figure 1 shows that the general direction of ground-water movement in most of east-central Washington is south and southwest. The relationship between ground-water conditions in the Almira and Odessa areas is not presently known, but continued collection of data in both areas is vital to the understanding of this relationship.

In basalt, most ground water occurs and moves in well-defined, nearly horizontal permeable zones at or near the contacts between individual basalt flows. These aquifers are separated from one another by the dense nearly impermeable center parts of the flows. Hydraulic heads in the individual aquifers, as reflected by water levels in wells that tap them, usually vary with depth. In much of east-central Washington the water levels are highest in the shallow basalt aquifers and lowest in the deeper aquifers. Most wells tapping the basalt are largely uncased, and a well that is open to both shallow and deep aquifers may have a significant downward flow of water within the well bore. This downward flow of ground water in deep wells, and the decreasing head or water level with depth, result in an average, or composite, water level that may be misleading in an evaluation of the relationship between pumping and water-level declines. Nearly all deep wells available for observation of water levels in east-central Washington have such composite water levels. In view of the serious water-level declines occurring in some areas--and potential declines in other areas--properly constructed test-observation wells that reflect water levels in individual aquifers are essential for obtaining a curate and reliable data necessary for a full understanding of the ground-water-flow system and an accurate prediction of aquifer response to increased development.

INVESTIGATIONAL PROCEDURES

The Well

The Almira test-observation well was drilled on State school land that is under the jurisdiction of the State of Washington Department of Natural Resources. The State of Washington Department of Ecology and the U.S. Geological Survey were provided long-term access to the well for the purposes of observation and testing.

Because of the inadequacies of the usual observation wells, which generally are open to all aquifers penetrated, all decisions of design and construction of the Almira well were calculated to permit isolation and measurement of water levels in individual aquifers or aquifer zones. The air-rotary drilling method was used throughout construction to provide a smooth, straight borehole for ease of installation of water-level measuring equipment, and to lessen the possibility of plugging the aquifers with drilling mud.

The 10-inch, 750-foot well was drilled and tested during the period November 23, 1970-May 11, 1971, by the Adcock Drilling Co. of Lewiston, Idaho. Cased to a depth of 60 feet, the well penetrates chiefly basalt (table 1), in which four distinct aquifers or aquifer zones were identified during the drilling and testing. The well was test-pumped when drilling had

TABLE 1.--Driller's log of Almira test-observation well

Material	Thickness (feet)	Depth (feet)
Drilled by Adcock Drilling Co., Nov. 23, 1970-Feb. 10, 1971. Located about 0.45 mile south and 120 ft east of the NW corner sec. 16, T. 24 N., R. 31 E.		
Silt	8	8
Basalt, weathered, brown	12	20
Basalt, medium firm, vesicular, brown	30	50
Basalt, somewhat broken, dark brown	5	55
Basalt, medium soft, greenish black	11	66
Basalt, brown and tan, "pillow-zone?"	4	70
Basalt, hard, black and brown	7	77
Clay, hard, tan to buff	3	80
Basalt, vesicular, brown	3	83
Basalt, hard, gray-black	24	107
Basalt, soft, slightly vesicular, gray-green	4	111
Basalt, medium hard, black	3	114
Clay, plastic, tan-brown	2	116
Basalt, soft, weathered, brown	3	119
Basalt, medium hard, gray-black	13	132
Basalt, medium soft, vesicular, gray-brown	14	146
Basalt, hard, gray-green	8	154
Basalt, soft, vesicular, brown	3	157
Basalt, medium hard, gray-brown	7	164
Basalt, medium hard, gray-black, appears badly broken from 172 to 175 ft	30	194
Basalt, medium hard, black	26	220
Basalt, very hard, black, a few phenocrysts, some green opallike material	24	244
Basalt, hard, gray-brown	12	256
Basalt, soft, slightly vesicular, black, some hard black interbedded clay	5	261
Basalt, medium hard, black	6	267
Basalt, medium hard, gray-brown	12	279
Basalt, medium soft, trace of water	2	281
Basalt, hard, gray-black	7	288
Basalt, medium hard, gray-brown	12	300
Basalt, hard, gray-green	41	341

(continued)

TABLE 1.--Driller's log of Almira test-observation well--Con.

Material	Thickness (feet)	Depth (feet)
Basalt, medium hard, gray-green	26	367
Basalt, soft, brown	5	372
Basalt, medium, slightly vesicular, gray	66	438
Basalt, broken, brown and black, much hard yellow clay "pillow zone?", water-bearing	8	446
Basalt, medium hard, dense, gray	61	507
Basalt, very vesicular, brown, some hard brown clay: much water	28	535
Basalt, soft, vesicular, black	7	542
Basalt, hard, dense, dark gray	13	555
Basalt, medium hard, dark gray	14	569
Basalt, medium hard, fractured, dark gray	64	633
Basalt, hard, dark gray	22	655
Basalt, soft, vesicular, dark gray to brown, possibly some clay	29	684
Basalt. hard. some fractures, dark gray	10	694
Basalt, medium hard, dark gray	56	750

Casing: 10-inch to 60 ft.

reached a depth of 546 feet, and again at the final depth of 750 feet.

Geophysical Logs

Borehole geophysical logs were run at various times during the construction period to help define the locations of aquifers and select intervals for testing. The logs provided data on hole diameter, water resistivity, water temperature, and natural radiation of the rock units (fig. 2). The logs supplemented the driller's log as a basis for final design and selection of aquifers to be monitored. The aquifers can be identified in figure 2 by (1) indications on the caliper log of hole enlargements, which occur in the loose and broken basalt zones that tend to contain water, (2) abrupt changes in the temperature of water in the borehole, (3) changes in the resistivity (reflection of degree of mineralization) of water in and near the borehole, and (4) abrupt reversals in the trend of radiation (trace of the gamma log) below the static water level.

Fluid movement in the borehole was too slight to produce a meaningful flowmeter log; however, the water-temperature log indicates that cooler water from the upper part of the hole was moving down the borehole.

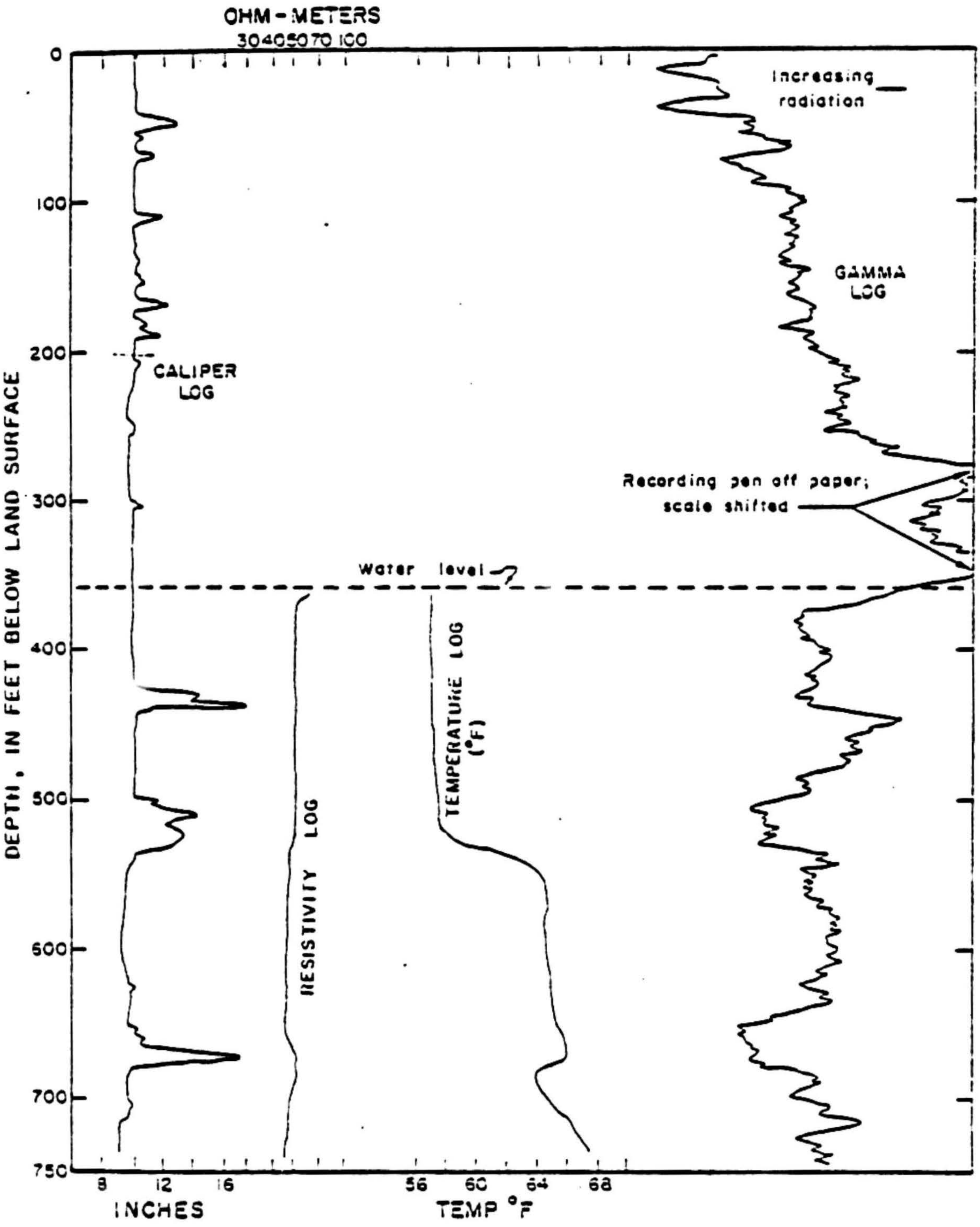

FIGURE 2.--Borehole geophysical logs of Almira test-observation well.

Piezometer Pipes

For water-level measurements in various aquifer zones, $1\frac{1}{4}$-inch-diameter piezometer pipes, with short well screens attached, were positioned in the test hole opposite each aquifer zone to be monitored (fig. 3). The borehole then was backfilled with washed gravel of nominal $1\frac{1}{4}$-inch diameter and smaller size, and a cement plug was placed at the top and base of each monitored zone to isolate it. In cases where the zones to be monitored were widely separated, an intermediate cement plug was added during backfilling. This procedure allows measurement of changes in water levels in four distinct aquifer zones with no connection through the borehole from one zone to another. The difference in water levels soon after the aquifers were isolated was about 180 feet (fig. 3). However, because the shallower aquifers had been draining into and recharging the deeper aquifers prior to the isolation of the aquifer zones, the difference in water levels is expected to increase as the shallower aquifers recover from this drainage and the preexisting pattern of heads in the basalt sequence is restored.

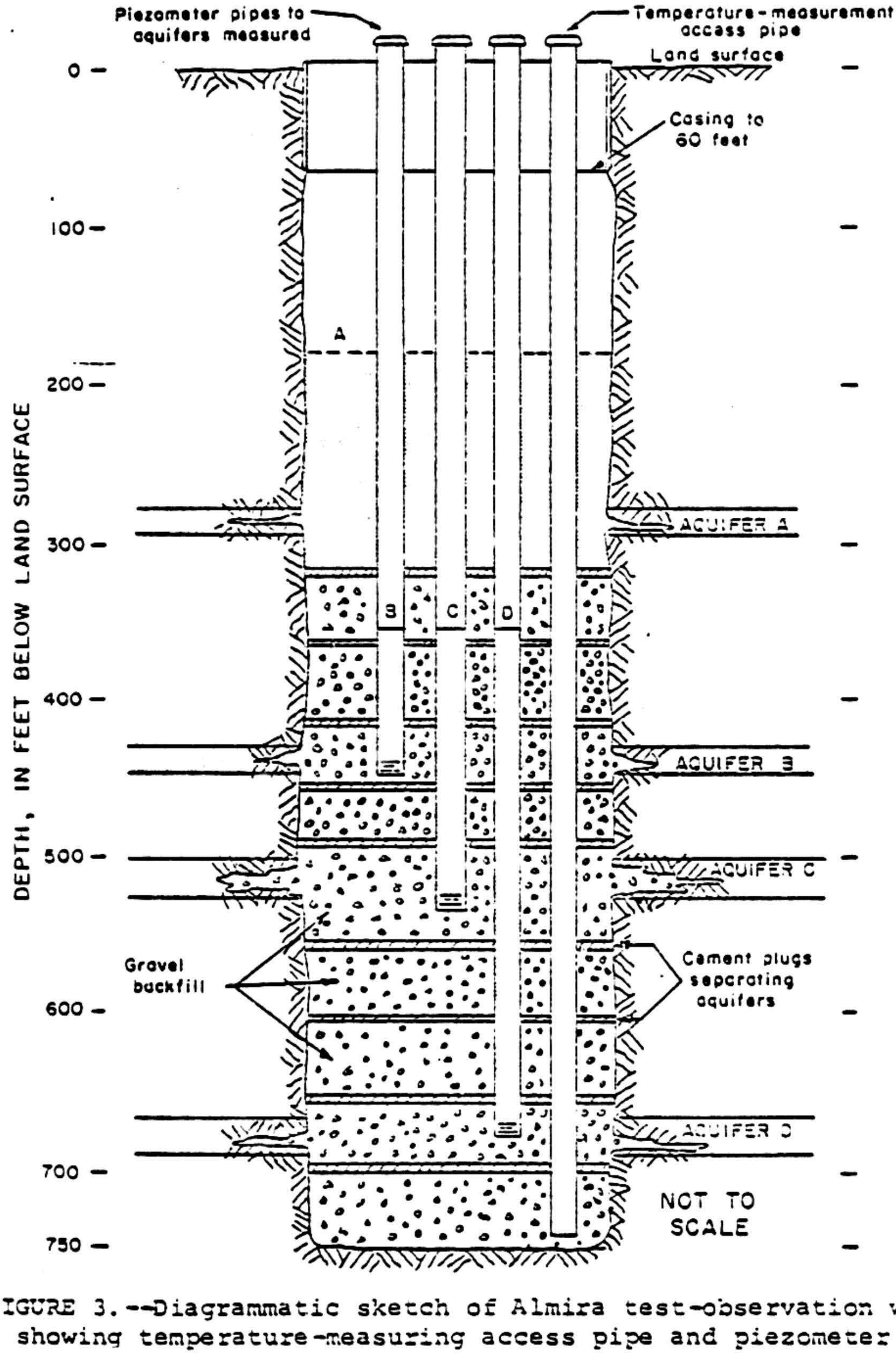

FIGURE 3.--Diagrammatic sketch of Almira test-observation well, showing temperature-measuring access pipe and piezometer pipes to three aquifer zones measured.

Temperature-Measurement Access Pipe

For the purpose of recording the differences in temperature of water from aquifers of different depths, 1½-inch pipe (fig. 3) was installed to accommodate a sensitive temperature-measuring instrument. Natural vertical movement of the ground water from one aquifer zone to another through cracks and joint systems in the dense rock, in response to the vertical head differences, may have a warming or cooling effect on the pattern of natural heat flow outward through the earth, thereby causing a distortion in the geothermal gradient. By careful measurement of this distortion, the rate of vertical ground-water movement--and recharge of one aquifer by water from another having a higher head--may be calculated with greater precision and at far less expense than by most other methods available.

RESULTS OF THE WORK

Pumping Tests

A pumping test to determine the hydrologic characteristics of aquifers A, B, and C (fig. 3) combined was conducted when the well had been drilled to a depth of 546 feet. At a pumping rate of about 510 gpm (gallons per minute) for about 9½ hours, the water level was drawn down from 373 feet below land surface to 378½ feet below land surface, indicating a specific capacity of about 92 gpm per foot of drawdown. (Specific capacity is the yield of the well in gallons per minute divided by the resultant drawdown of water level, in feet.)

A second pumping test was conducted when the well was at its final depth of 750 feet and open to all four aquifers penetrated. In this test, at a pumping rate of about 525 gpm for 24 hours, the water level was drawn down from about 363 to nearly 368 feet below land surface, and the specific capacity was about 96 gpm per foot of drawdown. When the entire pumping period of the second test is considered, the specific capacity of the well appears to have increased by only about 4 percent, even though penetration of saturated materials had been approximately doubled. However, when only the first 9½ hours (the length of the first test) are considered, the increase in specific capacity with increased depth amounted to about 14 percent.

Determinations of the transmissivity of the aquifer system were attempted from both the drawdown and recovery data of both pumping tests. In the absence of nearby wells to serve as observation wells, estimates of transmissivity were made by the graphical (straight-line) analysis of drawdown and residual drawdown in the test well versus time (Jacob, 1950; Theis, 1935).[/] Pumping and recovery water levels during the first test were erratic and, therefore, not suitable for determination of aquifer characteristics; during the second test they were more regular. Calculated values of transmissivity were 26,000 square feet per day (195,000 gallons per day per foot) and 35,300 square feet per day (265,000 gallons per day per foot) respectively, for the drawdown and recovery parts of the test.

Quality of Ground Water

Water samples for chemical analysis were collected near the end of each pumping test. The analyses of these samples are presented in table 2. The water is moderately hard and is suitable for most common uses. Water from the well after it was drilled to the final depth of 750 feet was slightly warmer and somewhat more mineralized than the water collected when the well was 546 feet deep.

[/] Jacob, C. E., 1950, Flow of ground water, chap. 5, *in* Rouse, Hunter, Engineering hydraulics: New York, John Wiley & Sons.

Theis, C.V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519-524.

TABLE 2.--Chemical analyses of water from the Almira test-observation well

Item	Values in milligrams per liter unless otherwise indicated	
Date of collection	1-8-71	5-11-71
Depth of well, in ft	546	750
Silica (SiO_2)	47	54
Aluminum (Al)	.01	.00
Iron (Fe)	.05	.05
Manganese (Mn)	<.02	.02
Calcium (Ca)	16	17
Magnesium (Mg)	9.0	9.1
Sodium (Na)	24	25
Potassium (K)	5.3	5.0
Bicarbonate (HCO_3)	137	145
Carbonate (CO_3)	0	0
Sulfate (SO_4)	14	23
Chloride (Cl)	5.2	4.8
Fluoride (F)	.6	.5
Nitrate (NO_3)	1.1	.68
Dissolved solids (calculated)	189	213
Hardness as $CaCO_3$	77	80
Hardness, noncarbonate	0	0
Specific conductance (micromhos per liter at 25°C)	270	272
pH (in pH units)	7.9	7.7
Temperature (°C)	17.6	18.8
Color (in color units)	0	3

ADDITIONAL INFORMATION EXPECTED

Besides the information obtained on the sequence of aquifers at the test site, the relative yields of the test-observation well at different depth intervals, the geophysical profiles, and the general quality of the ground water, the well is expected to yield additional valuable data, as summarized below.

1. Data on differences in the hydraulic head at the various depths monitored by the piezometer pipes will define vertical hydraulic gradients. These, in turn, are essential to estimating the vertical movement of water through the ground-water reservoir, for a quantitative understanding of the ground-water-flow system.
2. Seasonal differences in the patterns of water-level fluctuation in the various piezometer pipes will clearly define the intensively pumped aquifers, and should allow a better evaluation of the hydrologic impact of vertical leakage from one aquifer to another through the many unlined well bores in the region.
3. Accurate temperature measurements through the access pipe will assist in the interpretation of the general pattern of ground-water flow, and also may provide the basis for an independent method of estimating vertical ground-water movement through the basalt sequence.

4. The piezometer pipes are available to monitor major changes in degree of mineralization by means of down-hole-conductivity sensors or, of water quality, by removal of samples for chemical analysis.

In summary, the data already provided by the test-observation well constitute valuable information needed for water-management decisions. These data could not have been obtained by other practical means. Additional data that are expected from the well may prove to be even more helpful for management of the invaluable ground-water resources of the region.