UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DATA FROM PUMPING AND INJECTION TESTS AND CHEMICAL SAMPLING IN THE GEOTHERMAL AQUIFER AT KLAMATH FALLS, OREGON

By S. M. Benson, C. J. Janik, D. C. Long, R. D. Solbau, P. J. Lienau, G. G. Culver, E. A. Sammel, S. R. Swanson, D. N. Hart, Andrew Yee, A. F. White, M. L. Stallard, A. P. Brown, M. C. Wheeler, T. L. Winnett, Grace Fong, and G. B. Eakin

---

Open-File Report 84-146

Prepared in cooperation with the
U.S. DEPARTMENT OF ENERGY
Contract No. DE-AC03-83SF11928

Menlo Park, California

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to

Regional Hydrologist, USGS
345 Middlefield Road MS 466
Menlo Park, Ca 94025

Copies of the report can
be purchased from:

Open-File Services Section
Western Distribution Branch
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 234-5888)

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

CONVERSION OF UNITS OF MEASUREMENT

INCH-POUND TO METRIC

Multiply inch-pound units	by	To obtain SI units
Length		
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
Flow		
gallon per minute (gal/min)	0.06308	liter per second (L/s)
Temperature		
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)
Pressure		
pound per square inch ($lb/in.^2$)	6.895	kilopascal (kPa)

METRIC TO INCH-POUND

Multiply SI units	by	To obtain inch-pounds units
Length		
meter (m)	3.281	foot (ft)
Temperature		
degree Celsius (°C)	°F = 9/5 °C + 32	degree Fahrenheit (°F)

DATA FROM PUMPING AND INJECTION TESTS AND CHEMICAL SAMPLING IN THE GEOTHERMAL AQUIFER AT KLAMATH FALLS, OREGON

By

S. M. Benson [1/], C. J. Janik [2/], D. C. Long[3/], R. D. Solbau[1/], P. J. Lienau[4/], G. G. Culver[4/], E. A. Sammel[2/], S. R. Swanson[3/], D. M. Hart[5/], Andrew Yee[1/], A. F. White[1/], M. L. Stallard[2/], A. P. Brown[2/], M. C. Wheeler[2/], T. L. Winnett[2/], Grace Fong[2/], and G. B. Eakin[2/]

ABSTRACT

A seven-week pumping and injection test in the geothermal aquifer at Klamath Falls, Oregon, in 1983 provided new information on hydraulic properties of the aquifer. The Open-File Data Report on the tests includes graphs of water levels measured in 50 wells, temperature measurement ln 17 wells, daily air-temperatures in relation to discharge of thermal water from more than 70 pumped and artesian wells, tables of monthly mean air temperatures and estimates of discharges of thermal water during a normal year, and tables of chemical and isotopic analyses on samples from 12 wells.

The water-level measurements reflect the effects of pumping, injection, and recovery over about 1.7 square miles of the hot-well area of Klamath Falls. The pumped well, City Well #1, and the injection well at the Klamath County Museum are components of a proposed District Heating Plan. The study was funded principally under contracts from the U.S. Department of Energy to the Lawrence Berkeley Laboratory, Stanford University, and the Oregon Institute of Technology, with coordination and chemical sampling provided under the Geothermal Research Program, U.S. Geological Survey. Support was received from the City of Klamath Falls, Klamath County Chamber of Commerce, Citizens for Responsible Geothermal Development, and many citizen volunteers.

1/ Lawrence Berkeley Laboratory, Berkeley, California

2/ U.S. Geological Survey, Menlo Park, California

3/ Energyman, Inc., Klamath Falls, Oregon

4/ Oregon Institute of Technology, Klamath Falls, Oregon

5/ Citizens for Responsible Geothermal Development, Klamath Falls, Oregon

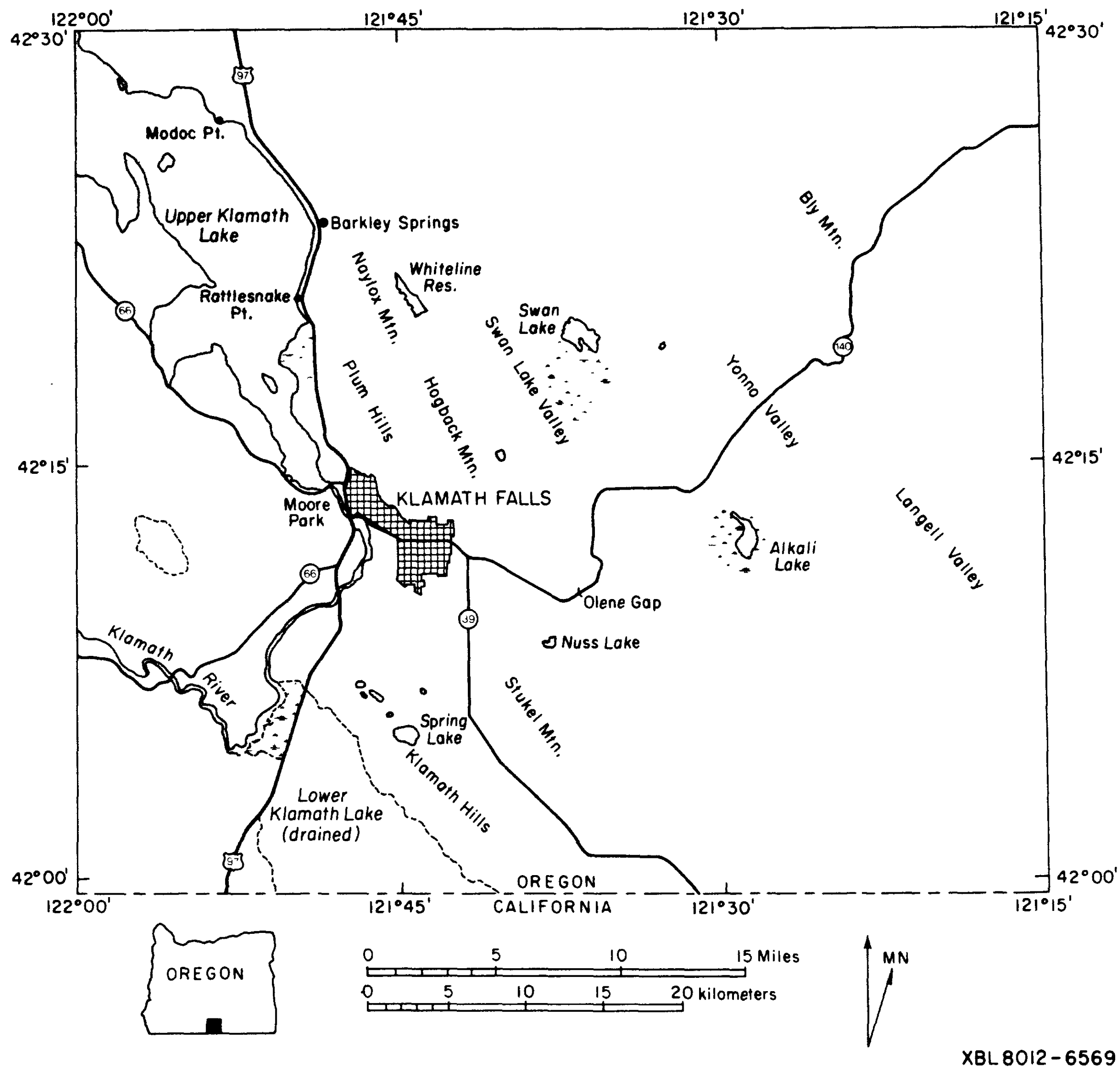


Figure 1-1. -- Index map of Klamath Falls area.

CHAPTER 1. INTRODUCTION

This report presents data from a series of tests that were designed to evaluate the geothermal potential of the shallow hot-water aquifer at Klamath Falls. Funded by a grant from the U.S. Department of Energy (DOE), tracer studies were begun in May, 1983, under the direction of J. S. Gudmundsson; a seven-week pumping and reinjection test was begun in July 1983, under the direction of S. M. Benson; and support activities and facilities were provided by the Geo-heat Center, Oregon Institute of Technology (OIT), Paul Lienau, Director. Overall direction and coordination were the responsibility of E. A. Sammel, who served as Principal Investigator as a part of project activities within the Geothermal Research Program of the U.S. Geological Survey (USGS). During the test period, samples were collected for chemical and isotopic analyses to be performed by Lawrence Berkeley Laboratory (LBL) and the USGS. Alfred Truesdell (USGS) will discuss these results in a subsequent interpretive report. Preliminary findings of the tracer studies have been published previously (Gudmundsson and others, 1983). A final report on the tracer studies will be published by Stanford University.

Prior investigations of the geothermal system at Klamath Falls are described by Lund (1978) and by Sammel (1980). Short-duration interference tests of several geothermal wells in the area were carried out by LBL during the years 1979 through 1982. Data from these tests are given by Benson, Goranson, and Schroder (1980), Benson (1982a), Benson (1982b), and Bodvarsson and Benson (1982). In preparation for the present tests, new data were collected on geothermal wells and springs at Klamath Falls beginning in March, 1983, under a program initiated by the Renewable Energy Committee of the Klamath County Chamber of Commerce and supported by the Klamath County Economic Development Association and the City of Klamath Falls. A large number of citizen volunteers aided in this effort. A Geothermal Committee of the Chamber of Commerce, chaired by D. C. Long, coordinated the data collection. Significant help was provided by a local group, Citizens for Responsible Geothermal Development (CRGD); data collection and well monitoring by this group were coordinated by Deborah and I. H. (Bud) Hart.

The collection of historical and recent geothermal data at Klamath Falls represents an unprecedented achievement. A central file now contains records of water levels and temperatures kept by individual well owners over a span of 40 years or more, a preliminary data base established by the Geo-Heat Center at OIT in 1974, and the currently expanded data base which comprises records from more than 450 geothermal wells and springs in the Klamath Falls urban area. Plans for the maintenance and updating of these records are now being formulated by a geothermal advisory group in Klamath Falls.

It is not possible to acknowledge individually all persons, probably numbering in the hundreds, who have aided in the data collection and testing program. Several individuals deserve mention however, and we thank especially Dick Sexton and Frank Ganong, (Chamber of Commerce); Bud Hart, Al Stone, Dick Hessig, and George Wardell (CRGD); Charles Leib, Kent Colahan, and Gene Gjertsen A special commendation is due the local news media for thorough, accurate, and timely news coverage that played an essential part in the educational aspects of the program.

This report includes only data that are directly relevant to the aquifer tests performed in 1983 under the DOE grant. Most results are shown in graphical form for the convenience of an assumed majority of users who do not require the basic numerical records. Physical data on wells monitored for the aquifer test are shown in table 2-3. All information collected for this investigation will be part of the central data file at Klamath Falls and will be available for public inspection and use.

Monitoring of selected thermal wells will continue through the 1983-84 heating season and perhaps indefinitely. A final interpretive report will contain estimates of aquifer properties and will describe the geothermal fluid flow and the probable physical consequences of at least one proposed plan for development.

References

Benson, S. M., Goranson, C. B., and Schroeder, R. C., 1980, Evaluation of City Well 1, Klamath Falls, Oregon: Lawrence Berkeley Laboratory, unpublished report to the City of Klamath Falls.

Benson, S. M., 1982a, Klamath Falls (WP-1, Supply and distribution network, Museum Well) system check, February 8 through 12, 1982: Lawrence Berkeley Laboratory, unpublished report to the City of KLamath Falls.

Benson, S. M., 1982b, Klamath Falls (WP-1 and WP-2) System check, September 29 through 30, 1981: Lawrence Berkeley Laboratory, unpublished report to the City of Klamath Falls.

Bodvarsson, M. G., and Benson, S. M., 1982, Well test data from geothermal reservoirs: Lawrence Berkeley Laboratory, Report LBL-13295, 57 p.

Gudmundsson, J. S., Johnson, S. E., Horne, R. N., Jackson, P. B., and Culver, G. G., 1983, Doublet tracer testing in Klamath Falls, Oregon: Stanford University, Ninth Workshop on Geothermal Reservoir Engineering, December 1983, Proceedings, in press.

Lund, J. W., 1978, Geothermal hydrology and geochemistry of Klamath Falls, Oregon urban area: Klamath Falls, Oregon Institute of Technology, Geo-heat Center, final report to the U.S. Geological Survey, USGS Grant No. 14-08-0001-G-291.

Sammel, E. A., 1980, Hydrogeologic appraisal of the Klamath Falls geothermal area, Oregon: U.S. Geological Survey Professional Paper 1044-G, 45 p.

CHAPTER 2. DATA FROM PUMPING AND INJECTION TEST

July 5 through September 7, 1983

by

S. M. Benson and R. D. Solbau
Earth Sciences Division
Lawrence Berkeley Laboratory

Activity summary of Lawrence Berkeley Laboratory Personnel

6-21-83 Leave LBL for Klamath Falls, Oregon.

6-22-83 Meet with Dennis Long and Susan Swanson of Energyman, Inc. with regard to test plan and monitor wells.

6-23-83 Make arrangements with Interstate Pump to pull the heating coils at the County Museum well.

6-24-83 Meet with the Well Selection Committee to make final selection of monitor wells.

Run temperature profile in Head well.

Install geophone in Head well.

Calibrate all pressure transducers.

6-25-83 Install downhole pressure probe in the Head well at a depth of approximately 38 m.

Install downhole pressure probe in the Dearborn well at a depth of approximately 6 m.

6-26-83 Install downhole pressure probe in the Assembly of God well at a depth of approximately 5.5 m.

6-27-83 Install downhole pressure probe in the Parks well at a depth of approximately 30.5 m.

Install injectors into A-Canal.

6-28-83 Run temperature profile in the Page well.

Install downhole pressure probe in the Page well at a depth of approximately 15 m.

6-30-83 Install downhole pressure probe in the Vlahos well at a depth of approximately 16.0 m.

7-1-83 Install downhole pressure probe in the Parks Steamer well at a depth of approximately 19.5 m.

7-2-83 Install downhole pressure probe in the Rogers well at a depth of approximately 17 m.

7-5-83 Install downhole pressure probe in the Carroll well at a depth of approximately 37.5 m.

Start pumping (3:10 p.m.) CW-1 at a rate of 720 gallons per minute (gpm). (Pumped water dumped into the A-Canal.)

Pull heating coils from the Museum well.

7-16-83 Remove downhole pressure probe from Vlahos well. Recalibrate transducer.

7-18-83 Pull pump from Harley Davidson well.

7-19-83 Install downhole pressure probe in the Harley Davidson well at a depth of approximately 25 m.
Remove downhole pressure probe from the Dearborn well.
Recalibrate transducer.

7-20-83 Remove downhole pressure probe from the Rogers well. Recalibrate transducer.
Install another downhole pressure probe in the Rogers well at a depth of approximately 17 m.
Install downhole pressure probe in the Medo-Bel Dairy well at a depth of 19 m.

7-21-83 Remove downhole pressure probe from the Parks well. Recalibrate transducer.
Install downhole pressure probe in the Spire's and Mest well at a depth of approximately 3 m.

7-24-83 Run sinker bar into the County Museum well in order to detect fill.
Run temperature profile in the County Museum well.

7-25-83 Start reinjection into County Museum well at 10:50 a.m.
Stop reinjection due to packing failure at 11:20 a.m.
Replace packing on the injection well.

7-26-83 Start reinjection into the County Museum well at 10:11 a.m. Shut in valve to the A-Canal at 10:12 a.m.

7-27-83 Run spinner survey in the injection well.

8-1-83 Medo-Bel Dairy well starts to flow under a small artesian head.

8-9-83 Remove downhole pressure probe from the Parks Steamer well.
Recalibrate transducer. Transducer fails.

8-15-83 Run spinner survey in the injection well.

8-21-83 Install downhole pressure probe in the Parks Steamer well at a depth of 19.5 m (transducer repaired by manufacturer).

8-22-83 Lightning from a large storm knocks out data from seven wells.

8-23-83 Replace line drivers from the Head, Rogers, and Spires and Mest wells. Data back on line.
Replace series 700 computer with two series 600 computers; Medo-Bel Dairy, and Harley Davidson wells back on line.
Parks Steamer well transducer seriously damaged. Send transducer back to manufacturer.
Remove downhole pressure probe from Medo-Bel Dairy well. Recalibrate transducer.

8-24-83 Install transducer from Medo-Bel Dairy well in the Parks Steamer well at a depth of approximately 19.5 m.
Run temperature profile in the injection well.
Shut in CW-1 and County Museum well at 5:35 p.m.

8-31-83 Remove downhole pressure probe from Rogers well.

9-1-83 Remove downhole pressure probe from the injection well.
Remove downhole pressure probe from the Harley Davidson well.
Remove downhole pressure probe from the Parks Steamer well.

9-2-83 Remove geophone and downhole pressure probe from the Head well.

9-3-83 Run 7 inch disk into the County Museum well.
Remove downhole pressure probe from Assembly of God well.

9-4-83 Recalibrate all working pressure transducers.
Calibrate wellhead temperature guage at CW-1.
Remove downhole pressure probe from the Carroll well. Recalibrate transducer.

9-6-83 Remove downhole pressure probe from the Spires and Mest well.
Finish packing equipment.

9-7-83 Leave Klamath Falls for LBL.

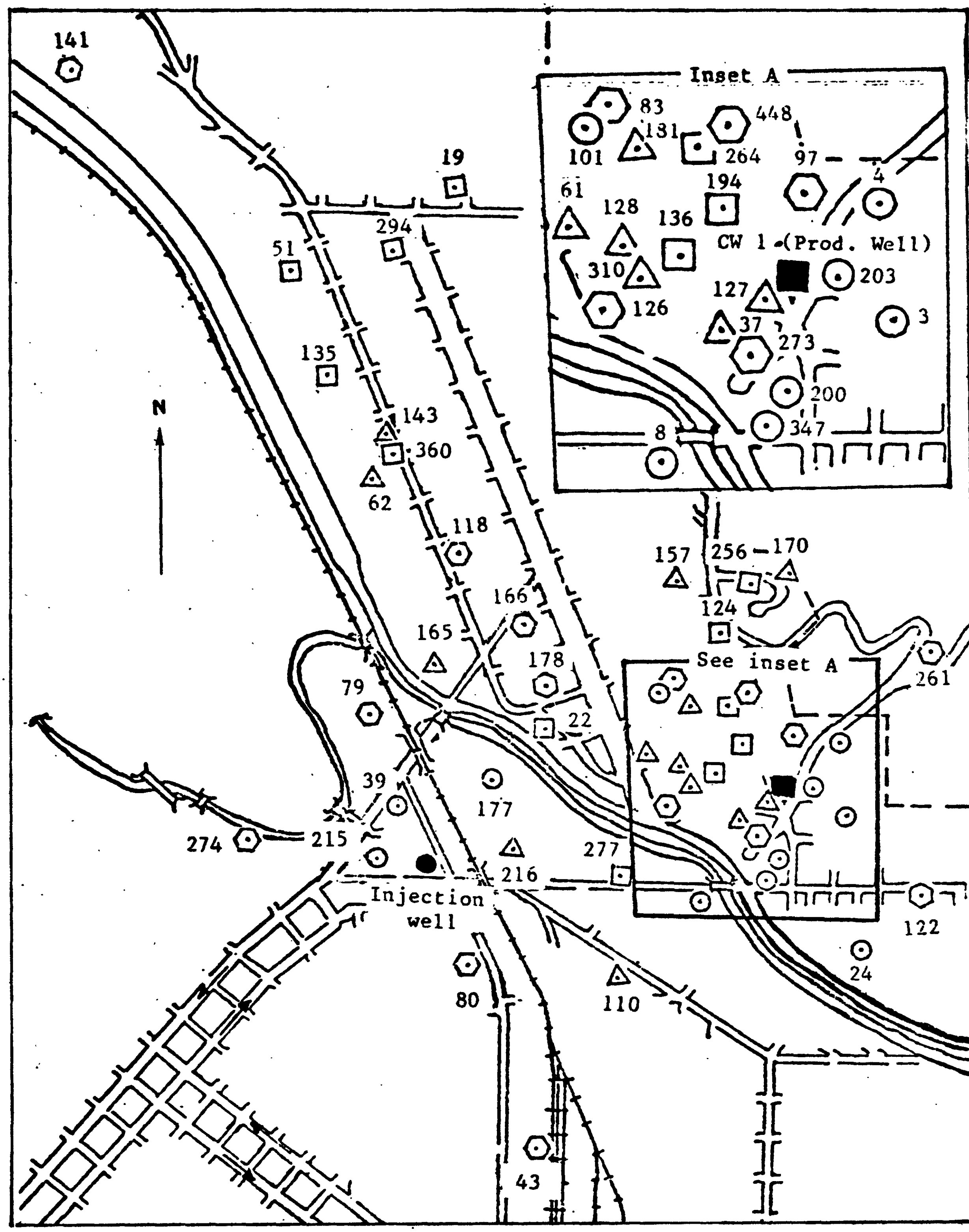


Figure 2-1. -- Locations of wells monitored during aquifer test

Injection well location ● Production well location ■

Symbols ⬡ Type F recorder □ Hand measured by D. C. Long

◯ LBL transducer/type F recorder △ Owner monitored

0 1200 2400 ft

Production well

History

The production well, CW-1, was completed to a depth of 900 ft in January 1980. (See location map, fig. 2-1.) The well penetrates alternating layers of clay, tuff, and basic volcanic fragments. The lithology is shown schematically in figure 2-2. Also shown in figure 2-2 is the temperature profile measured shortly after the well was completed. Note that the maximum temperature in the well occurs at a depth of approximately 73 m (240 ft). Below this depth the temperature decreases and remains nearly isothermal between 76 m (250 ft) and the bottom of the well.

CW-1 was first pump tested in January, 1980. At that time, the well was cased to 360 ft. The well produced 88°C (190°F) water at a maximum rate of 3.7 kg/s (60 gpm) with a drawdown of 51.8 m (170 ft). The low temperature of the water and very low well productivity of 7.14×10^{-2} kg/s/m (0.35 gpm/ft) made the well unsuitable for its intended use. Consequently, the well was perforated from 59.4 m to 73.2 m (195 ft to 240 ft).

Shortly thereafter the well was pump tested. A maximum rate of 56 kg/s (900 gpm) of 101°C (214°F) water was obtained with a drawdown of 15.2 m (50 ft). After perforation the productivity index of the well was 3.73 kg/s/m (18 gpm/ft). The significant increase in the well productivity after perforation indicates that nearly all of the water is entering the well between 59.4 m and 73.2 m (195 ft and 240 ft).

In late 1981 and early 1982, two short pump tests were conducted on CW-1. During the first test, the well was pumped at a reported rate of 49 kg/s (780 gpm) with a drawdown of 2.5 m (8 ft) for two hours (Benson, 1982a). At this rate the measured wellhead temperature was 98.3°C (209°F). The calculated productivity index of the well at this time was 19.6 kg/s/m (97.5 gpm/ft). In February 1982, the well was pumped at a reported rate of 34 kg/s (540 gpm) for approximately four days. A drawdown of 1.4 m (4.5 ft) and a temperature of 97.8°C (208°F) were measured. The calculated productivity index was 24.3 kg/s/m (120 gpm/ft).

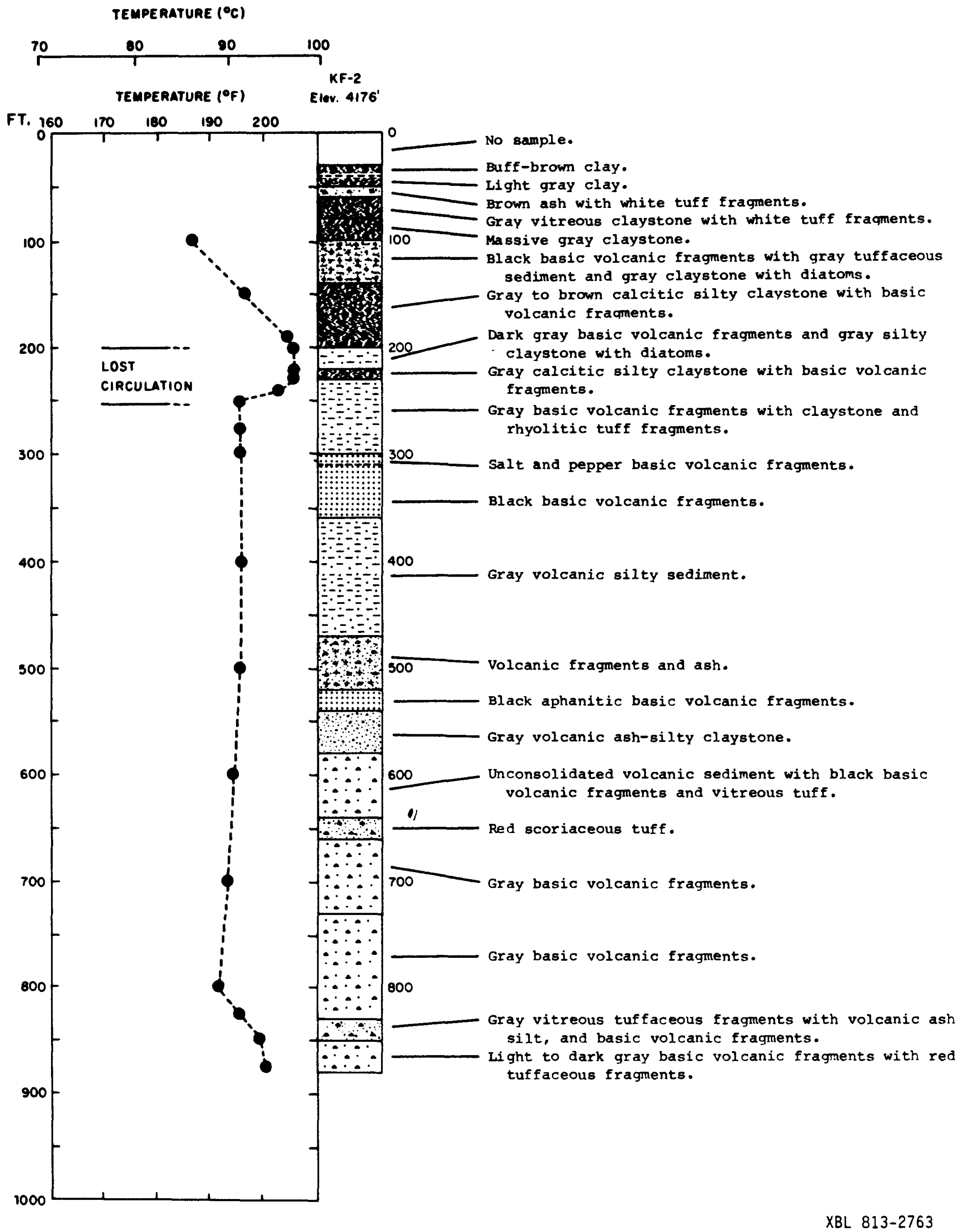


Figure 2-2. -- Temperature profile and lithologic log in City Well-1 (production well)

Aquifer Test, July 5 - August 24, 1983

Pumping rates and drawdown were measured daily throughout the test (table 2-1). For the first twenty days of the test the rate was maintained at 43.5 kg/s (720 gpm) (fig. 2-3). The drawdown varied from 2.5 to 3 m (8 to 10 ft). The wellhead temperature remained constant at 100°C (212.3°F). On the twenty-first day of the test, reinjection began. The back presssure created by the reinjection well resulted in a slightly lower and variable flowrate. The rate decreased from 41.8 kg/s (690 gpm) to 40.0 kg/s (660 gpm) over the remaining four weeks of the test. The temperature of the pumped water remained steady throughout the entire test. The productivity index for the well, based on these data, is 15 kg/s/m (72 gpm/ft).

A review of the historical and current test data on this well indicates:

(1) The produced fluid enters the wellbore between 59.4 m and 73.2 m (195-240 ft).

(2) The production temperature is rate dependent; the higher the flowrate, the higher the temperature of the produced water.

(3) The well draws water from a large reservoir of apparently constant temperature.

(4) The productivity index of the well is in the range of 15 kg/s/m to 24.3 kg/s/m (72 gpm-120 gpm/ft). The variation in the value is probably the result of instrument discrepancies rather than a long-term trend.

Injection well

History

The County Museum well was completed to a total depth of 376.4 m (1,235 ft) in May 1975. (See location map, fig. 2-1.) The well was drilled with a rotary rig. The lithology, shown in figure 2-4, consists primarily of alternating layers of clay, shale (probably some tuff also), and basalt. Many of the basalt layers appeared to be fractured. The well was cased from the surface to a

Table 2-1. -- Production-well and injection-well data

Date	Flowrate (gpm)	Pump well: Temperature (°F)[1/]	Pump well: Water level (ft)[2/]	Injection well well-head pressure (psi)
7-05-83[3/]	0,720	212.3	64,72	0
7-06-83	720	212.3	74	0
7-07-83	720	212.3	74	0
7-08-83	720	212.3	74	0
7-09-83	720	212.3	74	0
7-10-83	720	212.3	74	0
7-11-83	720	212.3	74	0
7-12-83	720	212.3	74	0
7-13-83	720	212.3	74	0
7-14-83	720	212.3	74	0
7-15-83	720	212.3	74	0
7-16-83	720	212.3	74	0
7-17-83	720	212.3	74	0
7-18-83	720	212.3	74	0
7-19-83	720	212.3	74	0
7-20-83	720	212.3	74	0
7-21-83	720	212.3	74	0
7-22-83	720	212.3	74	0
7-23-83	720	212.3	72	0
7-24-83	720	212.3	72	0
7-25-83	720	212.3	72	0
7-26-83[4/]	720,695	212.3	72	0,37
7-27-83	690	212.3	71	39
7-28-83	685	212.3	69.5	36
7-29-83	695	212.3	69.5	37
7-30-83	695	212.3	69.5	37
7-31-83	695	212.3	69.5	38
8-01-83	690	212.3	69.5	38
8-02-83	690	212.3	68.5	38
8-03-83	690	212.3	68.5	38
8-04-83	690	212.3	67.5	38
8-05-83	690	212.3	67.5	39
8-06-83	685	212.3	67.5	39
8-07-83	685	212.3	67.5	39
8-08-83	685	212.3	67.5	40
8-09-83	680	212.3	67.5	40
8-10-83	680	212.3	67.5	40
8-11-83	680	212.3	67.5	40
8-12-83	680	212.3	67.5	40
8-13-83	680	212.3	67.5	40
8-14-83	680	212.3	67.5	40
8-15-83	680	212.3	67.5	40
8-16-83	675	212.3	67.5	--
8-17-83	670	212.3	67.5	--
8-18-83	665	212.3	67.5	--
8-19-83	665	212.3	67.5	42
8-20-83	665	212.3	67.5	43
8-21-83	665	212.3	67.5	42
8-22-83	665	212.3	66.5	43
8-23-83	660	212.3	66.5	43
8-24-83[5/]	660	212.3	66.5, 63	43

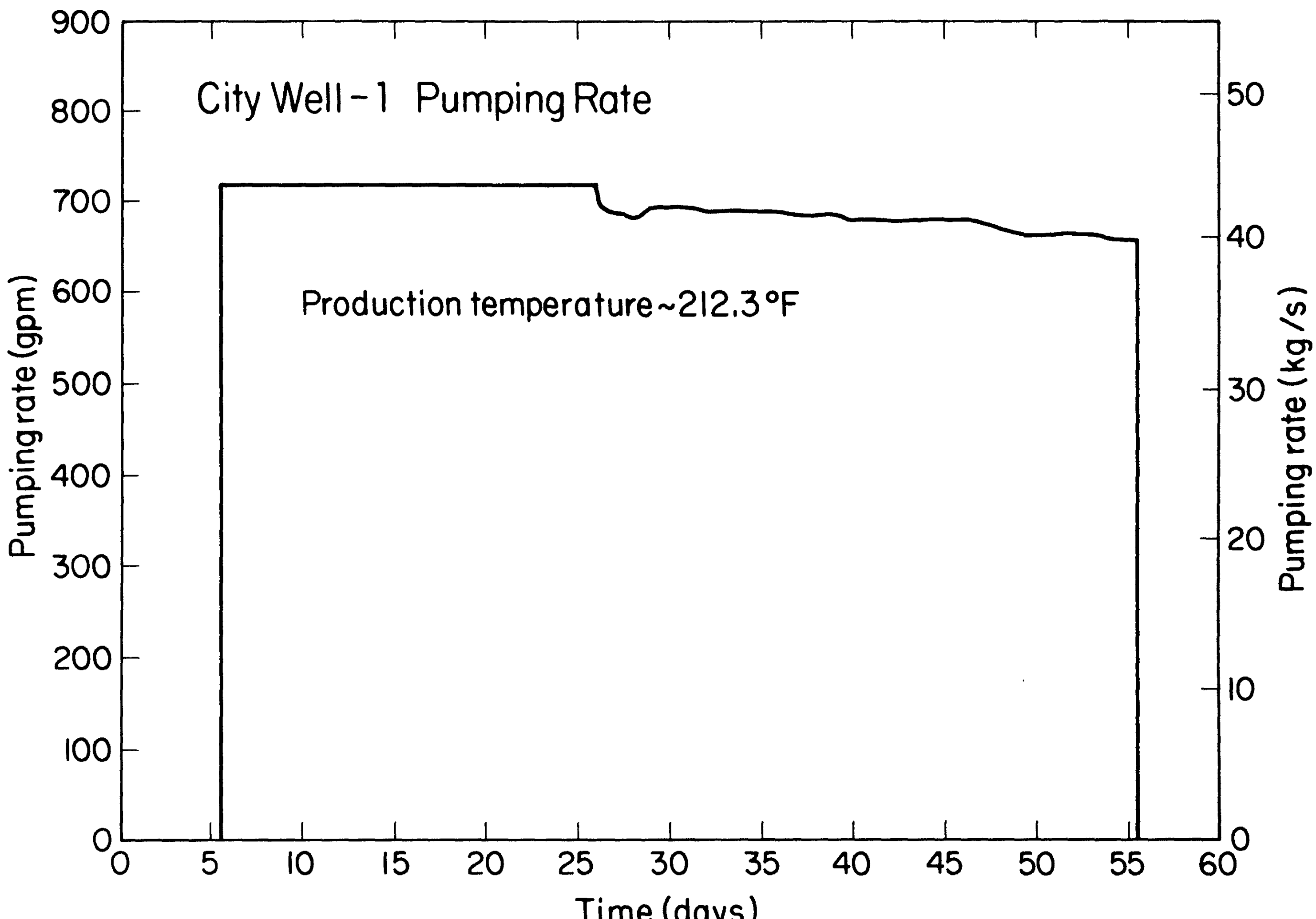
1/ Reported temperatures are corrected to post-test calibration. Calibration indicated that the gauge was reading 3.25°F low throughout the test.

2/ Gauge resolution of 0.5 psi equivalent column of water (~1.15 feet).

3/ Pumping starts at 15:10 (3:10 p.m.).

4/ Injection starts at 10:11.

5/ Shut in at 17:35:41 (~5:35 p.m.)



XBL 8311-2314

Figure 2-3. -- City well-1 pumping rate (production well) depth of 137.31 m (450.5 ft) with a 10.75-inch (1/4-inch wall thickness) liner. The remainder of the well is uncased. A schematic of the final well configuration is shown in figure 2-4.

Upon completion, the well was flow tested. The shut-in pressure of the artesian well was approximately 2 psig, and, wide open, the well produced approximately 11.4 kg/s (188 gpm) of 86.7°C (188°F) water. In August 1976, the Oregon Institute of Technology conducted a 28-hour production/interference test on the County Museum well. The well was pumped at three rates, 19.4 kg/s (320 gpm), 28.5 kg/s (470 gpm), and 40.6 kg/s (670 gpm). At the highest rate the reported productivity index was 66 kg/s/m (23.10 gpm/ft) (Lund, 1978). Since completion, the well has been used with a downhole heating loop to heat the County Museum. During recent years, in the winter months, the artesian head drops below the ground surface and a small pump is required to maintain the surface temperatre of the water.

In September 1981, a sixteen-hour injection test was conducted on the well. Approximately 99°C (210°F) water from city wells CW-1 and CW-2 was injected into the Museum Well at a maximum rate of 58 kg/s (960 gpm). An injectivity index of 1.65 kg/s/m (8.5 gpm/ft) was reported (Benson 1982a). After the injection test test it was determined by running a sinker bar that the well bottom had filled with debris from the original depth of 376.4 m (1,235 ft) to a depth of 364.2 m (1,195 ft) (Charles Leib, personal commun., 1983).

A second injection test was conducted in February, 1982. For five days, approximately 32.7 kg/s (549 gpm) of 76 to 96°C (170-205°F) water from CW-1 was injected into the well. An injectivity index of 5.8 kg/s/m (29 gpm/ft) was reported (Benson, 1982b).

At the present time, the County Museum Well serves the dual purposes of heating the museum with a downhole loop and being the injection well for the Klamath Falls District Heating System. As part of the 1983 Klamath Falls Resource Study, the well was used for injection during the second phase of the program. Three types of data were obtained from the well: temperature and downhole flowmeter logs, well injectivity, and pressure-transient falloff data. These data are discussed in the following sections.

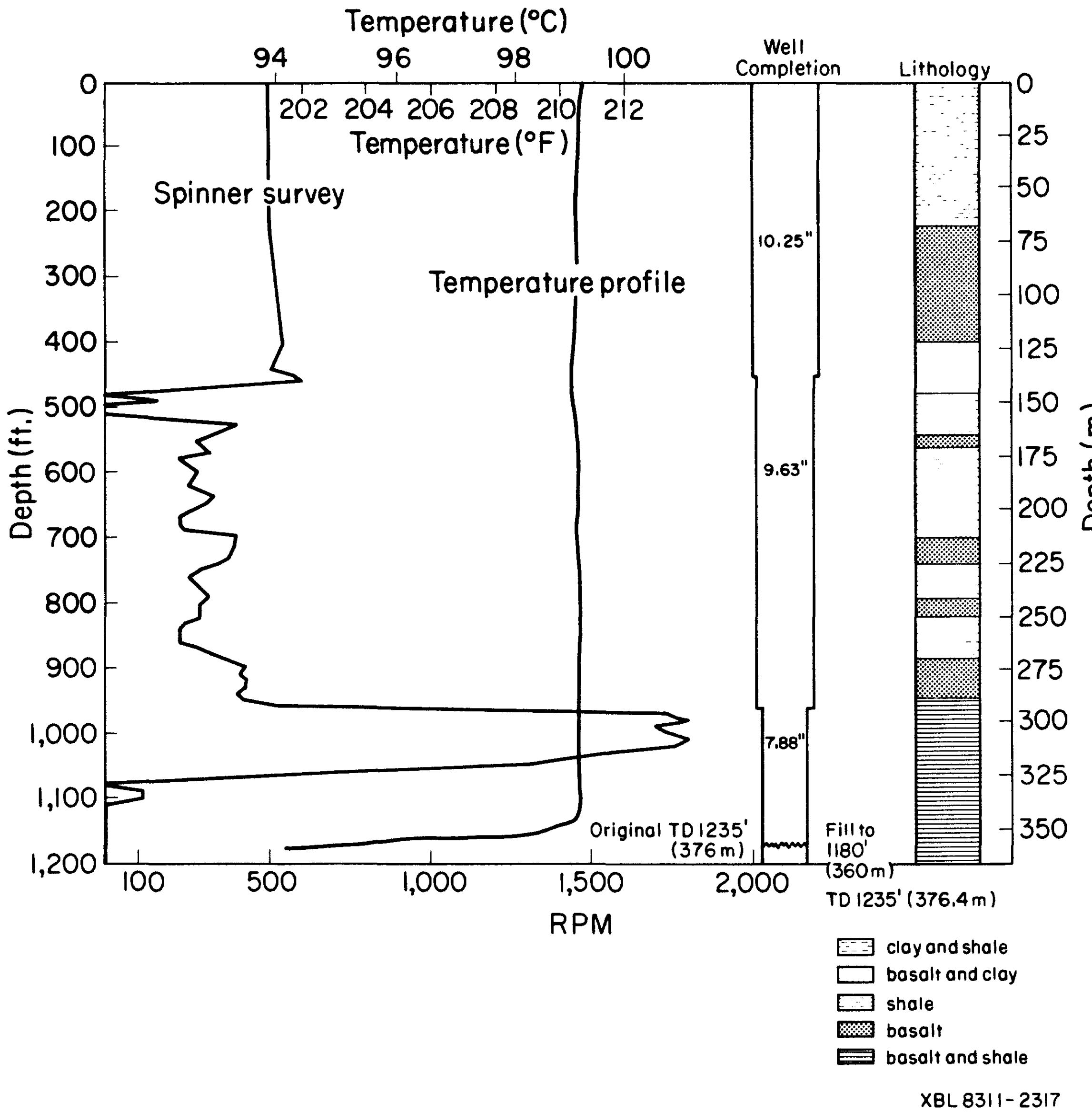


Figure 2-4. -- Well completion, lithology, temperature profile, and spinner (fluid velocity) survey in the County Museum Well (injection well)

The 1983 Injection Test

Borehole Logs

A total of five logs were successfully run in the County Museum Well during the injection phase of the test; a sinker bar test to locate the bottom of the well, a static temperature profile, a downhole flowmeter survey to identify the lithologic units accepting the injected fluid, an "injection temperature profile", and a seven inch disk was lowered to the bottom of the well to locate borehole constrictions. To facilitate running the logs, the downhole heating loop was removed from the well.

On July 24, 1983, prior to injection, a sinker bar was run into the well. The well "bottom" was located at a depth of 358.7 m (1,177 ft). Slow sinking of the probe, once located on the bottom, indicated that the well was at least partially filled with soft muddy material. This survey suggested that an additional 4 to 6 m (15-20 ft) of fill had sloughed into the well since the previous measurement in 1981. The temperature profile shown in figure 2-5 was also obtained at this time. A maximum temperature of 92.9°C (199°F) was measured at a depth of 305 m (1,000 ft). From a depth of approximately 183 m (600 ft) to the bottom of the well, the temperature profile is nearly isothermal, indicating a convective thermal regime in the reservoir or inter-zone flow in the wellbore. Without additional information it is not possible to distinguish between these two possibilities.

On August 15 a downhole flowmeter (spinner) survey was conducted in order to determine which interval(s) were accepting the injected water. A spinner is essentially a vertical water-velocity meter. Therefore, as the instrument is lowered into the well, and fluid is injected into the rock strata above the instrument, the water velocity should decrease (if bore diameter remains constant). In practice, it is often found, especially in wells that are completed without a liner, that the vertical velocity is highly erratic, reflecting variations in the bore diameter, rather than the distribution of permeable strata. If such is the case, only a crude interpretation of the data is possible without an independent measurement of the bore diameter.

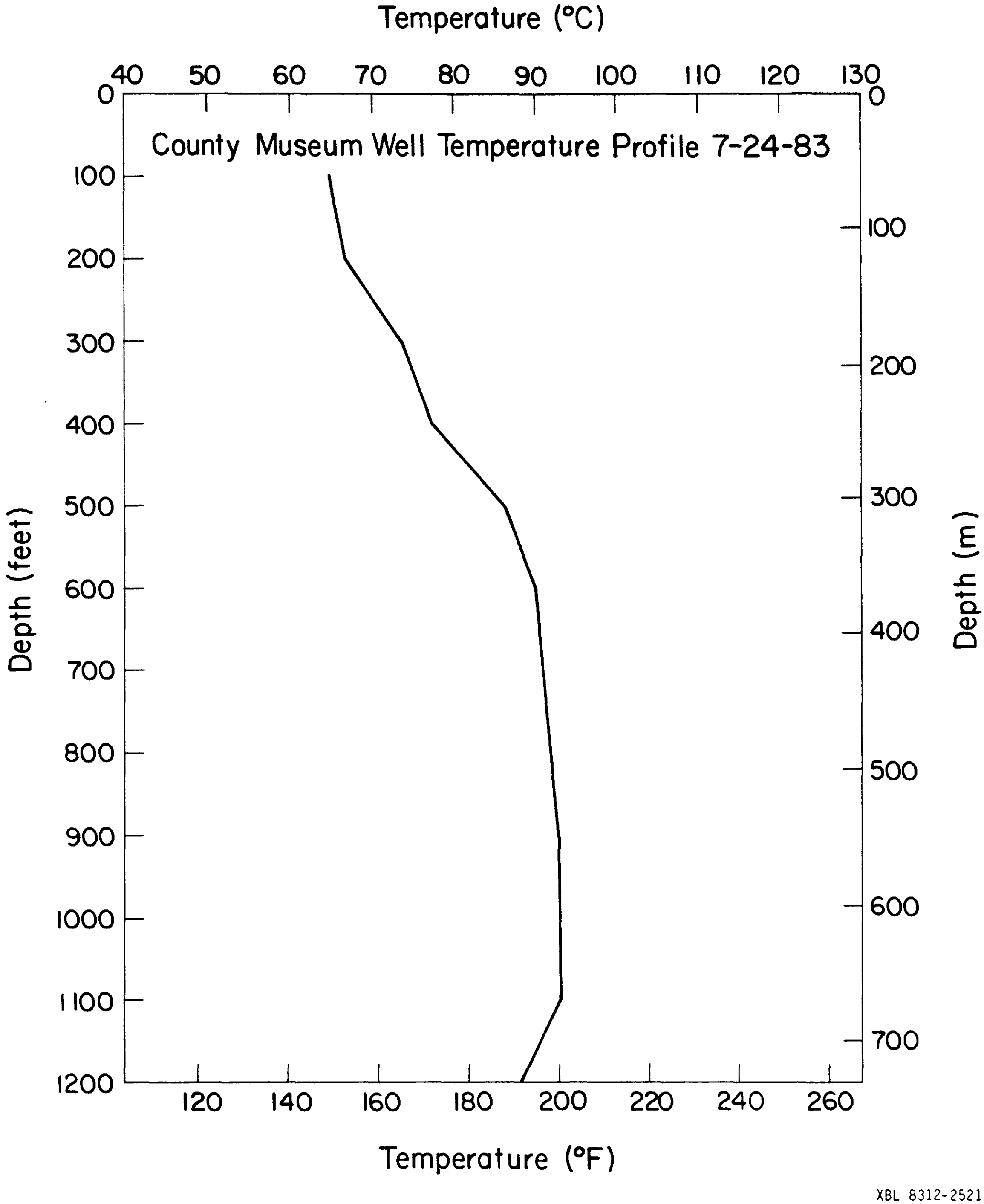


Figure 2-5. -- Temperature profile measured in the County Museum Well (injection well) prior to fluid injection

The spinner survey from the County Museum Well is shown in figure 2-4. Through the cased portion of the well, the fluid velocity (RPM) is nearly constant, as expected. Below the casing, the vertical fluid velocity is highly erratic, reflecting substantial variations in the bore diameter. In fact, between the bottom of the casing and 1,585 m (520 ft) the well bore diameter increases to at least 1.5 feet. Comparison of the average fluid velocity in the casing to the average velocity below this interval indicates that approximately 50 percent of the injected fluid enters the rock formations between 143 m and 158.5 m (470-520 ft). It can not be determined if injection is evenly distributed over this entire interval or concentrated at one or several depths. As can be seen from the lithologic log in figure 2-4, this interval occurs in a shale (or tuff) which separates two basalt units. The shale (tuff), basalts and/or the contacts between these units are all potential candidates as the unit(s) accepting fluid. No injection appears to occur between 158.5 m and 310 m (520-1,017 ft). The large jump in vertical fluid velocity at 289 m (950 ft) results from the decrease in the drilled bore diameter. The remainder of fluid is injected into the well below 310 m (1,017 ft), probably between 310 m and 330 m. However, the lack of information on the bore diameter prevents conclusive interpretation. The lower injection interval occurs in a relatively thick basalt and shale (tuff) unit. The "injection temperature" profile shown in figure 2-4, confirms that fluid is being injected to a depth of at least 335 m (1,100 ft).

Well Injectivity

Injection rates and wellhead injection pressures were measured throughout the 29-day injection period. The data are tabulated in table 2-1. The injection rate, which decreased from 42 kg/s (695 gpm) to 40 kg/s (660 gpm) over the injection period, is shown in figure 2-6. The wellhead pressures increased from approximately 39 psig to 43 psig over the test period. The temperature of the injected fluid remained constant throughout at 99°C (210.5°F). Note that the injection temperature is 5 to 10°C (9-18°F) higher than the temperature previously measured in the Museum well (see figures 2-4 and 2-5). The average well injectivity during this test was 1.43 kg/s/m (7.1 gpm/ft). The apparent decrease of well injectivity (and productivity), both during the test and since the measurements in 1976 and 1982 may be attributed to the gradual filling of the wellbore with material sloughing into the well from the wellbore face, perhaps from between 143 and 158.5 m (470-520 ft).

Pressure-Falloff Data

On the last day of the injection test, a pressure transducer was lowered into the injection well. The injection pressure was measured at a depth of 274 m (900 ft) for several hours prior to shutin. The pressure falloff was then observed for eight days (table 2-2 and fig. 2-7). Analysis of the data indicated that total permeability-thickness of the formations penetrated by the well is $4.1 \times 10^{-10} m^3$ (1.35×10^6 md-ft) and that the well has a large positive skin factor. The large skin factor reflects the fact that the permeabilities of the rocks immediately adjacent to the wellbore are lower than those of the reservoir rocks. Large positive skin factors are usually indicative of near wellbore formation damage caused by drilling-mud invasion. However, there are several alternative explanations; the cause also could be a turbulent flow regime in the near-bore fractures, gradual permeability reduction due to particulate or bacterial plugging in the formation, or the geological distribution of permeable strata and fractures or faults.

References

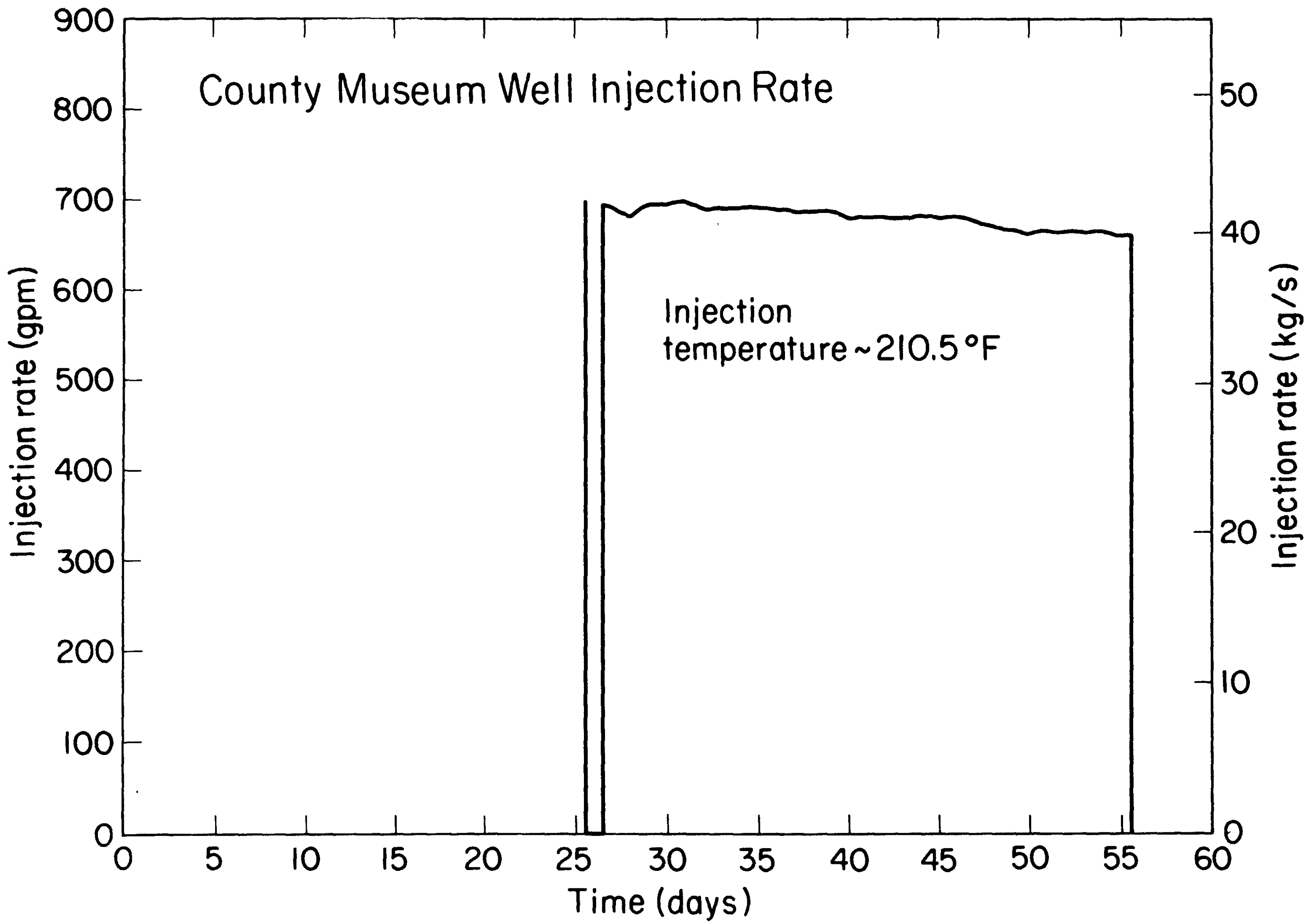
Benson, S. M., 1982a, Klamath Falls (WP-1 and WP-2) system check, September 29 through 30, 1981, unpublished report to the City of Klamath Falls, Oregon.

______, 1982b, Klamath Falls (WP-1, Supply and distribution network, Museum Well) system check, February 8 through 12, 1983, unpublished report to the City of Klamath Falls, Oregon.

Lund, J. W., 1978, Geothermal hydrology and geochemistry of Klamath Falls, Oregon, Urban Area, Oregon Institute of Technology, final report to the U.S. Geological Survey, USGS Grant No. 14-08-0001-G-291.

Table 2-2. -- Pressure-falloff data - injection well

Date	Time	Δ t seconds	Pressure psia
8-24-83	17:35:41	0	428.40
	17:35:42	1	427.43
	17:35:42	2	424.94
	17:35:46	5	416.45
	17:35:48	7	409.89
	17:35:51	10	404.70
	17:35:56	15	399.74
	17:36:01	20	397.21
	17:36:16	35	394.76
	17:36:31	50	394.28
	17:36:51	70	394.10
	17:37:21	100	393.95
	17:38:11	150	393.82
	17:39:01	200	393.73
	17:41:31	350	393.57
	17:44:01	500	393.46
	17:46:21	700	393.37
	17:51:21	1,000	393.18
	17:59:41	1,500	392.82
	18:08:01	2,000	392.55
	18:24:41	3,000	392.44
	18:41:21	4,000	392.42
	18:58:00	5,000	392.42
	19:31:20	7,000	392.36
	20:21:20	10,000	392.36
	22:00:00	15,000	392.40
8-25-83	04:00:00	36,600	392.27
	10:00:00	58,200	392.14
	20:00:00	94,200	392.00



XBL 8311-2315

Figure 2-6. -- County Museum Well injection rate

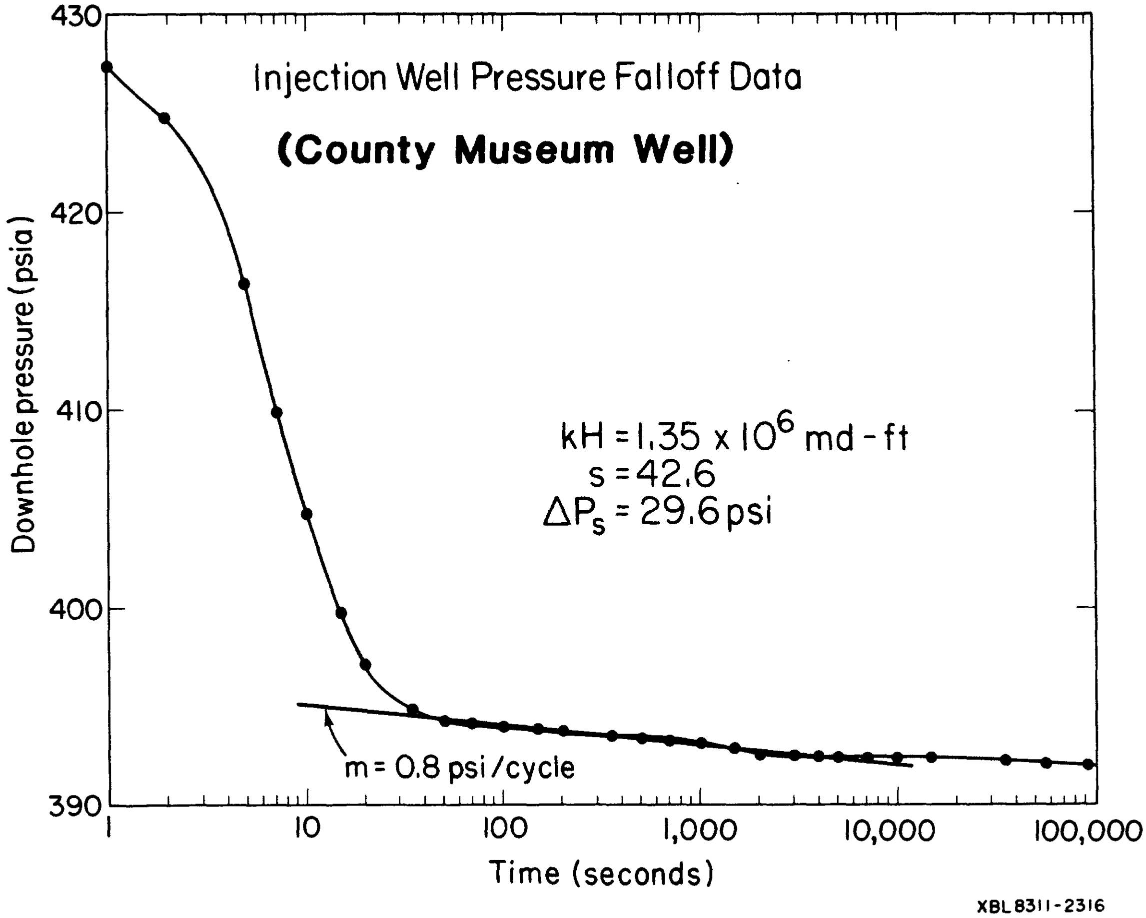


Figure 2-7. -- Injection-well pressure-falloff data, County Museum Well

Table 2-3. -- Wells monitored for the geothermal aquifer test

[DHE = Downhole Heat Exchange]

Well number	Owner	Address of well	Depth (ft)	Temperature Date	Temperature (°C)	Temperature Source	Heat extraction method	Distance to production well (ft)	Distance to injection well (ft)	Water level [1/], in feet below measuring point: Pre-production July 5	Pre-injection July 26	Stop pump Aug.24
LBL Transducers/ Type F recorder ○												
3	Carroll	155 N. Wendling	303	---	101	OIT	Unused	540	3,200	99.66	103.77	100.14
4	Parks	325 Old Fort Rd.	795	---	112	OIT	Unused	703	3,460	70.51	73.40	72.60
										Instrument removed 07-17-83		
8	Vlahos	2022 Main	198	---	65	OIT	DHE	930	2,130	---	---	---
24	Assembly of God	235 S. Laguna	363	---	91	OIT	DHE	1,280	3,460	43.24	46.38	42.57
39	Medo-Bel Dairy	1500 Esplanade	765	---	98	OIT	Unused	2,740	630	---	11.48	(artesian)
101	Head	2051 Erie	250	---	93	OIT	Unused	1,030	2,120	75.02	79.14	75.61
123	Spires & Mest	120 East Main	900	---	86	OIT	Artesian	2,100	750	---	4.97	+1.13[2/]
177	Page	1721 Menlo Way	465	06-82	88	Drill. log	Unused	2,200	860	10.93	13.45	8.74
200	Rogers	132 Laguna	329	03-80	93	Drill. log	DHE	409	2,660	36.17	40.16	34.20
203	Parks Steamer	Gibbs & Old Fort Rd	---	08-76	101	Drill. log	Unused	122	2,840	49.21	53.93	50.81
215	Harley Davidson	1409 Main St.	205	1978	60	OIT	Pumped	2,770	160	---	6.42	1.52
347	Dearborn	Main & Alameda	300	12-68	97	Drill. log	DHE	630	2,570	23.46	28.05	24.21

1/ Wells 3 through 215 on this page were monitored solely by LBL using a down-hole transducer. Well #39 (Medo-Bel Dairy) not measured at start of test; instrument removed 07-31-83 when well began to flow. Wells #123 (Spires and Mest) and #215 (Harley Davidson) not measured at start of test.

2/ Water level measured in standpipe above land surface.

Table 2-3. -- Wells monitored for the geothermal aquifer test (Continued)

[DHE = Downhole Heat Exchange]

Well number	Owner	Address of well	Depth (ft)	Temperature Date	Temperature (°C)	Temperature Source	Heat extraction method	Distance to production well (ft)	Distance to injection well (ft)	Water level, in feet below measuring point: Pre-production July 5	Pre-injection July 26	Stop pump Aug.24
Type F Recorder (Stevens) ⬡												
43	Klamath Cold Storage	661 Spring	1,100	---	44	OIT	Pumped	3,000	2,460	---	8.4	4.1
79	Klamath Union High School	Monclaire St.	240	---	67	OIT	Pump/ reinject	3,060	1,290	---	8.22	---
80	Jones	310 Spring & 312 Spring	485	---	67	OIT	Pumped-DHE	2,730	1,120	8.0	10.8	5.9
83	Stanke	424 Hillside	136	---	99	OIT	Unused	1,120	2,310	109.40	112.83	109.0
97	Angel	307 Damont	392	---	95	OIT	DHE	380	2,750	94.1	97.7	93.7
118	Svanevik	1932 Portland	340	---	94	OIT	DHE	3,100	2,450	74.1	76.81	72.62
122	Ponderosa School	107 S. Williams	429	---	93	OIT	DHE	1,260	3,700	50.9	52.58	49.85
126	Christian Center	115 N. Alameda	516	---	88	OIT	Unused	950	1,780	15.36	17.9	14.55
141	Eldorado Place	2200 N. Eldorado	407	11-75	26	Drill. log	Unused	7,180	6,200	---	97.63	95.46
166	Card	1902 Esplanade	613	08-79	99	Drill. log	DHE	2,380	1,620	41.3	44.6	40.5
178	Phillips	1945 Auburn	360	03-83	88	Drill. log	DHE	2,000	1,600	---	40.38	36.24
261	Olson	516 Old Fort Rd.	975	09-80	102	Drill. log	Unused	1,620	4,050	120.2	123.7	120.7
273	Eck	2130 Herbert	199	07-76	97	Drill. log	Unused	360	2,500	38.0	42.7	39.1
274	Zion Church	Eleventh St.	838	11-82	54	Drill. log	Unused	3,990	1,340	7.1	7.9	7.3
448	Murphy 1/	443 Laguna	---	---	---	---	DHE	1,050	2,710	152.86	---	---

1/ Graphic plot not included in figures.

Table 2-3. -- Wells monitored for the geothermal aquifer test (Continued)

[DHE = Downhole Heat Exchange]

Well number	Owner	Address of well	Depth (ft)	Temperature: Date	Temperature: (°C)	Temperature: Source	Heat extraction method	Distance to production well (ft)	Distance to injection well (ft)	Water level, in feet below measuring point: Pre-production July 5	Pre-injection July 26	Stop pump Aug.24
Hand measured by D. C. Long □												
19	Glidden	1800 Fairmount	638	---	92	OIT	DHE	6,380	6,290	239.15 1/	244.73 1/	241.35 1/
22	Thexton	235 N. Alameda	254	---	94	OIT	DHE	1,250	1,460	20.41	22.67	19.39
51	Bailey	1850 Lowell	625	---	94	OIT	DHE	5,600	4,730	95.77	97.28	93.97
124	Hardt/Davis	535 Laguna	997	---	84	OIT	DHE	1,350	2,780	218.48 1/	227.18 1/	224.88 1/
135	Ross	1879 Del Moro	152	08-56	93	Drill. log	DHE	4,600	3,850	72.48	75.94	71.79
186	Fillmore	212 Hillside	150	06-79	93	Drill. log	DHE	500	2,200	52.82	56.17	52.46
194	Terrier	234 Laguna	240	05-58	103	Drill. log	DHE	140	2,560	57.68	60.37	56.63
256	Kent	2325 Linda Vista	1,080	04-79	130	OIT	DHE	1,790	3,260	291.29 2/	309.05 2/	305.36 2/
264	Cooper	430 Laguna	268	10-77	102	Drill. log	DHE	960	2,540	131.63	135.32	132.52
294	Spielman	1500 Pacific Terrace	525	05-83	93	CRGD 3/	DHE	5,270	4,780	132.30	(7-29-83) 135.50	131.34
360	Carter	1100 N. Eldorado	125	02-81	89	Drill. log	DHE	4,060	3,150	46.82	49.18	47.34

1/ Reported water-level measurements considered unreliable as a result of instrument error.

2/ Graphic plot not included in figures. Reported water-level measurements considered unreliable as a result of instrument error.

3/ Data obtained by Citizens for Responsible Geothermal Development.

Table 2-3. -- Wells monitored for the geothermal aquifer test (Continued)

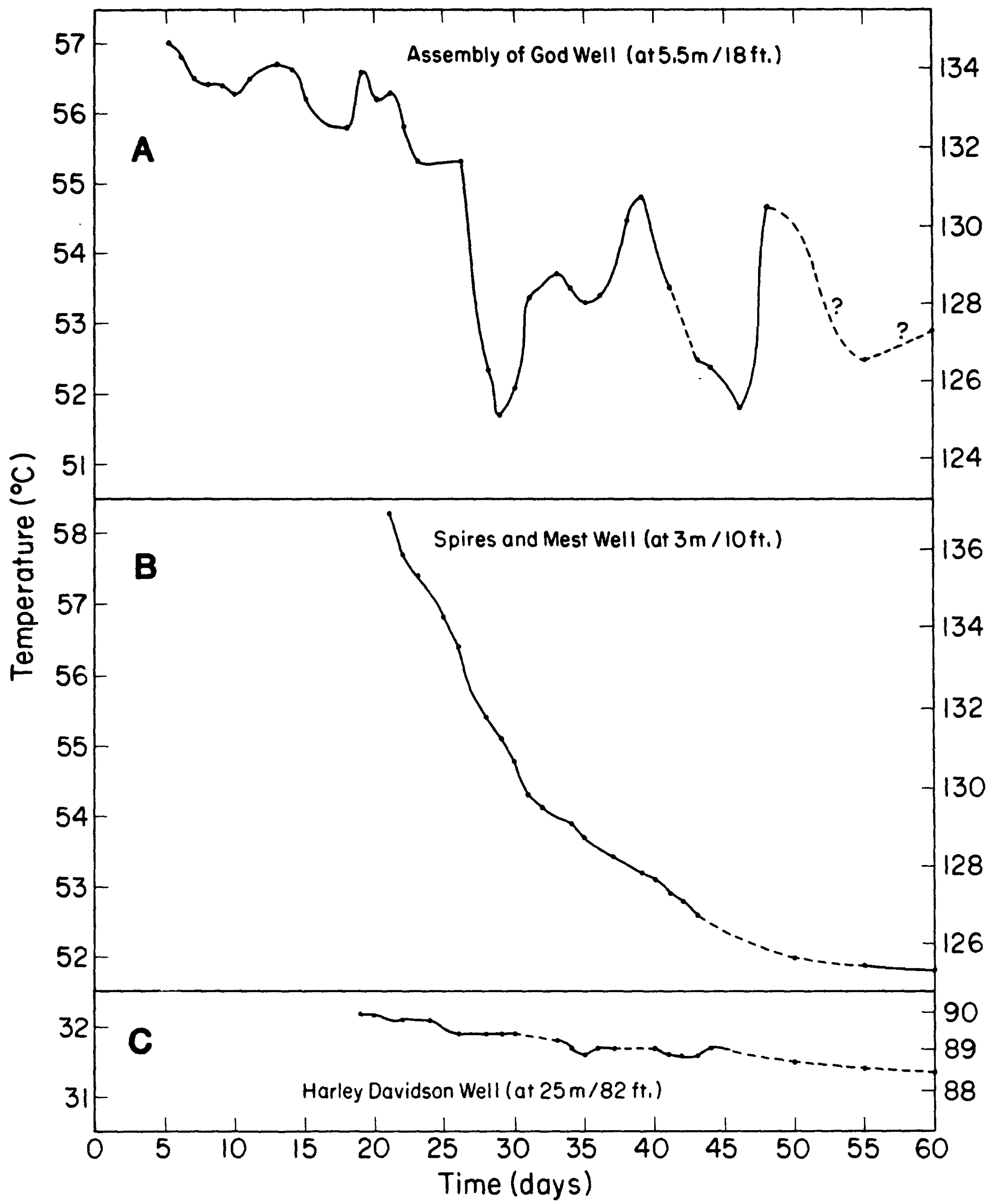
[DHE = Downhole Heat Exchange]

Well number	Owner	Address of well	Depth (ft)	Temperature Date	Temperature (°C)	Temperature Source	Heat extraction method	Distance to production well (ft)	Distance to injection well (ft)	Water level, in feet below measuring point: Pre-production July 5	Pre-injection July 26	Stop pump Aug.24
Owner monitored △												
37	Stone	133 Hillside	200	---	102	OIT	DHE	420	2,380	38.8	42.0	37.4
61	Juckeland	2043 Lavey	275	---	88	OIT	DHE	880	2,050	76.6	79.5	75.8
62	Phelps	1868 Fremont	126	---	91	OIT	DHE	3,950	2,980	44.2	46.5	42.4
110	East Main Apts[1/]	236 East Main	452	---	72	OIT	Artesian Pumped	1,850	1,850	0.0 (6-28-83)	3.6 (07-24-83)	+0.46 (8-24-83)
127	Adamcheck[2/]	Laguna & Old Fort Rd.	233	---	100	OIT	DHE	140	2,640	49.8	52.75	49.0
128	Hart	2052 Lavey	---	---	72	OIT	DHE	810	2,030	56.25	59.92	55.92
143	Raney	1126 Eldorado	152	07-48	96	Drill.log	DHE	4,190	3,310	---	59.3	55.2
157	Heaton & Wardell	700 Loma Linda	455	02-57	103	Drill.log	DHE	2,030	2,890	246.5	249.2	244.5
165	Mathews	1832 Earle	180	06-83	82	Owner	DHE	2,800	1,570	29.2	32.0	---
170	Lawrence	2384 Linda Vista	805	08-73	106	Drill.log	DHE	1,420	2,920	245.6	248.9	244.8
181	Hessig	410 Hillside	163	01-63	93	Drill.log	DHE	990	2,220	102.7	106.7	102.3
216	Hart[1/]	125 Eldorado	690	03-83	71	S.Swanson	Artesian	1,930	760	+2.5	5.0	---
277	Klamath Medical Clinic[1/]	1905 Main	---	04-58	96	Drill.log	DHE	1,160	1,620	---	7.25 (07-24-83)	3.42
310	Feeback	207 Haskins	470	1956	100	CRGD[2/]	DHE	1,480	2,250	36.25	38.7	35.5

1/ Well monitored by Charles Leib.

2/ Well monitored by A. L. Stone.

Lawrence Berkeley Laboratory Temperature Data



XBL 8311-2325

Figure 2-8. -- Temperature changes with time during aquifer test:

A. #24 Assembly of God well

B. #123 Spires and Mest well

C. #215 Harley Davidson well

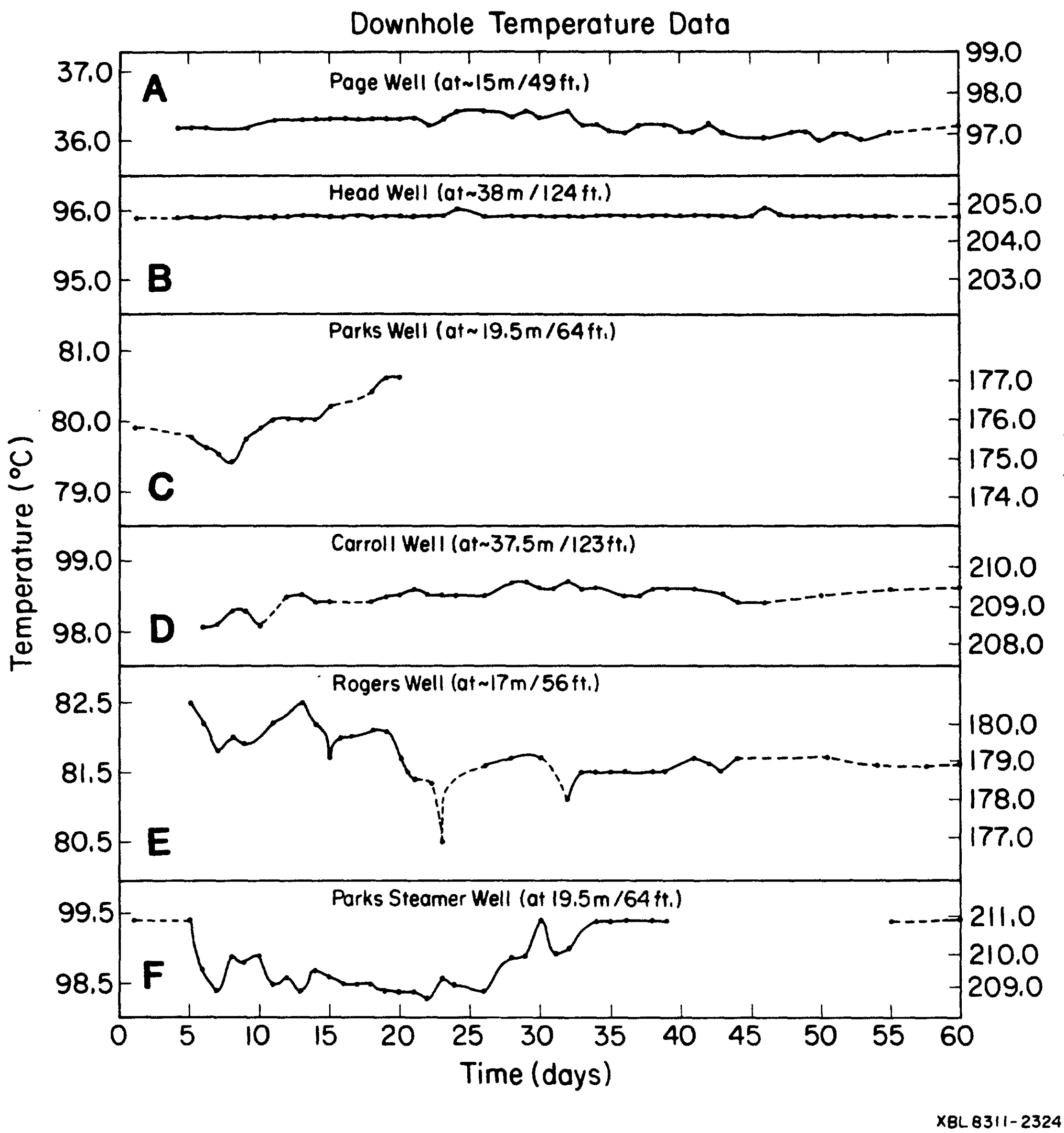


Figure 2-9. -- Temperature changes with time during aquifer test:

A. #177 Page well	D. #3 Carroll well
B. #101 Head well	E. #200 Rogers well
C. #4 Parks well	F. #203 Parks steamer well

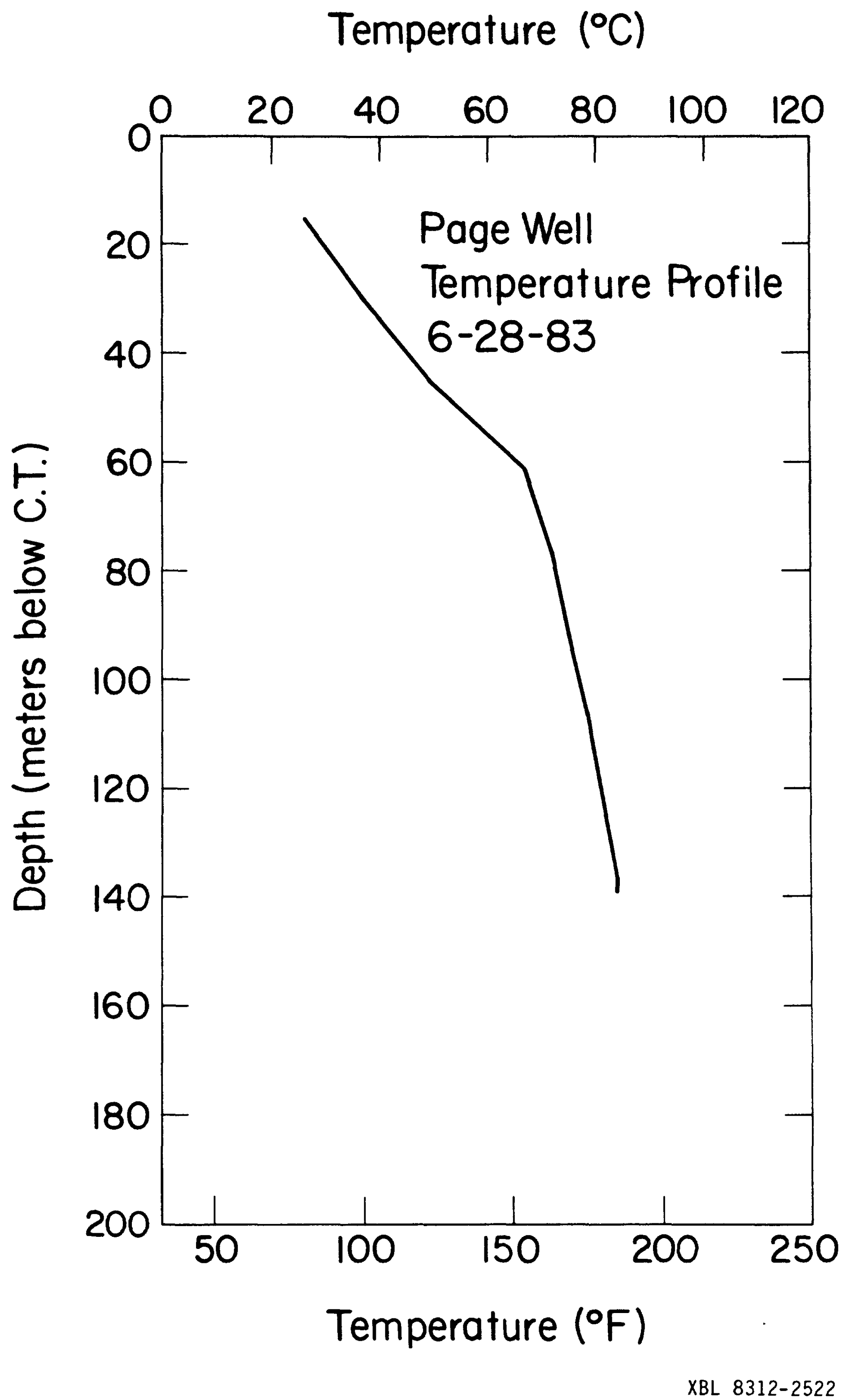


Figure 2-10. -- #177 Page well temperature profile, 6-28-83

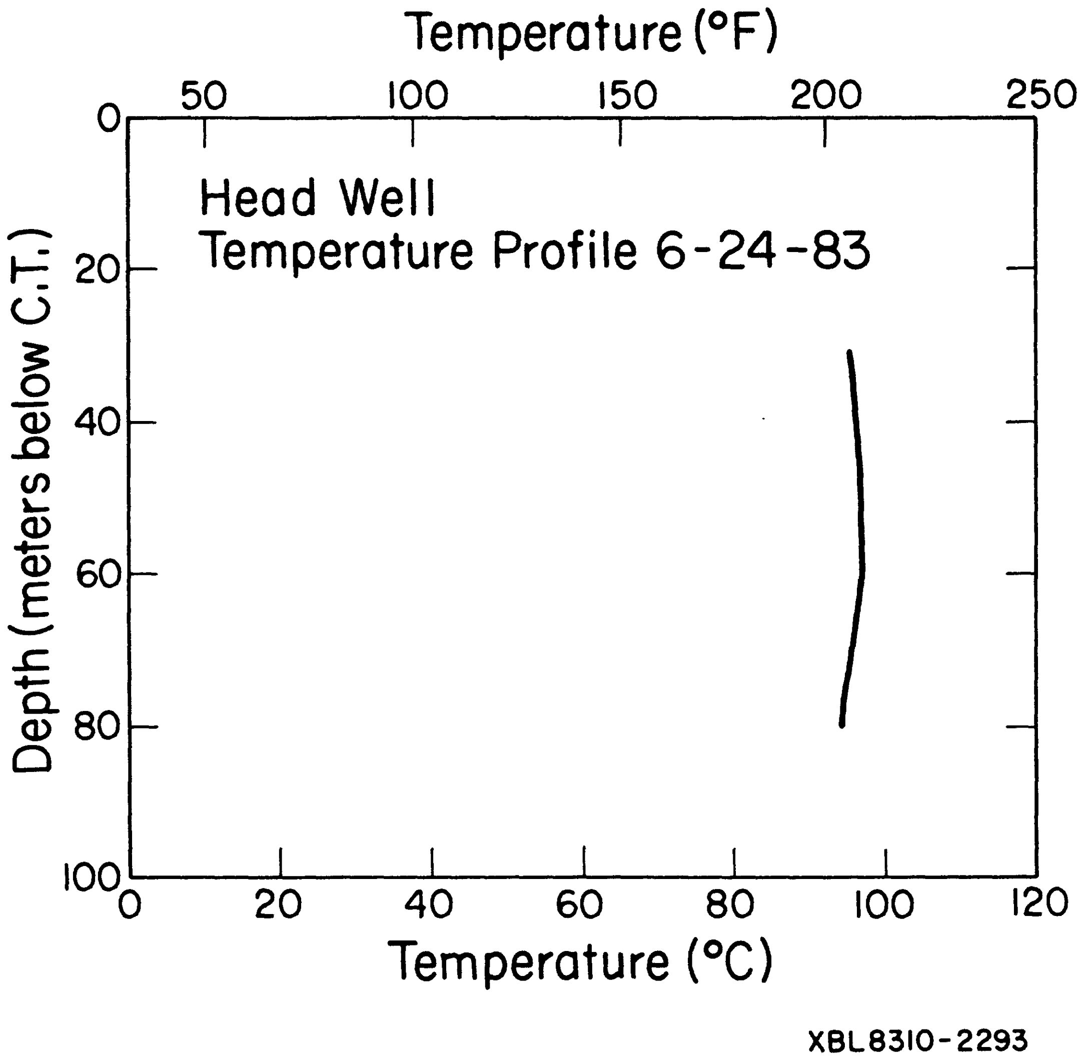


Figure 2-11. -- #101 Head well temperature profile, 6-24-83

Lawrence Berkeley Laboratory well-interference data

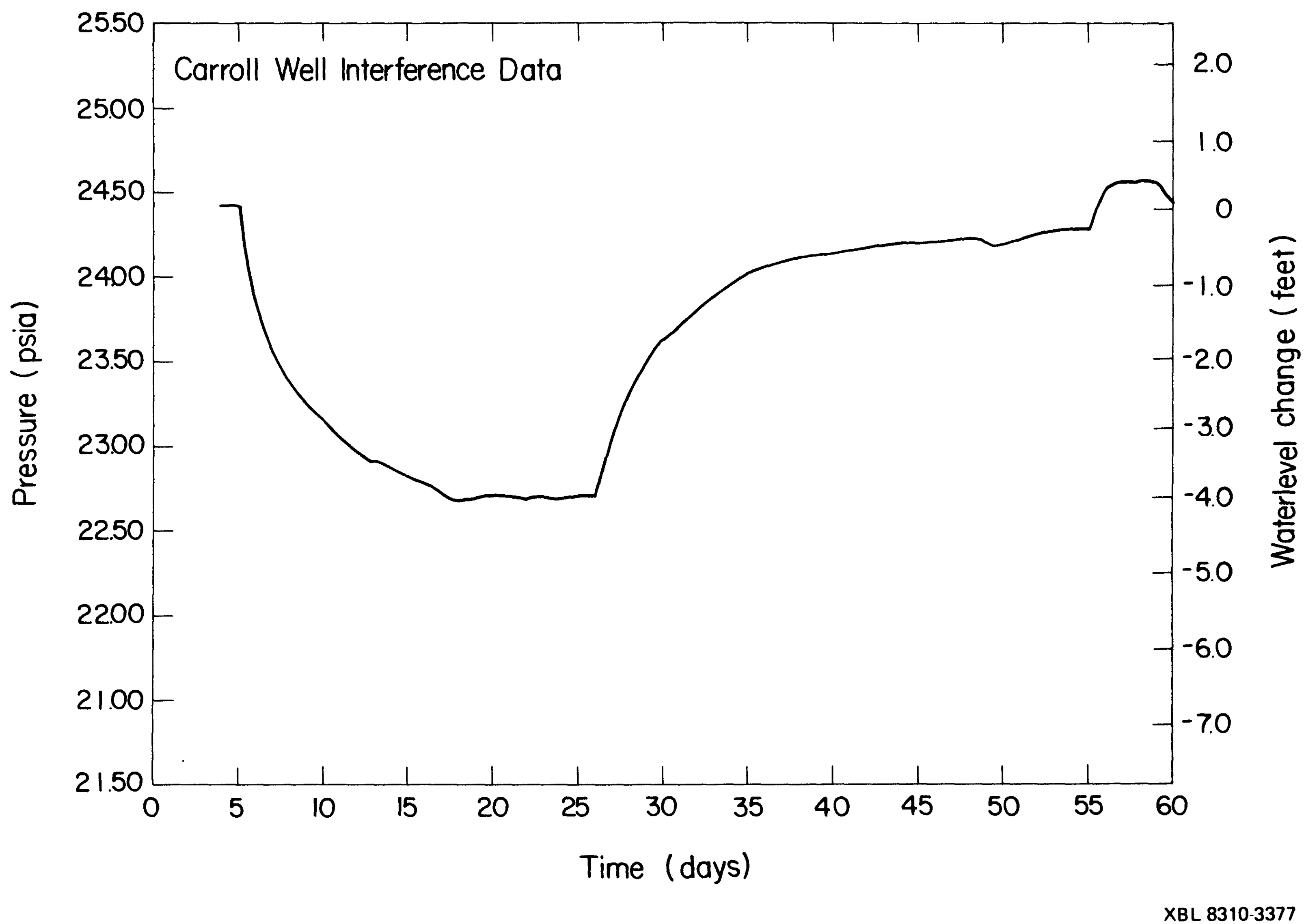
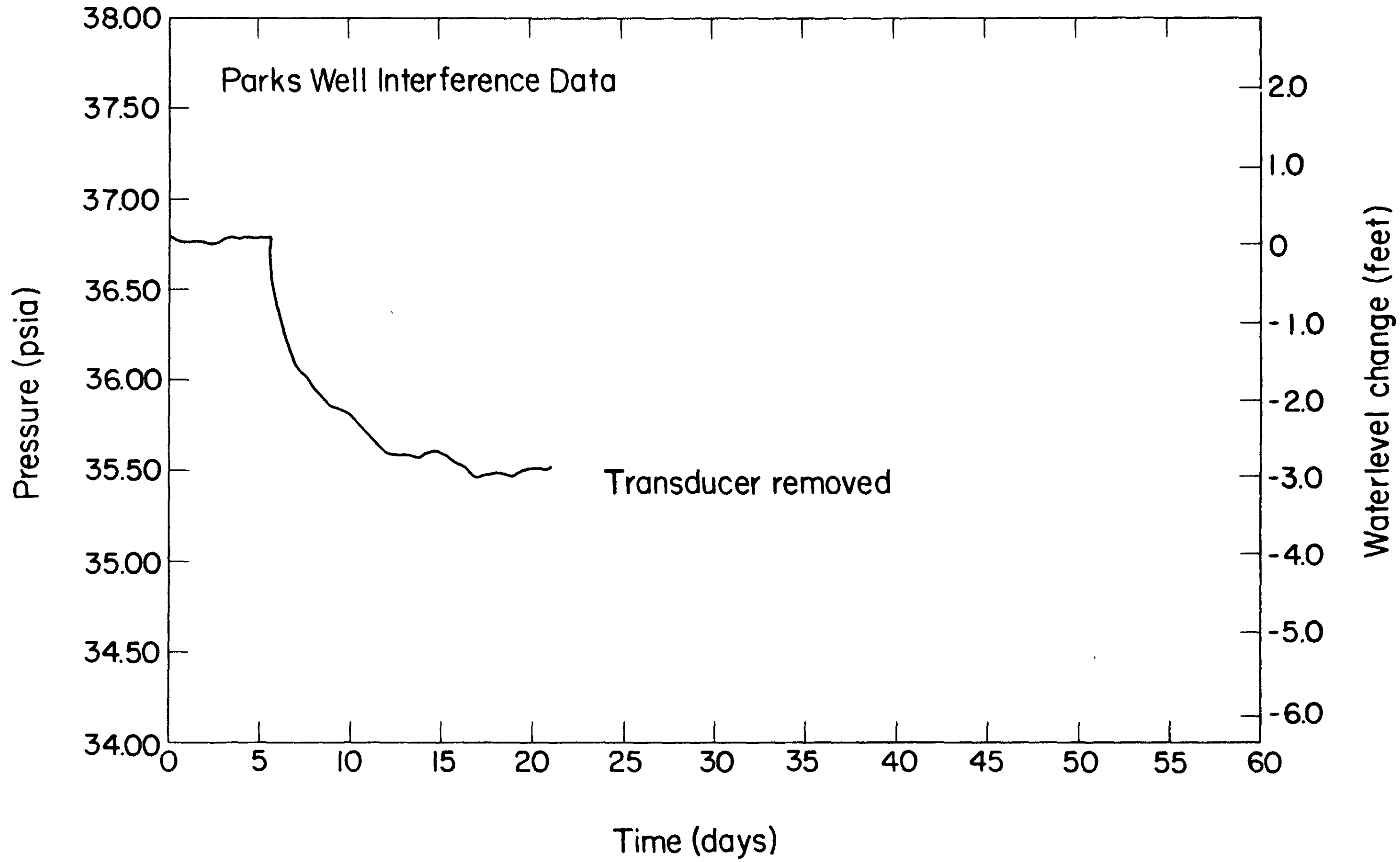


Figure 2-12. -- #3 Carroll well



XBL 8311-3382

Figure 2-13. -- #4 Parks well

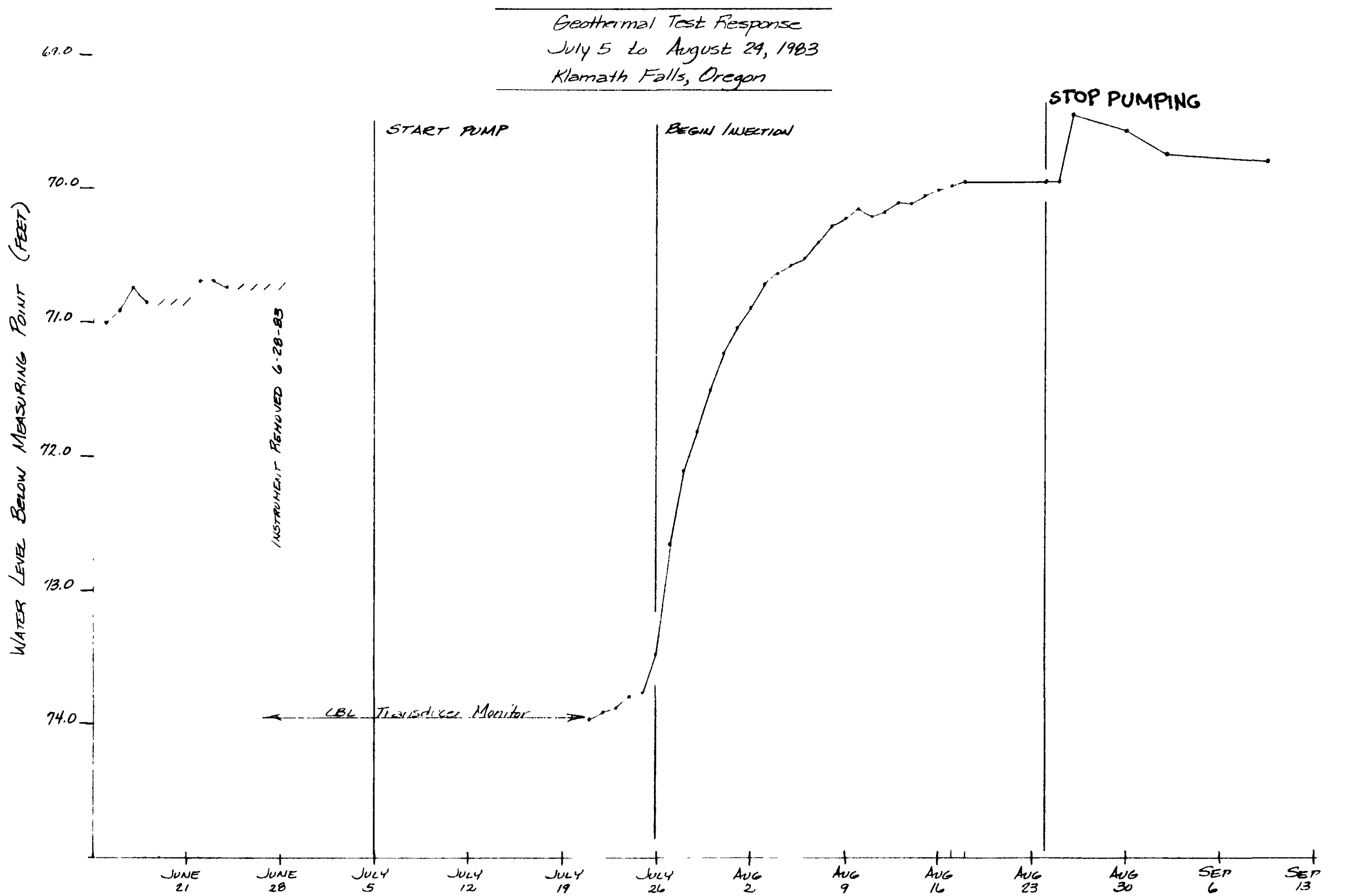
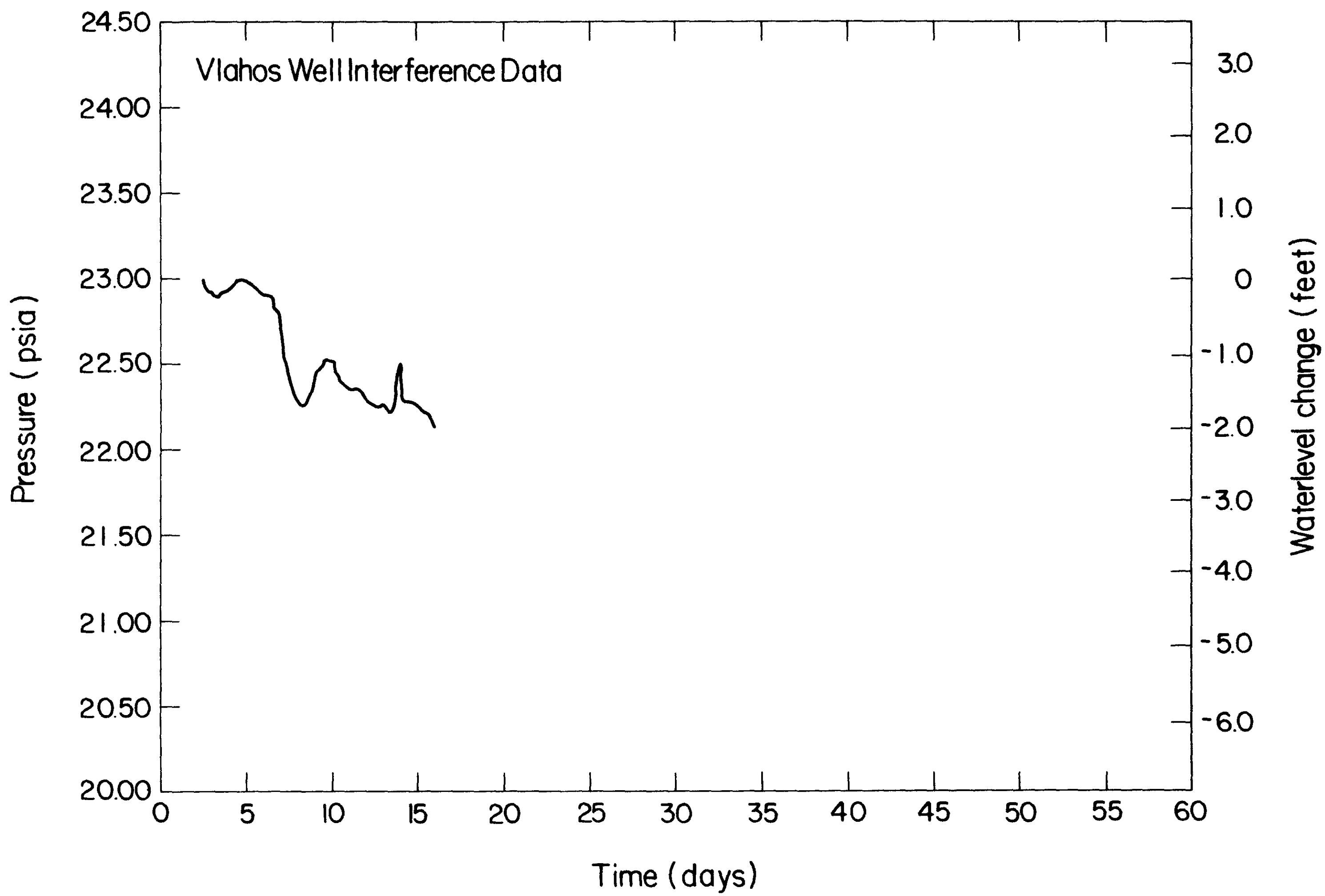


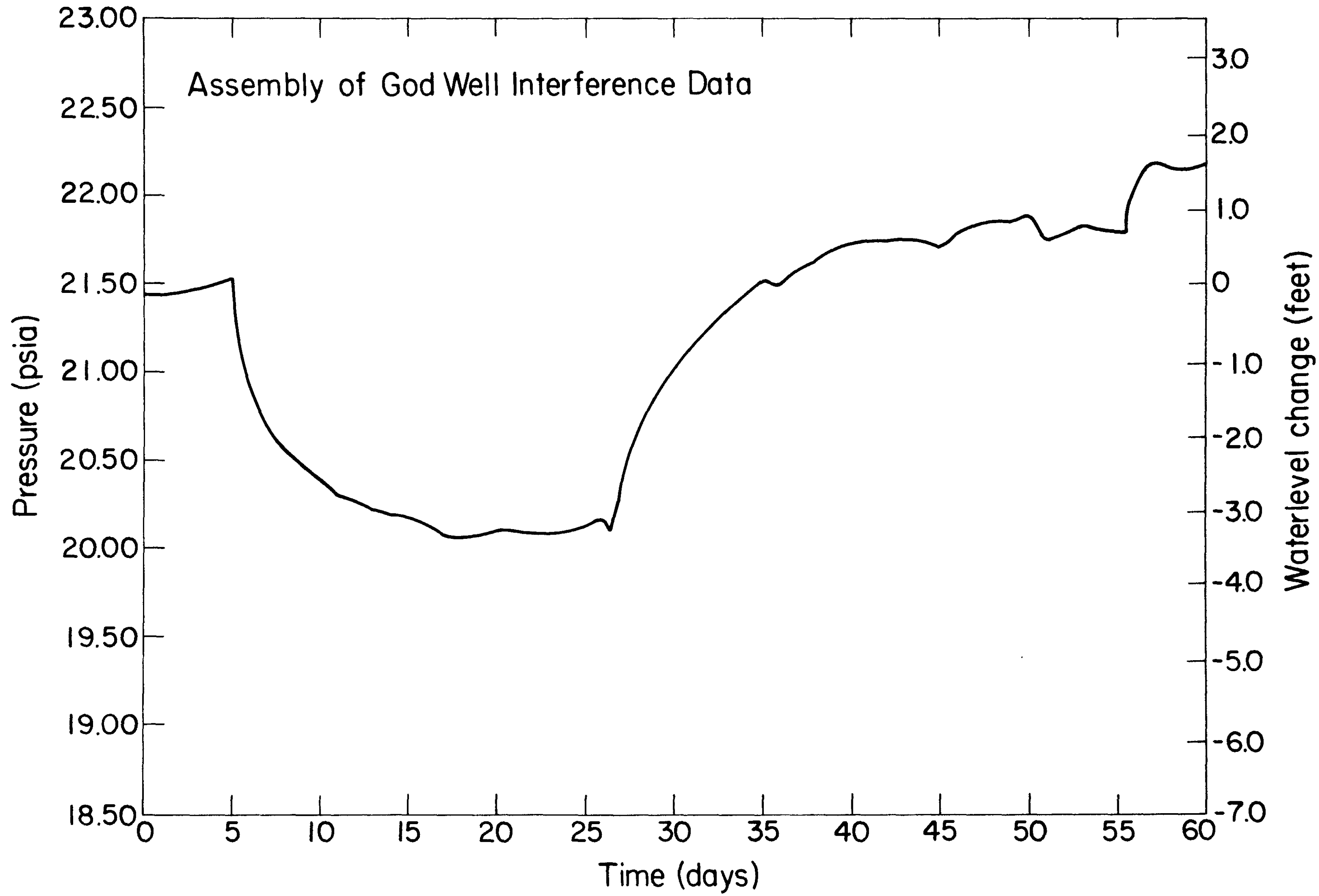
Figure 2-14 -- Water levels measured during the pumping and injection test

#4 Parks	Stevens Recorder	Distance to production well:	703 ft.
325 Old Fort Rd.		Distance to injection well:	3,460 ft.
(July 21 - September 9, 1983)		Depth:	795 ft.



XBL 8310-3376

Figure 2-15. -- #8 Vlahos well



XBL 8311-4008

Figure 2-16. -- #24 Assembly of God well

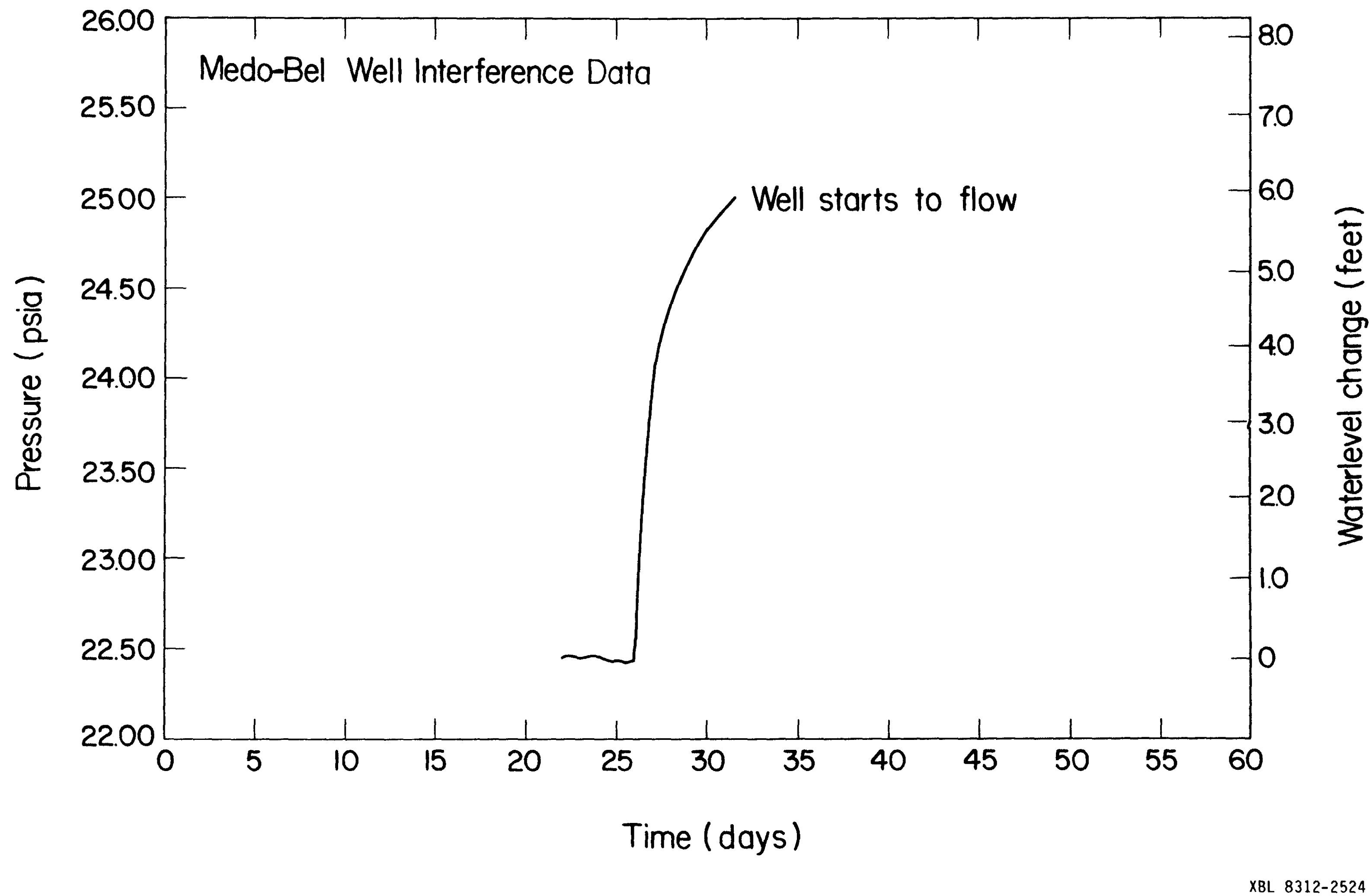
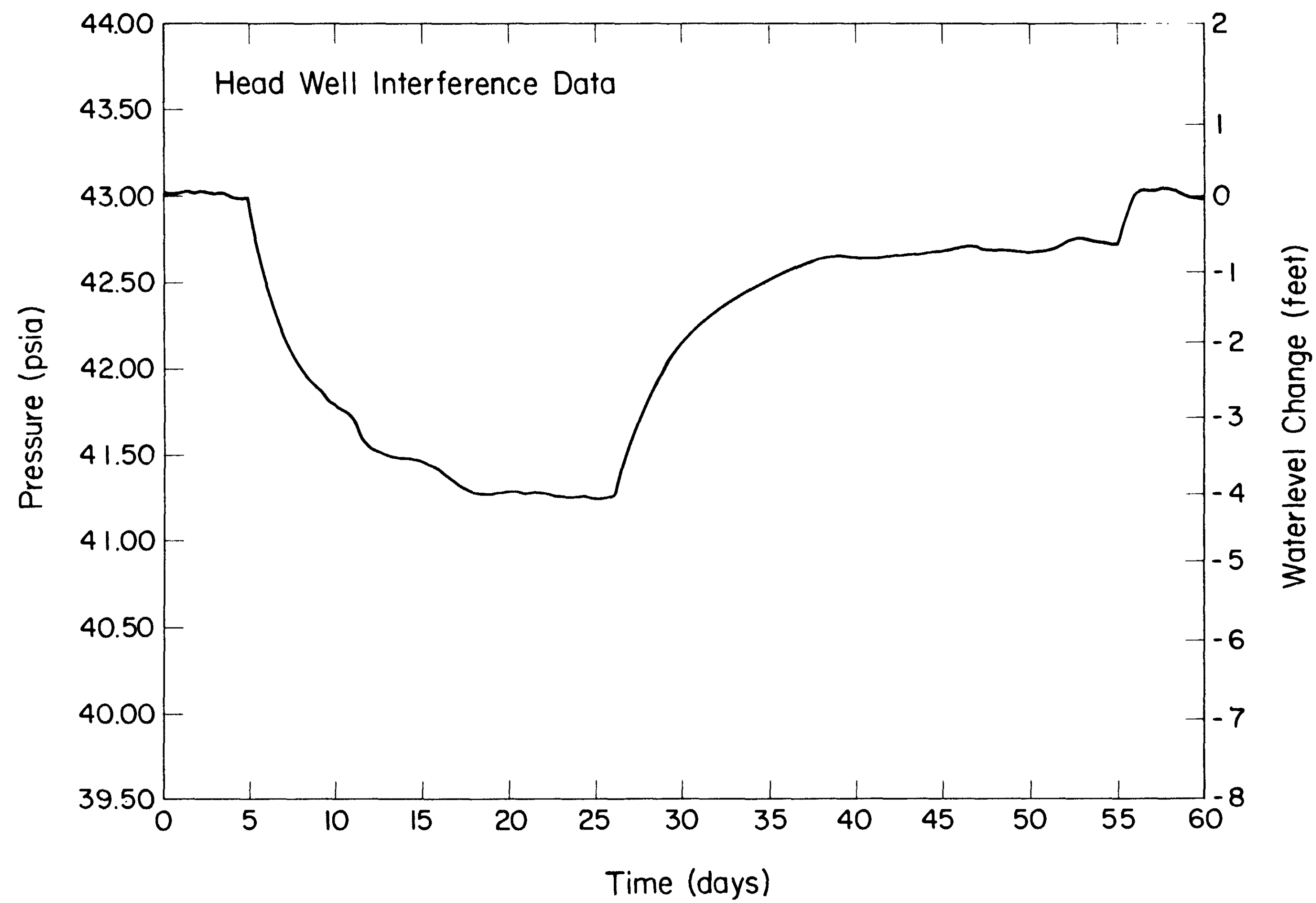
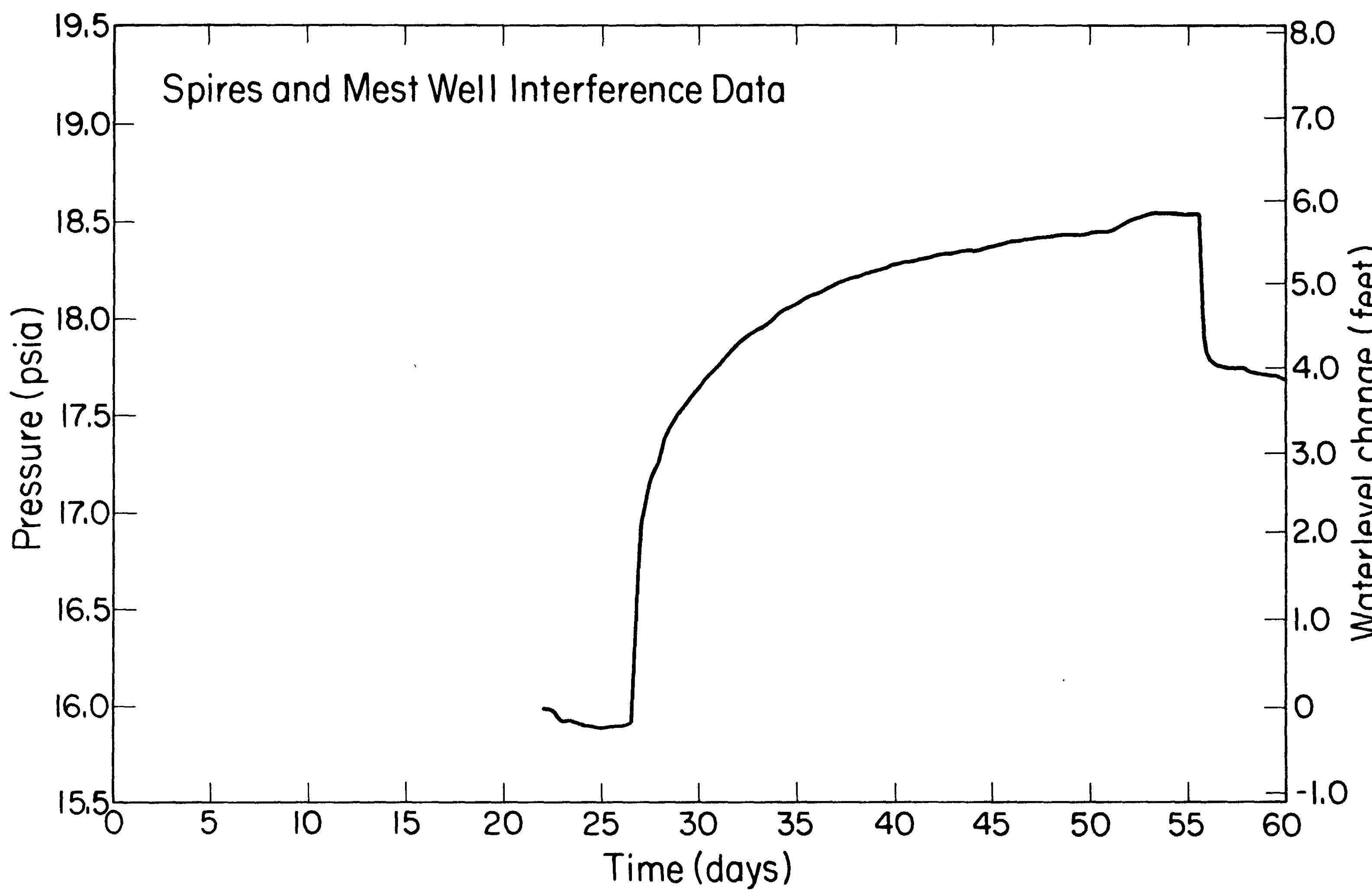


Figure 2-17. -- #39 Medo-Bel Dairy well



XBL 8311-4014

Figure 2-18. -- #101 Head well



XBL 8312-2525

Figure 2-19. -- #123 Spires and Mest well

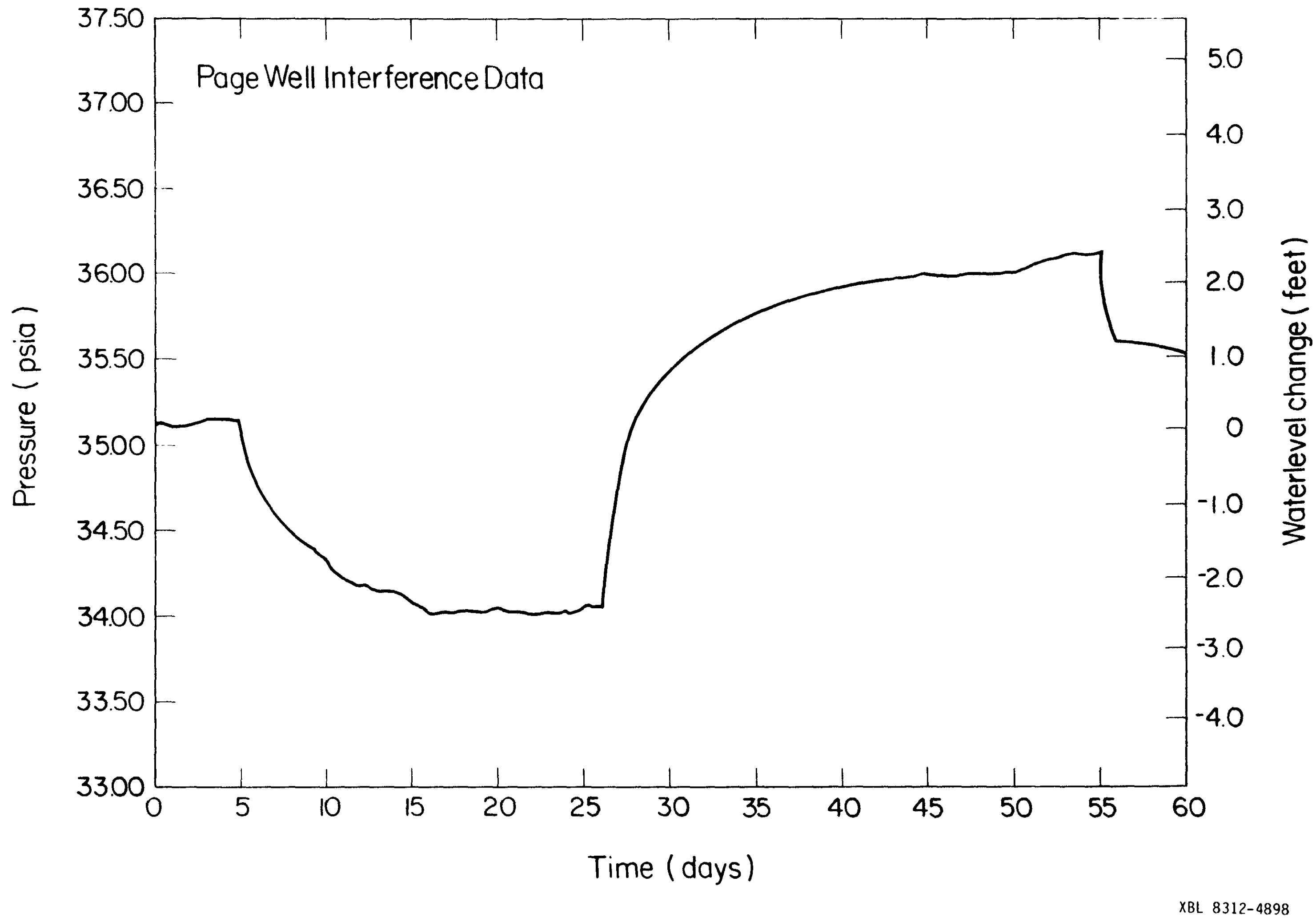


Figure 2-20. -- #177 Page well

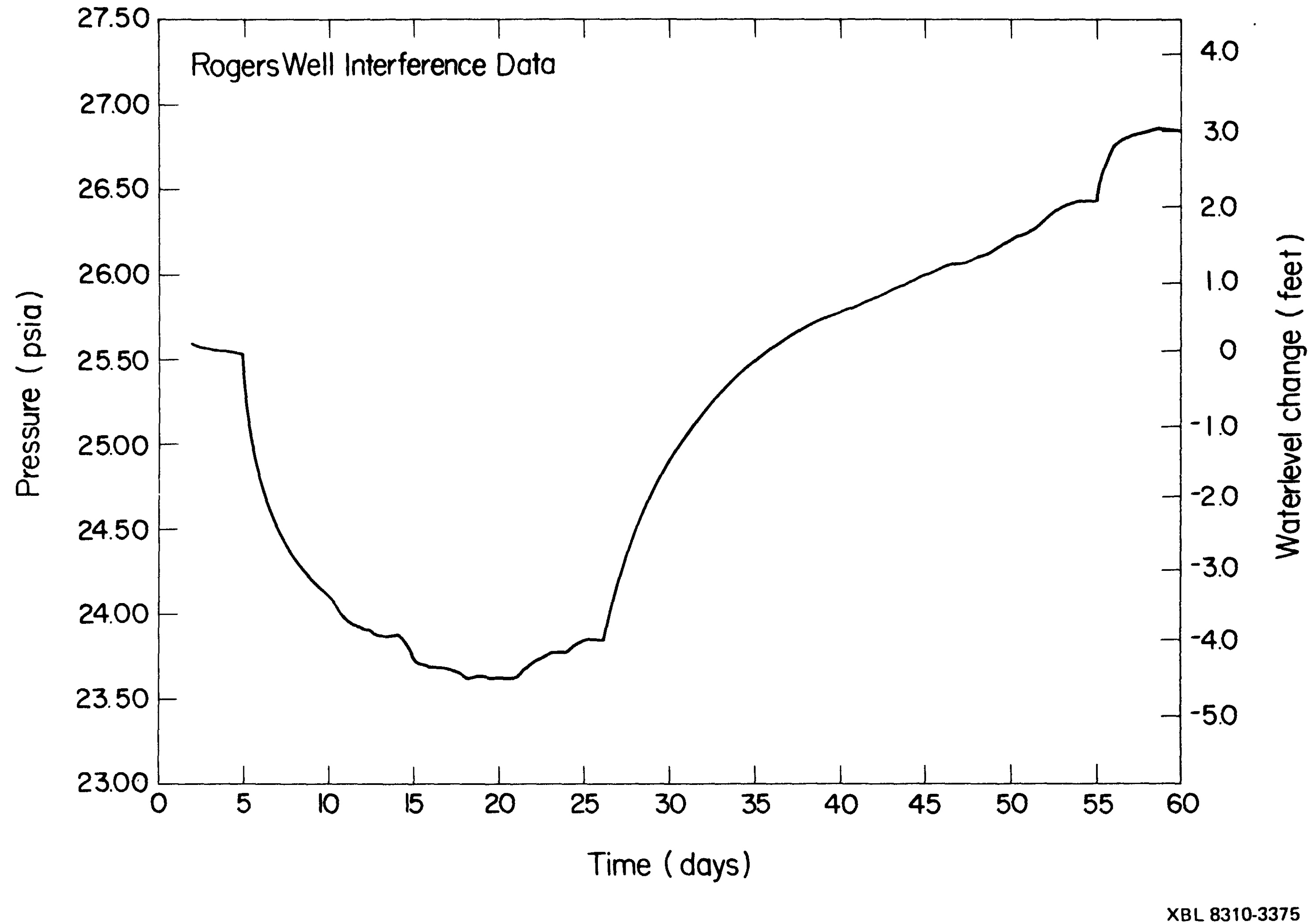


Figure 2-21. -- #200 Rogers well

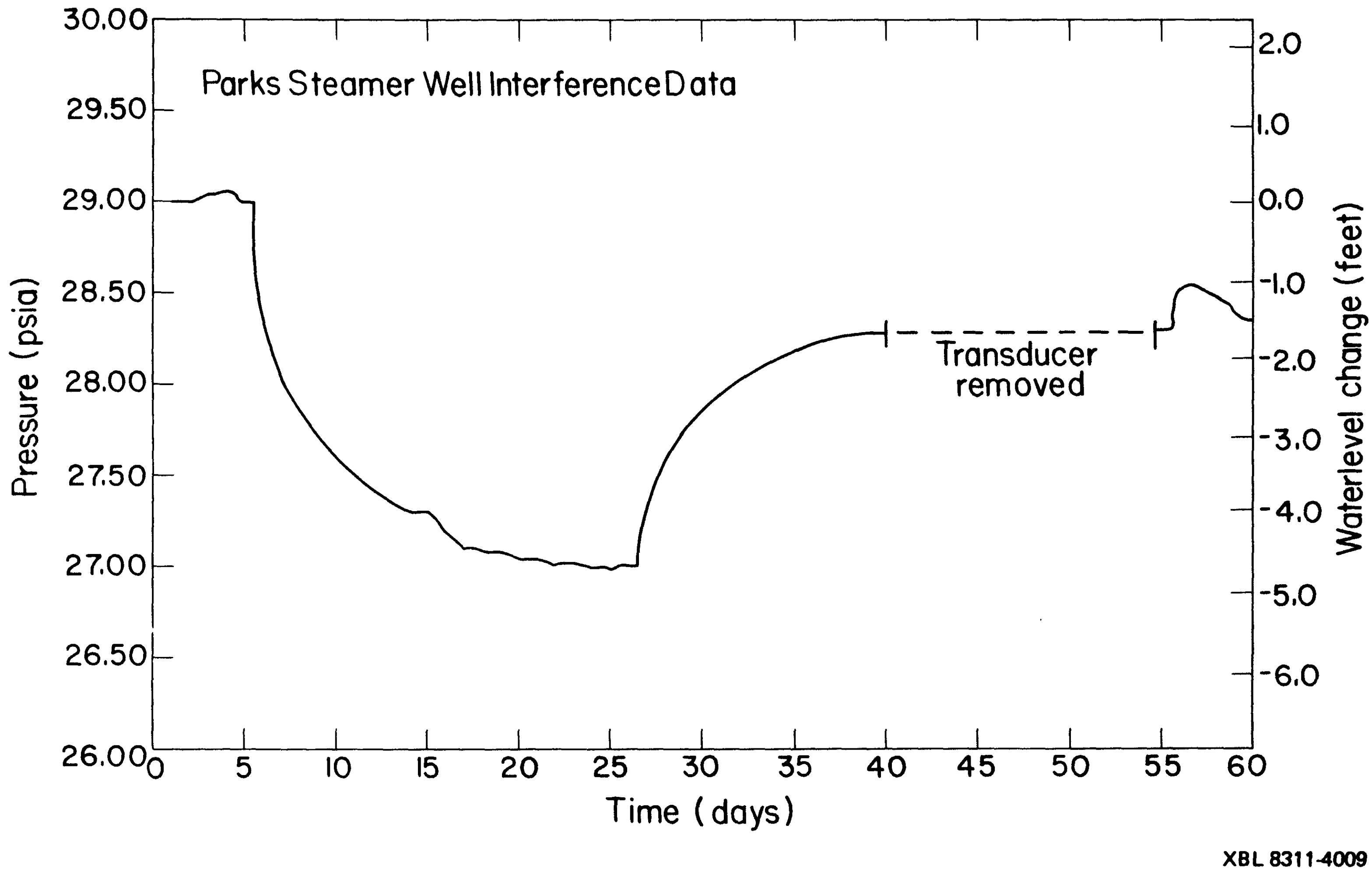


Figure 2-22. -- #203 Parks steamer well

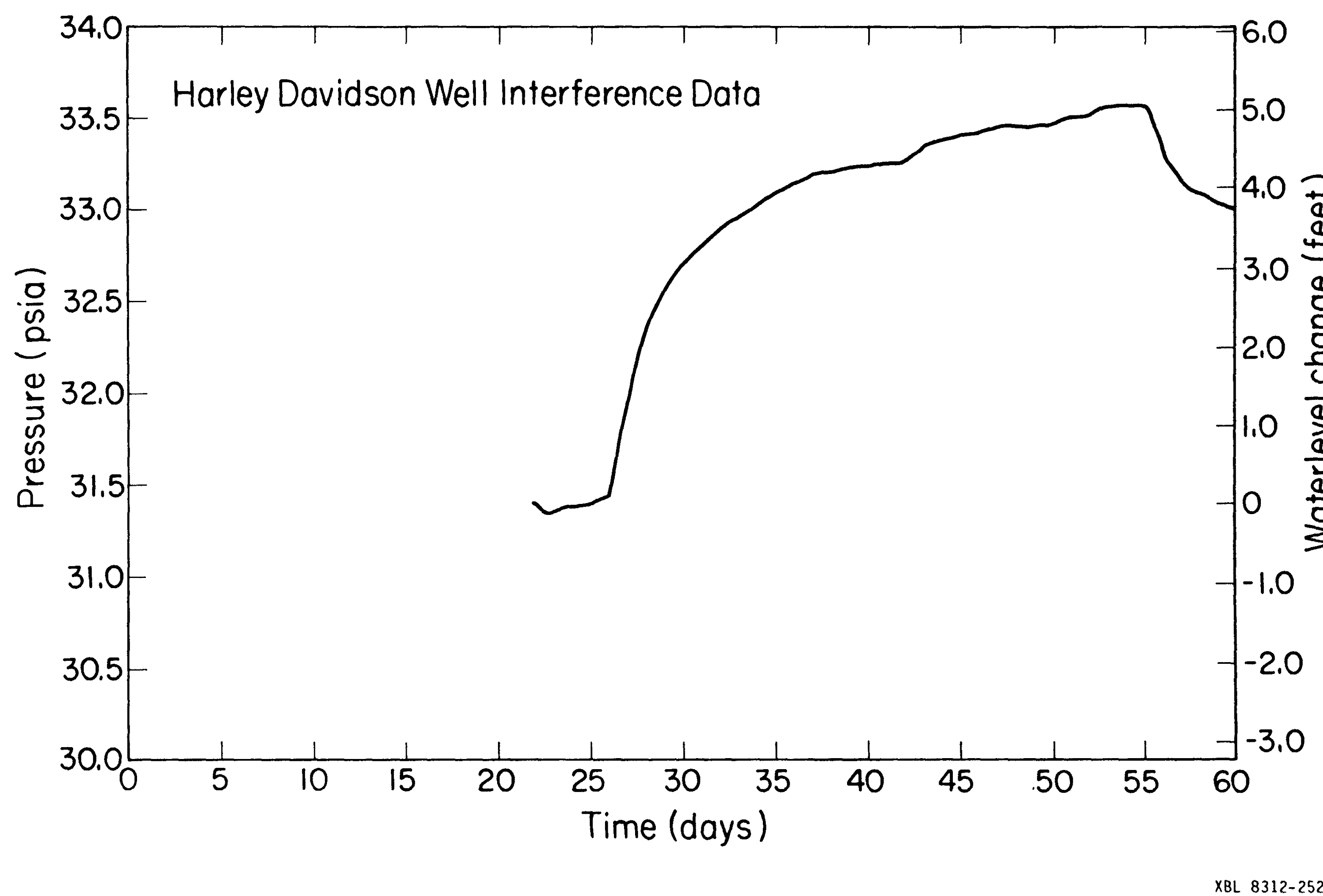
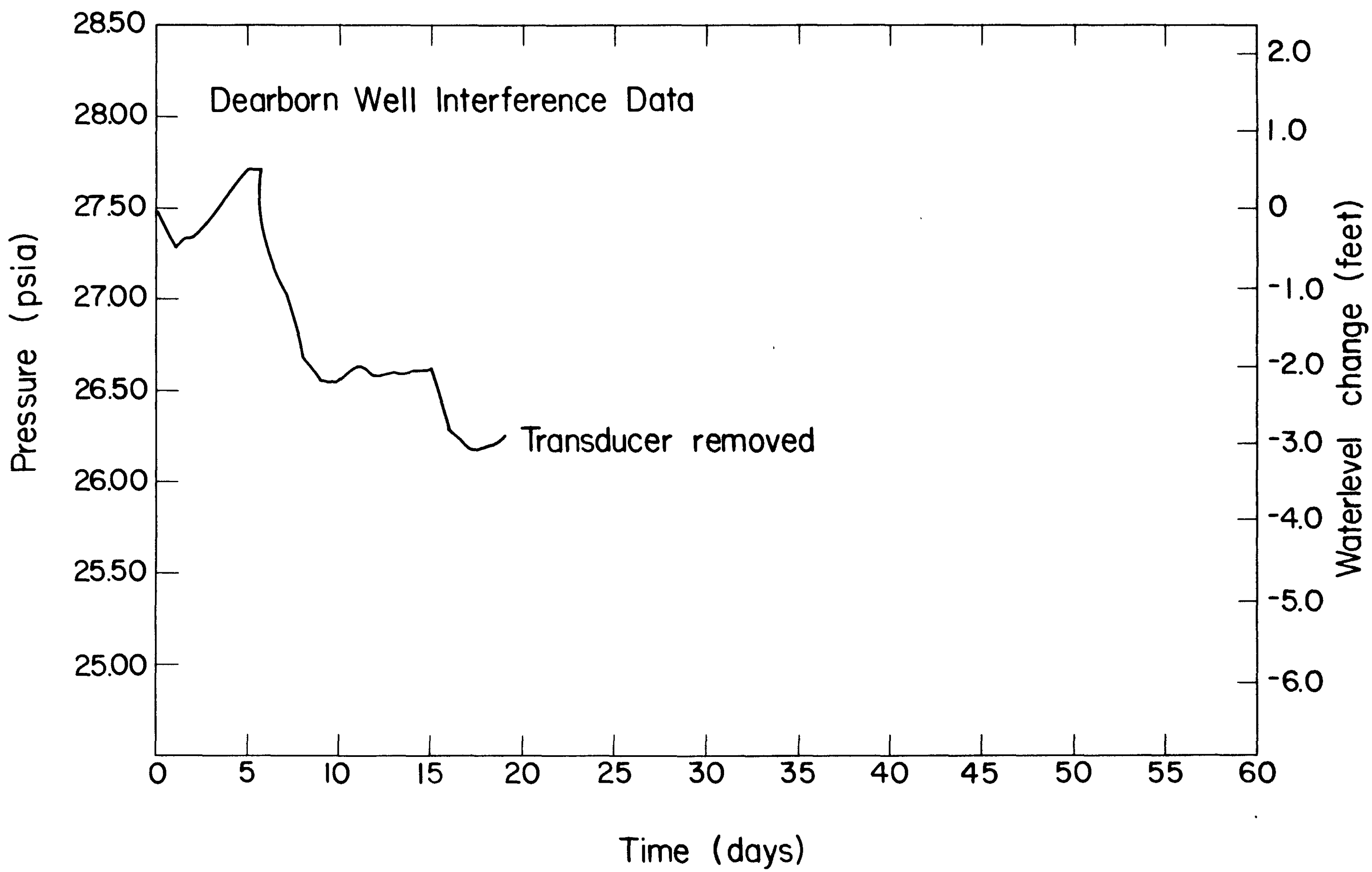


Figure 2-23. -- #215 Harley Davidson well



XBL 8312-2520

Figure 2-24. -- #347 Dearborn well

CHAPTER 3. ADDITIONAL WATER LEVELS AND TEMPERATURES MEASURED DURING THE PUMPING AND INJECTION TEST

By

D. C. Long, S. R. Swanson, D. N. Hart, and P. J. Lineau

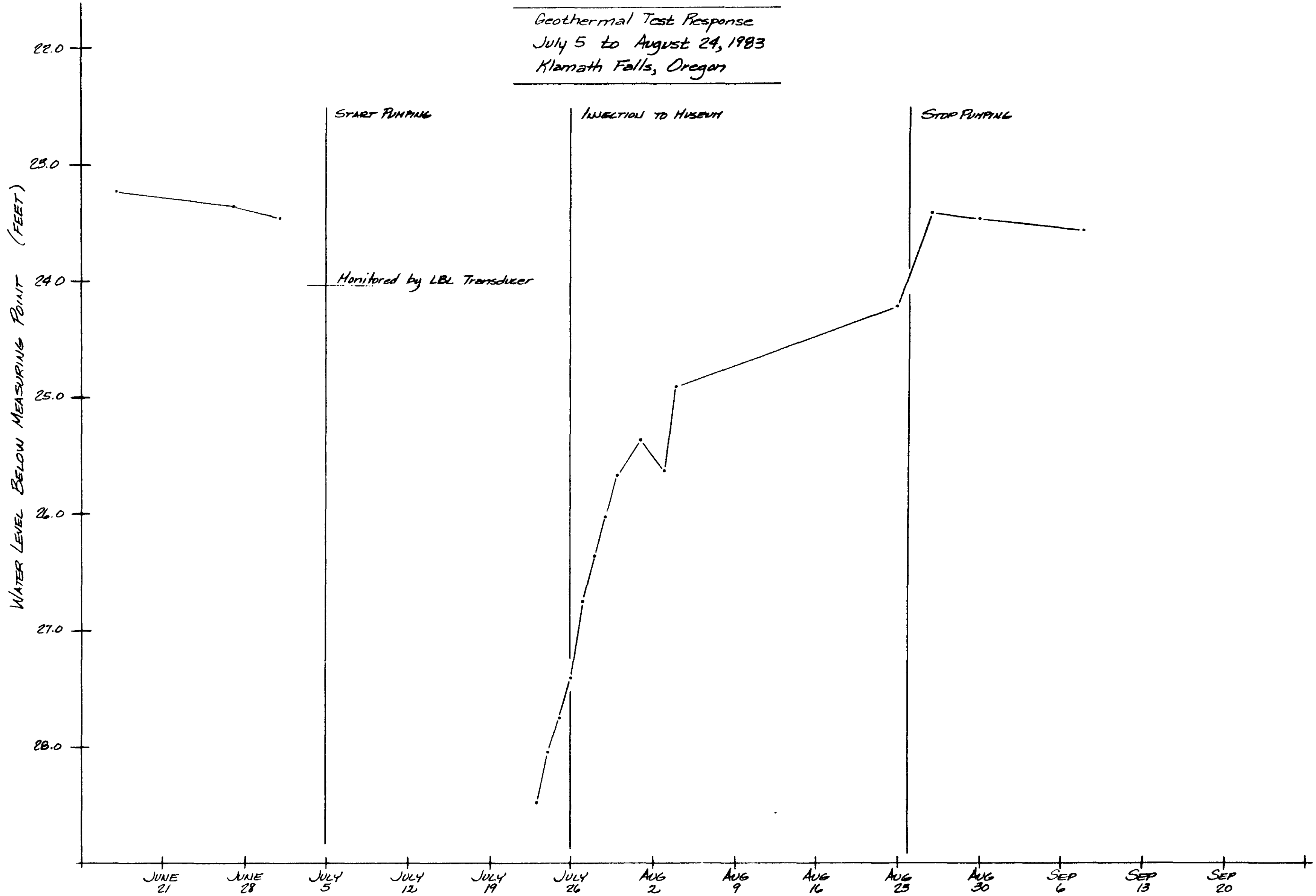


Figure 3-1. -- Water levels measured during the pumping and injection test

#347 Dearborn Main and Alameda	Hand measurement and LBL transducer	Distance to production well:	630 ft.
		Distance to injection well:	2,570 ft.
		Depth:	300 ft.

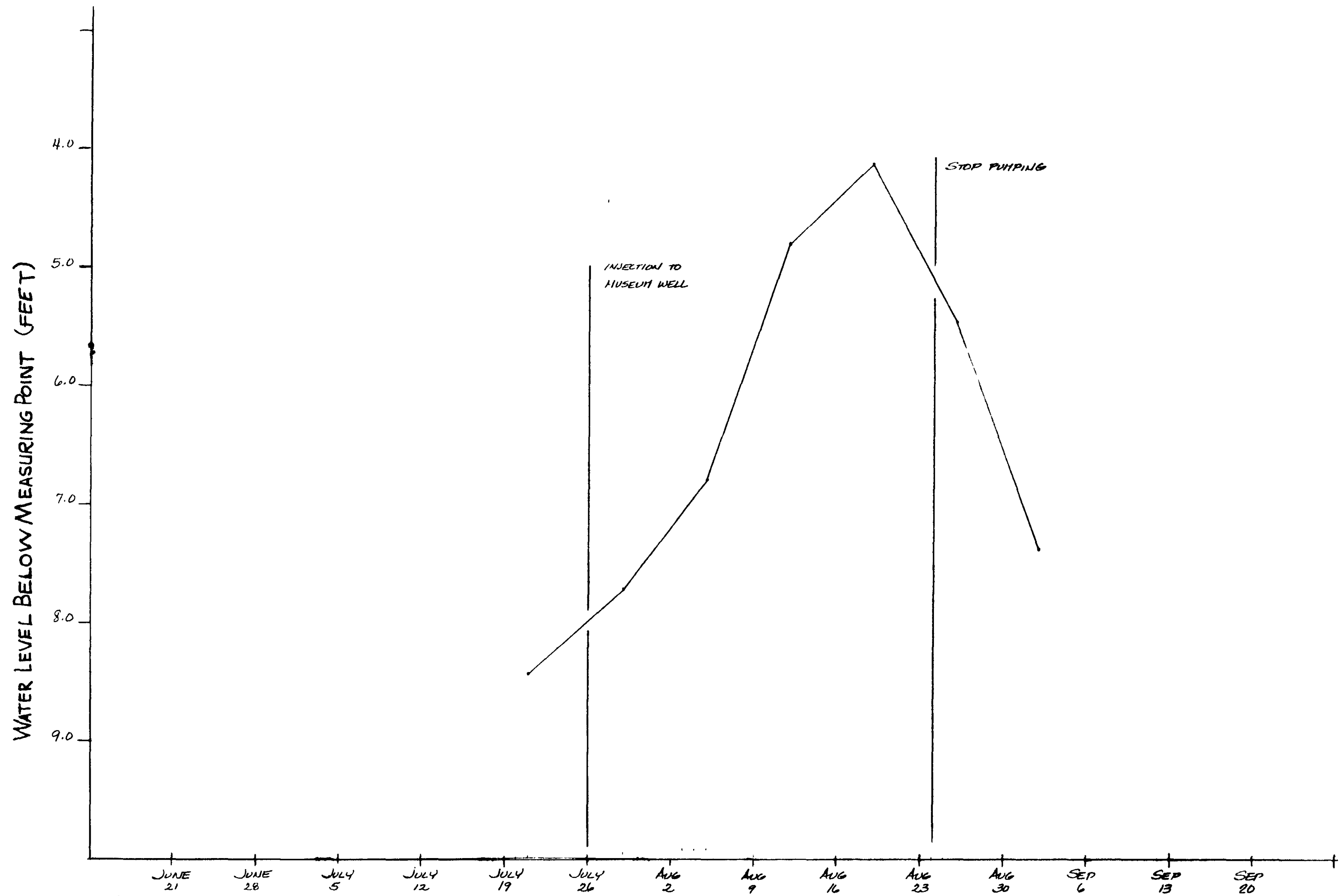


Figure 3-2. -- Water levels measured during the pumping and injection test

#43 Klamath Cold Storage	Stevens Recorder	Distance to production well:	3,000 ft.
661 Spring		Distance to injection well:	2,460 ft.
		Depth:	1,100 ft.

Data points are those measured at changing of chart.

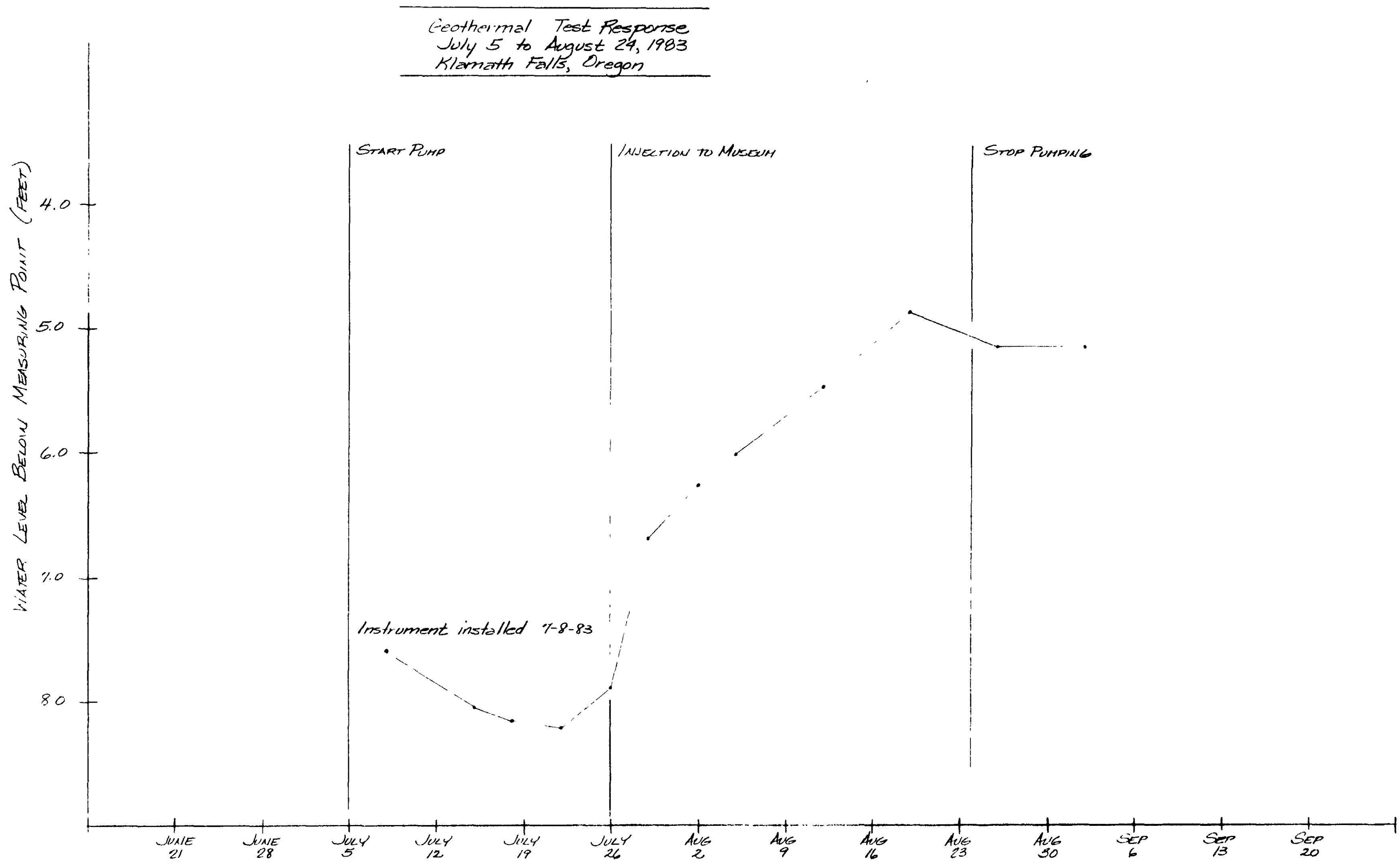


Figure 3-3. -- Water levels measured during the pumping and injection test

#79 Klamath Union High School Monclaire St.	Stevens Recorder	Distance to production well:	3,060 ft.
		Distance to injection well:	1,290 ft.
		Depth:	240 ft.

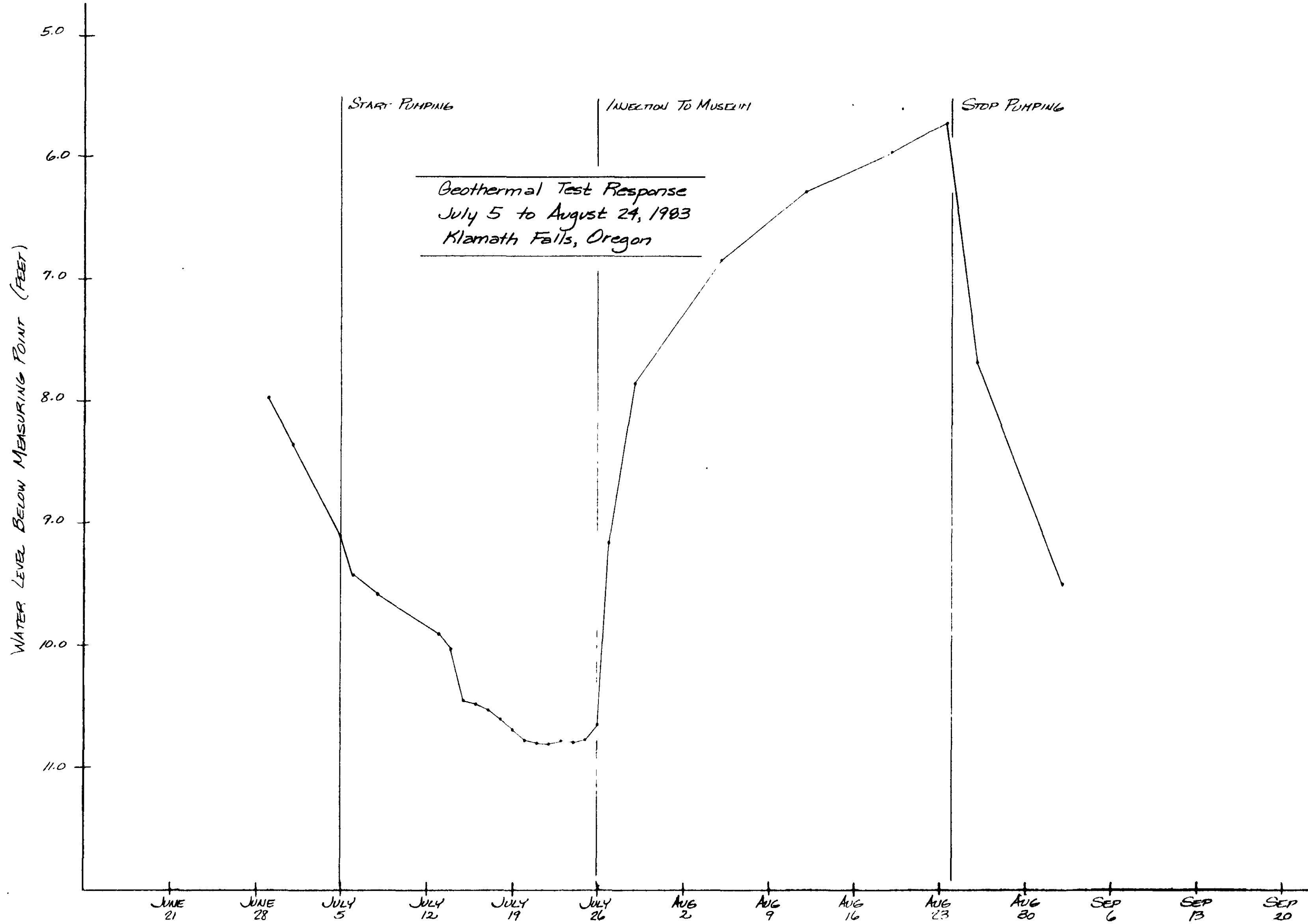


Figure 3-4. -- Water levels measured during the pumping and injection test

#80 Jones 310 and 312 Spring St.	Stevens Recorder	Distance to production well:	2,730 ft.
		Distance to injection well:	1,120 ft.
		Depth:	485 ft.

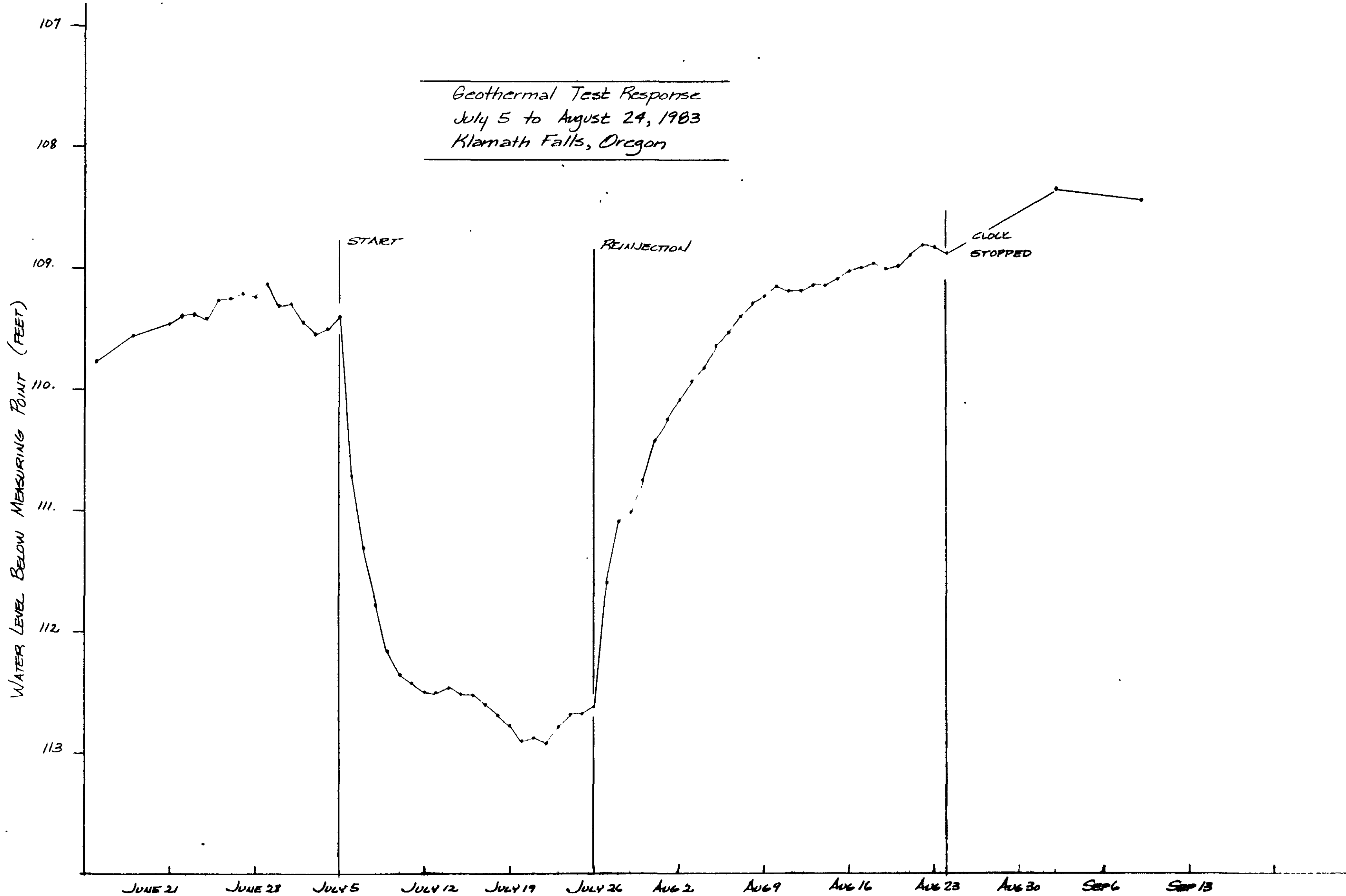


Figure 3-5. -- Water levels measured during the pumping and injection test.

#83 Stanke 424 Hillside	Stevens Recorder	Distance to production well:	1,120 ft.
		Distance to injection well:	2,310 ft.
		Depth:	136 ft.

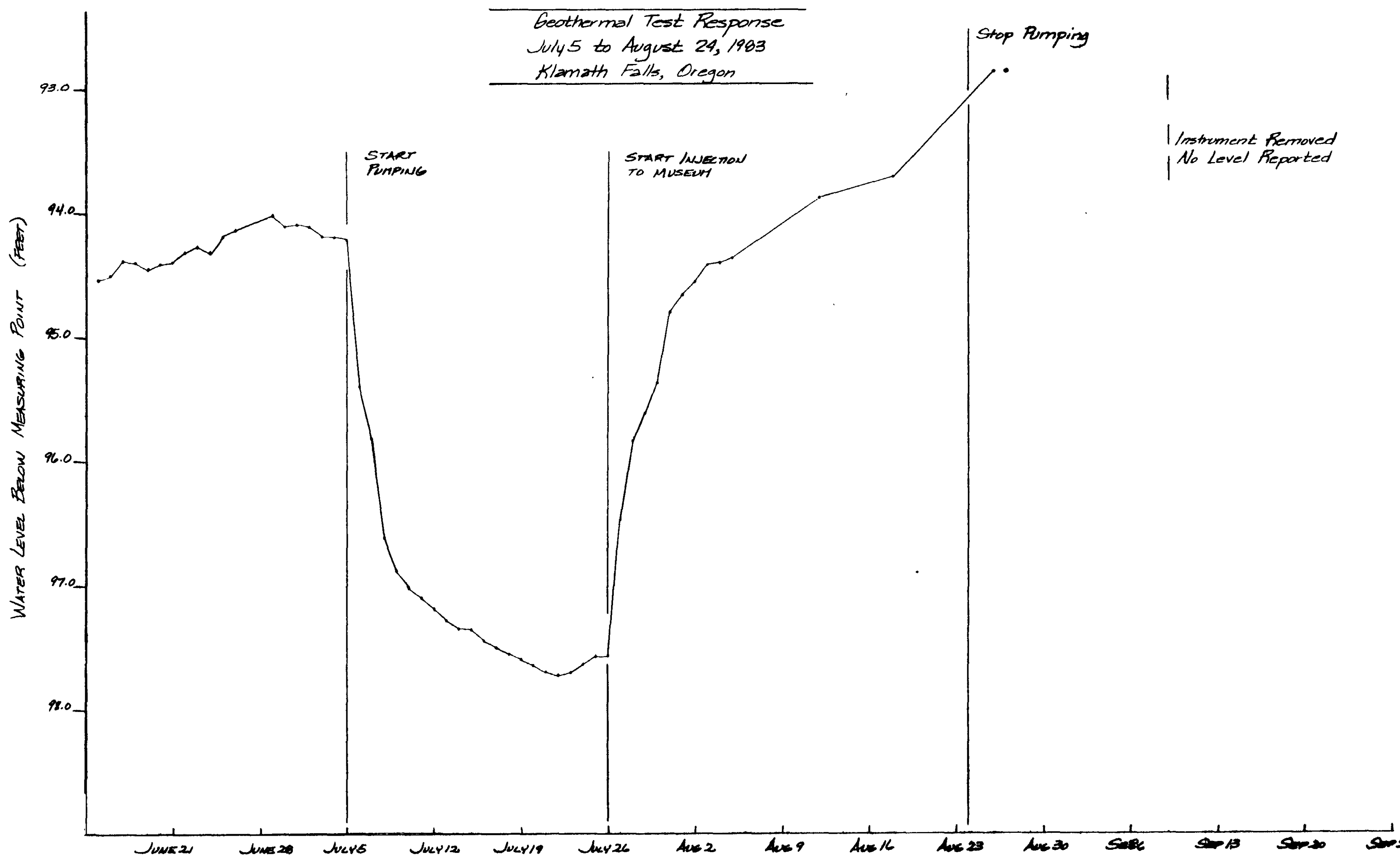


Figure 3-6. -- Water levels measured during the pumping and injection test

#97 Angel 307 Damont	Stevens Recorder	Distance to production well:	380 ft.
		Distance to injection well:	2,750 ft.
		Depth:	392 ft.

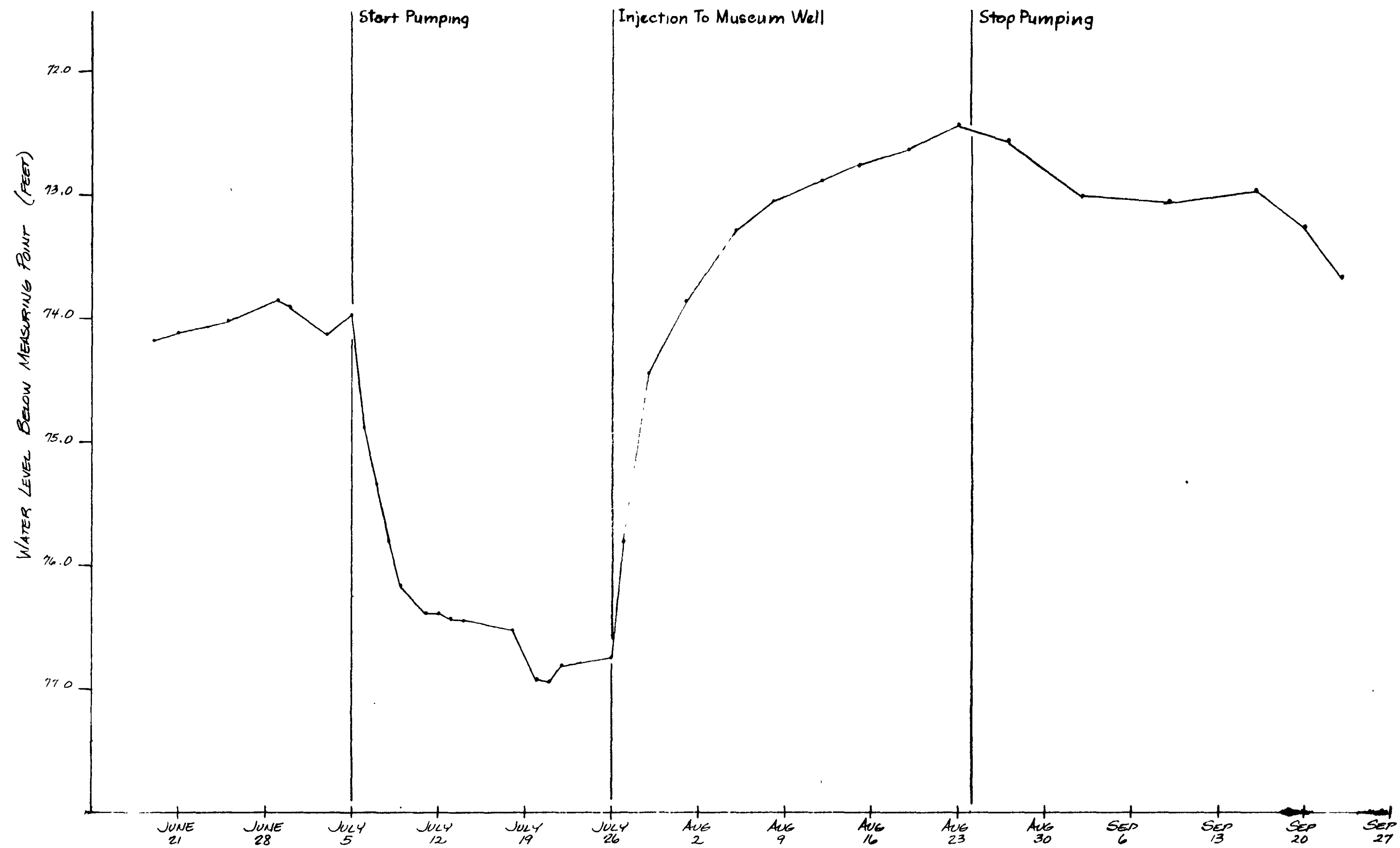


Figure 3-7. -- Water levels measured during the pumping and injection test

#118 Svanevik 1932 Portland	Stevens Recorder	Distance to production well:	3,100 ft.
		Distance to injection well:	2,450 ft.
		Depth:	340 ft.

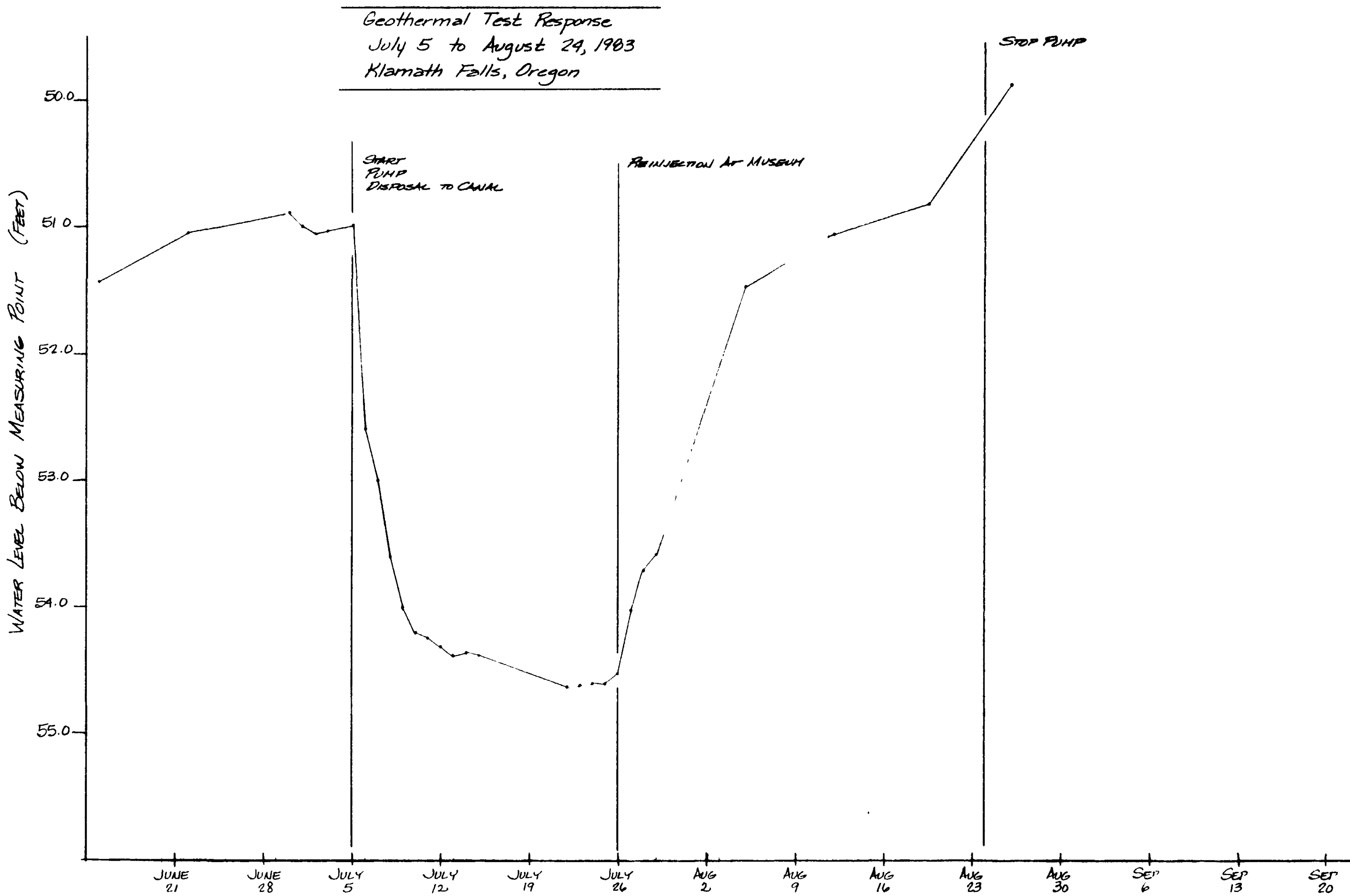


Figure 3-8. -- Water levels measured during the pumping and injection test

#122 Ponderosa	Stevens Recorder	Distance to production well:	1,260 ft.
107 S. Williams		Distance to injection well:	3,700 ft.
		Depth:	429 ft.

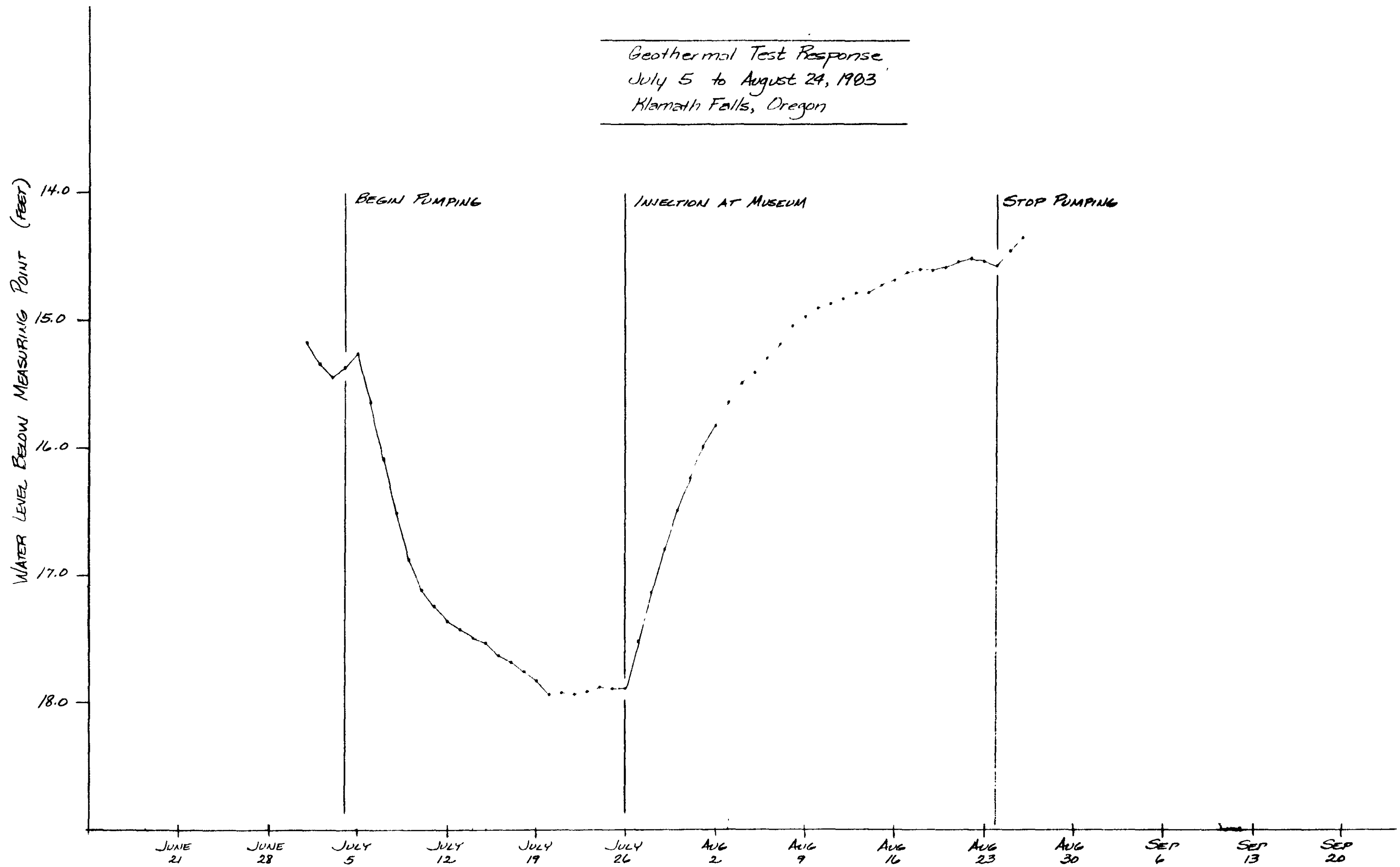


Figure 3-9. -- Water levels measured during the pumping and injection test

#126 Christian Center	Stevens Recorder	Distance to production well:	950 ft.
115 N. Alameda		Distance to injection well:	1,780 ft.
		Depth:	516 ft.

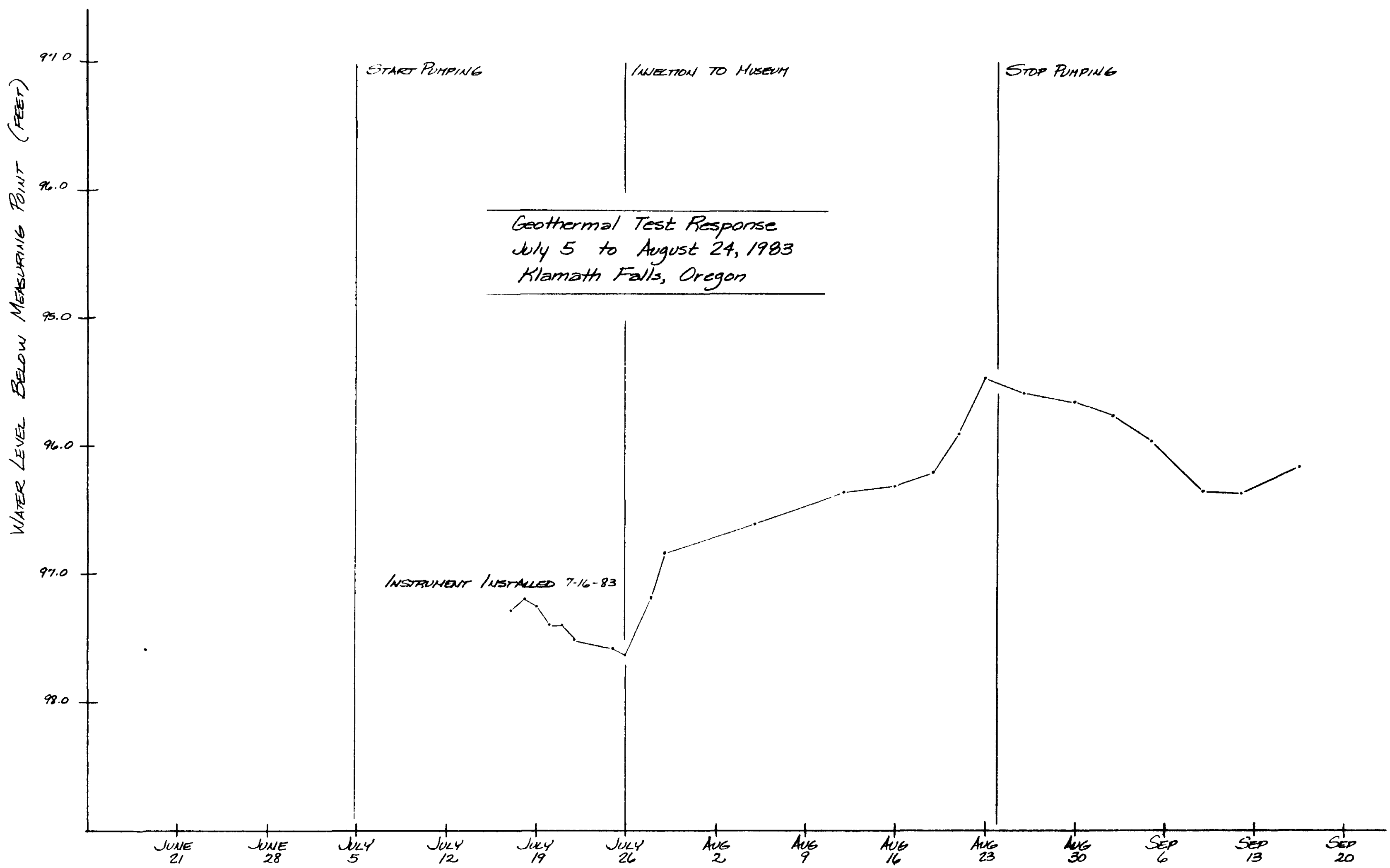


Figure 3-10. -- Water levels measured during the pumping and injection test

#141 Eldorado Place 2200 N. Eldorado	Stevens Recorder	Distance to production well: Distance to injection well: Depth:	7,180 ft. 6,200 ft. 407 ft.

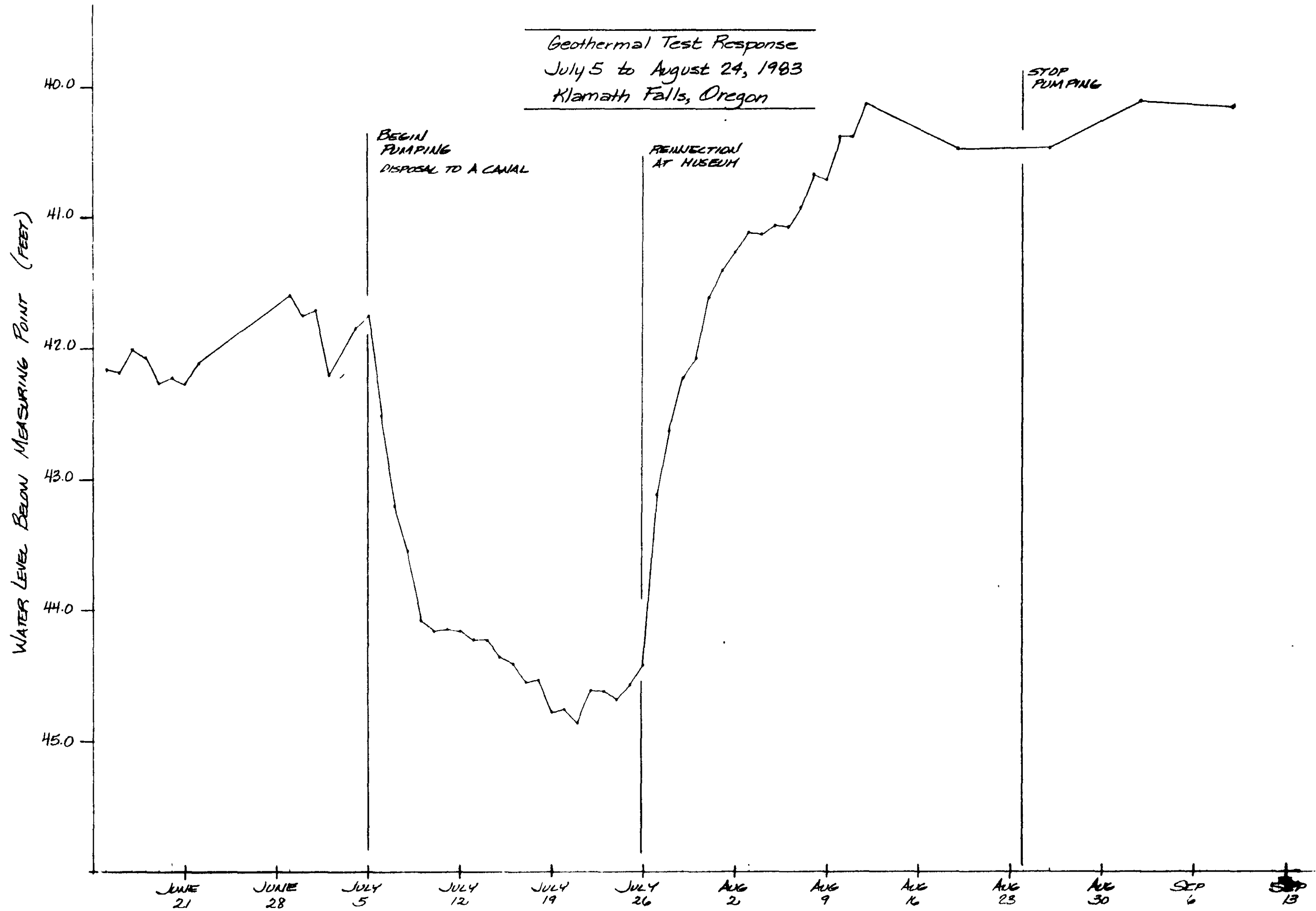


Figure 3-11. -- Water levels measured during the pumping and injection test

#166 Card 1902 Esplanade	Stevens Recorder	Distance to production well:	2,380 ft.
		Distance to injection well:	1,620 ft.
		Depth:	613 ft.

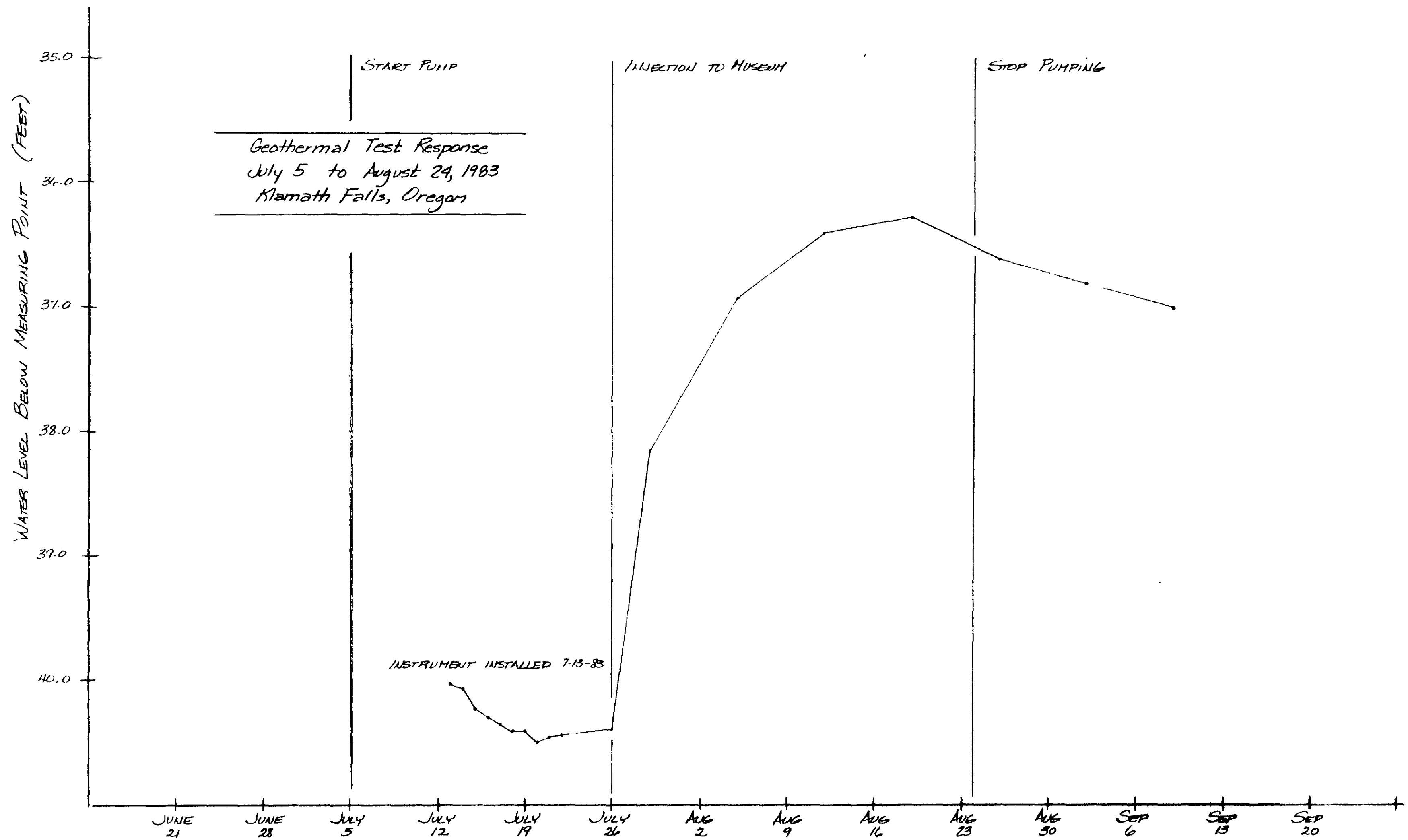


Figure 3-12. -- Water levels measured during the pumping and injection test

#178 Phillips 1945 Auburn St.	Stevens Recorder	Distance to production well:	2,000 ft.
		Distance to injection well:	1,600 ft.
		Depth:	360 ft.

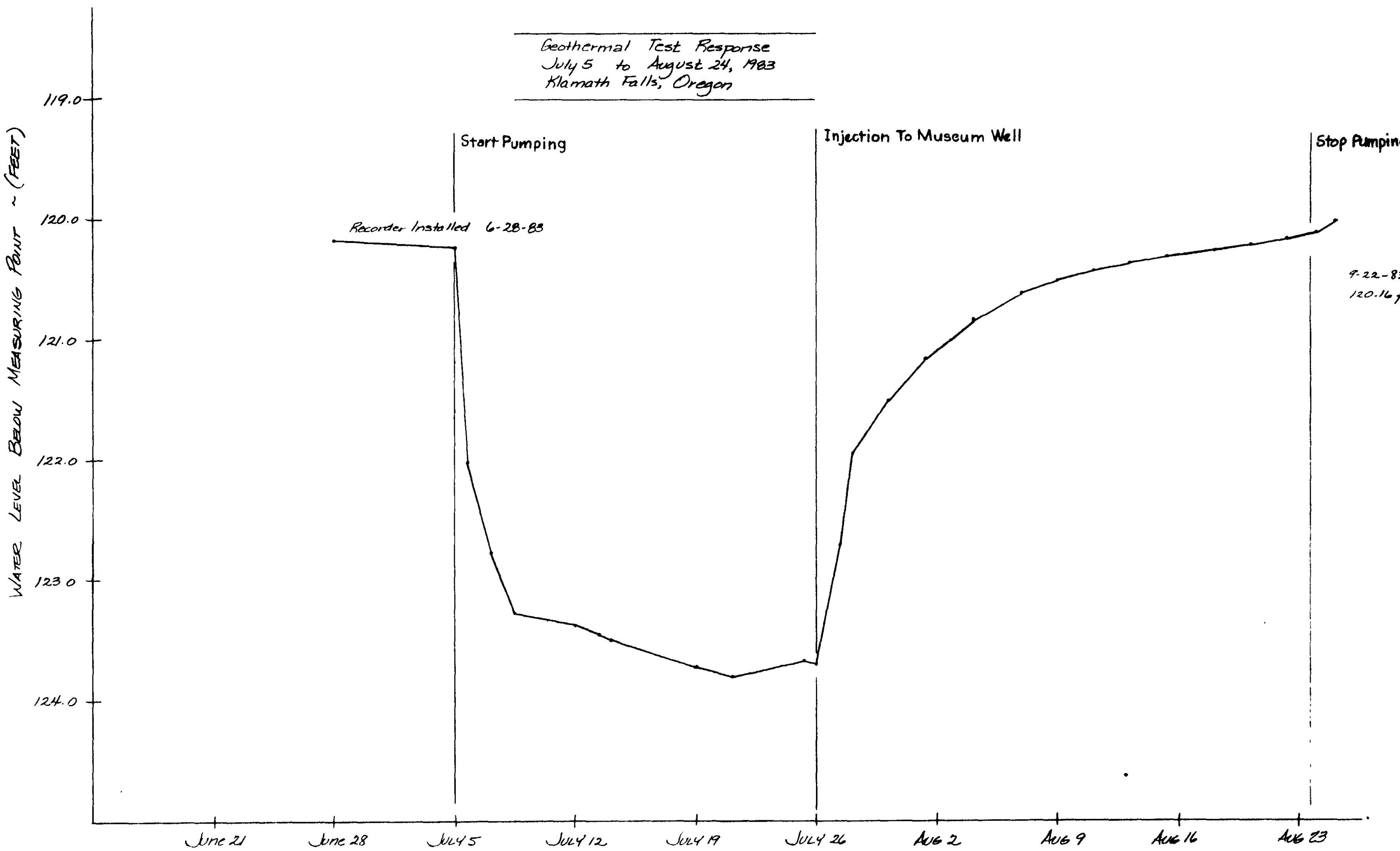


Figure 3-13. -- Water levels measured during the pumping and injection test

#261 Olson 516 Old Fort Rd.	Stevens Recorder	Distance to production well: Distance to injection well: Depth:	1,620 ft. 4,050 ft. 975 ft.

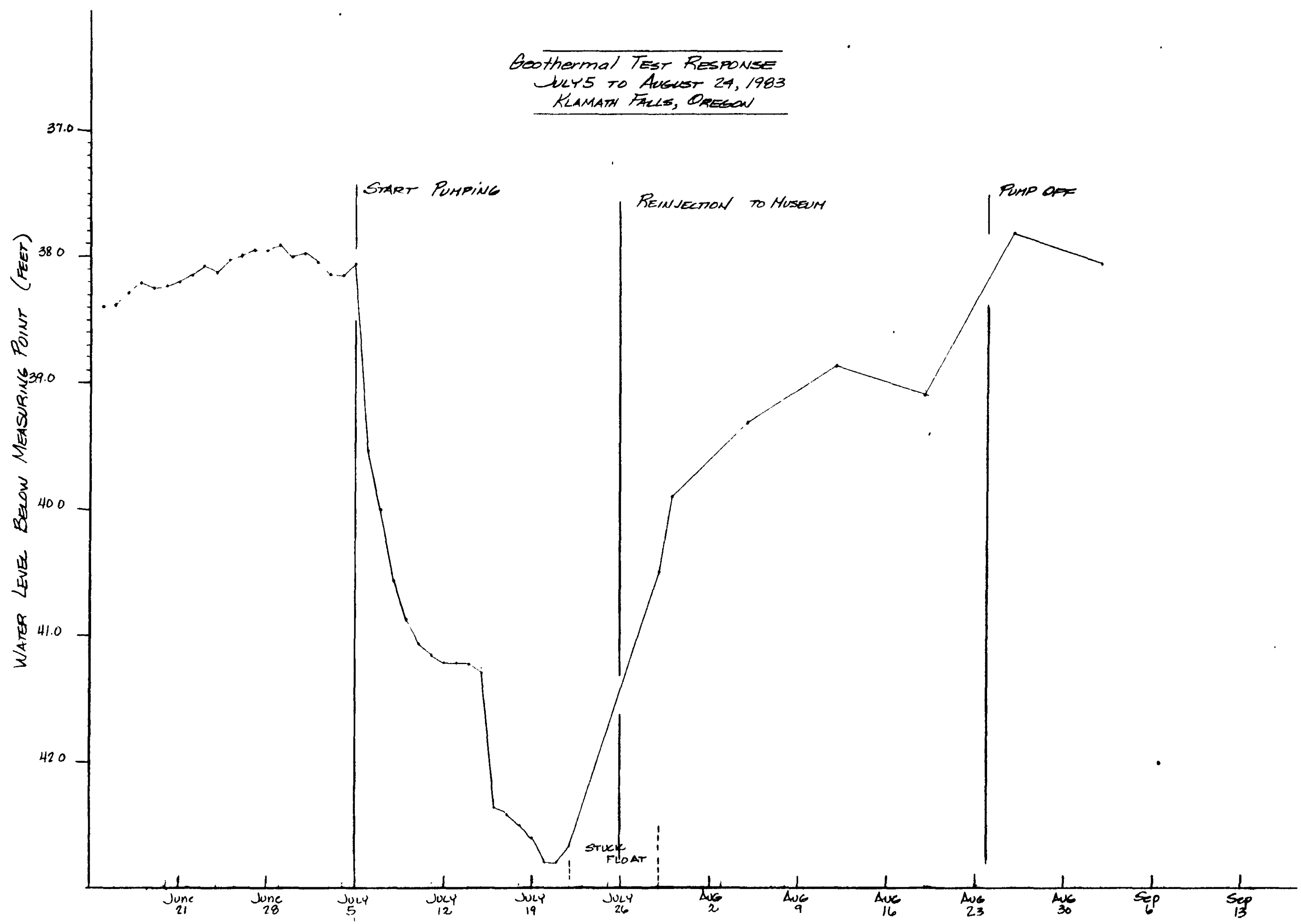


Figure 3-14. -- Water levels measured during the pumping and injection test

#273 Eck 2130 Herbert	Stevens Recorder	Distance to production well:	360 ft.
		Distance to injection well:	2,500 ft.
		Depth:	199 ft.

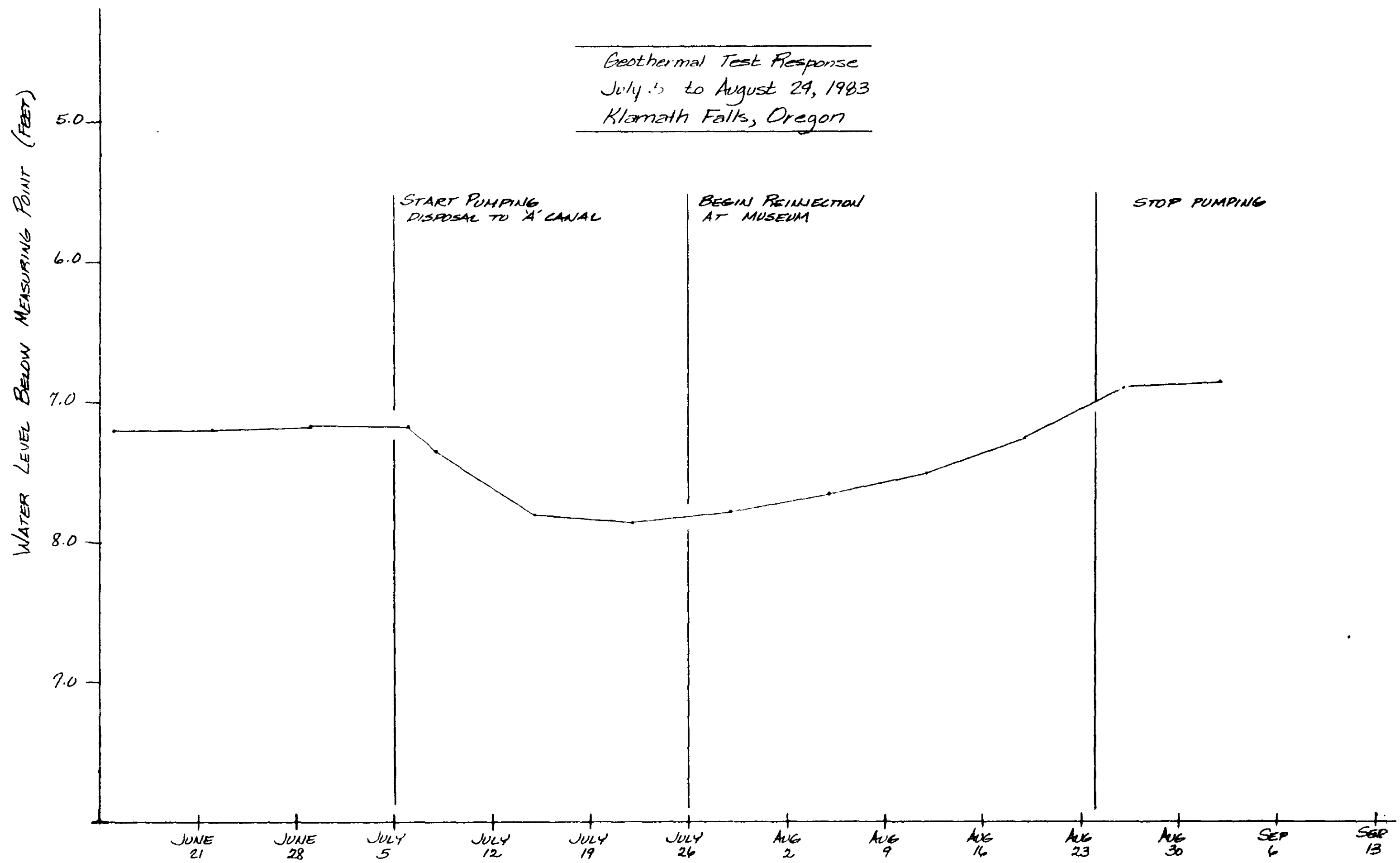


Figure 3-15. -- Water levels measured during the pumping and injection test

#274 Zion Church Eleventh St.	Stevens Recorder	Distance to production well:	3,990 ft.
		Distance to injection well:	1,340 ft.
		Depth:	838 ft.

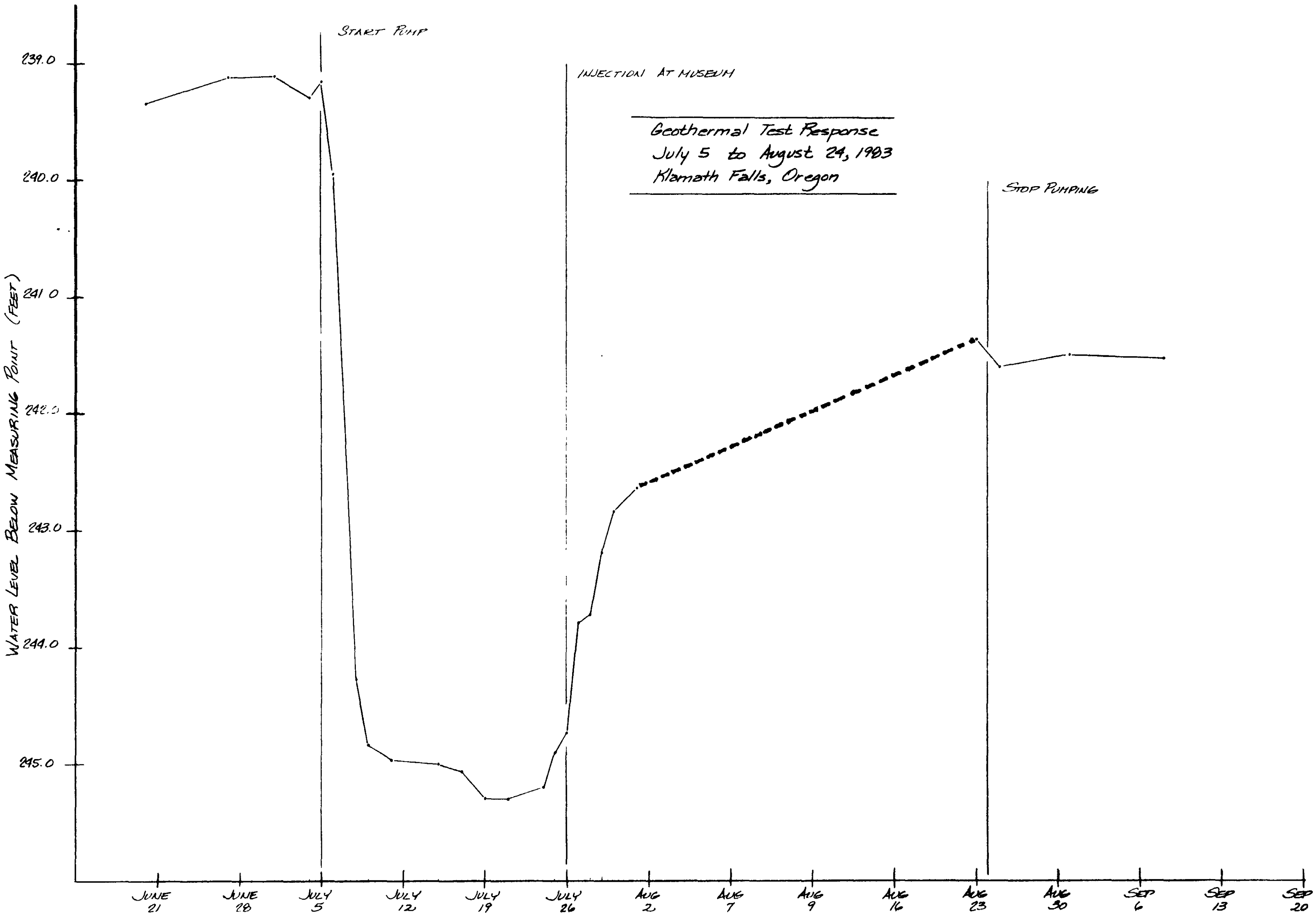


Figure 3-16. -- Water levels measured during the pumping and injection test

#19 Glidden 1800 Fairmount	Hand measurement	Distance to production well:	6,380 ft.
		Distance to injection well:	6,290 ft.
		Depth:	638 ft.

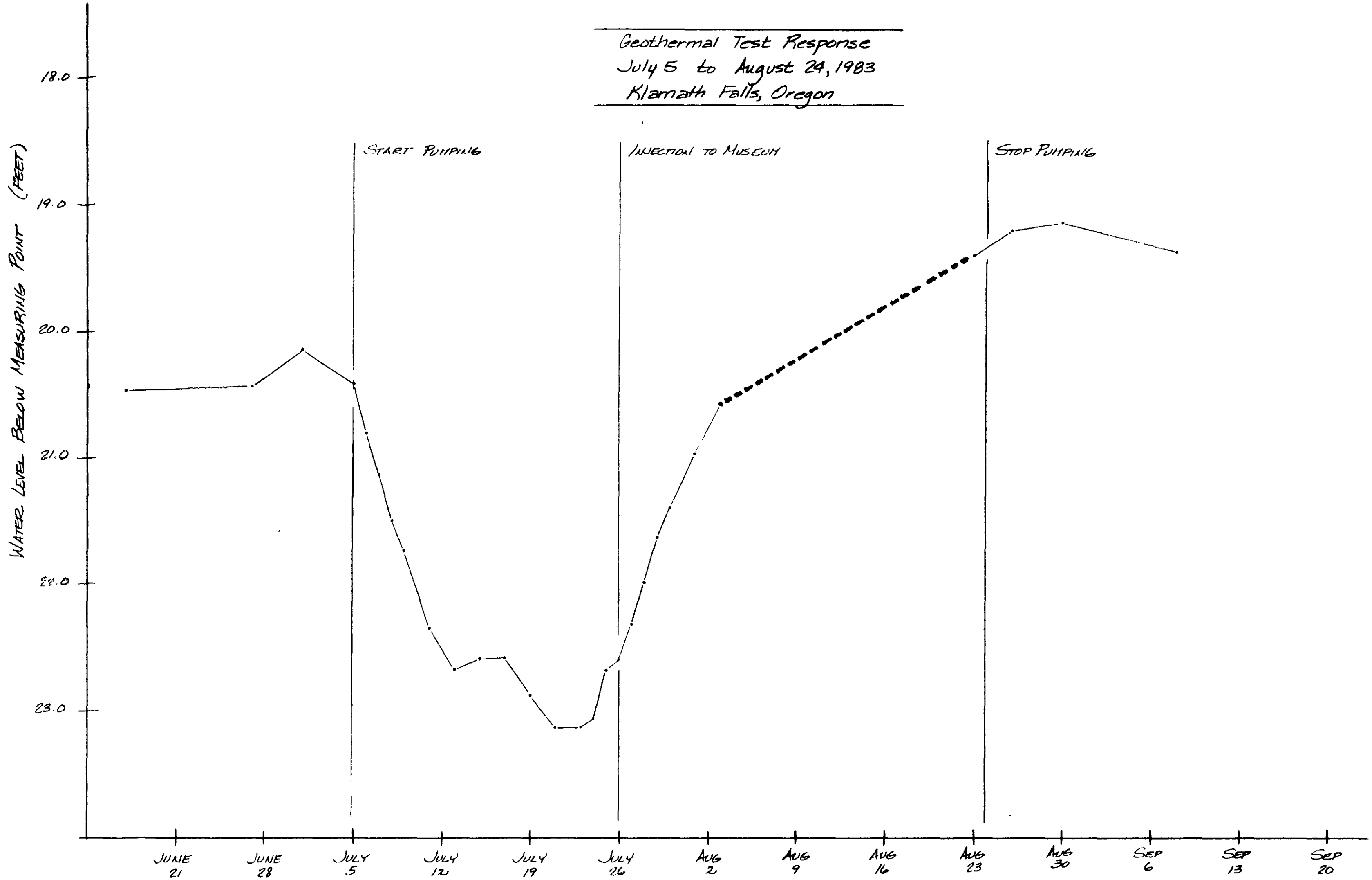


Figure 3-17. -- Water levels measured during the pumping and injection test

#22 Thexton 235 N. Alameda	Hand measurement	Distance to production well:	1,250 ft.
		Distance to injection well:	1,460 ft.
		Depth:	254 ft.

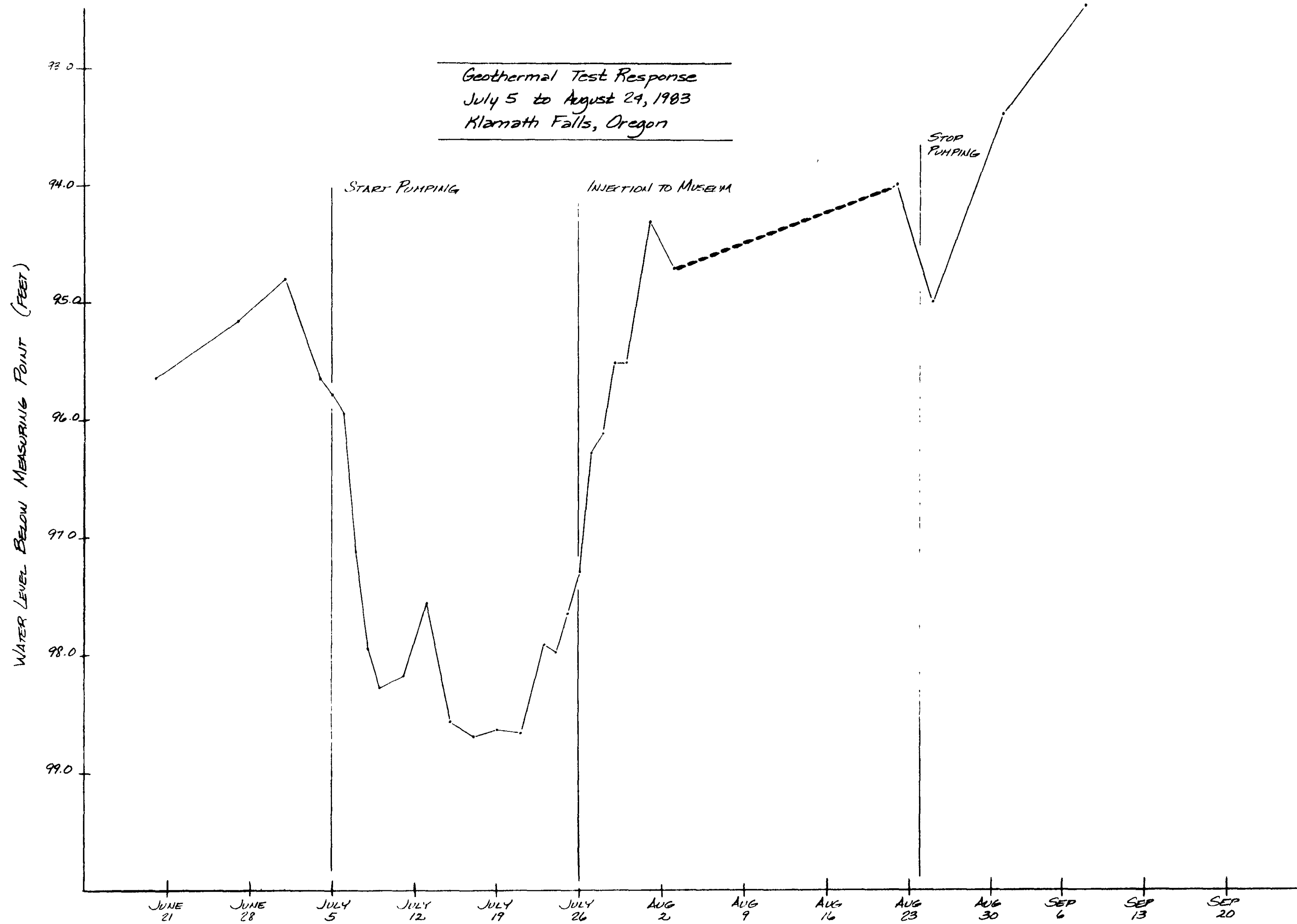


Figure 3-18 -- Water levels measured during the pumping and injection test

#51 Bailey 1850 Lowell St.	Hand measurement	Distance to production well:	5,600 ft.
		Distance to injection well:	4,730 ft.
		Depth:	625 ft.

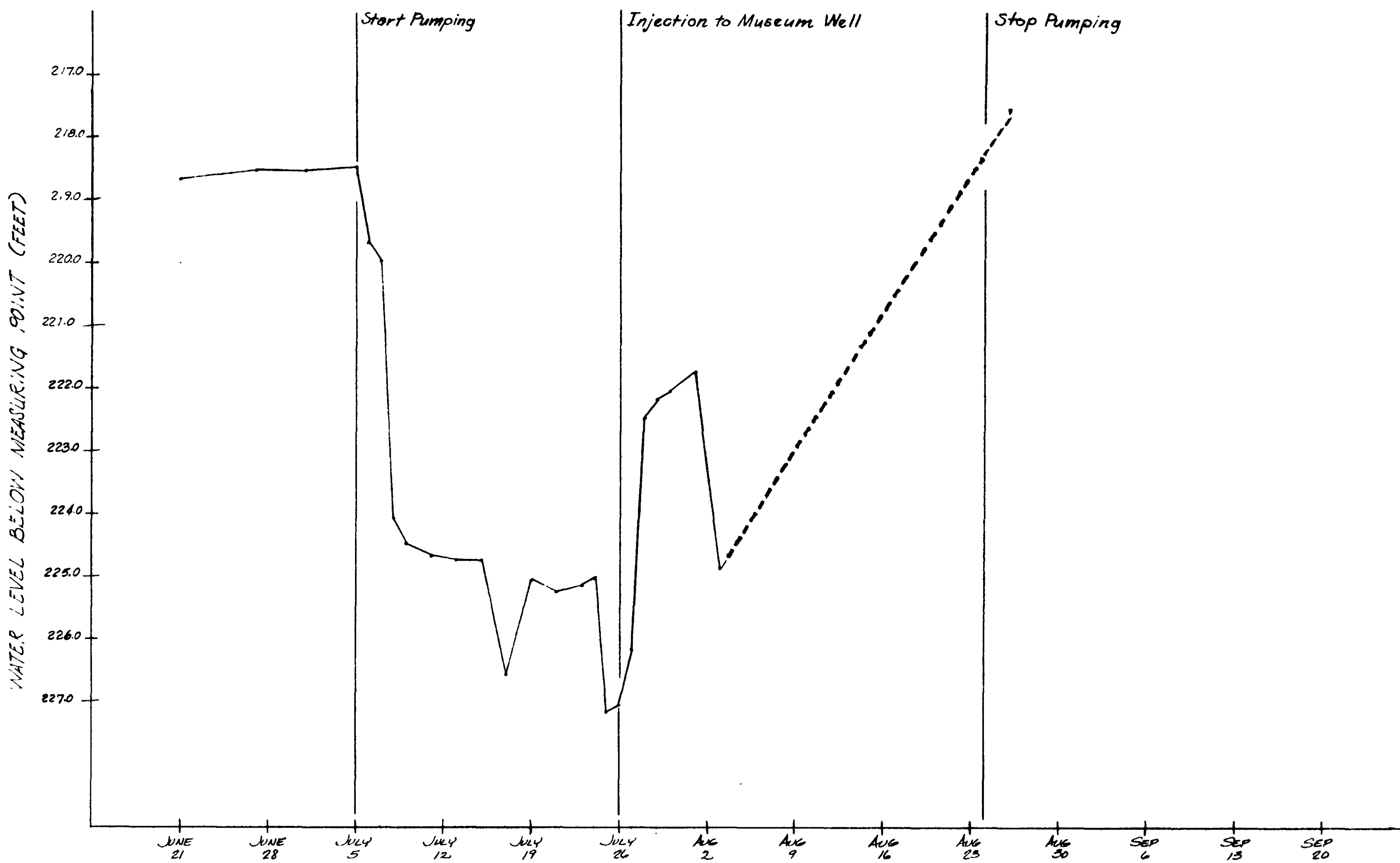


Figure 3-19. -- Water levels measured during the pumping and injection test

#124 Hardt/Davis 535 Laguna	Hand measurement	Distance to production well:	1,350 ft.
		Distance to injection well:	2,780 ft.
		Depth:	997 ft.

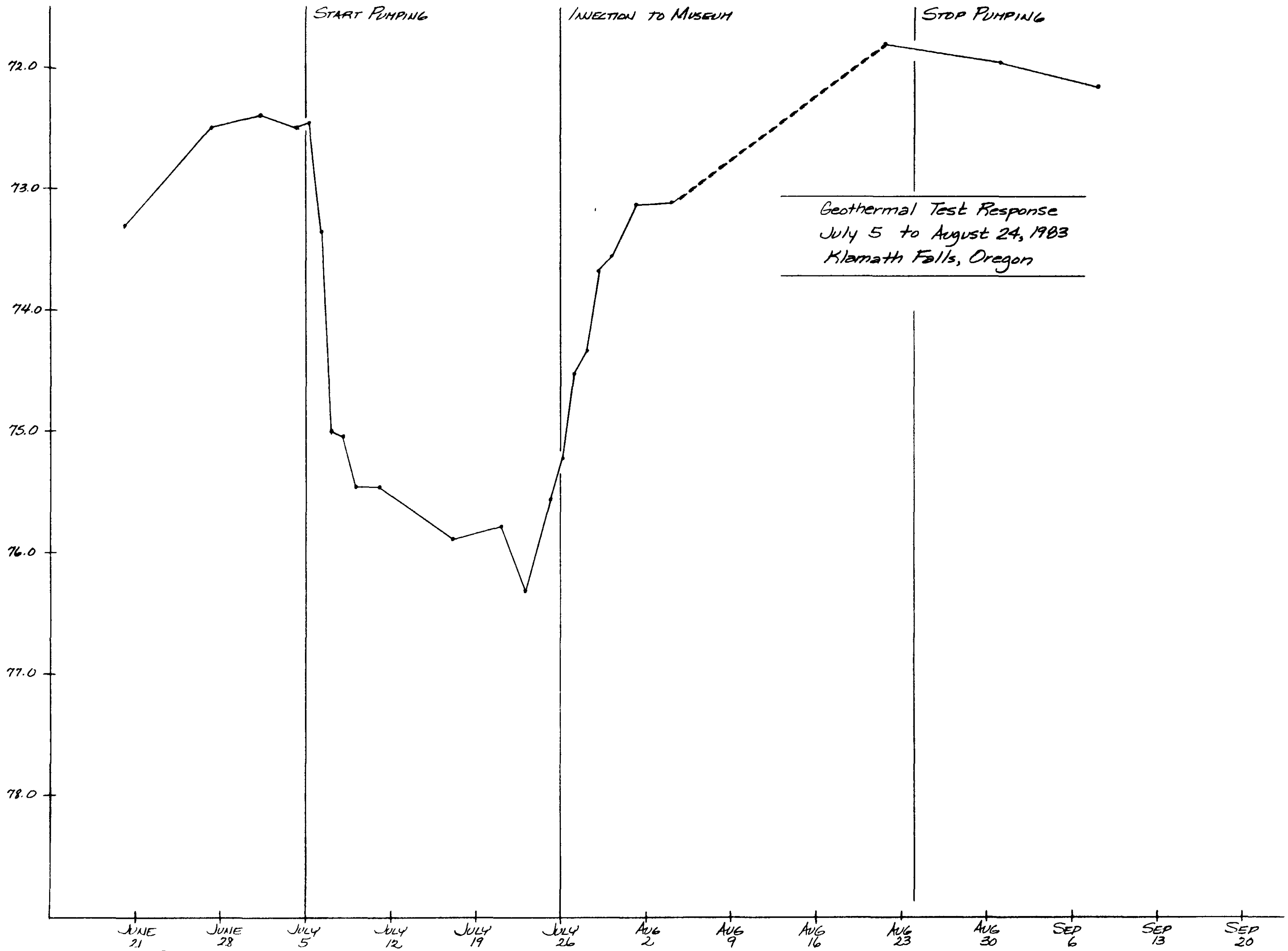


Figure 3-20. -- Water levels measured during the pumping and injection test

#135 Ross 1879 Del Moro	Hand measurement	Distance to production well:	4,600 ft.
		Distance to injection well:	3,850 ft.
		Depth:	152 ft.

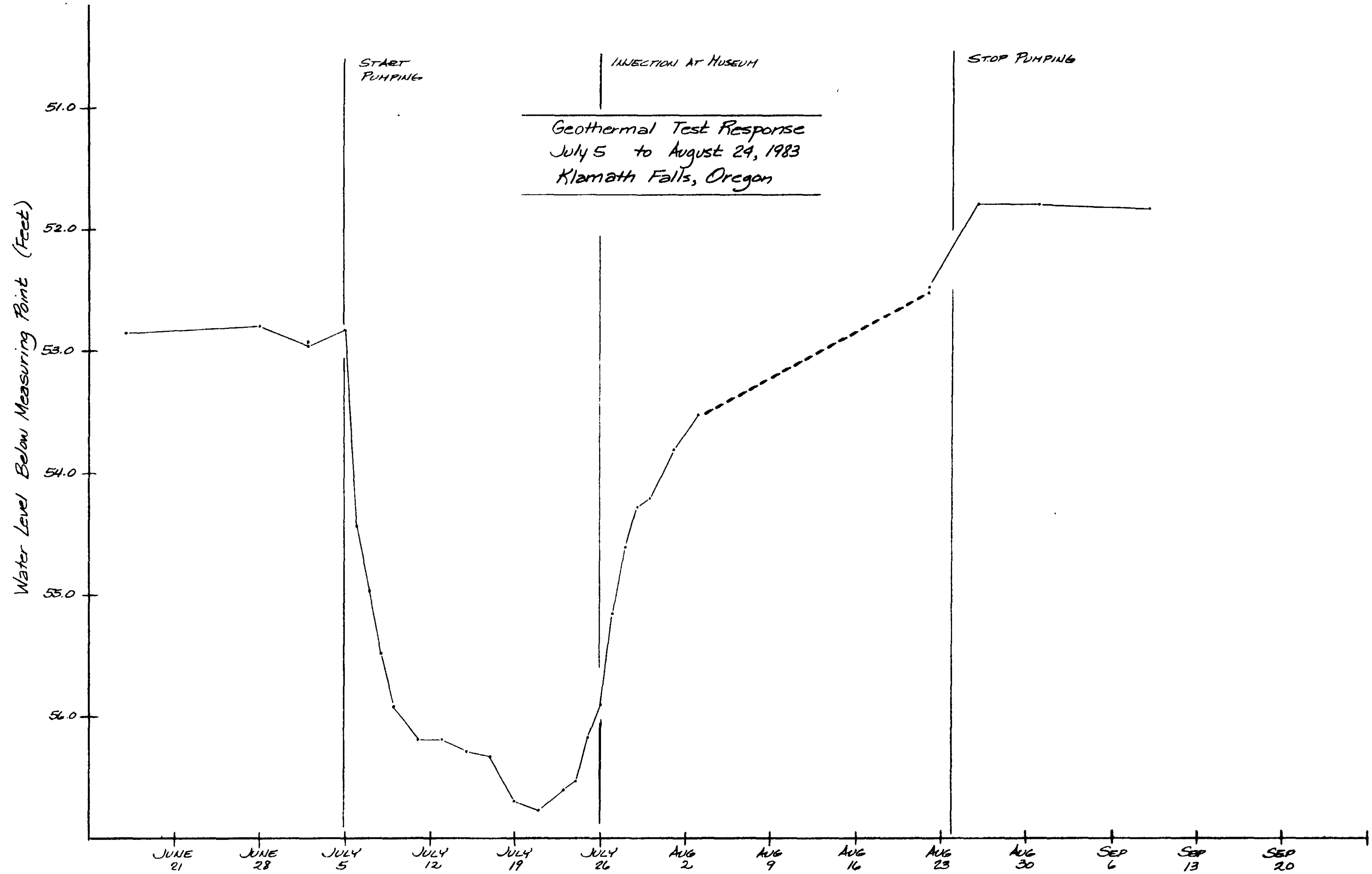


Figure 3-21. -- Water levels measured during the pumping and injection test

#186 Fillmore 212 Hillside	Hand measurement	Distance to production well:	500 ft.
		Distance to injection well:	2,200 ft.
		Depth:	150 ft.

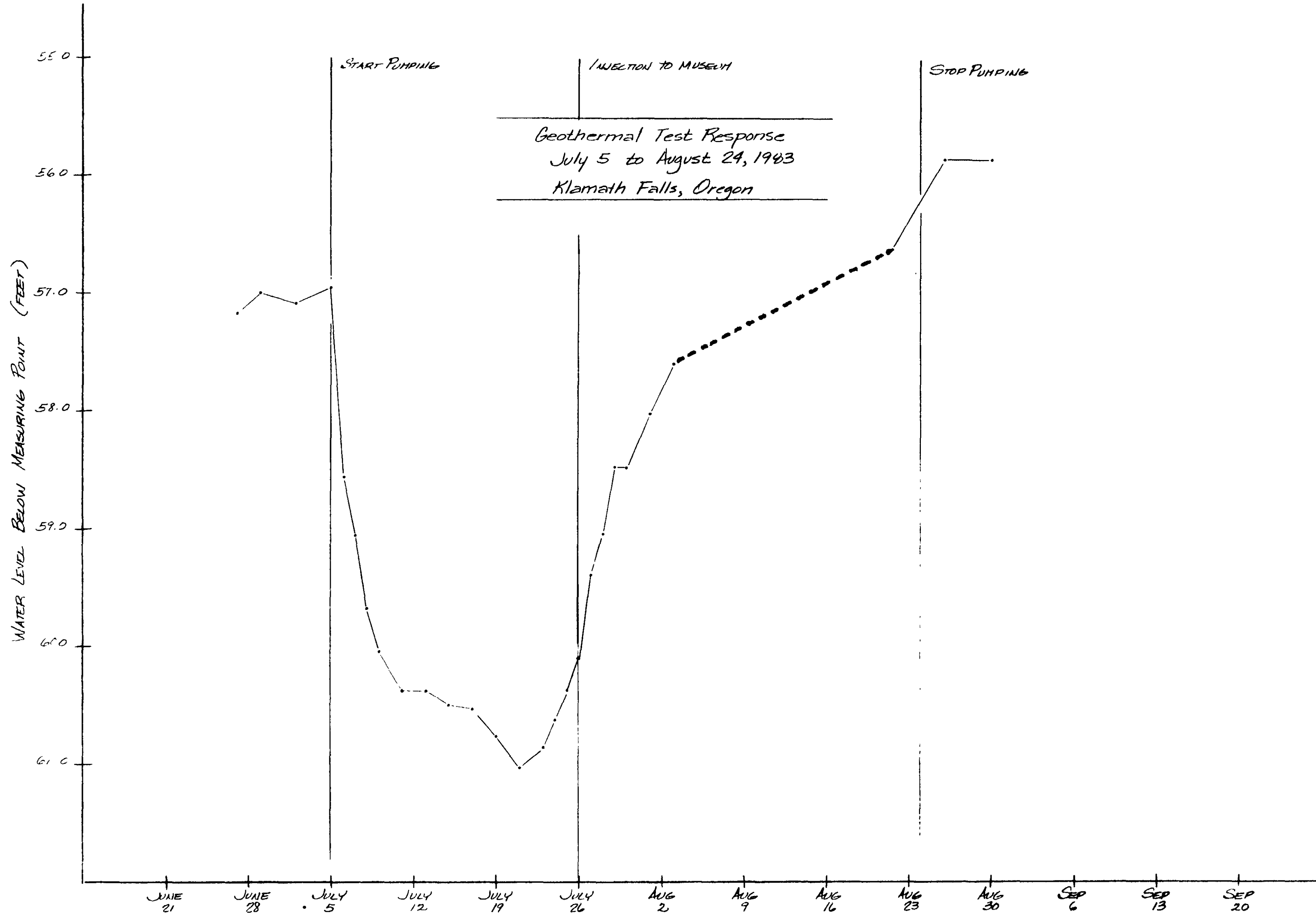


Figure 3-22. -- Water levels measured during the pumping and injection test

#194 Terrier 234 Laguna	Hand measurement	Distance to production well:	140 ft.
		Distance to injection well:	2,560 ft.
		Depth:	240 ft.

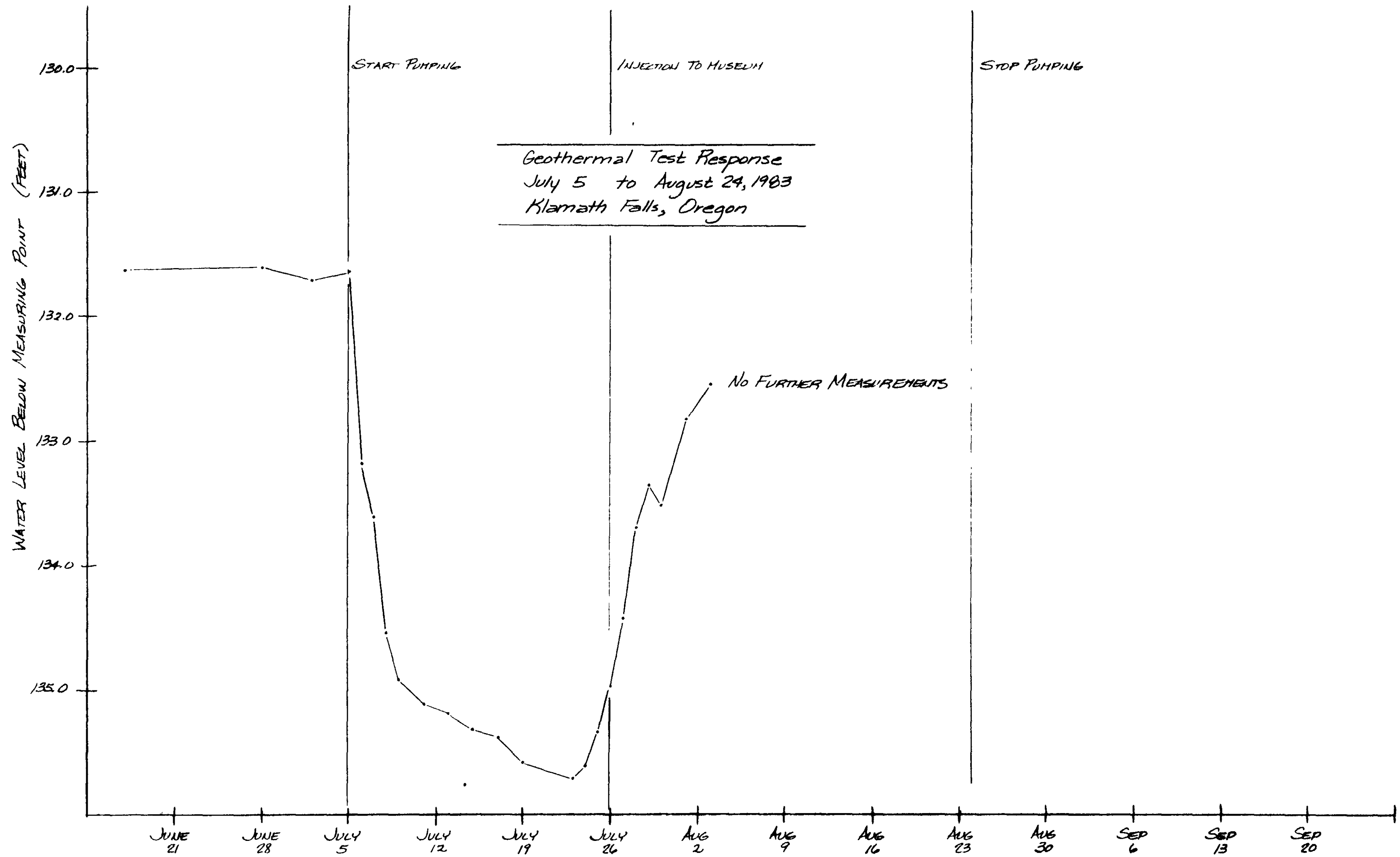


Figure 3-23. -- Water levels measured during the pumping and injection test

#264 Cooper 430 Laguna	Hand measurement	Distance to production well:	960 ft.
		Distance to injection well:	2,540 ft.
		Depth:	268 ft.

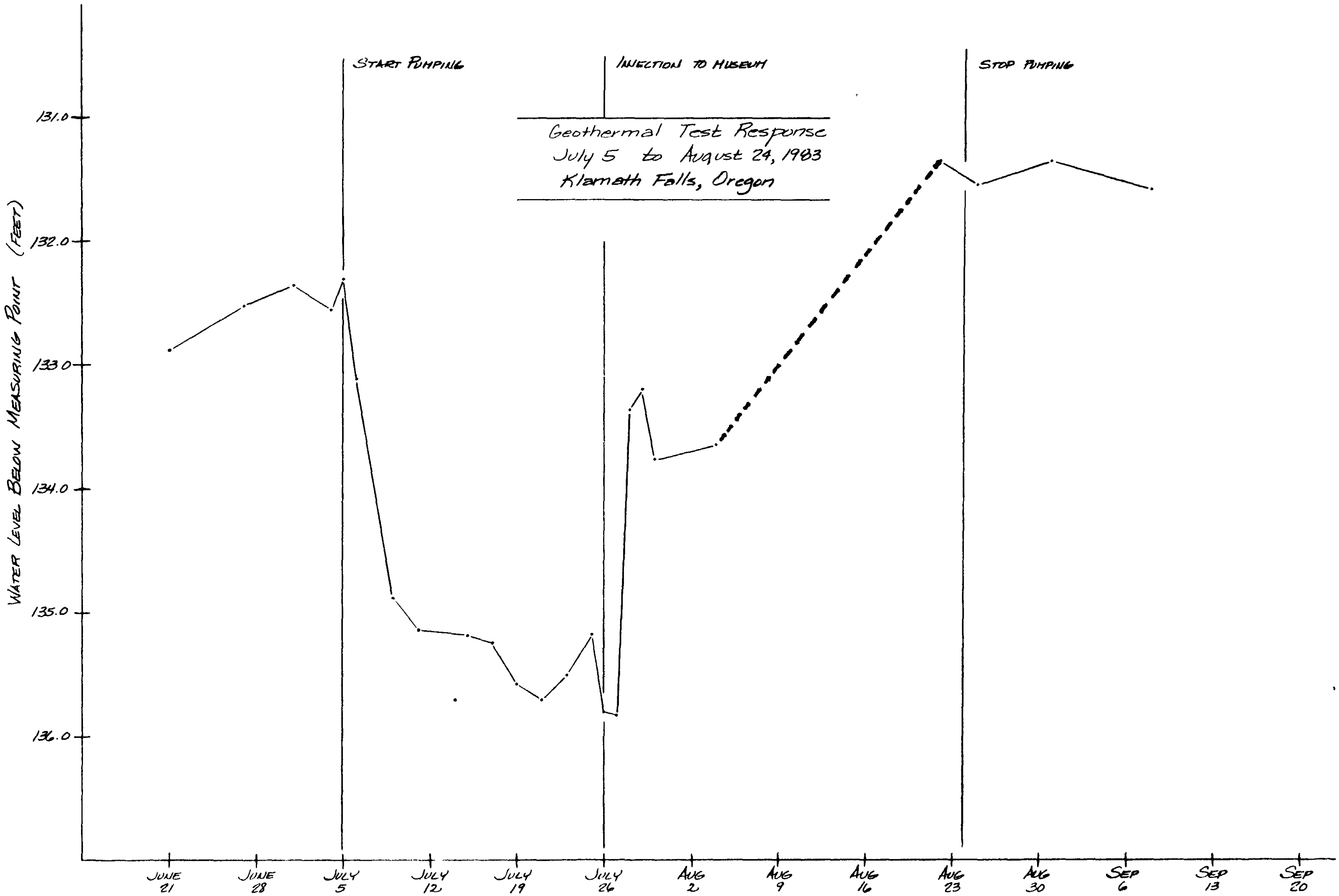


Figure 3-24. -- Water levels measured during the pumping and injection test

#294 Spielman 1500 Pacific Terrace	Hand measurement	Distance to production well:	5,270 ft.
		Distance to injection well:	4,780 ft.
		Depth:	525 ft.

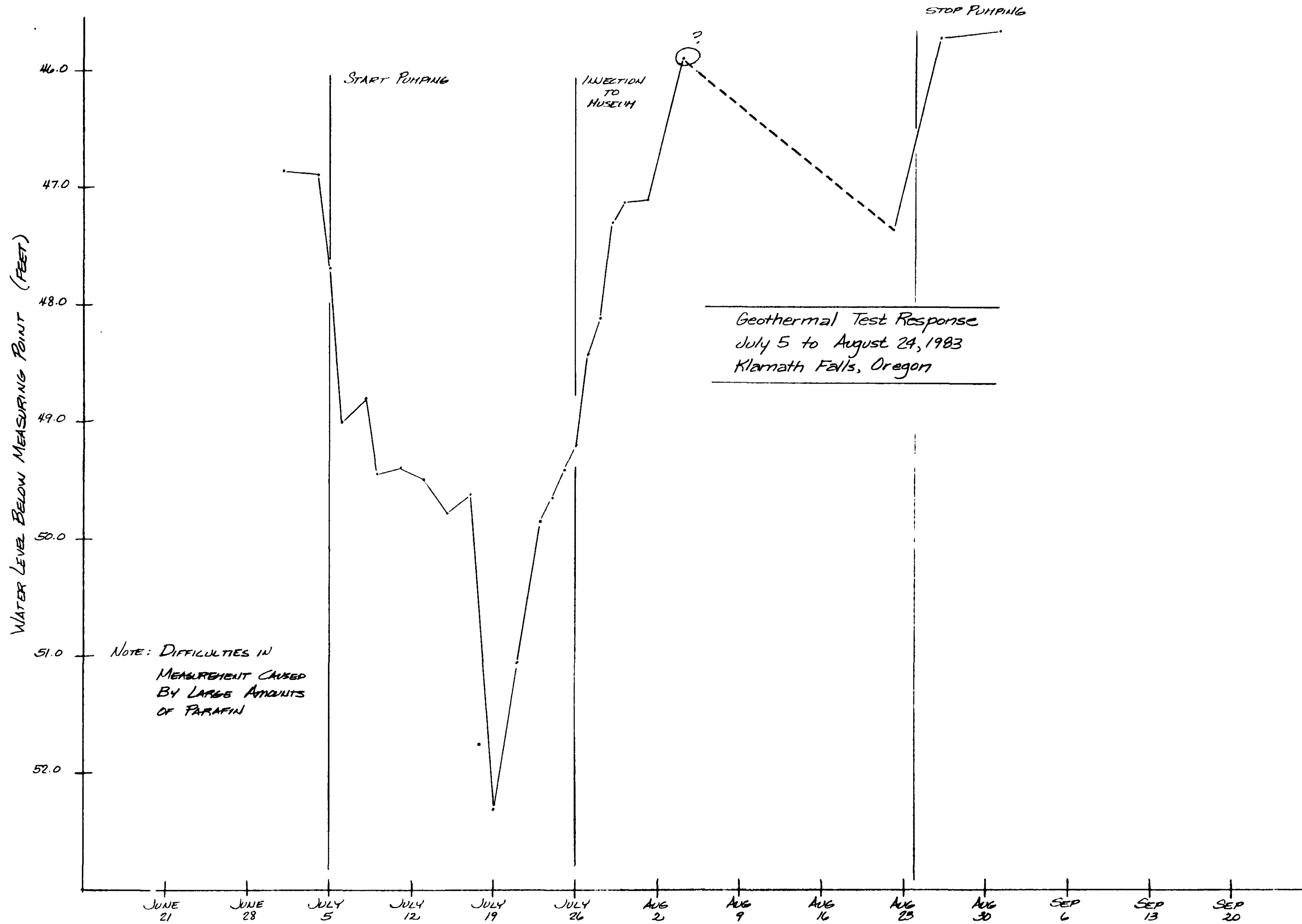


Figure 3-25. -- Water levels measured during the pumping and injection test

#360 Carter 1100 N. Eldorado	Hand measurement	Distance to production well:	4,060 ft.
		Distance to injection well:	3,150 ft.
		Depth:	125 ft.

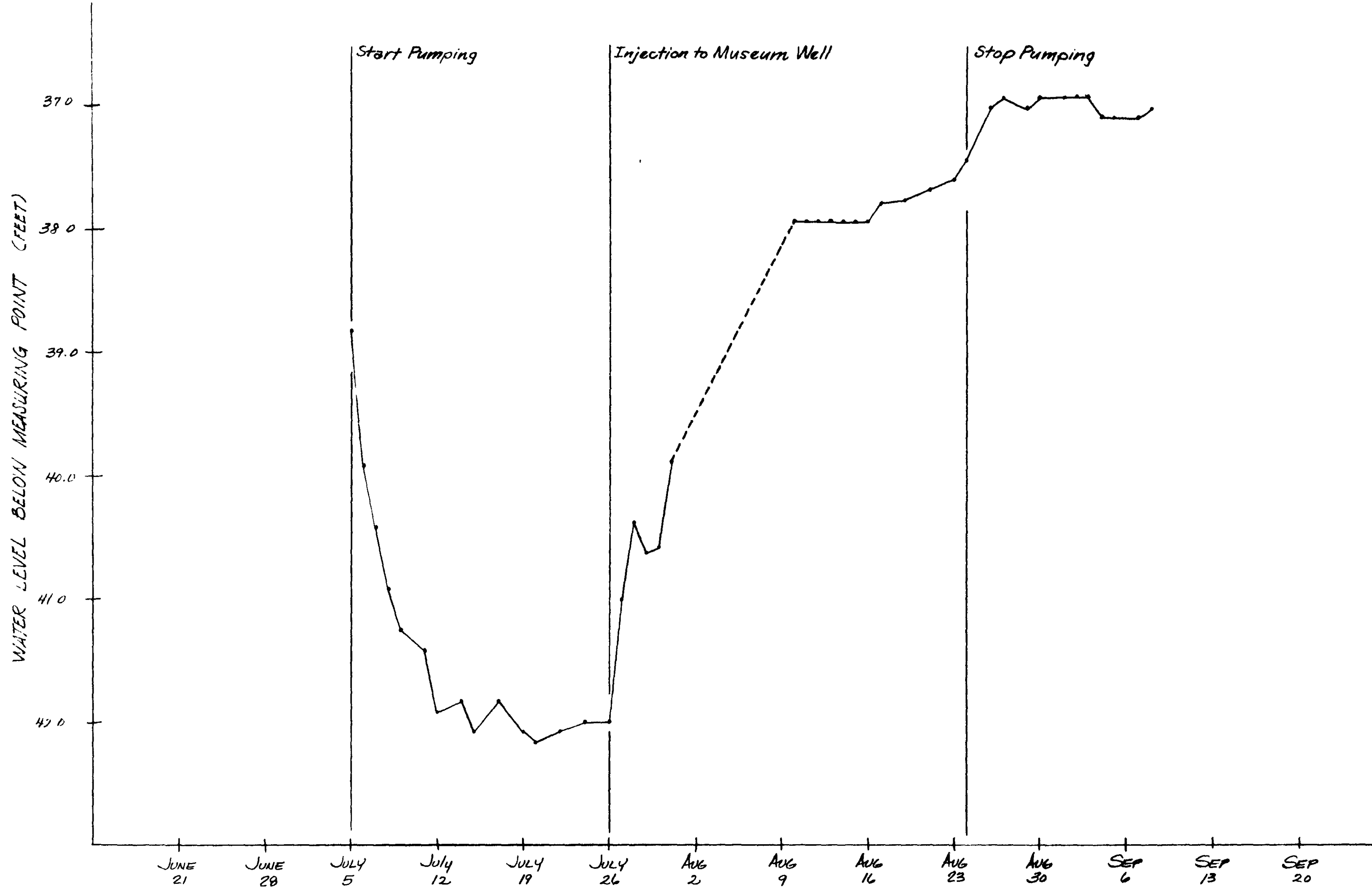


Figure 3-26. -- Water levels measured during the pumping and injection test

#37 Stone 133 Hillside	Owner monitored	Distance to production well:	420 ft.
		Distance to injection well:	2,380 ft.
		Depth:	200 ft.

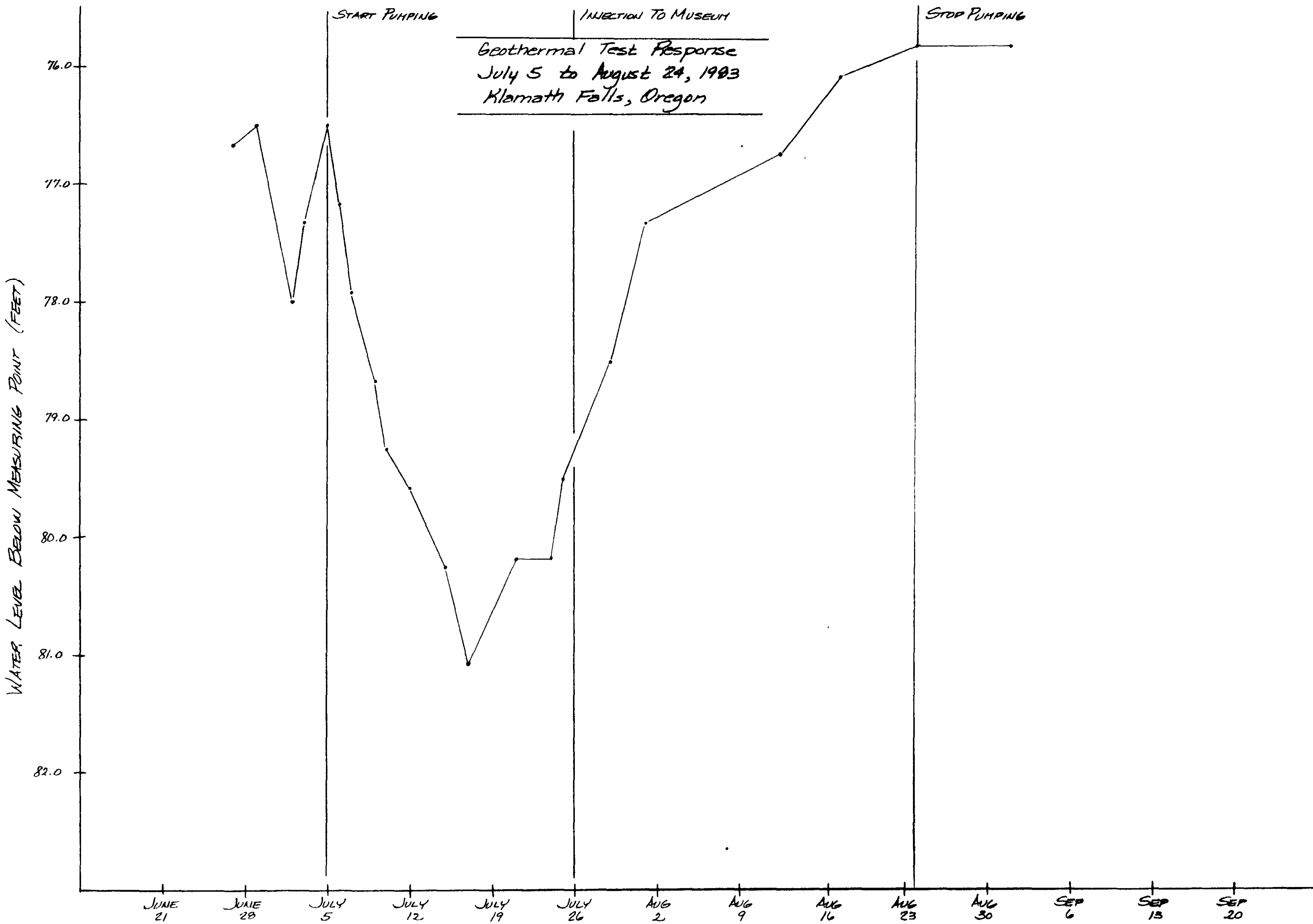


Figure 3-27. -- Water levels measured during the pumping and injection test

#61 Juckeland 2043 Lavey	Owner monitored	Distance to production well: Distance to injection well: Depth:	880 ft. 2,050 ft. 275 ft.

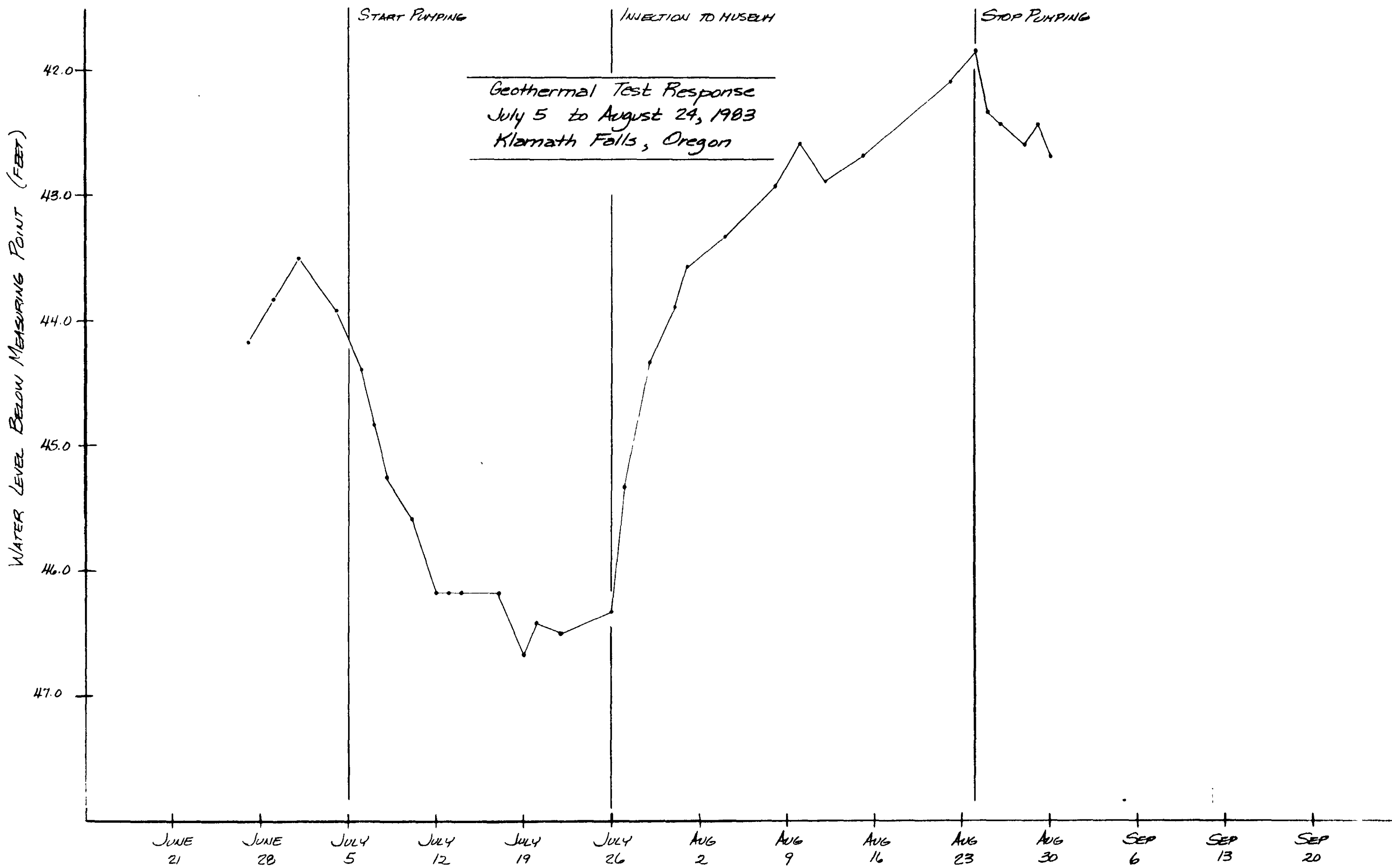


Figure 3-28. -- Water levels measured during the pumping and injection test

#62 Phelps 1868 Fremont	Owner monitored	Distance to production well:	3,950 ft.
		Distance to injection well:	2,980 ft.
		Depth:	126 ft.

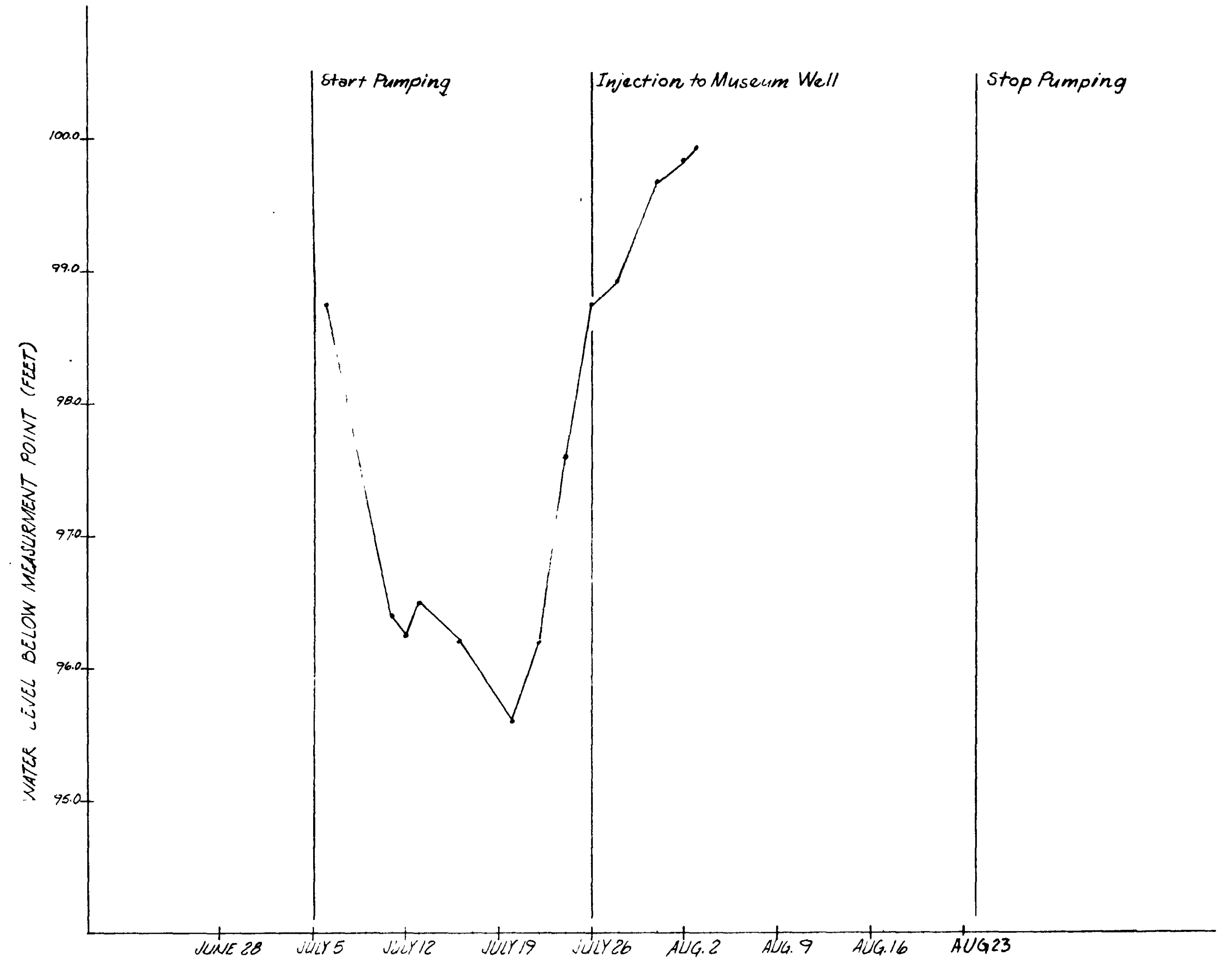


Figure 3-29. -- Water levels measured during the pumping and injection test

#110 East Main St. Apts.	Measured by	Distance to production well:	1,850 ft.
236 E. Main St.	Charles Leib	Distance to injection well:	1,850 ft.
		Depth:	452 ft.

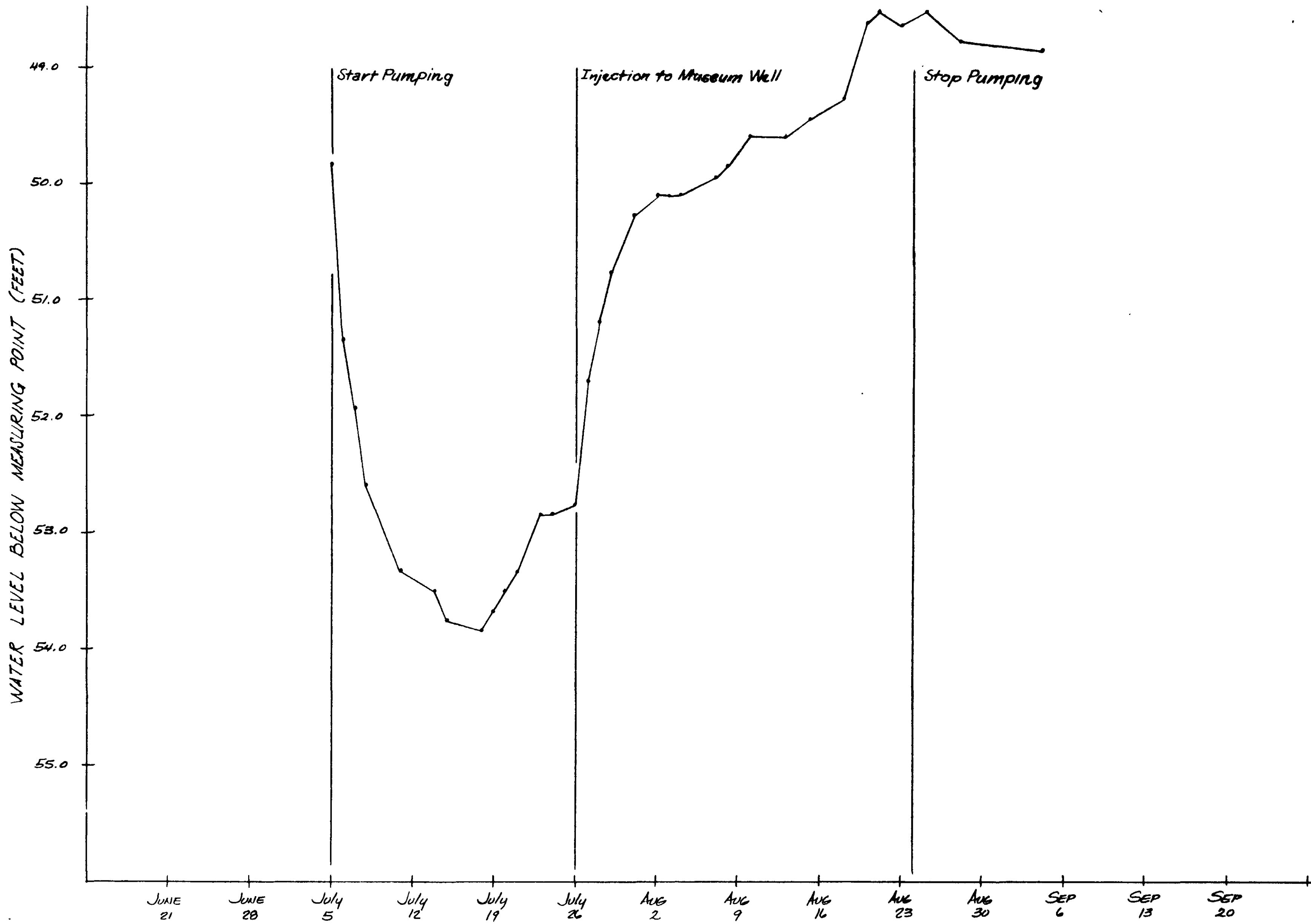


Figure 3-30. -- Water levels measured during the pumping and injection test

#127 Adamcheck	Measured by	Distance to production well:	140 ft.
Laguna and Old Fort Rd.	A. L. Stone	Distance to injection well:	2,640 ft.
		Depth:	233 ft.

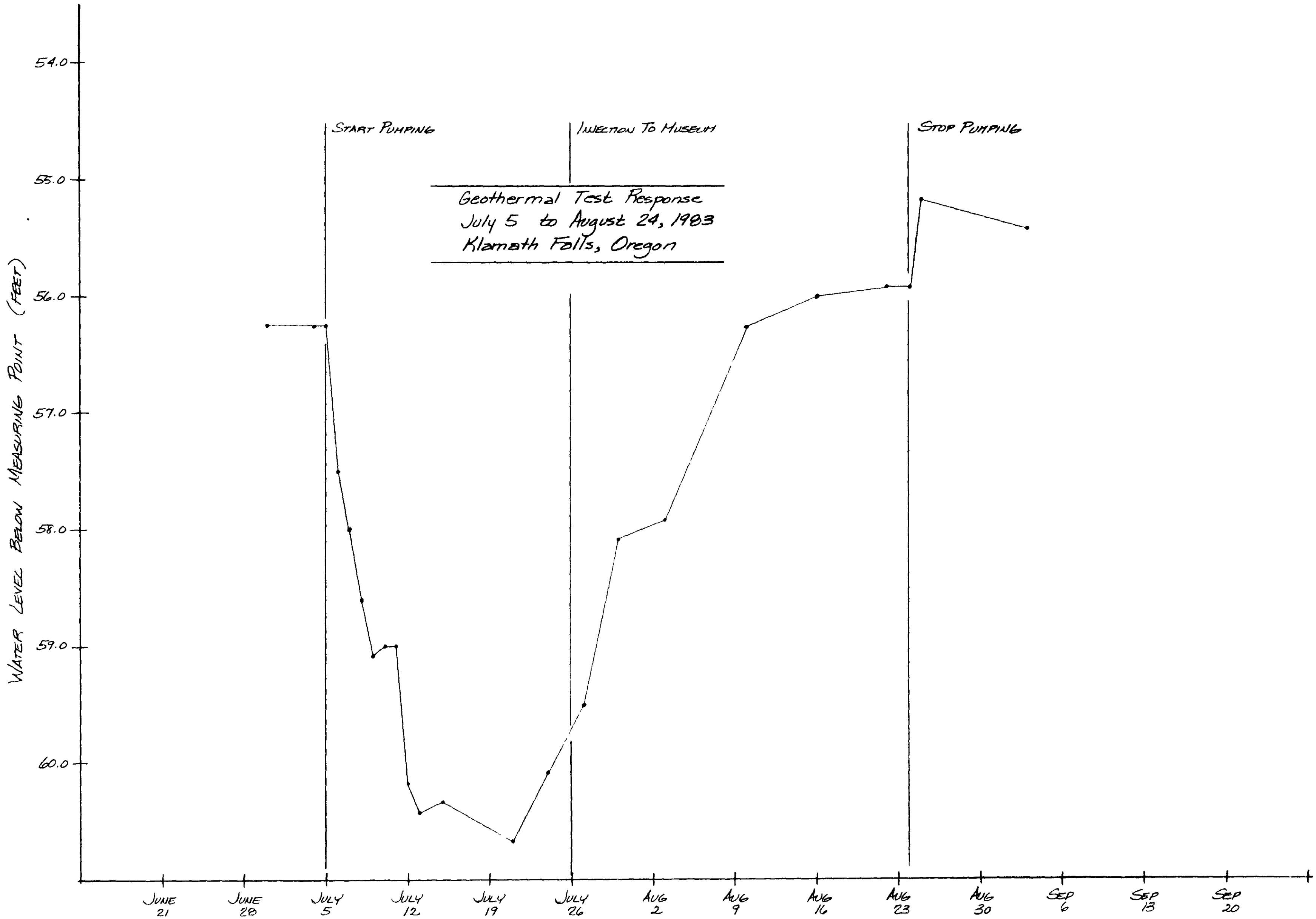


Figure 3-31. -- Water levels measured during the pumping and injection test

#128 Hart 2052 Lavey	Owner monitored	Distance to production well: Distance to injection well: Depth:	810 ft. 2,030 ft. --- ft.

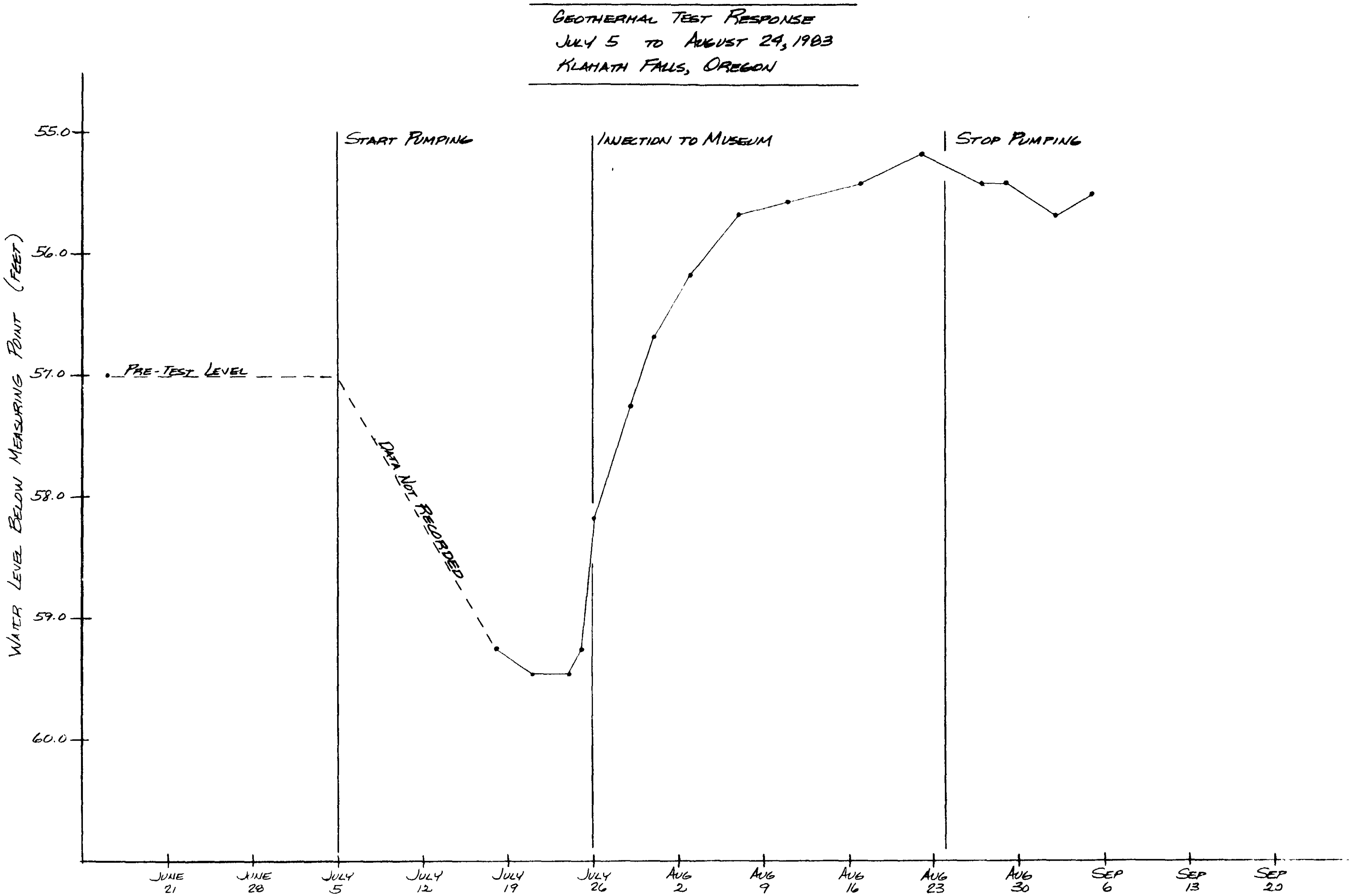


Figure 3-32. -- Water levels measured during the pumping and injection test

#143 Raney 1126 Eldorado	Owner monitored	Distance to production well:	4,190 ft.
		Distance to injection well:	3,310 ft.
		Depth:	152 ft.

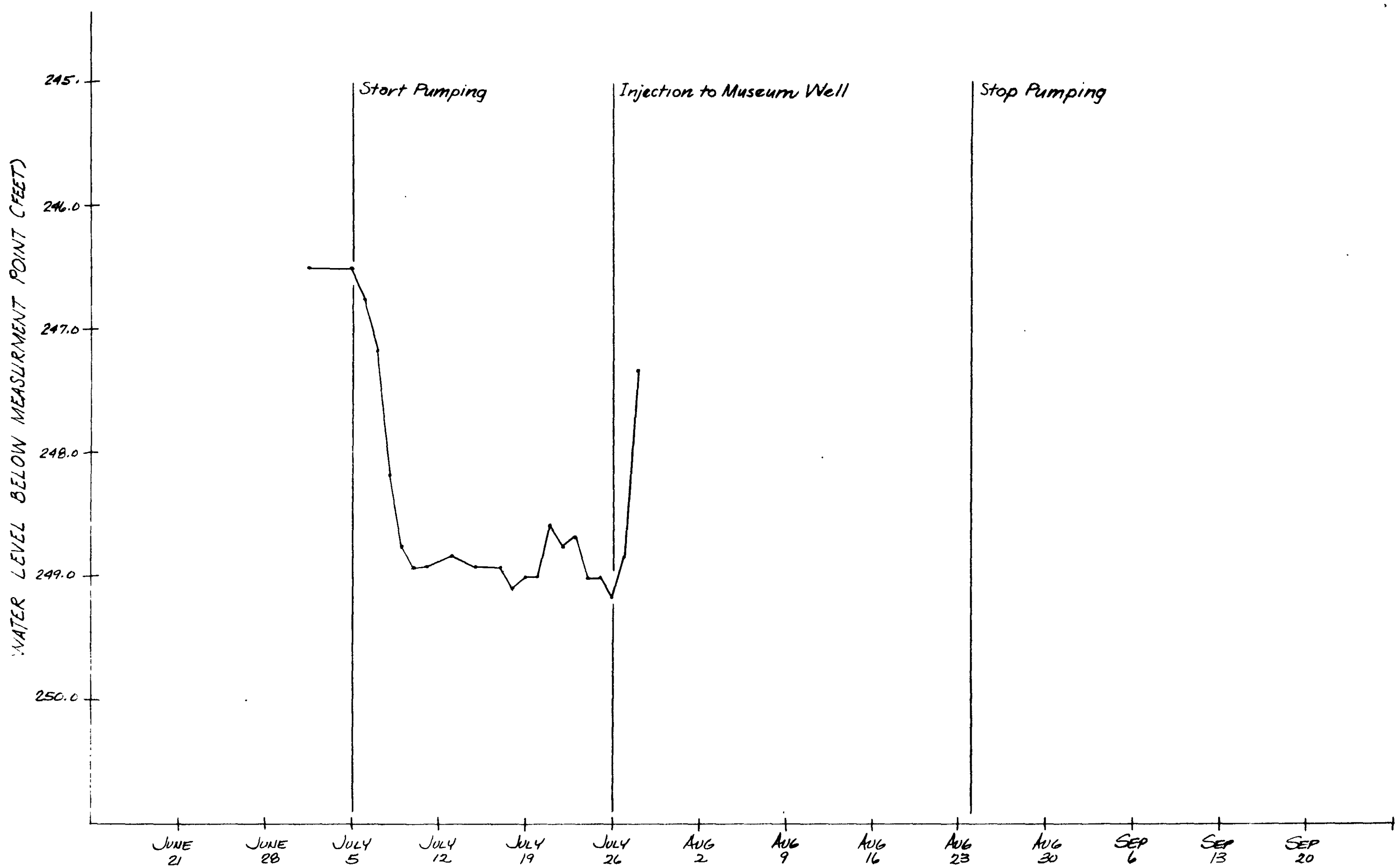


Figure 3-33. -- Water levels measured during the pumping and injection test

#157 Heaton & Wardell 700 Loma Linda	Owner monitored	Distance to production well: Distance to injection well: Depth:	2,030 ft. 2,890 ft. 455 ft.

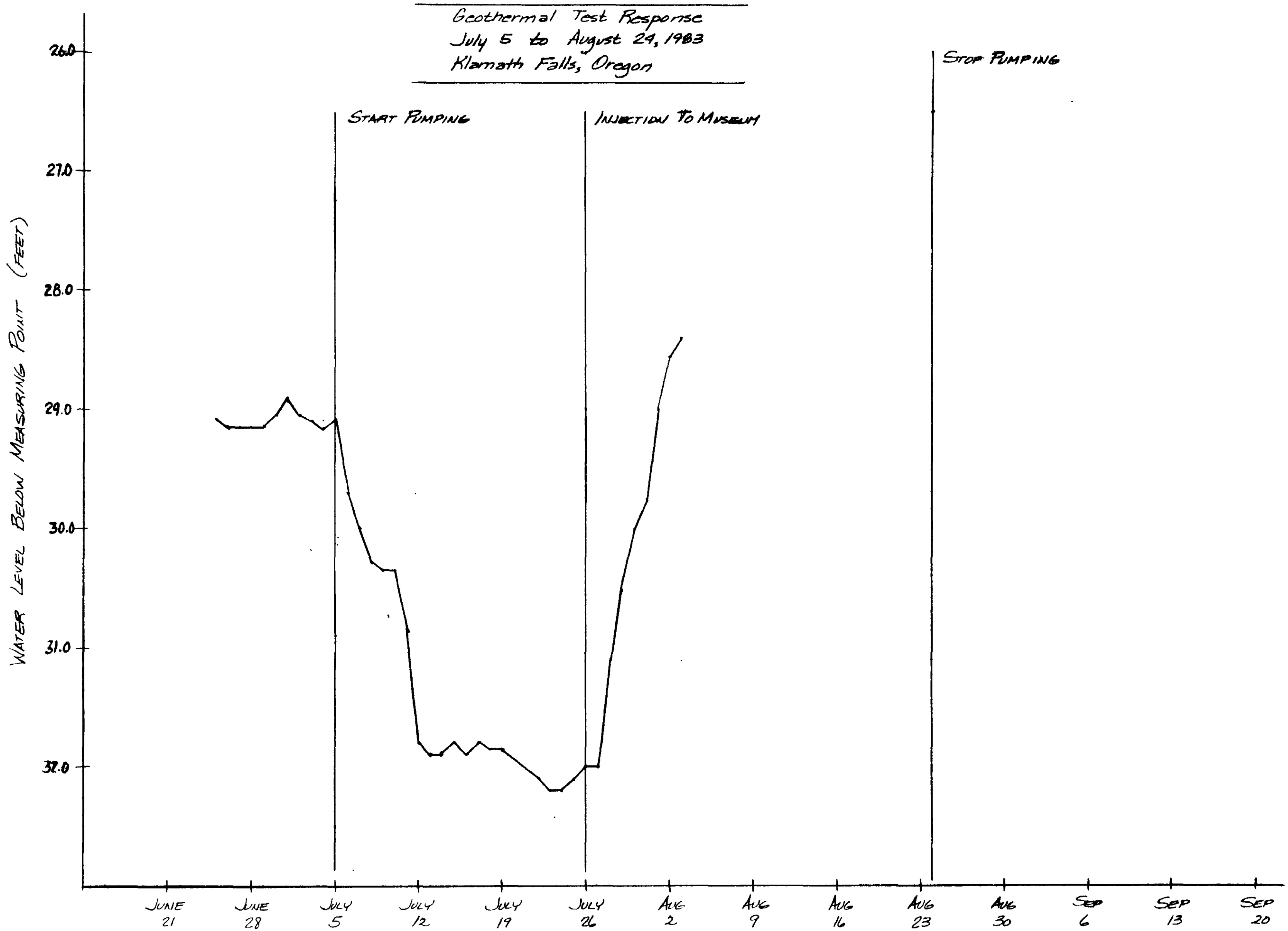


Figure 3-34. -- Water levels measured during the pumping and injection test

#165 Mathews 1832 Earle	Owner monitored	Distance to production well:	2,800 ft.
		Distance to injection well:	1,570 ft.
		Depth:	180 ft.

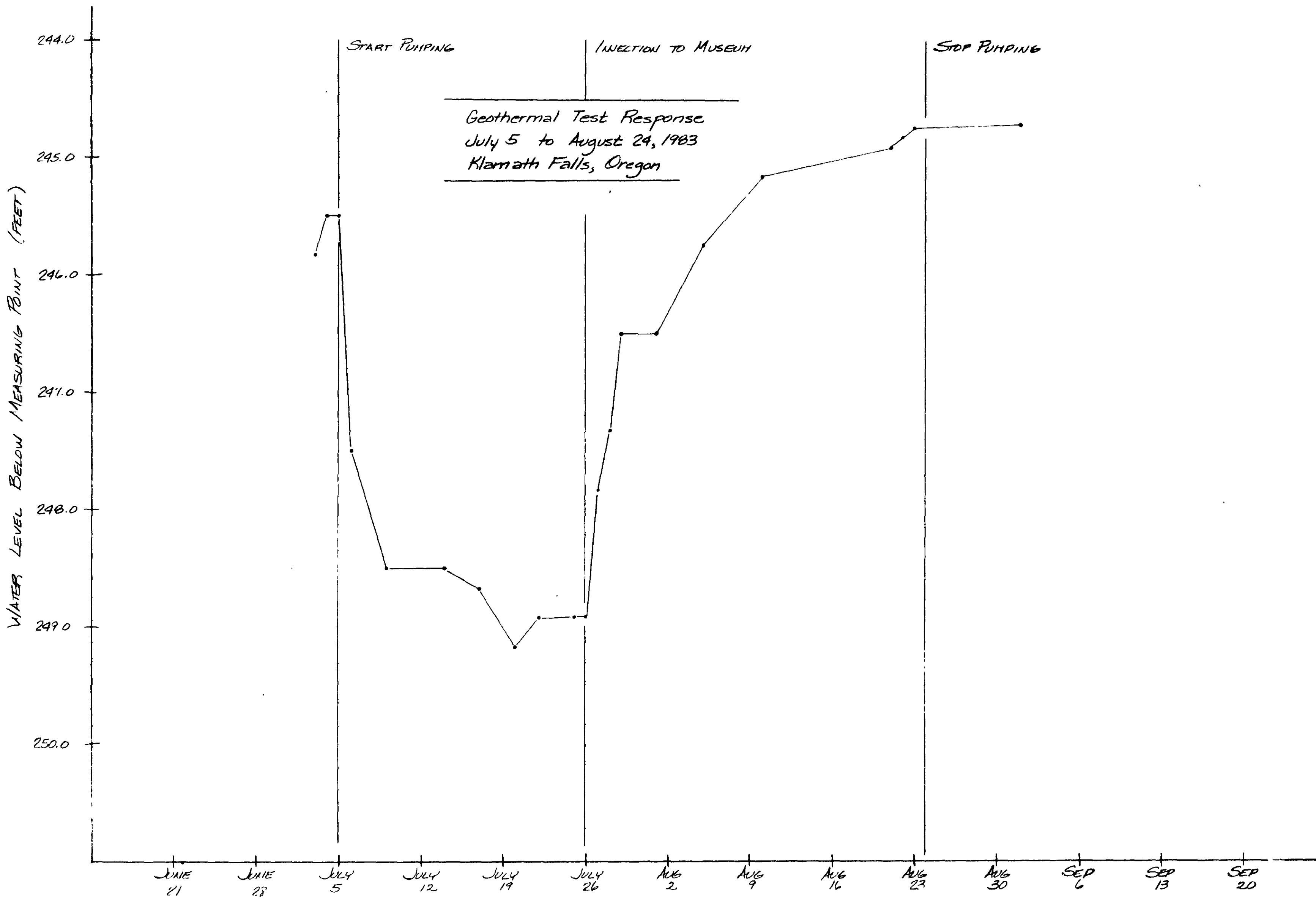


Figure 3-35. -- Water levels measured during the pumping and injection test

#170 Lawrence 2384 Linda Vista	Owner monitored	Distance to production well:	1,420 ft.
		Distance to injection well:	2,920 ft.
		Depth:	805 ft.

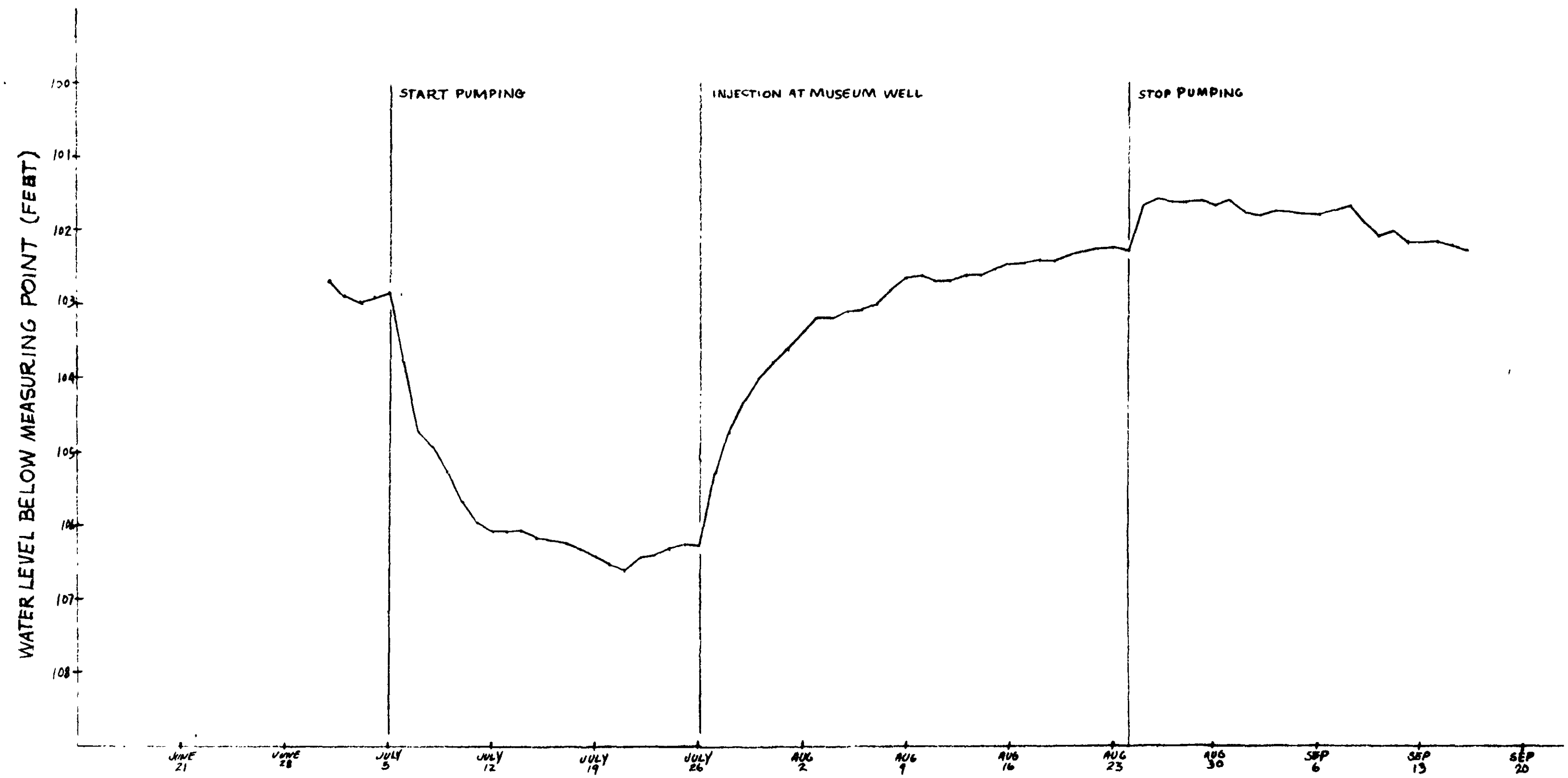


Figure 3-36. -- Water levels measured during the pumping and injection test

#181 Hessig 410 Hillside	Owner monitored	Distance to production well: Distance to injection well: Depth:	990 ft. 2,220 ft. 163 ft.

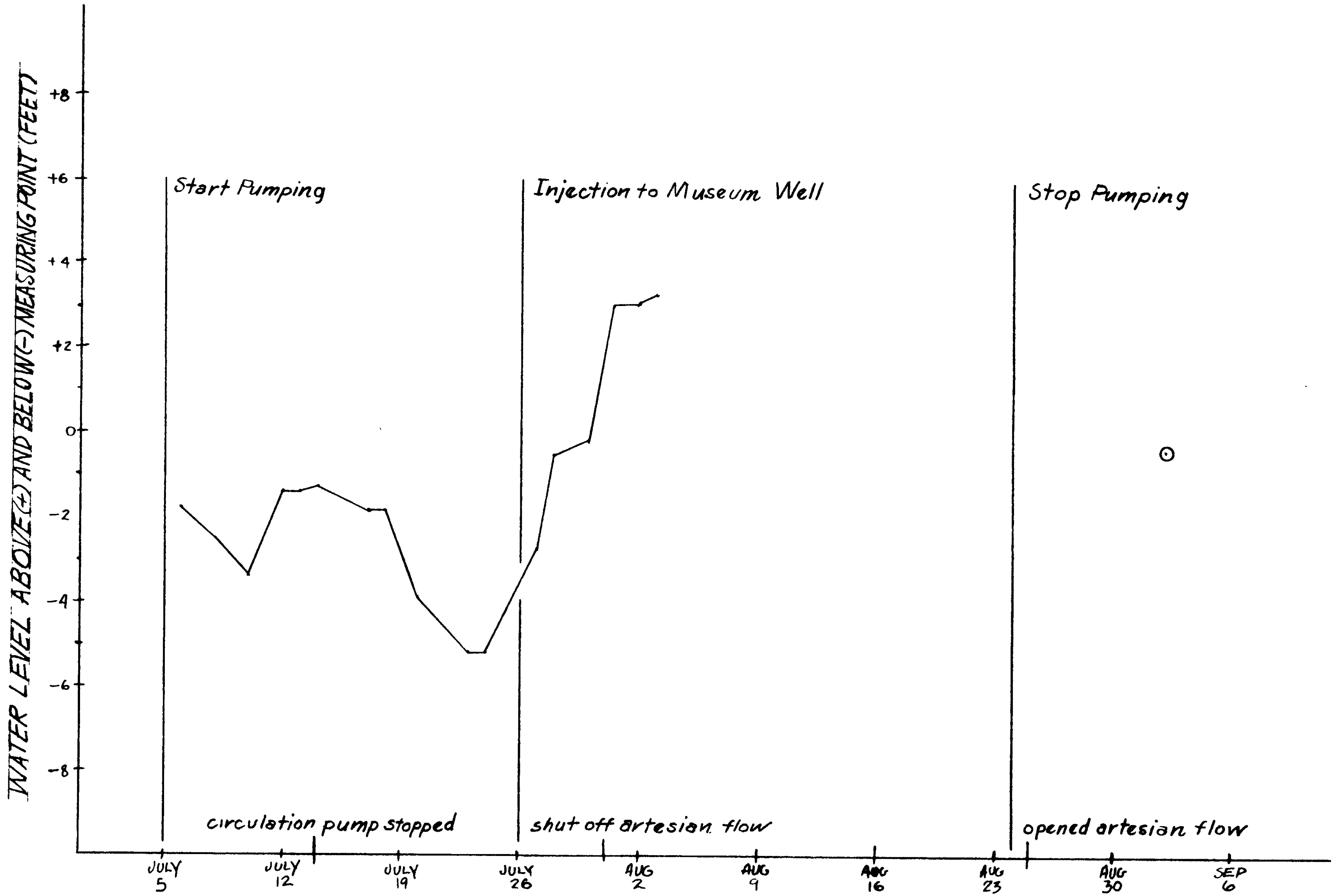


Figure 3-37. -- Water levels measured during the pumping and injection test

#216 Hart 125 Eldorado	Measured by Charles Leib	Distance to production well: Distance to injection well: Depth:	1,930 ft. 760 ft. 690 ft.

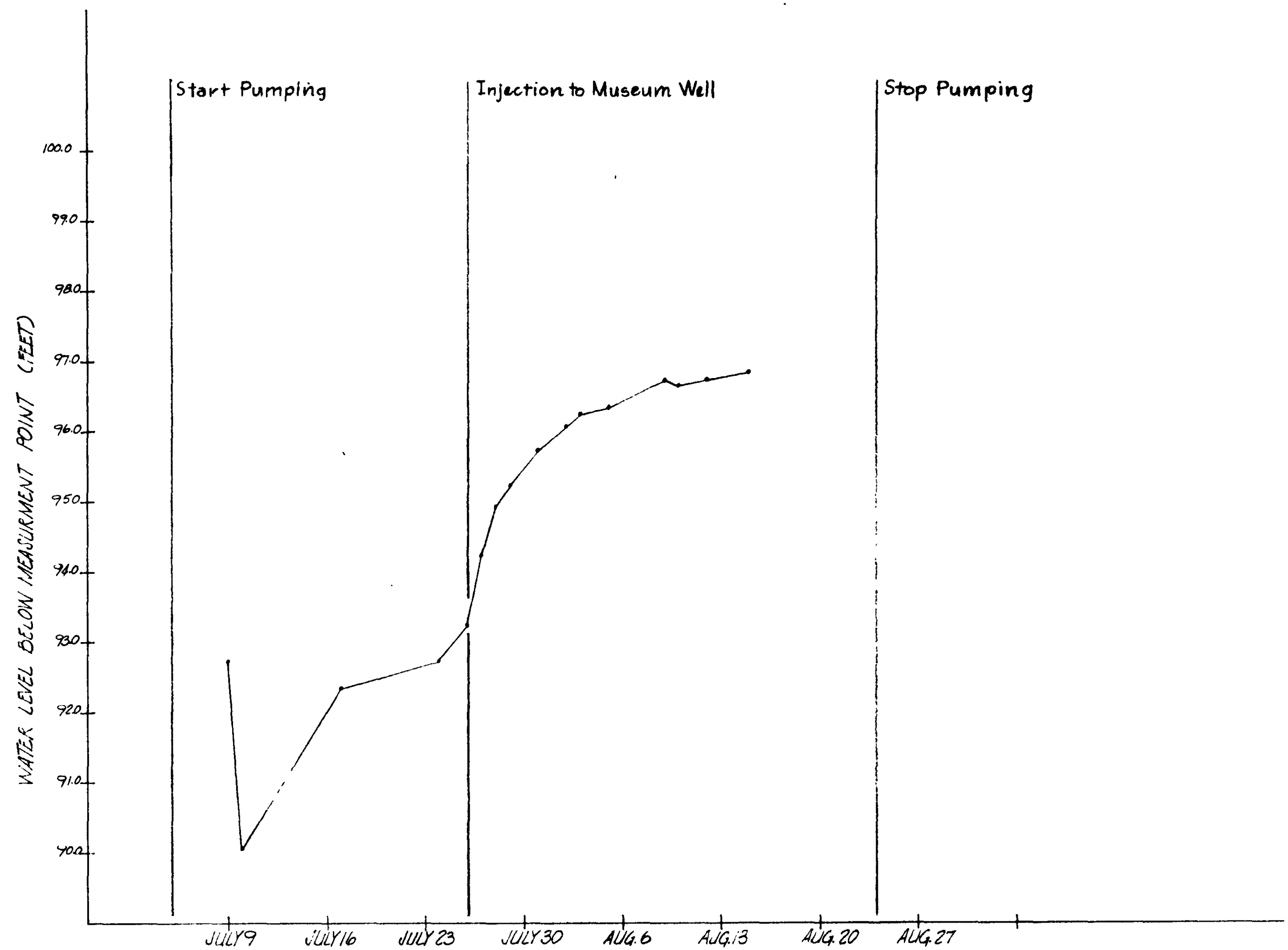


Figure 3-38. -- Water levels measured during the pumping and injection test

#277 Klamath Medical Clinic	Measured by	Distance to production well:	1,160 ft.
1905 Main	Charles Leib	Distance to injection well:	1,620 ft.
		Depth:	--- ft.

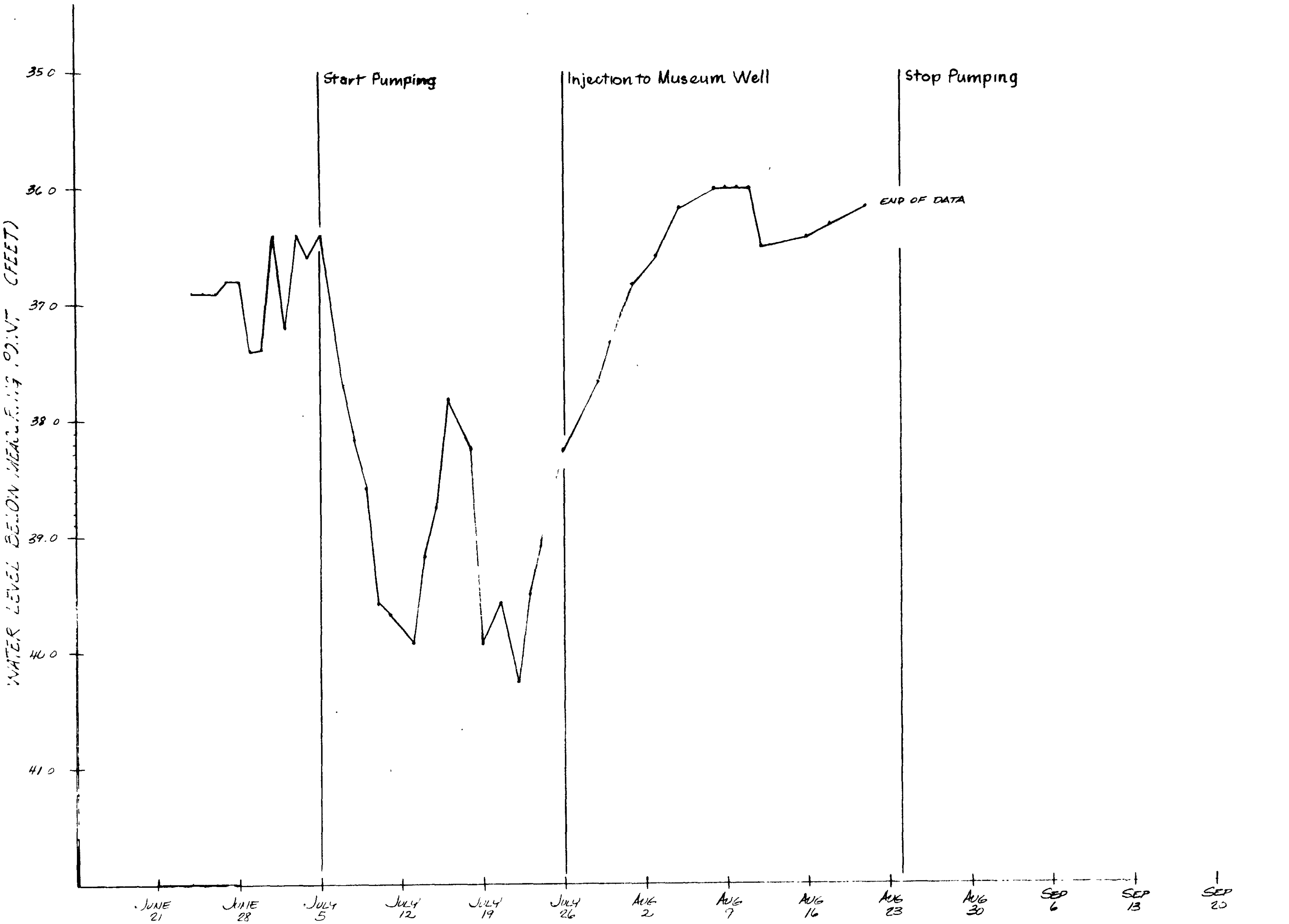


Figure 3-39. -- Water levels measured during the pumping and injection test

#310 Feeback 207 Haskins	Owner monitored	Distance to production well: Distance to injection well: Depth:	1,480 ft. 2,250 ft. 470 ft.

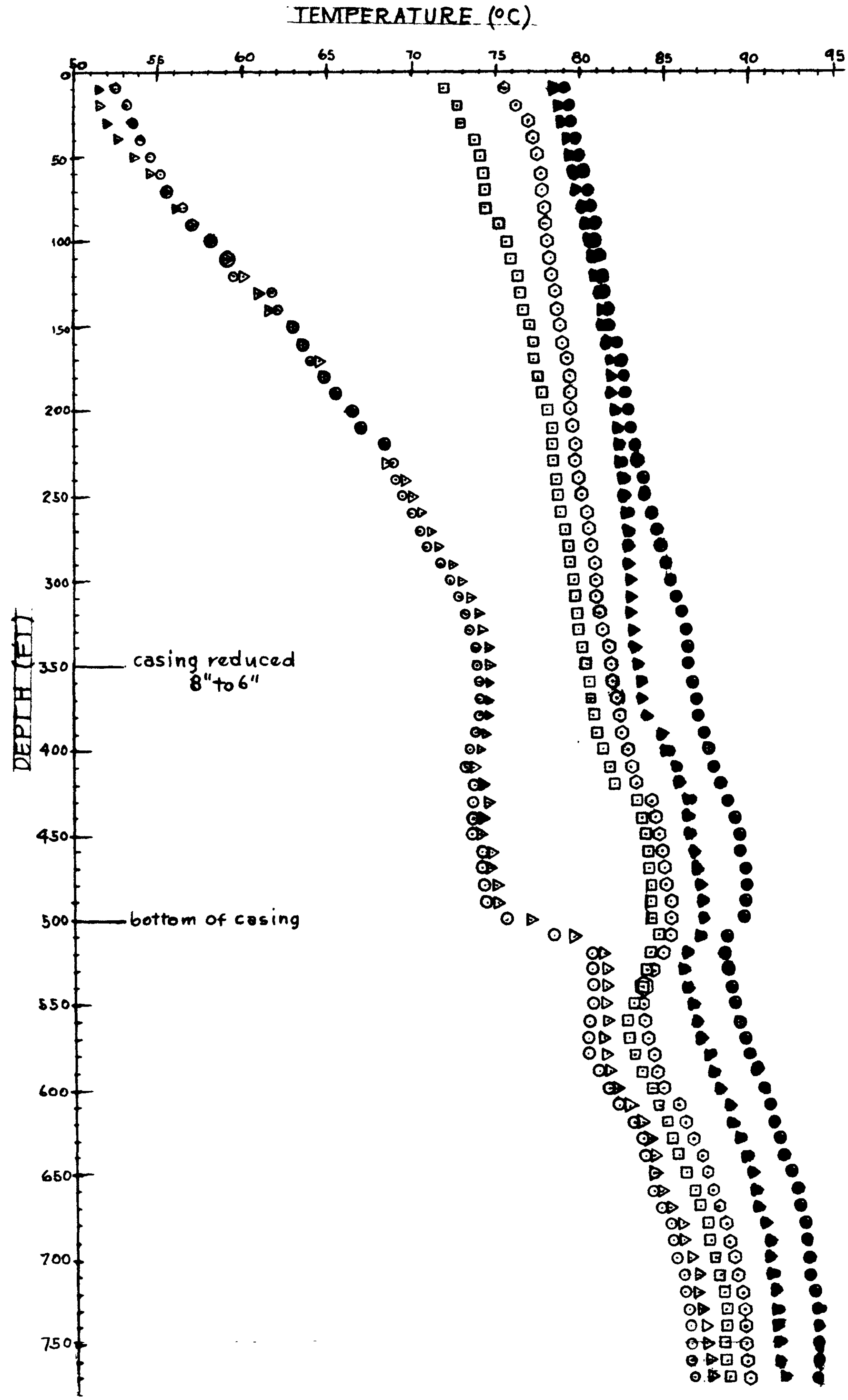


Figure 3-40. -- Temperature profiles in the Medo-Bel Dairy well obtained during the injection phase of the aquifer test. The well began to flow sometime between July 29 and August 1. Measured by P. J. Lienau.

27 July ○ 29 July △ 1 August □ 2 August ⬡ 5 August ▲ 8 August ●

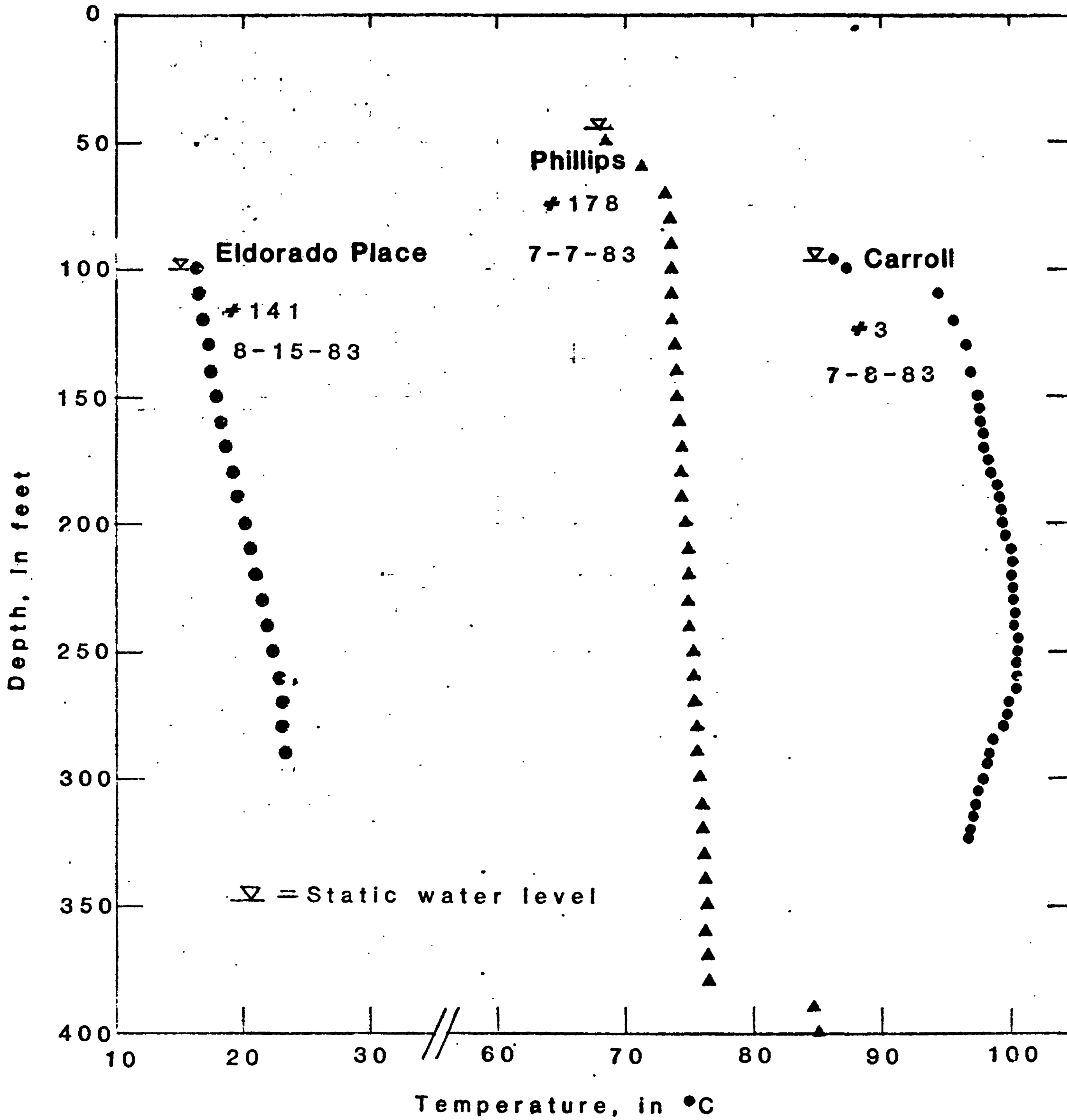


Figure 3-41. -- Temperature profiles in three geothermal wells.

Measured by P. J. Lienau

CHAPTER 4. CHEMICAL AND ISOTOPIC DATA ON WELL DISCHARGES OF THE KLAMATH FALLS GEOTHERMAL SYSTEM

By

C. J. Janik[1/], Andrew Yee[2/], A. F. White[2/], M. L. Stallard[1/], A. P. Brown[1/], M. C. Wheeler[1/], S. R. Swanson[3/], T. L. Winnett[1/], and Grace Fong[1/]

Sample Collection

Samples of cold and thermal discharges from wells in Klamath Falls, Oregon, were collected in June through August, 1983, by Susan Swanson in association with Alfred H. Truesdell, U. S. Geological Survey, Menlo Park, California. The locations of the wells sampled for chemical and isotopic analyses are shown in figure 4-1. Standard collection methods were used throughout. Most of these methods have been described by Truesdell and Hulston (1980).

Water samples for dissolved salts were filtered through a 0.45 micron pore membrane filter and collected in 250 mL plastic bottles. Samples for cation analysis were acidified with concentrated HNO_3 to pH < 2 to prevent precipitation of Ca or Mg carbonates or adsorption of cations on the walls of the bottles.

Samples for SiO_2 analysis were collected by pipetting 10 mL of unfiltered well discharge into a plastic bottle containing 50 mL of deionized-distilled H_2O. Dilution insured that the SiO_2 concentrations were sufficiently low to prevent polymerization.

Water samples for isotopic analyses ($\delta^{18}O$ and δD) were collected without filtration in 125 mL glass bottles fitted with polyseal caps. Samples for oxygen isotopes in dissolved sulfate were collected in 500 mL plastic bottles and preserved with formaldehyde to prevent bacterial oxidation of

1/ U. S. Geological Survey, Menlo Park, CA

2/ Lawrence Berkeley Laboratory, Berkeley, CA

3/ U. S. Geological Survey, Menlo Park, CA; residing in Klamath Falls, OR

dissolved H_2S to $SO_4^=$. Total dissolved CO_2 for carbon isotope analysis was precipitated immediately as $SrCO_3$ by treating a sample of water with concentrated NH_4OH saturated with $SrCl_2$. Samples for tritium analysis were collected in 500 mL plastic bottles fitted with polyseal caps.

Methods for Chemical Analyses

Chemical analyses were performed at Lawrence Berkeley Laboratory, Berkeley, California, in cooperation with the U. S. Geological Survey. Sodium, potassium, calcium, lithium and magnesium were analyzed by atomic absorption spectrophotometry using a Perkin-Elmer model 3030. Aluminum was analyzed by the fluorometric method (Japan Analyst, 1967) with Lumogallion (5-chloro-6-(2,4-dihydroxyphenylazo)-1-hydroxybenzene-2-sulfonic acid) using a Kontron spectrofluorometer model SFM23 equipped with a flow-through cell. Silica was determined by the molybdosilicate method (APHA/AWWA/WPCF, 1971) using a Cary 16 spectrophotometer. Chloride, fluoride, and sulfate analyses were by ion-chromatography using a Dionex Ion Chromatograph model 2020i. Bicarbonate concentrations were determined by titration with 0.01 N HCl.

Methods for Isotopic Analyses

Stable isotope analyses (δD, $\delta^{18}O$, and $\delta^{13}C$) were performed at the U. S. Geological Survey, Menlo Park, California. Isotopic analyses were made on purified CO_2 and H_2 on an isotope ratio mass spectrometer. Most of the analytical methods have been described by O'Neil (1979). Analyses of $^{18}O/^{16}O$ in cold and hot water discharges were made by the CO_2-water equilibration method, and D/H analyses by reduction to H_2 on uranium metal.

Dissolved sulfate in water samples was purified and concentrated by anion exchange and precipitated as $BaSO_4$ by standard methods. Oxygen isotopes were analyzed on CO_2 evolved by high-temperature graphite reduction of the $BaSO_4$ (Nehring et al., 1977).

Samples containing $SrCO_3$ for carbon isotope analysis of total dissolved CO_2 were filtered through a 1.2 micron pore membrane filter. The precipitate was vacuum dried and then sieved to insure isotopic homogeneity.

Carbon isotopes were analyzed on CO_2 evolved with phosphoric acid. CO_2 yields were measured to determine the total CO_2 content of the precipitate.

Tritium was analyzed by the University of Miami Tritium Laboratory (headed by Dr. H. G. Ostlund) in the Rosenstiel School of Marine and Atmospheric Science, Miami, Florida, under contract with the U. S. Geological Survey. These analyses were performed by electrolytic enrichment and low-level gas proportional counting of water samples. Laboratory procedures for tritium measurements have been described by Ostlund and Werner (1962) and Ostlund and Dorsey (1977).

Analytical Data

Physical data on Klamath Falls wells sampled for chemical and isotopic analyses are contained in table 4-1. The analytical data on well discharges are contained in two tables: table 4-2 presents chemical analyses on cold and thermal waters; table 4-3 presents analyses of water isotopes (D/H and $^{18}O/^{16}O$), tritium, $^{18}O/^{16}O$ in dissolved sulfate, $^{13}C/^{12}C$ in total dissolved CO_2, as well as gravimetric analyses of dissolved sulfate and total dissolved CO_2. Both tables give data specific to the collection (date, temperature, and pH). Temperatures of the thermal waters were measured with a maximum registering thermometer. E. Merck reagent indicator sticks were used to determine the pH of the discharge at the time of collection.

References

APHA/AWWA/WPCF, 1971, Silica, sec. 151B, in Standard Methods for the Examination of Water and Wastewater, 13th ed.: APHA/AWWA/WPCF publication, p. 303-306.

Japan Analyst, 1967, Fluorophotometric determination of aluminum and gallium with Lumogallion, in Japan Analyst, v. 16, p.692-697.

Nehring, N. L., Bowen, P. A., and Truesdell, A. H., 1977, Techniques for the conversion to carbon dioxide of oxygen from dissolved sulfate in thermal waters: Geothermics, v. 5, p. 63-66.

O'Neil, J. R., 1979, Stable isotope geochemistry of rocks and minerals, in Jager, E., and Hunziker, J. C., eds., Lectures in isotope geology: Springer-Verlag, New York, p. 235-263.

Ostlund, H. G., and Dorsey, H. G., 1977, Rapid electrolytic enrichment and hydrogen gas proportional counting of tritium, in Low-Radioactivity Measurements and Applications: Proceedings of the International Conference on Low-Radioactivity Measurements and Applications, 6-10 October 1975, The High Tatras, Czechoslovakia, Slovenske Pedagogicke Nakladatel'stvo, Bratislava.

Ostlund, H. G., and Werner, E., 1962, The electrolytic enrichment of tritium and deuterium for natural tritium measurements, in Tritium in the Physical and Biological Sciences: International Atomic Energy Agency, Vienna, Austria, 1962.

Truesdell, A. H., and Hulston, J. R., 1980, Isotopic evidence on environments of geothermal systems, in Fritz, P., and Fontes, J. C., eds., Handbook of Environmental Isotopes: Amsterdam, Elsevier, p. 179-225.

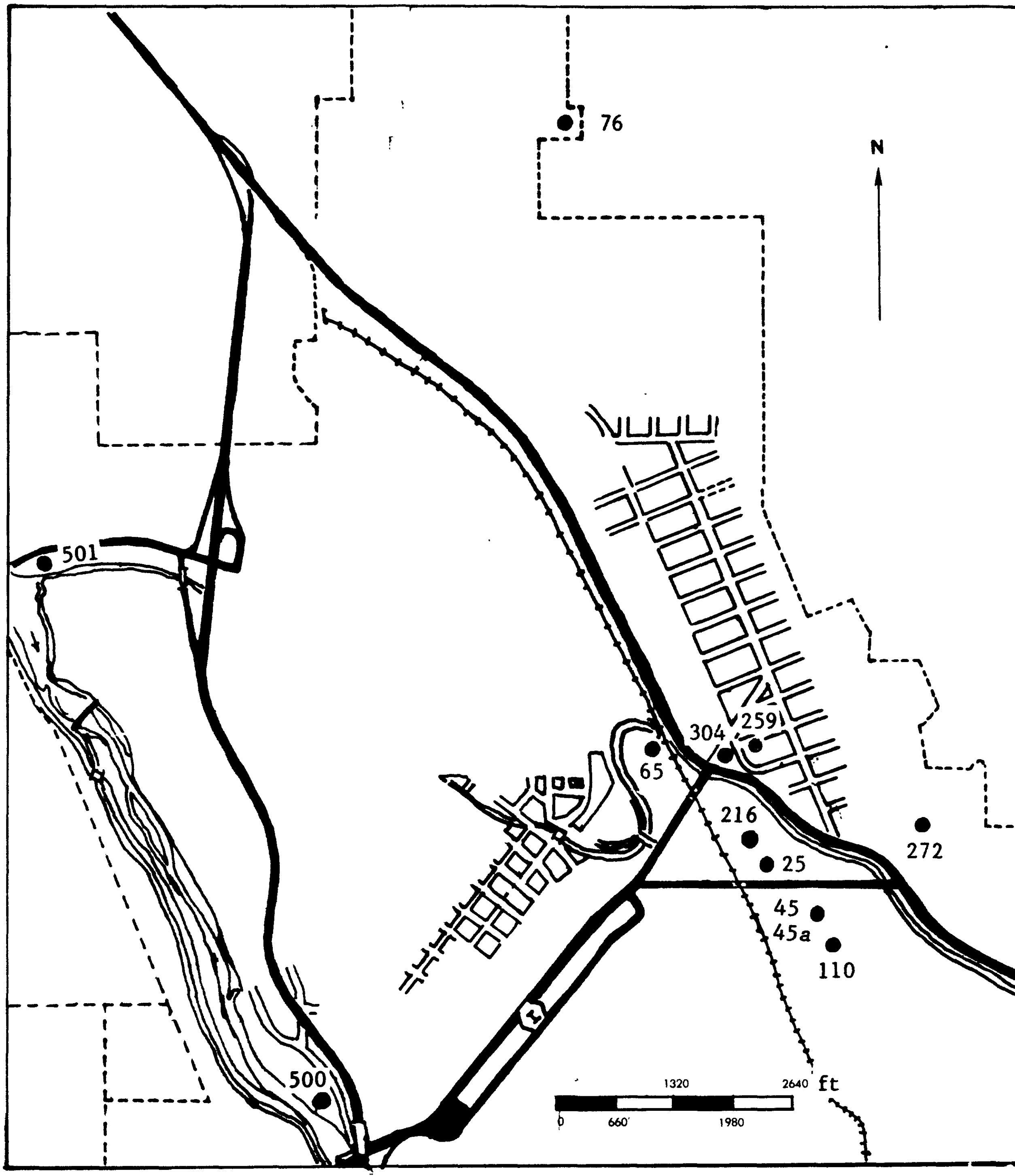


Figure 4-1. -- Location of wells sampled for chemical analysis

Table 4-1. -- Physical data on wells sampled for chemical analysis

Number	Name	Address	Depth	Temperature (°C)	Date
25	Friessen Plumbing	1715 Main	563	78	06-04-83
45	Glodowski	2111 Holly	398	88	06-09-83
45a	Glodowski	2111 Holly	398	80	06-09-83
65	Klamath Union High School	Monclaire	257	66	06-14-83
76	OIT #5	Campus	1,716	78	06-07-83
110	East Main Apts.	236 E. Main	452	91	06-21-83
216	Hart	125 Eldorado	690	72	06-29-83
259	Wayburn	547 Eldorado	200	56	06-08-83
272	City well #1	Old Fort Rd and Laguna	900	95	07-08-83
304	Butler	1800 Esplanade	390	56	06-08-83
500	City well #6	Conger Ave.	---	21	06-20-83
501	City of Klamath Falls	Nevada Ave.	701	17	06-23-83

Table 4-2. Chemical analyses on Klamath Falls well discharges.

Well Id.	Date 1983	Temp °C	Field pH	Lab pH	SiO_2 ppm	Na ppm	K ppm	Li ppm	Ca ppm	Mg ppm	Al ppb	mequiv. cations	Cl ppm	F ppm	SO_4 ppm	HCO_3 ppm	mequiv. anions
25	6/04	78	6.7	---	98.0	206	5.08	**	26.5	0.02	27	10.46	36.9	*	454	45.2	11.30
25	8/10	82	6.8	8.6	126.0	216	5.94	0.28	11.7	0.06	25	10.18	37.3	1.3	422	43.9	10.63
45	6/09	88	7.0	---	98.6	207	5.47	**	21.2	0.05	27	10.25	36.9	*	451	46.4	11.26
45	8/15	84	6.3	8.6	120.7	225	6.52	0.31	11.5	0.09	30	10.58	40.4	1.3	449	43.9	11.28
45A	6/09	80	7.3	---	172.0	220	6.65	**	20.4	0.12	135	10.81	38.3	*	450	47.6	11.30
65	6/14	66	6.7	---	83.0	194	4.30	**	25.3	0.05	27	9.86	32.3	*	388	50.0	9.88
76	6/07	78	7.5	---	90.7	189	5.08	**	20.4	0.02	27	9.41	33.4	*	346	46.4	9.92
110	6/21	91	7.0	---	98.6	213	5.47	**	20.8	0.02	27	10.49	39.7	*	460	46.4	11.53
216	6/29	72	7.1	8.4	123.2	217	5.84	0.31	10.1	0.04	22	10.14	34.5	1.2	404	43.3	10.16
216	8/16	71	6.9	8.7	109.3	214	5.89	0.30	9.9	0.03	19	10.00	36.4	1.3	434	45.1	10.87
259	6/08	56	7.5	---	89.7	205	5.08	**	20.8	0.05	27	10.13	37.9	*	450	45.8	11.26
272	7/08	95	6.9	8.6	119.8	230	7.44	0.38	14.4	0.05	30	10.97	40.4	1.3	422	41.4	10.67
272	8/09	98	7.3	8.8	130.1	228	7.17	0.38	13.1	0.03	25	10.81	41.1	1.3	457	40.9	11.41
272	8/24	89	8.0	8.7	120.7	228	7.52	0.36	14.0	0.05	26	10.86	38.2	1.4	472	40.3	11.64
304	6/08	56	7.3	---	80.2	175	3.91	**	17.6	0.02	27	8.64	30.1	*	308	86.0	8.74
304	8/17	47	7.1	8.6	97.3	177	4.59	0.28	8.8	0.05	10	8.30	30.9	1.2	319	90.3	9.06
500	6/20	21	6.7	---	58.0	23.5	2.74	---	8.8	4.37	27	1.88	3.9	---	2.2	123	2.15
501	6/23	17	6.0	---	50.1	20.0	3.13	---	14.0	7.73	27	2.28	3.6	---	1.8	136	2.71

* estimated value of 1.3 ppm used in milliequivalent calculation
** estimated value of 0.3 ppm used in milliequivalent calculation

Chemical analyses were performed at Lawrence Berkeley Laboratory, Berkeley, Calif., under the direction of A. Yee and A. F. White.

Table 4-3. Isotopic analyses and gravimetric determinations of SO_4 and total dissolved CO_2 on Klamath Falls well discharges.

Well Id.	Date 1983	Temp °C	Fld pH	Trit TU	δD H_2O	$\delta^{18}O$ H_2O	$\delta^{13}C$ aq CO_2	ΣCO_2 ppm	$\delta^{18}O$ aq SO_4	SO_4 ppm
25	6/04	78	6.7	0.23	-119.4	-14.78	-14.79	15	-5.34	398
25	8/10	82	6.8	--	-120.2	-14.54	-14.69	18	-5.40	408
45	6/09	88	7.0	0.33	-119.4	-14.50	-19.18	8	-5.18	425
45	8/15	84	6.3	--	-122.0	-14.53	-15.02	16	-5.08	428
45A	6/09	80	7.3	0.04	-120.2	-14.69	--	12	-5.37	421
65	6/14	66	6.7	1.03	-119.8	-14.54	-16.43	31	-5.12	382
76	7/14	78	7.5	0.25	-119.4	-14.72	-17.37	13	-5.44	362
110	6/21	91	7.0	0.52	-121.3	-14.45	-16.14	18	-5.43	423
216	6/29	72	7.1	0.56	-121.3	-14.53	-14.77	13	-5.36	409
216	8/16	71	6.9	--	-119.0	-14.48	-15.41	20	-5.49	407
259	6/08	56	7.5	0.21	-120.3	-14.61	-19.87	14	-5.21	324
272	7/08	95	6.9	0.12	-121.4	-14.63	-14.34	6	-5.07	419
272	8/09	98	7.3	--	-122.1	-14.41	-14.92	10	-5.62	441
272	8/24	89	8.0	--	-120.8	-14.56	-13.90	14	-5.14	450
304	6/08	56	7.3	8.35	-116.1	-14.05	-20.60	50	-4.56	293
304	8/17	47	7.1	--	-115.7	-13.96	-17.93	50	-4.66	294
500	6/20	21	6.7	0.14	-112.3	-14.86	-15.26	72	--	2.6
501	6/23	17	6.0	0.17	-108.8	-14.26	-13.91	96	--	5.0

Tritium was analyzed by the Univ. of Miami Tritium Laboratory (Dr. H. G. Ostlund, head) in the Rosenstiel School of Marine and Atmospheric Science, Miami, Florida.

The following analyses were performed at the U. S. Geological Survey, Menlo Park, California:

1) δD by M. L. Stallard and M. C. Wheeler
2) $\delta^{18}O(H_2O)$ by A. Brown and T. Winnett
3) total dissolved CO_2 and $\delta^{13}C$ by C. J. Janik and G. Fong
4) dissolved SO_4 preparations by M. C. Wheeler and G. Fong
5) $\delta^{18}O(SO_4)$ by M. C. Wheeler and M. L. Stallard.

δD and $\delta^{18}O$ values are given in permil relative to V-SMOW. $\delta^{13}C$ values are given in permil relative to PDB.

The analytical precision of 1 standard deviation (1 σ) for reported isotope value is: δD ± 1.0; $\delta^{18}O(H_2O)$ ± 0.1; $\delta^{18}O(SO_4)$ ± 0.2; $\delta^{13}C$ ± 0.2.

CHAPTER 5. AIR TEMPERATURES AND DISCHARGES OF THERMAL WATER FROM PUMPED AND FLOWING WELLS

by

G. G. Culver[1/]

During the aquifer test period (July 5 - August 26, 1983) most of the known pumped and artesian wells in Klamath Falls were visited and measurements or estimates of discharge were made. Estimates based on the discharges of 77 wells are shown in figure 5-1 together with daily air temperatures reported by the National Weather Service at Kingsley Field. A discharge of about 300 gal/min was estimated to represent a minimum base flow that continued, independent of air temperature, during the observation period.

During the fall and winter of 1983-84, additional measurements and estimates of thermal discharge were made. Discharge to four storm-drain systems and the "A" canal was measured and estimates were made of all nonmeasured thermal discharge. The relationship between average daily discharge and average daily air temperature (fig. 5-2) was surprisingly consistent. Several tests in individual storm drains showed that measured flows and flows calculated on the basis of the relationship in figure 5-2 agreed within 10 percent. A base flow that continues all year, independent of air temperature, is estimated to be about 10 percent of peak flow. This discharge is used in part to supply domestic hot water.

Average monthly thermal discharges calculated on the basis of the relationships shown in figure 5-2 are given in table 5-1 together with monthly mean air temperatures recorded at Kingsley Field. The method is probably not reliable during the warmer months and no estimates are included for the period June through September. The observations made during July and August 1983 (fig. 5-1) indicate the magnitude of discharge during a summer period when temperatures were generally lower than normal.

[1/] Geo-Heat Center, Oregon Institute of Technology

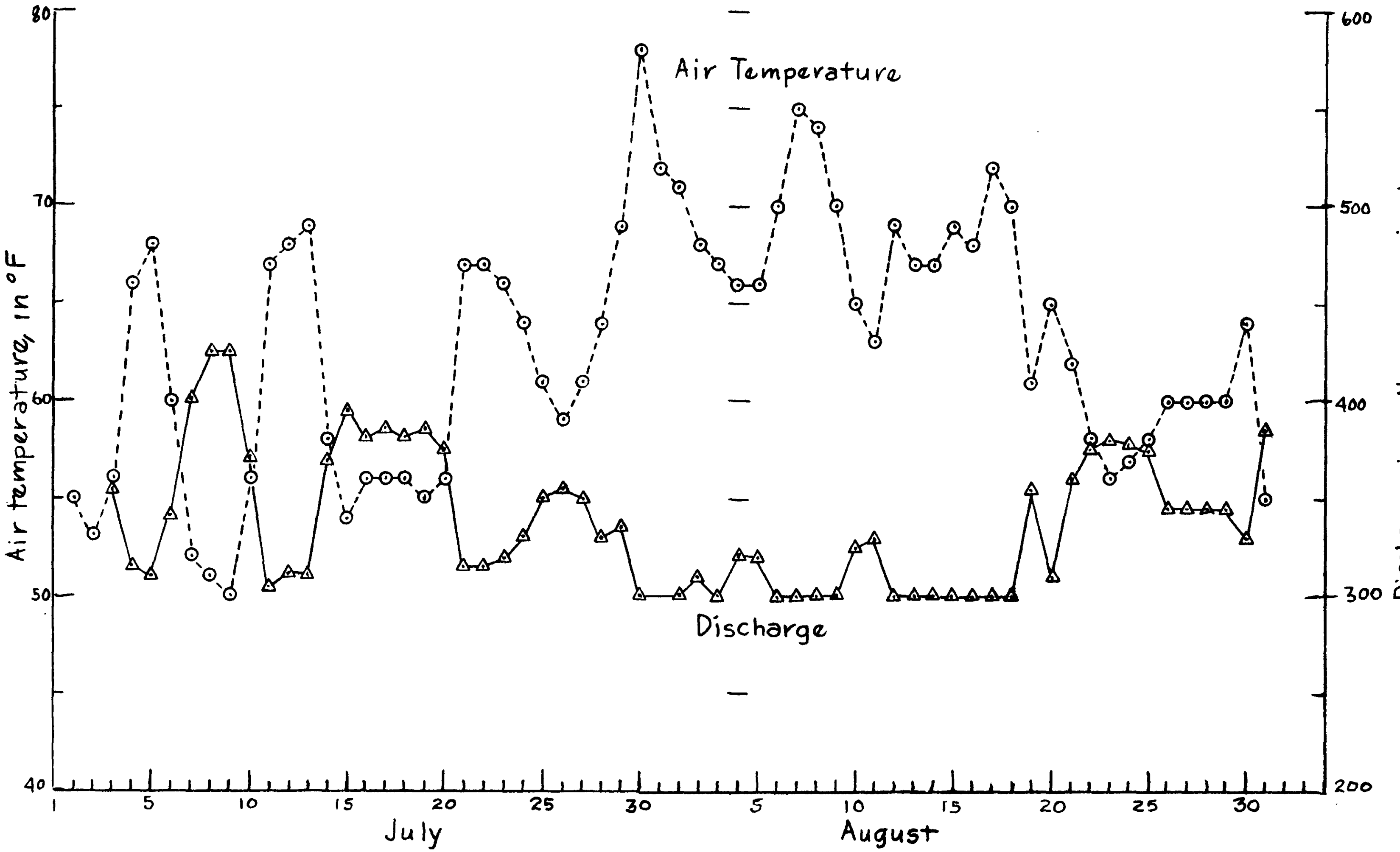


Figure 5-1. -- Average daily air temperature and average daily discharge of thermal water from pumped and artesian wells (July 1 through August 31, 1983)

Air temperature from U.S. Weather Service records at Kingsley Field. Discharge measured and estimated by G. G. Culver, Oregon Institute of Technology Geo-Heat Center.

Air temperature ○ Discharge △

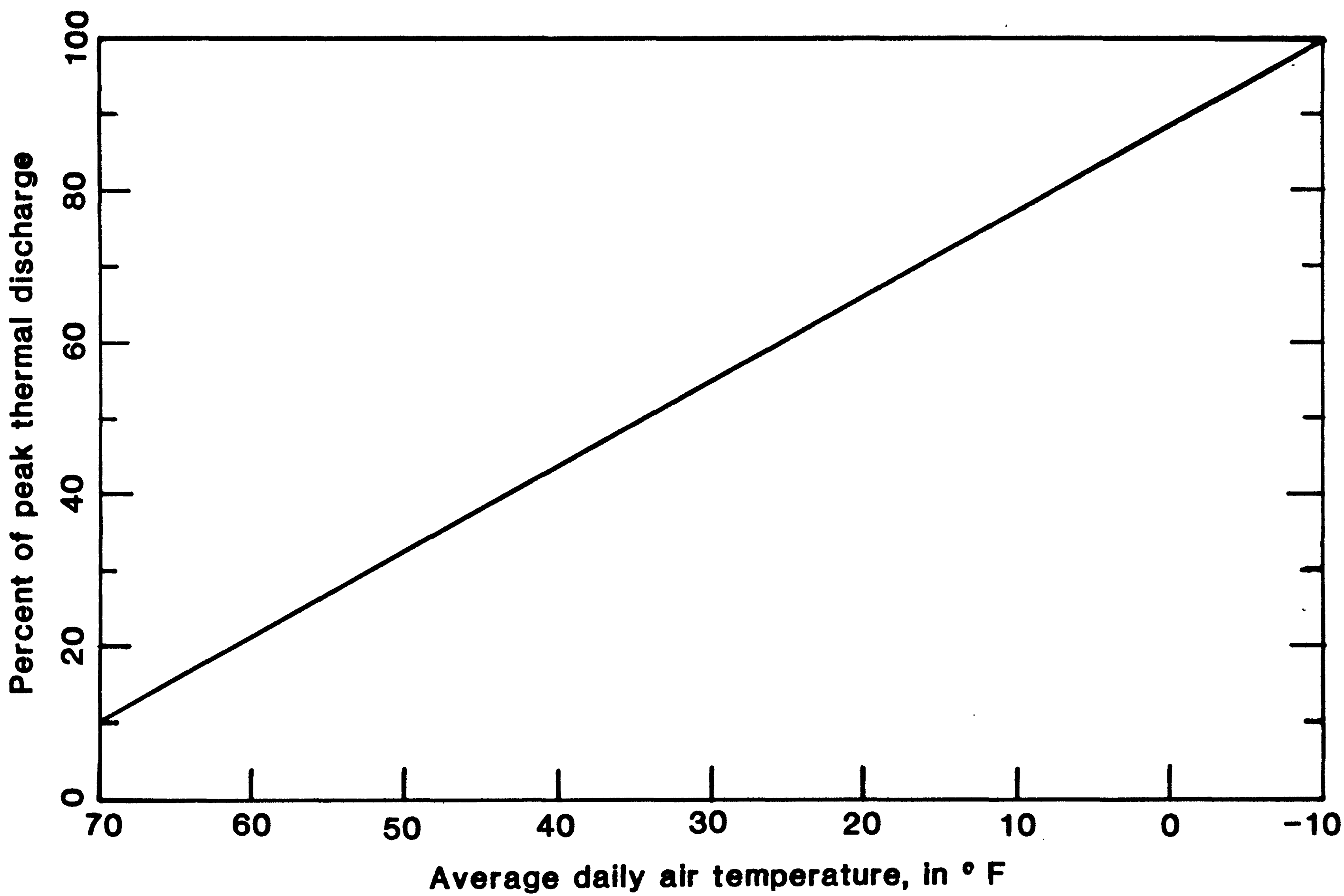


Figure 5-2. -- The relationship between average daily air temperature and percent of peak thermal discharge

Table 5-1. -- Monthly mean air temperatures and discharges of thermal water from pumped and artesian wells. Air temperature from National Weather Service records at Kingsley Field; discharge estimated from measurements and observations by G. G. Culver.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly mean temperature (°F)	28	33	37.5	40	53	59	66	65	59	46	36	33
Thermal discharge[1/] (gal/min)	720	690	660	650	560(?)	--	--	--	--	610	670	690

[1/] Limited to wells in the principal hot-well area of Klamath Falls.