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EVALUATION OF CITY WELL 1, KLAMATH FALLS, OREGON

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ABSTRACT

A city-wide geothermal space heating project is currently under development at Klamath Falls, Oregon. The first phase of the project will require two production wells. Geothermally heated water will be used to heat 14 city, county, state, and federal buildings. At peak load the heating system will require approximately 750gpm of 200°F (or greater) geothermal brine.

The first production well was spudded on August 29, 1979. During drilling a major lost circulation zone was encountered between 340 and 360 ft depth. At this time the well was cleaned, reamed, cased to 300 ft, and then pump tested. The well was pumped for a total of 15½ hr. A maximum flow rate of 680, with 77 ft of drawdown, was held constant for 7½ hr. Discharge temperature was approximately 218°F.

Three observation wells were monitored to determine the impact of producing large quantities of brine on the many private geothermal wells already in use for space heating. Preliminary indications are that the water level decline in the area will be small (2 to 3 ft). However, further testing is recommended to determine the effects of reservoir heterogeneity on the water level decline.

INTRODUCTION

A city-wide geothermal space heating project is currently under development at Klamath Falls, Oregon. Phase I of the project involves drilling two production wells, constructing a pipeline to transport the geothermal brine, designing a heat-exchanger system, and retrofitting 14 city, county, state, and federal buildings to use geothermally heated water. A flow rate of approximately 750 gpm of 200°F brine is required to meet the maximum heat load for Phase I of the project.

The first of two production wells was spudded on August 21, 1979. The selection of the drill site was based on several factors: proximity to the most active thermal region, availability of land, and distance from the existing private geothermal wells already in use. As part of the overall resource delineation study, lithologic logs from roughly 40 wells have been collected and examined. From these, two likely production zones have been identified. The first is at a depth of 200 ft, and the second is at a depth of 750 ft. While drilling the first well, a lost circulation zone was encountered between 340 and 360 ft. At this time, the well was reamed to 17½ in. A 12-in. casing was then set at 300 ft. The well was pump tested for a total of 15½ hr.

The purpose of the pump-test was twofold. First, the flow rate, well drawdown, and the well-head production temperature were measured to determine the feasibility of using this aquifer as the production zone for Phase I of the district heating project. It was also necessary to measure the impact of producing large quantities of fluid from this zone on the many private geothermal wells in the area. If excessive drawdown of the surrounding wells took place, it would not be possible to use this aquifer as a producing zone for the project. A short term interference test (8 hr) was run in conjunction with a productivity test to determine inter-well communication and, if possible, to predict the effect of sustained production on the surrounding wells. The results of the tests will be discussed here.

WELL COMPLETION AND LITHOLOGY

A summary of the drilling rate, lost circulation zones, and lithology for City Well-1 is shown in Table 1. As is typical of the wells in this area, a sequence of roughly 250 ft of lacustrine and volcanic sediments overlie larger units of black, grey and "red" basalts. Several substantial lost circulation zones were encountered, one at about 195 ft and a second at 350 ft. The first occurred in a brown shale, and the second in an altered reddish basalt previously identified as a potential producing aquifer. When the second zone was encountered, the well was reamed to 17½ in. and a 12-in. casing was cemented from ground level down to 300 ft. From 300 to 360 ft the well was left uncased.

WELL TEST DESIGN

The well test was designed with three primary objectives:

1. To determine if the shallow aquifer is

suitable as a production zone for Phase I of the district heating program.

2. To obtain a more comprehensive model of the hydrogeology of the Klamath Falls KGRA (Known Geothermal Resource).

3. To assist in obtaining a data base to be used in establishing a resource management program.

To accomplish these objectives, a productivity test and a short term interference test were performed simultaneously. In this paper, we will discuss the results of this test insofar as they pertain to the development of the district heating project.

Several factors must be taken into account in determining if the shallow aquifer is a suitable production zone for Phase I of the district heating program. First, flowing wellhead temperatures must be greater than 200°F to satisfy the heat-exchanger design specifications. A flow rate of 350 gpm with less than 250 ft of drawdown in the well must be obtained (one-half the required total flow rate based on peak load demands.) Finally, there must be a negligible impact (both thermal and hydrologic) on the many private geothermal wells in use for space heating, domestic hot water, and industrial processing.

PRODUCTION TEST RESULTS

For the production test, City Well-1 was pumped for a total of 15½ hr. Table 2 summarizes the pumping time, flow rate, flowing wellhead temperature, and drawdown. During the test, a maximum pumping rate of approximately 680 gpm with 77 ft of drawdown was held constant for 7½ hr. Discharge temperatures measured at this time varied between 217 and 219°F. The small drawdown at this rate far exceeded estimates for the shallow aquifer production capacity.

The water level in the pumped well was measured using an electric probe. The primary flow rate measuring device used was an orifice plate with a bourdon tube pressure gauge on the upstream side of the orifice. Because the brine flashed downstream of the orifice, the accuracy of the measured flow rate is poor. However, other methods were also used to estimate the flow rates, and those values were in close agreement with those obtained from the orifice measurement. The estimated flow rates are probably not accurate to better than 15% of the stated value. Higher flow rates could have been obtained with a deeper pump setting if the surface equipment (discharge pipe, pump platform, pump packing) had been more suitable (water well pumping equipment was used). Wellhead temperatures were measured continuously upstream from the orifice using an RTD probe. These values are believed to be accurate to ±0.2°F.

INTERFERENCE TESTING

Three observation wells were used to monitor the impact of pumping large volumes of fluid from City Well-1. Figure 1 shows the location of these wells. Two of the wells, the Head Well and the Adamcheck Well, are in an area where a large number of geothermal wells are currently in use. The monitor wells are completed in a similar manner and to similar depths as the many existing wells in this area. These monitor wells will most likely reflect the behavior in other existing wells.

In Figure 2 the well completion and well lithology are shown for each well. As shown in the figure, two of the wells, Head and Adamcheck, are shallower than the city well. The lithologic logs from these wells are not available at this time. Well logs from several surrounding wells indicate that these two wells penetrate approximately 200 ft of lacustrine sediments, which are underlain by a highly permeable volcanic tuff or pumice. It is doubtful that these wells penetrate the red basalt strata, which is the production zone for the city well. The difficulties encountered in correlating individual strata from one well to another indicate complex faulting in the area (or lake bed sediments deposited in a tectonically active area). The Parks Well is open to the same reservoir interval as the city well. However, correlation on individual strata between the two wells is not obvious.

INTERFERENCE MONITORING EQUIPMENT

Water levels in the Adamcheck Well and the Head Well were monitored using Leupold-Stevens continuous-recording water level devices. Changes in water level of ½ in. can be easily resolved. Background data were obtained from these wells for several months before the test. At the onset of the cold season in September, a decline of the water levels took place at a similar rate of approximately 3 ft/mo. when the pump test began. Figure 3 shows the water level data obtained during the interference test.

Water level changes in the Parks Well were measured using a downhole Paro-Scientific pressure transducer. The transducer measures changes of water level by measuring the weight of the column of water above it. The instrument has a resolution of approximately 0.01 psi (better than ½ in.) Pressure data are recorded automatically at specified time intervals ranging from 1 sec to 2 hr. For this test, data points were recorded at 10-sec intervals each time the pump was turned on or off and at 2-min intervals when water level changes occurred less rapidly. Table 3 summarizes the instrumentation and the location of the wells used in the test. Figure 4 shows the data obtained from the Parks Well during the interference test.

INTERFERENCE TEST ANALYSIS

The rapid drop in water levels at the onset of production from City Well-1 indicates a high degree of hydrologic reservoir continuity. Response time at the Parks Well (150 ft) was less than 10 sec after the pump was turned on. At the other two observation wells, response time was short but difficult to measure because of the non-digital time display. Interference tests can be used to determine the reservoir parameters that control reservoir drawdown and continuity. Together with an accurate hydrogeologic model of the reservoir, these parameters can be combined to predict how the system will respond to pumping (and/or injection) with any arbitrary flow rate schedule and well configuration.

Interference test data are usually analyzed using a simplified reservoir model. The model assumed in this analysis was that on which the Theis solution is based. This model assumes the production well fully penetrates an isothermal, isotropic, homogeneous, porous medium of infinite areal extent and constant thickness. The data from the Adamcheck Well and the Head Well are shown matched to the Theis curve in Figures 5 and 6 respectively. The match of the data is acceptable for these small measured drawdowns. The transmissivity values calculated range from 1.4 X 10^7 to 1.5 X 10^7 md-ft/cp and the storativity values range from 2.4 X 10^{-3} to 7.8 X 10^{-3} ft/psi. The data begin departing from the Theis curve toward the end of the test, indicating that some sort of hydrologic boundary or reservoir heterogeneity may be affecting the reservoir response. Another explanation for the departure from the Theis curve is that the reservoir water level trend recorded before the test is affecting the drawdown.

A nonlinear least-squares matching program developed at LBL was then used to determine if an impermeable reservoir boundary was affecting the drawdown at the observation wells. The program uses the method of images to locate reservoir boundaries. The matches obtained from the computer analysis are shown in Figures 7, 8, and 9. Two of the wells, the Adamcheck Well and the Parks Well, suggest that an impermeable boundary may be affecting the data. The location of this boundary, however, is nonunique. A longer test with a constant background pressure is necessary to determine both the existence and location of a boundary. Table 4 summarizes the results obtained from the computer analysis.

Figure 10 shows a log ΔS vs. log t/r^2 plot for all of the observation wells. If the reservoir model discussed above was accurate, the data should plot as one curve. The discrepancy could be caused by any of several factors: reservoir heterogeneity, fractures, reservoir boundaries, partial penetration, dual porosity and so on. To accurately discern the cause of the discrepancy, an interference test of longer duration would be necessary.

The values obtained from the analysis indicate that the shallow reservoir permeability is very high. Assuming an aquifer thickness of 40 ft, and a viscosity value of 0.3 cp (220°F water), the calculated permeability value is approximately 100 darcies. The porosity value extracted from the storativity value (ϕcH) using a compressibility of 5 X 10^{-5} psi^{-1} is approximately 0.5. This is anomalously high, indicating that the values used for the compressibility and reservoir thickness are uncertain.

CONCLUSIONS

The tests of the Klamath City Well-1 show that the shallow test aquifer is capable of sustained production of at least 680 at a temperature of about 218°F. Rapid water level changes in the surrounding wells indicate a high degree of hydrodynamic reservoir continuity through several distinct lithologic units. This would indicate that a fracture network may possibly be controlling fluid movement in the reservoir. Calculated transmissivity values from the interference test indicate a permeability of approximately 100 darcies. When the pressure behavior over the 8-hr interference test are extrapolated to several years, drawdowns of 2 to 3 ft are predicted at a sustained production rate of 680. The departure of the data at later times from the Theis curve used for this analysis indicates that water level changes may be larger than the predicted values. However, the data show a departure from the Theis curve match near the end of the test interval. This departure could imply greater drawdowns at a much greater time interval than the test segment. At present no unique explanation can be given to account for this departure. To accurately predict the effects of sustained production over the lifetime of this project a longer test must be conducted to determine the effects of reservoir heterogeneity on the water level decline in surrounding wells. Present indications, from reservoir testing at the Klamath Falls, are that this system has a very promising potential for development of a large-scale district heating project.

ACKNOWLEDGEMENTS

We would like to thank G. Parks, G. Head, C. Adamscheck, and T. Fillmore for allowing us to use their wells in previous and subsequent reservoir tests at Klamath Falls. We also thank John Lund, Paul Lienau, and Gene Culver from Oregon Institute of Technology Geo-Heat Utilization Center for their help in obtaining information on the Klamath Falls resource. Finally, we would like to thank Harold Derrah, Assistant City Manager of Klamath Falls, for his patience and help.

TABLE 1

DRILLING AND COMPLETION HISTORY OF CITY WELL

KLAMATH FALLS CITY WELL 1

SPUD DATE AND TIME - AUGUST 21, 1979, 1640 HOURS

COMPLETION DATE - SEPTEMBER 17, 1979

CASING RECORD - 300 FT OF 12 IN BLANK CASING

DEPTH-FT	DRILLING RATE FT/HR	MUD TEMP °C	MUD LOSSES/ WARM ENTRY	LITHOLOGIC COLUMN	SAMPLE DESCRIPTION--PRELIMINARY
					0-2 FT - TOP SOIL
10	50	--	—		2-20 FT - DIATOMITE, WHITE, SILICA FILLED VEINS
20	50	--	—		20-47 FT - DIATOMITE, WHITE
30	60	16	—		47-66 FT - DIATOMITE, SOME GREY SHALE
40	60	16	—		
50	50	17	—		
60	18	20	—		66-93 FT - GREY SHALE AND CLAY
70	17	21	—		
80	17	23	—		
90	17	24	—		93-104 FT - BLACK SHALE
100	17	26	—		
110	30	29	—		104-116 FT - GREY SHALE
120	40	30	—		
130	40	32	—		116-147 FT - BROWN SHALE AND CLAY
140	40	34	—		
150	40	35	—		147-152 FT - GREY SHALE AND CLAY
160	40	36	- WARM WATER		152-160 FT - BROWN SHALE AND GREY TUFF
170	30	39	ENTRY 160-170FT		160-170 FT - GREY TUFF AND SHALE
180	25	37	- WARM WATER		
190	30	41	ENTRY 178-185 FT		170-198 FT - BROWN SHALE
195	20	40	- SUBSTANTIAL		
200	20	29	MUD LOSS-195 FT		198-243 FT - BLUE AND GREY SHALE
210	20	29			
220	20	29	- LOSING MUD		
230	20	30	195-245 FT		243-253 FT - STREAM DEPOSIT OVERLYING BLACK BASALT, CONSIDERABLE 'BLUE' QUARTZ VEINING
240	.5	31			
250	3	31	- LOST CIRCULATION		253-276 FT - GREY BASALT-SOFT
260	3	31	AT 248 FT		
265	10	31			276-279 FT - GREY BASALT-HARD
270	10	32	- CONTINUOUS		
280	15	36	SLOW LOSS OF MUD		279-285 FT - REDDISH BROWN BASALT
285	5	35	- LOST CIRCULATION		
290	3	39	292-298 FT		285-341 FT - HARD GREY BASALT AND CLAY
300	2	37	- LOSING MUD		
310	3				
320	3				
330	3				
340	2	MUD TEMP INCREASING	- LOSING MUD 340 - 360 FT		341 FT - END OF HARD BASALT
350	20				341-360 FT - RED BASALT
360	20				

TABLE 2

SUMMARY OF PRODUCTION TEST (CITY WELL 1)

TIME	FLOWRATE	TEMPERATURE	PUMPING LEVEL	DRAWDOWN
5 HRS	260 GPM	212° F	111 FT	35 FT
2 HRS	480 GPM	215°F	115 FT	39 FT
1 HRS	550 GPM	217°F	125 FT	49 FT
7.5 HRS	680 GPM	217-219°F	153 FT	77 FT

STATIC WATER LEVEL	~ 76 FT
WELL DEPTH	~360 FT
CASING SIZE	12 IN
OPEN INTERVAL	300-350 FT
PUMP SETTING	200 FT (5 IN. COLUMN, 8 IN. BOWLS)

TABLE 3

SUMMARY OF INTERFERENCE TEST

WELL	LOCATION	DISTANCE TO CITY WELL 1	INSTRUMENTATION	DRAWDOWN AFTER 7 1/2 HRS @ 680 GPM
PARKS	OLD FORT RD.	180 FT	DOWNHOLE PRESSURE TRANSDUCER	1.2 FT
ADAM-CHECK	HERBERT & LAGUNA ST.	1000 FT	CONTINUOUS WATER LEVEL RECORDER	7 IN
HEAD	NEWCASTLE	1420 FT	CONTINUOUS WATER LEVEL RECORDER	7 IN

TABLE 4

COMPUTER MATCH OF WELL DATA

WELL	DISTANCE TO CITY WELL-1	KH/μ (MD·FT/CP)	ΦCH (FT/PSI)	DISTANCE TO BOUNDARY
ADAMCHECK	1000 FT	$2.6 \cdot 10^{7}$	$1.1 \cdot 10^{-3}$	2280 FT
GLEN HEAD	1400 FT	$1.7 \cdot 10^{7}$	$1.4 \cdot 10^{-3}$	
PARKS	200 FT	$3.3 \cdot 10^{7}$	$9.1 \cdot 10^{-4}$	4300 FT

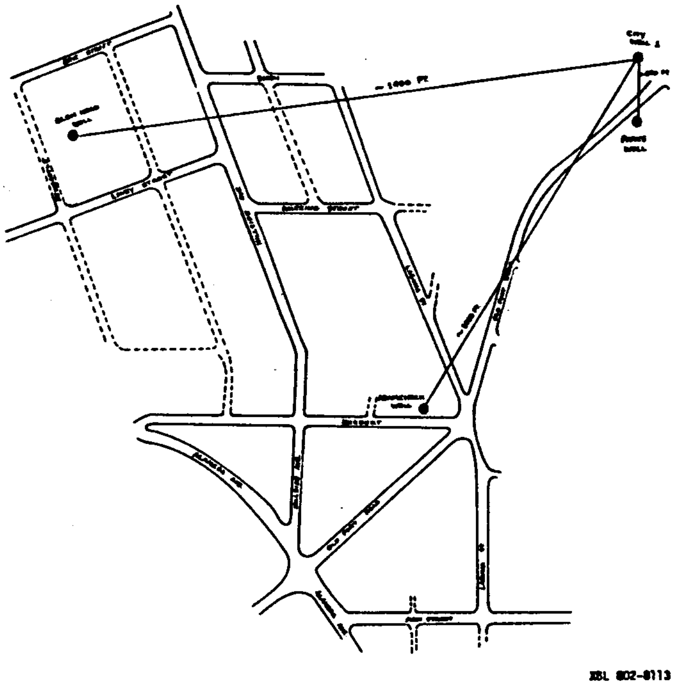

Figure 1. Locations of monitor wells and City Well-1.

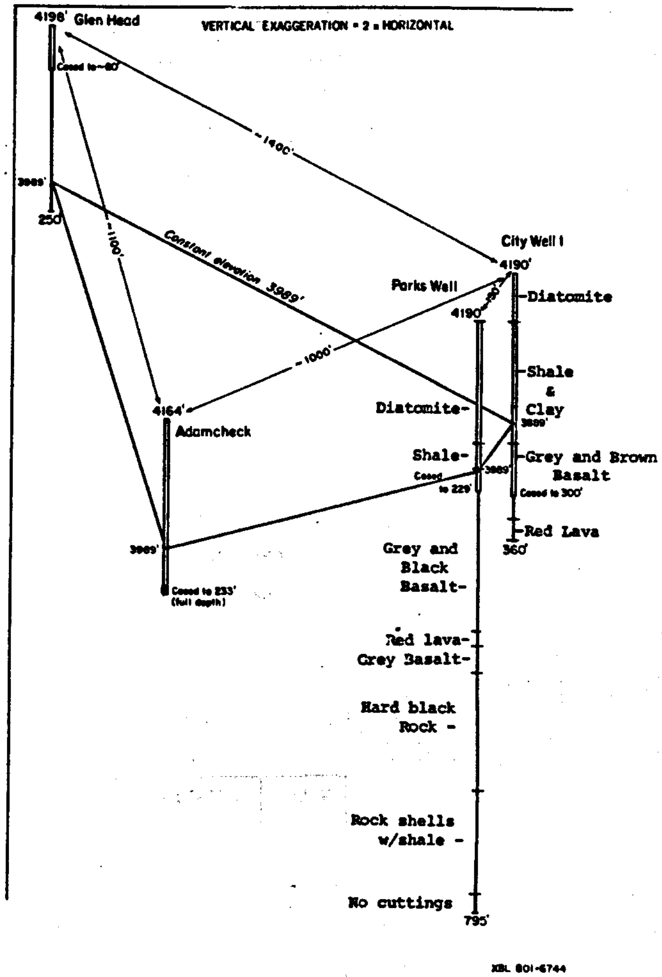

Figure 2. Fence diagram of monitor wells and City Well-1.

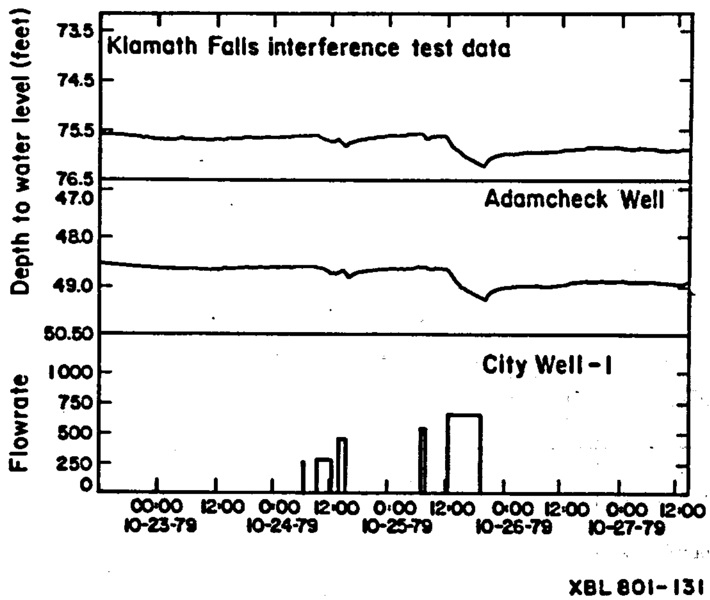

Figure 3. Interference test data from the Head Well and the Adamcheck Well.

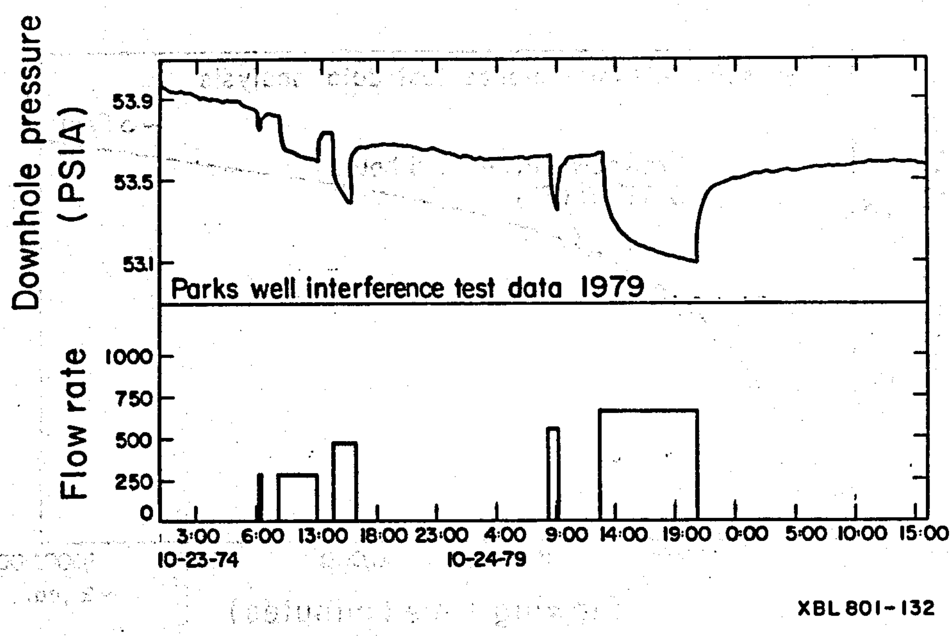

Figure 4. Interference data from the Head Well.

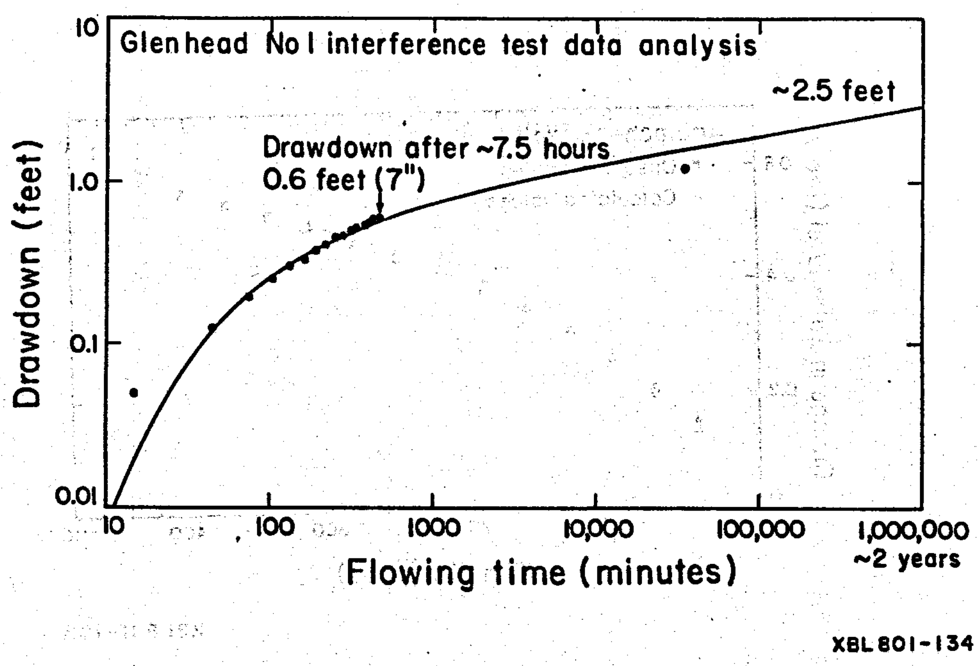

Figure 5. Theis curve match of interference test data from the Head Well.

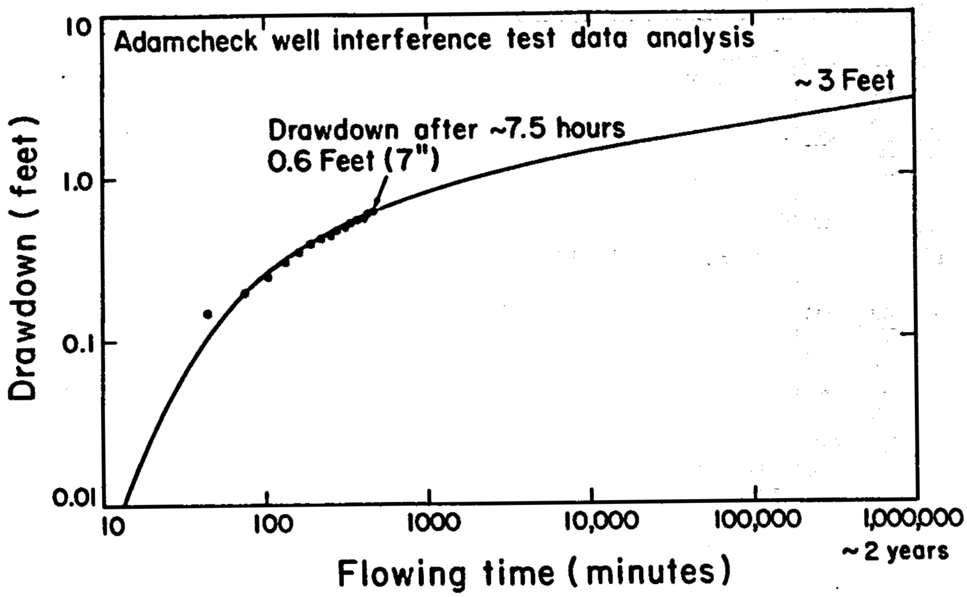

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Figure 6. Theis curve match of the Adamcheck well interference data.

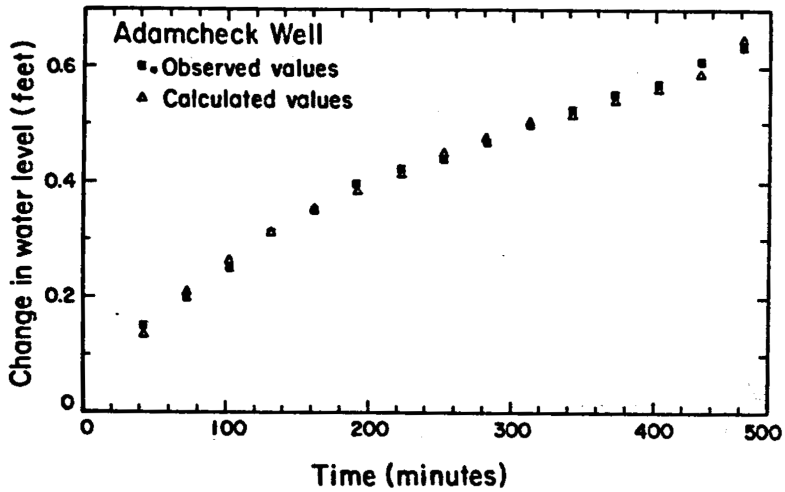

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Figure 7. Computer match of the Adamcheck Well interference data.

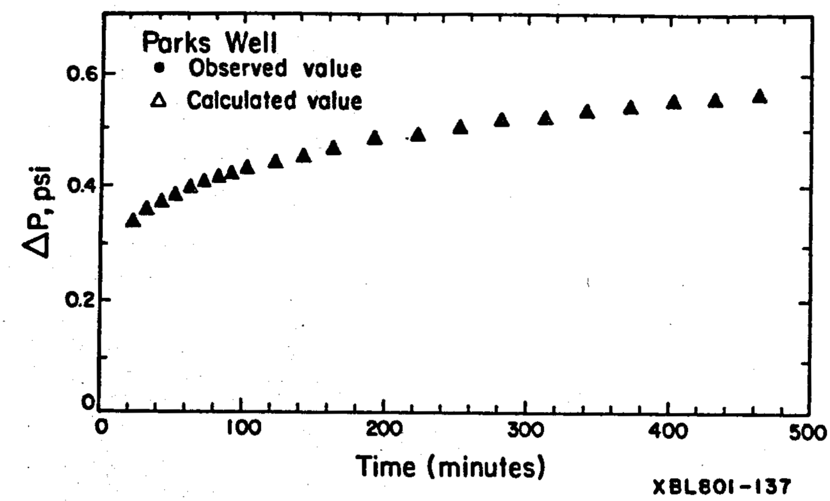

Figure 8. Computer match of the Parks Well interference test data.

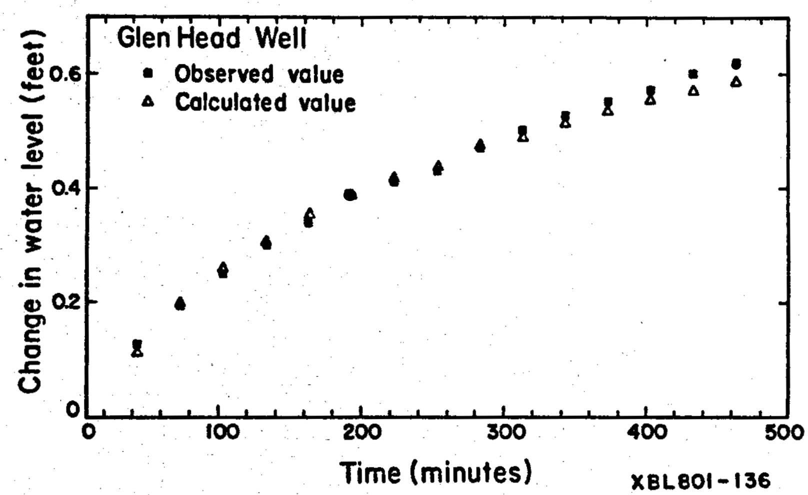

Figure 9. Computer match of the Head Well interference test data.

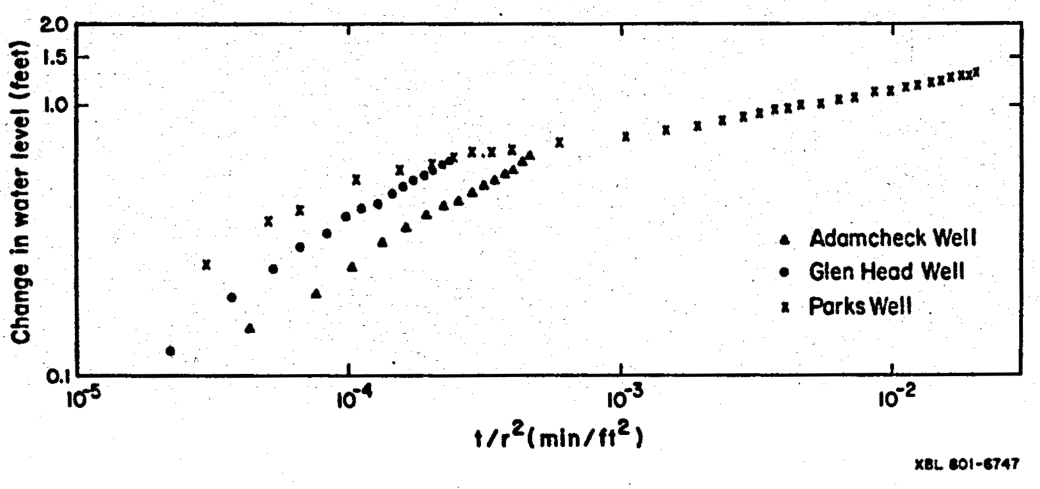

Figure 10. Log Δs vs. log ($\Delta t/r^2$) plot of the interference test data.