GL02976-17

PRELIMINARY EVALUATION OF RRGE-3 PRODUCTION TESTS
JUNE 1976 THROUGH DECEMBER 1977

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I. OBJECTIVES

The objectives of the tests reported herein include determination and/or estimation of:

1. local intrinsic transmissivity (kh)
2. local boundaries
3. interference effects at RRGI-4, RRGE-1, and RRGE-2
4. 5-year well performance.

II. SUMMARY OF RESULTS

This report presents the results of selected aquifer production tests at RRGE-3. The data and interpretations presented are intended to be preliminary and may be subject to change, pending current review of the presently available data. The estimated values of intrinsic transmissivity (kh) are presented here for the purpose of comparison only, since many of the classical assumptions that are required for estimating kh are violated in fractured geothermal systems.

Preliminary evaluation of the data indicate that RRGE-3 is capable of producing approximately 31.54 l/s (500 gpm) for five years, with a 2620.00 kPa (380 psi) decline. Interference with the production wells in the vicinity of RRGE-1 appears to be minimal, if present at all, for short-term tests (<22 days). The estimated results of the local intrinsic transmissivity for RRGE-3 differ greatly from those computed for either RRGE-1 or RRGE-2. The magnitude of these differences, along with the limited degree of communication between RRGE-3 and the vicinity around RRGE-1, indicate the presence of a significant inhomogeneity between the resource penetrated by RRGE-3 and the resource penetrated by RRGE-1 and RRGE-2.

Estimation of injectability of RRGE-3 based on its production capacity, also presented in this report, indicates that RRGE-3 is far less capable of receiving fluid than it is of producing.

III. EXPERIMENTAL PROCEDURE

To date, several aquifer production tests have been conducted since drilling was completed in June 1976. The tests which appear to best represent the aquifer characteristics of RRGE-3 are presented in this draft. A compilation of tests performed is presented in Table I.

The tests evaluated consist of one long-term artesian flow test (10 days), three short artesian-step tests, and four production tests, utilizing a downhole pump. Of the pump tests, two lasted one day each and two lasted 13 days and 22 days, respectively.

Pressure decline during the artesian tests was measured with a downhole probe and recorder. Drawdown in the wellbore during pumping tests was measured with a downhole bubbler. Transient wellhead pressure changes at RRGE-1, RRGE-2, and RRGI-4, when they were monitored, were measured with a digiquartz transducer and recorder. Intermittent flow activity at RRGE-1 and RRGI-4 disallowed their use as monitor wells during a few tests at RRGE-3.

1. Evaluation Method

Two methods for test analysis were used. These methods are the Theis Non-Equilibrium Method and the Jacob Modified Non-Equilibrium Method.

The Theis method involves the matching of a logarithmic graphic plot of pressure drawdown versus time, since discharge commenced with a Theis

TABLE I

Test	Date	Duration (min.)	Flow (gpm)	kh (Md-ft)	T (gpd/ft)	Well
1	June 8, 1976/ June 16, 1976	11,610	≈137	[a]12,000	[a]1,261	3p
				[b] 6,400	[b] 673	3p
				5,500	578	3r
				222,000	23,346	1i
2	January 26, 1977/ January 28, 1977	720	150	7,600	799	3p
		275	250	12,000	1,335	3p
		240	350	15,000	1,577	3p
3	June 7, 1977	1,440	600	7,400	778	3p
4	June 30, 1977	1,440	800	5,400	557	3p
5	July 6, 1977/ July 19, 1977	18,255	600	[c] 4,400	[c] 452	3p
				[d] 8,900	[d] 935	3p
6	November 28, 1977/ December 22, 1977	34,185	600	[c] 4,700	[c] 525	3p
				[d] 6,700	[d] 704	3p

[a] 1st case - 18 hrs.

[b] 2nd case - entire test

[c] before apparent break

[d] after apparent break

p - production test

r - recovery test

i - interference test

type curve. A match point is obtained which gives reservoir constants that can be used in calculating the transmissivity and in estimating the storage. The formula,

$$kh = \frac{q\mu Pd(.4)}{\nu \Delta P}$$

with q = well discharge
μ = viscosity of water at 300 °F
ν = constant
P_D and ΔP = reservoir constants

was used to calculate the reservoir transmissivity in conjunction with the Theis method. Storage was estimated by use of the formula:

$$\phi ch = \frac{wkht}{\mu t_d r_w^2}$$

with μ = viscosity of water at 300°F
w = constant
kh = reservoir transmissivity
t and t_d = reservoir constants
r_w^2 = 2600 feet

when data was evaluated using the Theis method. Deviation from the Theis type curve indicates that the cone of influence, caused by the discharging well, had encountered an area of differing reservoir parameters. The Theis method was used for the first test only. Analysis was done by Lawrence Berkeley Laboratory(1).

The Jacobs Modification of the Theis method involves plotting drawdown or pressure decline, on an arithmetic scale versus time since pumping commences on a logarithmic scale. The slope of the resulting straight line is used in calculating the reservoir transmissivity. The formula:

$$kh = \frac{5759\ q\mu}{\Delta P_{10}}$$

with q = well discharge
μ = viscosity of water at 300°F
ΔP_{10} = change in drawdown per log cycle

is used to calculate kh. Aquifer storage was not calculated using the Jacob method.

The transmissivities determined by the above methods are in units of millidarcy-feet. A darcy is the "standard unit of permeability" and is defined in the Glossary of Geology. Reservoir storage is a dimensionless quantity.

Deviations from the Theis type curve and changes in slope at the Jacob straight line are indicative of the cone of influence having reached a boundary to the supposed homogeneous, infinite aquifer. If the deviation shows that less drawdown than expected occurs, the boundary is positive (recharge). If the deviation shows that more drawdown occurs than expected, the boundary is negative (discharge).

IV. DATA EVALUATION

1. Test Results

The first test performed was a flow test conducted between June 8, 1976 and June 16, 1976, in which the discharge rate was maintained at approximately 8.64 l/s (137 gpm). Figure 1 shows the flow history for the test. A downhole probe was used to monitor pressure changes at RRGE-3, while wellhead instrumentation was used to monitor RRGE-1 and RRGE-2. This was the only test for which the downhole probe was used at RRGE-3.

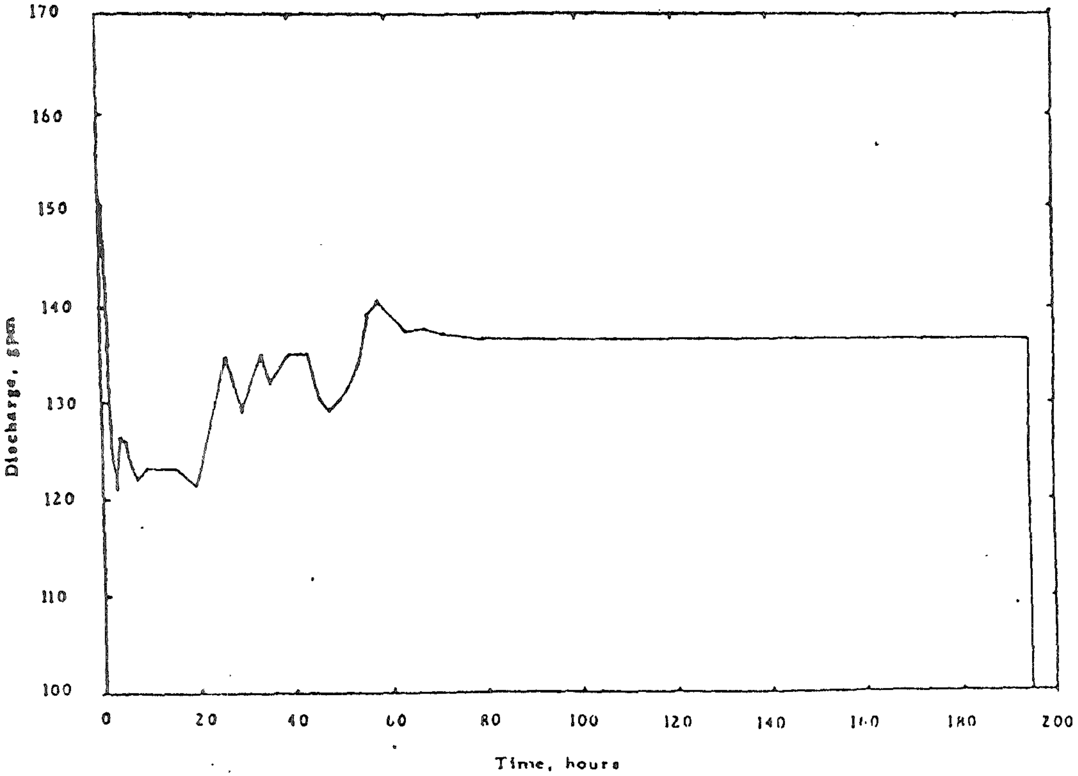

FIGURE 1

RRGE 3 Production history

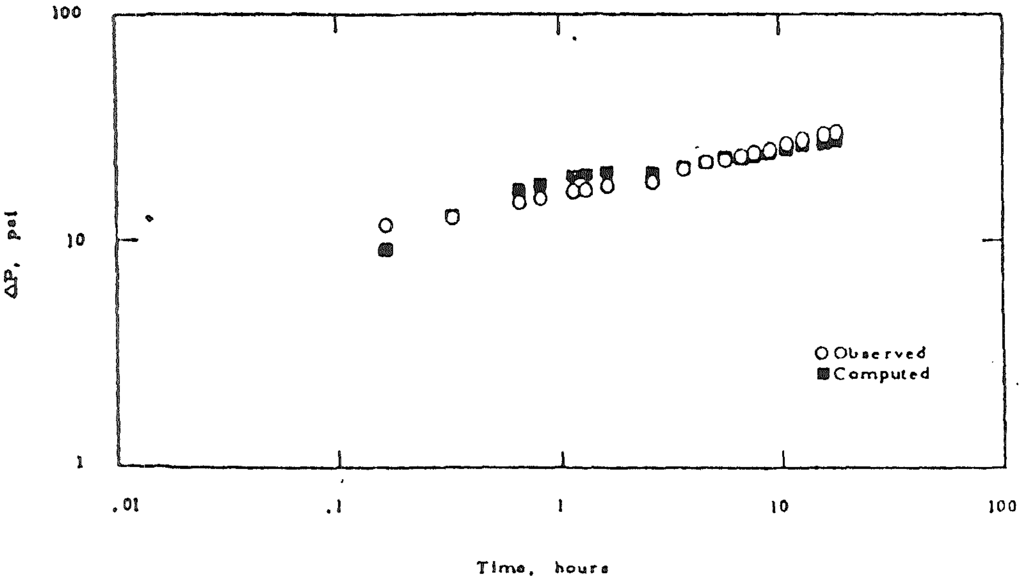

FIGURE 2

RRGE 3 Production test - drawdown analysis by variable discharge method

Due to the fluctuations in discharge rate (Figure 1), a variable discharge model with the conventional-type curves was used to interpret drawdown data. The test was analyzed in two parts, using this technique. The first part utilized the data prior to 18 hours to define reservoir characteristics, while the second considered all data from production, along with a portion of the recovery data after the well was shut in. A Theis interpretation of the results for each case is presented in Figures 2 and 3, respectively. The data in the former indicates a kh of about 12,000 millidarcy-ft. Computation based on the data from the latter indicated a kh of about 6,400 millidarcy-ft. The reason for the difference in the two results is attributed to boundary effects. The data shown in Figure 2 should be relatively free from boundary effects, since it is early in the drawdown history. The data in Figure 3 are integrated over a larger portion of aquifer in the vicinity of RRGE-3, due to the longer test duration which it represents.

The recovery data (Figure 4) were treated as effectively equivalent to superimposing an injection well on the production well, commencing at the time of shut in. Computations based on the data shown in Figure 4 indicate a kh of about 5,500 millidarcy-ft.

Results from interference data collected at RRGE-1 are presented in Figure 5. Using the variable discharge technique, the data indicate a kh of about 222,000 millidarcy-ft. This is at least 40.36 times greater than that computed for RRGE-3, and is indicative of a significant inhomogeneity between RRGE-3 and RRGE-1. No interference was detected at RRGE-2 while discharging RRGE-3.

Figure 6 presents a Jacobs interpretation for three 3-step flow tests conducted January 26, 1977. Data were taken with surface instrumentation and consequently are affected by the temporally dependent density change of the borehole fluid. Computations for the best-fitting straight lines after 100 minutes for each test indicate kh values of 7,600, 12,000, and 15,000 millidarcy-ft, respectively, for the 9.46, 15.77, and 22.08 l/s (150, 250, and 350 gpm) tests. The increase in kh values implies that the data from the 15.77 and 22.08 l/s (250 and 350 gpm) tests had not

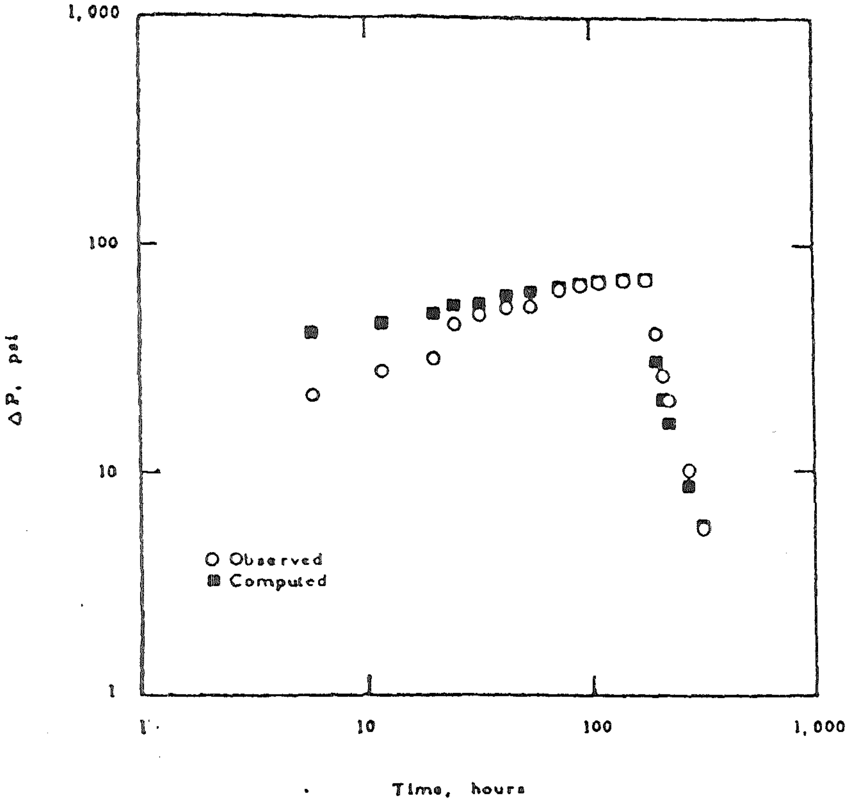

FIGURE 3

RRGE 3 Production test - drawdown and buildup analysis by variable discharge method

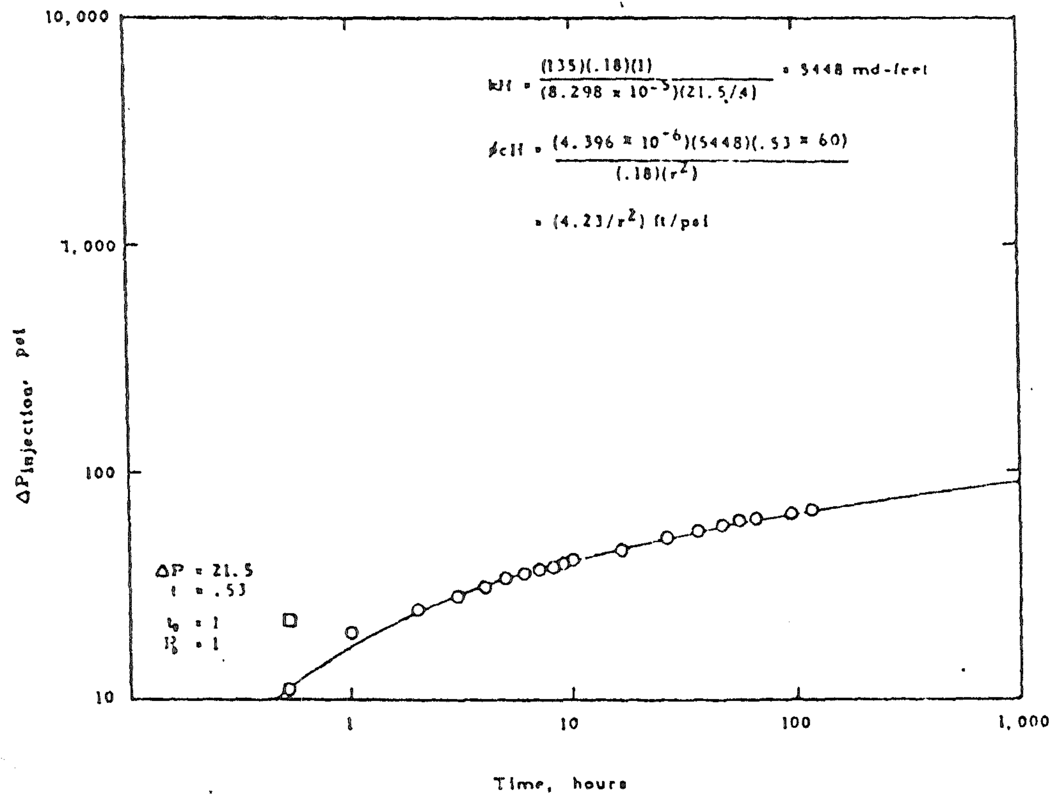

FIGURE 4

RRGE 3 Production test - buildup analysis

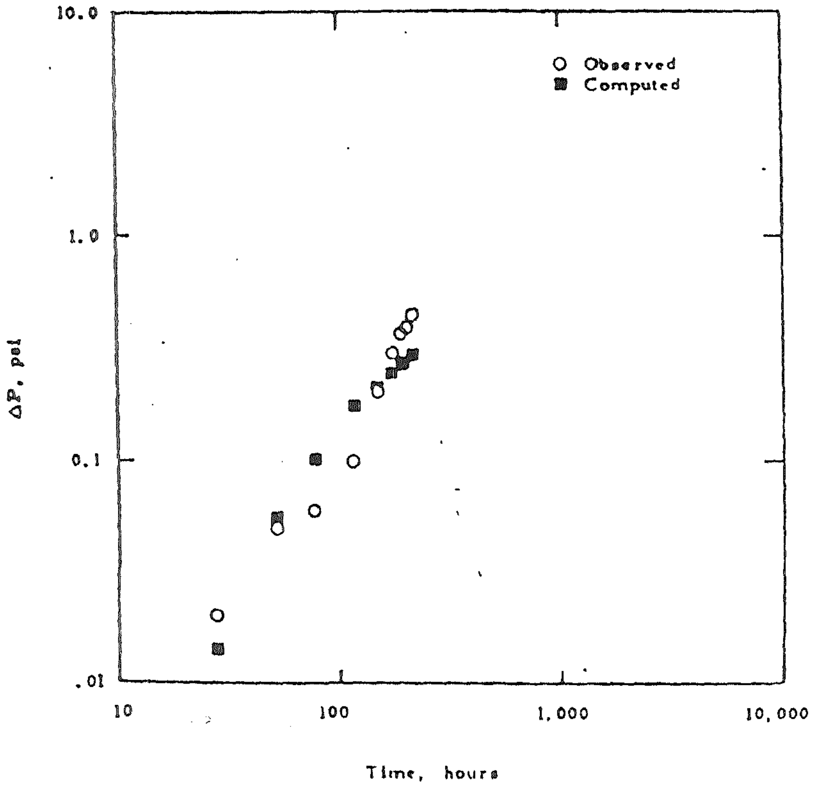

FIGURE 5

RRGE 1 Interference test analysis by variable discharge method

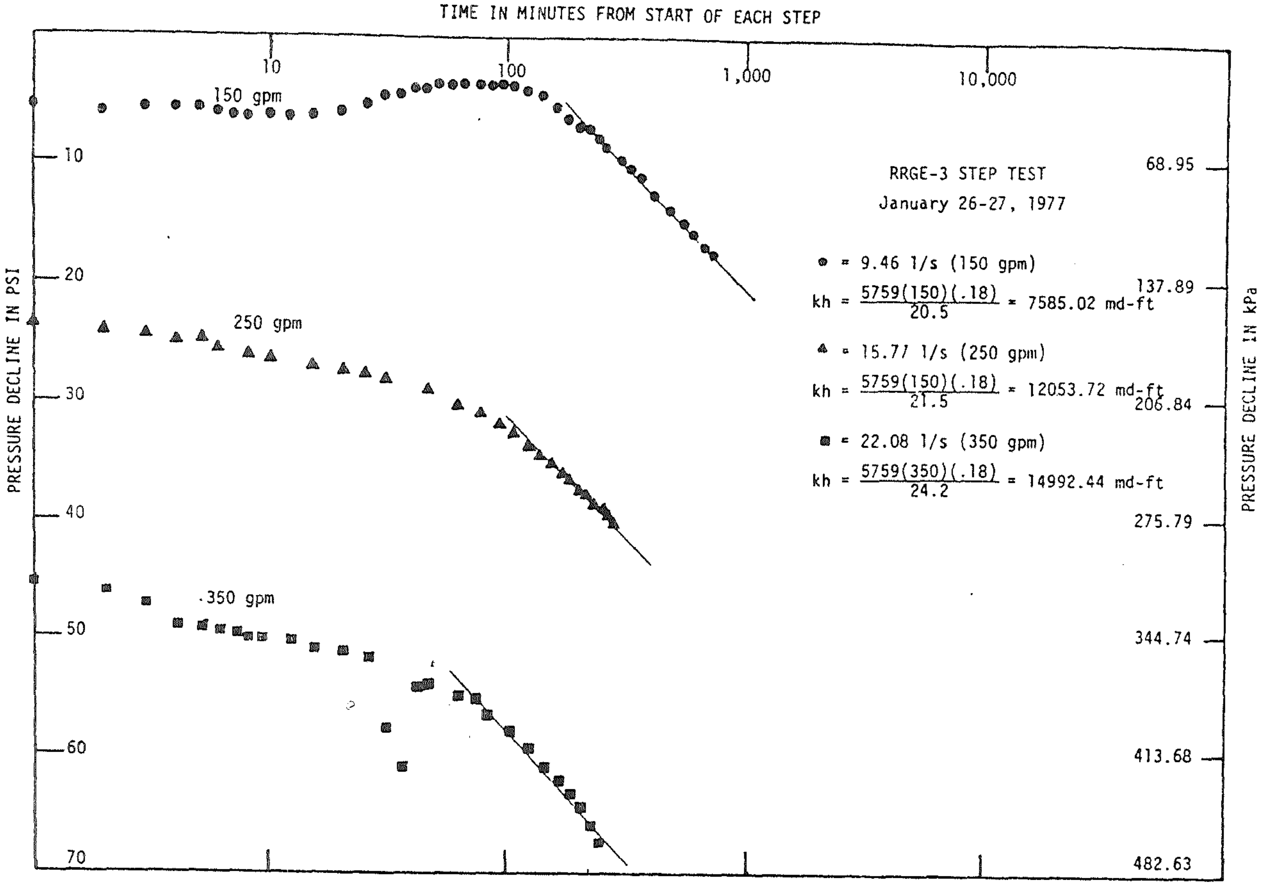

FIGURE 6

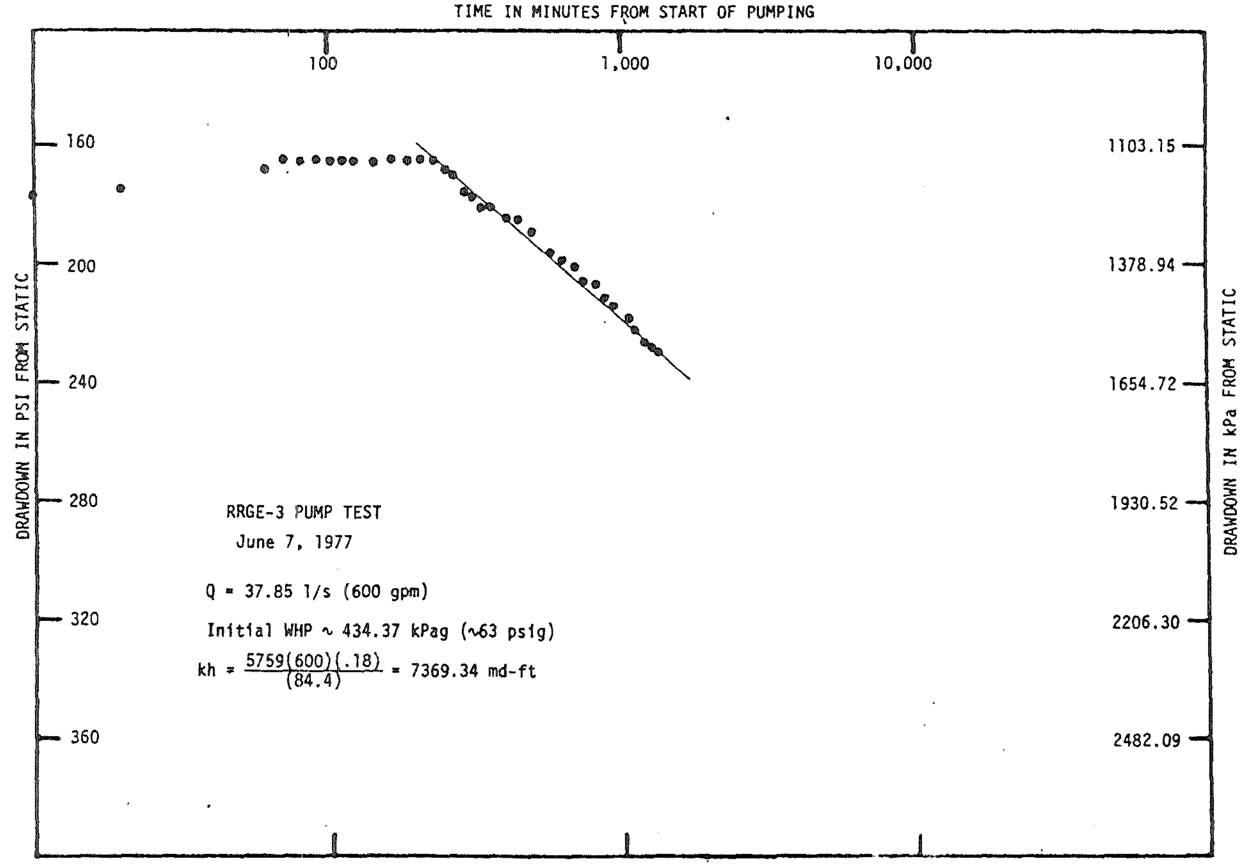

FIGURE 7

reached steady-shape conditions. That is, constant slopes of the pressure decline versus the log of time had not been achieved. Recovery data, as well as interference data from other wells, were not taken.

During May 1977, a pump was installed in RRGE-3 to a depth of 235.61 m (773 ft). With the pump, discharge rates were limited to 37.85 l/s (600 gpm) due to its size, and 50.46 l/s (800 gpm) due to well performance. Subsequently, a series of long and short pump tests were conducted within these discharge limits. Drawdown for each test was measured with the downhole bubbler.

Figure 7 presents a Jacobs interpretation of a 37.85 l/s (600 gpm) test conducted June 7, 1977. The data are again affected by fluid density changes in the wellbore prior to 200 minutes. After 200 minutes, drawdown is measurable, for which a kh of about 7,400 millidarcy-ft is estimated. No recovery or interference data were collected for this test.

Presented in Figure 8 are the data for a 50.46 l/s (800 gpm) test conducted June 30, 1977. Estimated kh from the data is about 5,400 millidarcy-ft. RRGE-4 and RRGE-2 were monitored for this test. There was no influence detected at RRGI-4 or RRGE-2. No recovery data were taken.

A long-term pump test was conducted at RRGE-3 between July 6, 1977 and July 19, 1977, at 600 gpm. During the test, RRGI-4 and RRGE-2 were monitored. RRGI-4 showed no detectable response while the response at RRGE-2, if any, was masked by flow activity at RRGE-1. The data collected at RRGE-3 are presented in Figure 9.

The data prior to about 300 minutes are thermally affected, while the best-fitting straight line after 300 minutes yields a kh of about 4,400 millidarcy-ft. Occurring at approximately 5,000 minutes is a decrease in the rate of drawdown versus the log of time, indicating the possible presence of a recharge boundary at some distance from RRGE-3. There are no simple solutions for estimating the distance to the boundary. The second straight line after the boundary gives an apparent kh value of about 8,900 millidarcy-ft.

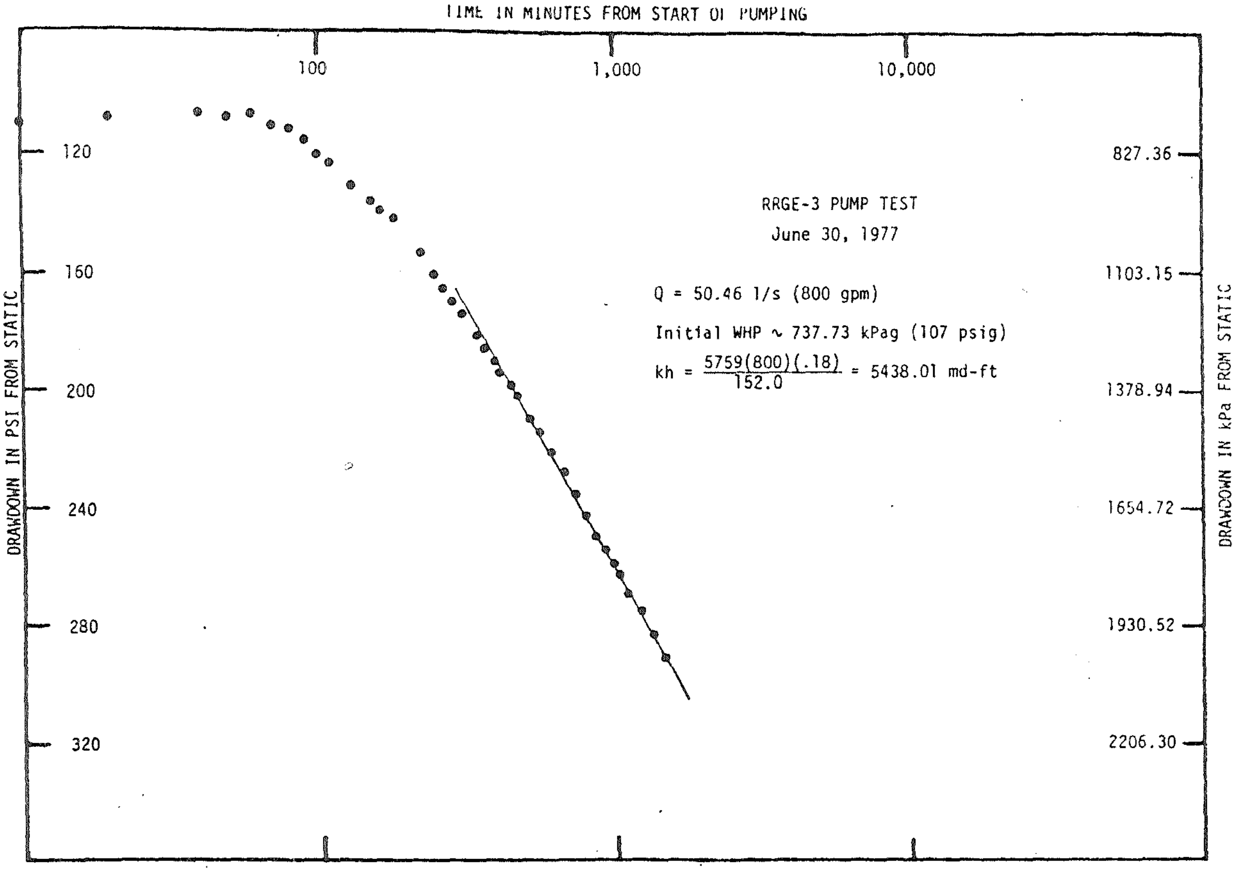

FIGURE 8

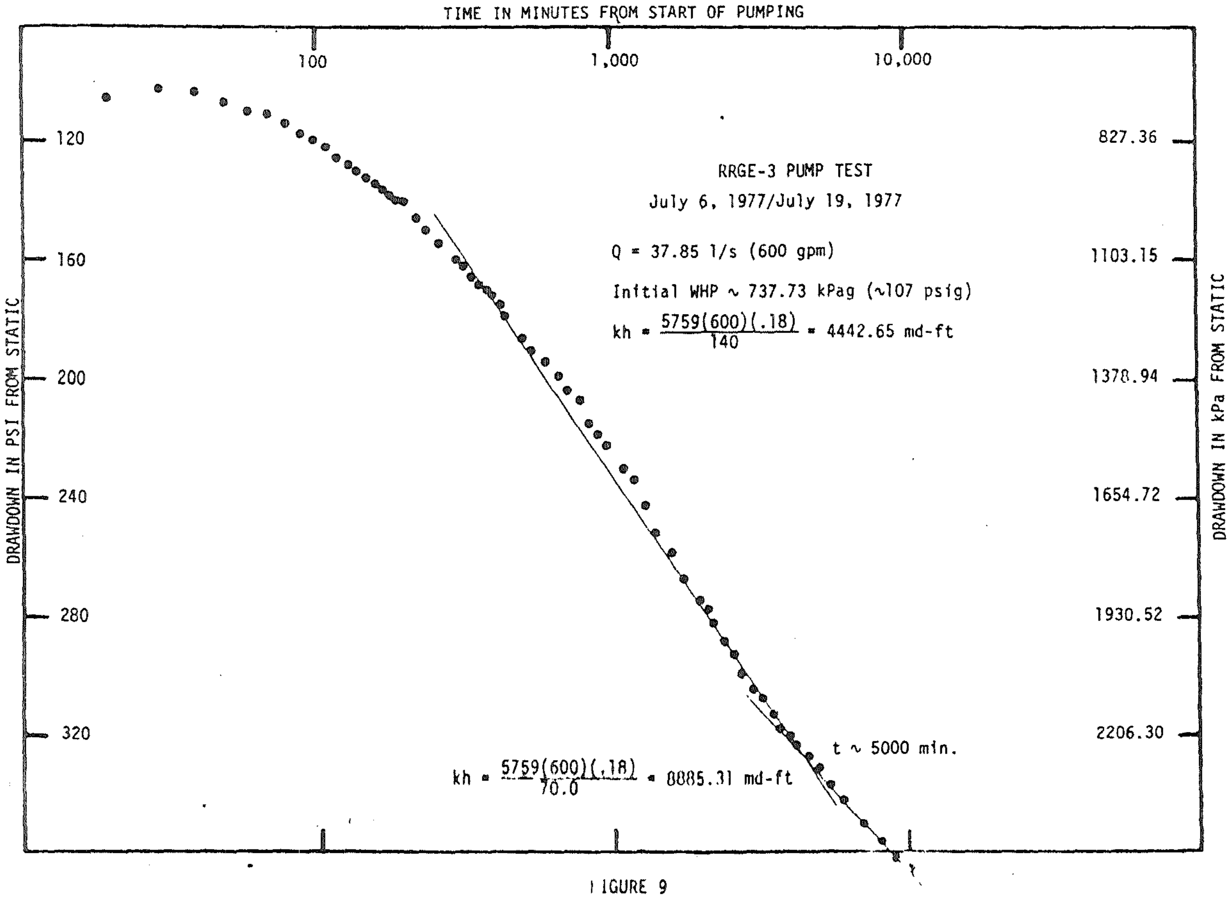

FIGURE 9

The last test performed at RRGE-3 began on November 28, 1977, and ended December 22, 1977. The well was pumped at 37.85 (600 gpm). The data collected during the test are presented in Figure 10. After the well had reached thermal equilibrium at about 350 minutes, a straight line is affixed to the data, suggesting a kh of about 4,700 millidarcy-ft.

A similar effect occurred at about 6,000 minutes during this test, as it did in the previous test. That is, the drawdown began to equilibrate partially with respect to the log of time. An apparent kh for the best straight line fit after 6,000 minutes is about 6,700 millidarcy-ft.

Interference at RRGI-4 for this test could not be monitored as it was in the midst of testing itself. RRGE-2 again saw no influence greater than what was created by flow activity at RRGE-1.

2. Discussion of Results

When comparing results obtained for RRGE-1 and RRGE-2 with those of RRGE-3, a specific inhomogeneity within the Raft River Geothermal Resource is indicated. The log mean kh for RRGE-3 is 7,420 millidarcy-ft. This is 15.5 times smaller than the value obtained for RRGE-1, which is 115,000 millidarcy-ft(2) and 6.4 times smaller than that obtained for RRGE-2, which is 47,200 millidarcy-ft(2). Interference obtained at RRGE-1 while discharging RRGE-3 indicates a kh of about 222,000 millidarcy-ft. This is 29.9 times greater than the log mean kh for RRGE-3. From these results, it is highly unlikely that the aquifer characteristics are everywhere similar throughout the volume of the resource between RRGE-3 and the area around RRGE-1 and RRGE-2. It is difficult to delineate the exact nature of the discontinuity between RRGE-3 and the area around RRGE-1 and RRGE-2; however, it is very likely that the resource penetrated by the latter is behaving as a falling-head recharge boundary when discharging RRGE-3. This is best exemplified in Figures 9 and 10, in which these data suggest that drawdown was approaching an equilibrium, as indicated by the decreasing slopes for the respective tests at 5,000 minutes

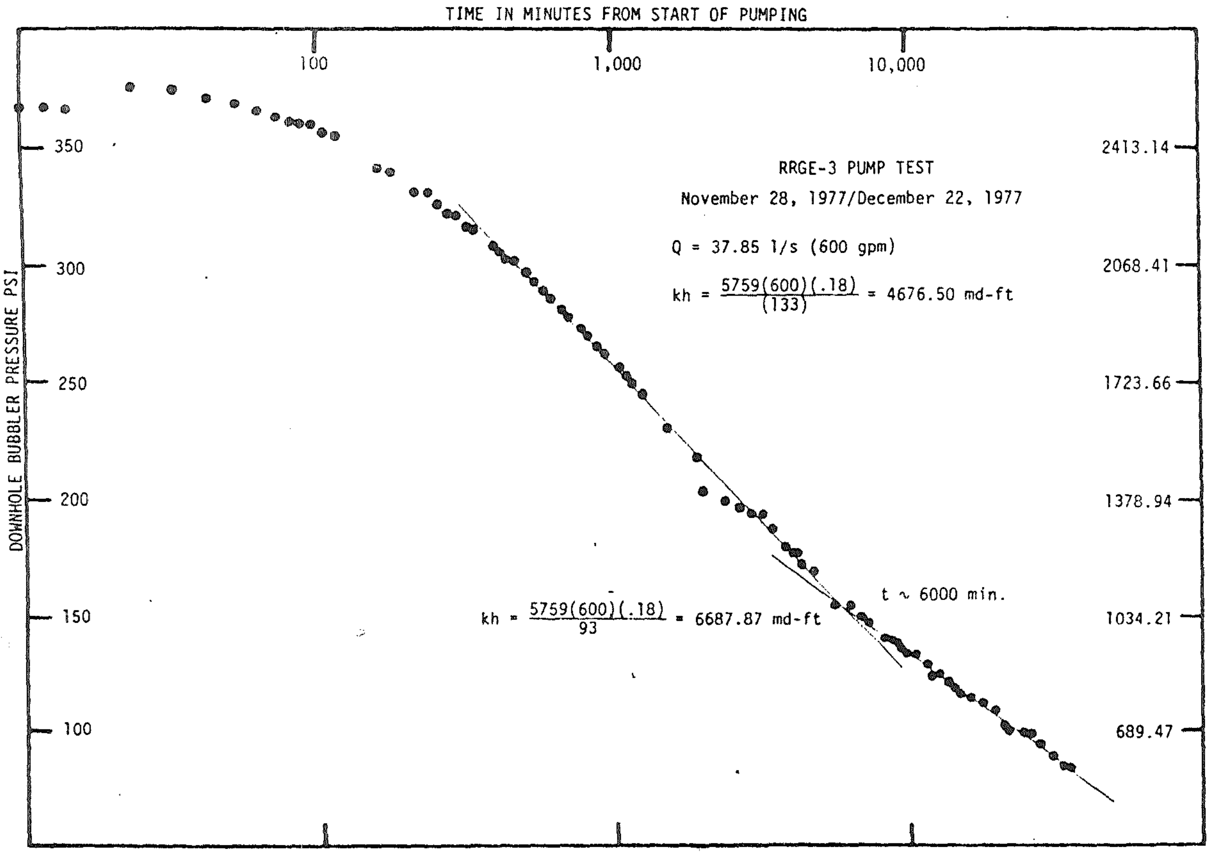
TIME IN MINUTES FROM START OF PUMPING
100
1,000
10,000
350
300
250
200
150
100
DOWNHOLE BUBBLER PRESSURE PSI
2413.14
2068.41
1723.66
1378.94
1034.21
689.47
DOWNHOLE BUBBLER PRESSURE kPa
RRGE-3 PUMP TEST
November 28, 1977/December 22, 1977
Q = 37.85 l/s (600 gpm)
kh = $\frac{5759(600)(.18)}{(133)}$ = 4676.50 md-ft
t ~ 6000 min.
kh = $\frac{5759(600)(.18)}{93}$ = 6687.87 md-ft

FIGURE 10

and 6,000 minutes. The expected source for the recharge is likely the Bridge and/or Narrows structure. One or both of these structures would then be considered non-constant head leaky faults, whereby the fault acts as a conduit for fluid movement into the aquifer or fracture system penetrated by RRGE-3 during the pumping test. In this case, there must be resistance to movement within the fault zone, and, consequently, at the point where the fault zone intersects the aquifer or fracture system penetrated by RRGE-3, the hydraulic head does not stay constant. If that were the case, influence at RRGE-1, RRGE-2, and, additionally, RRGI-4 (which penetrate these structures) would be very minor and conceivably could go unnoticed. Longer tests (several months) or higher discharge rates at RRGE-3 would be needed to verify this.

3. RRGE-3 Production Capability

When considering the 5-year deliverability of RRGE-3 as a production well, influence due to injection in the vicinity of RRGI-6 and RRGI-7 and production in the vicinity of RRGE-1 must be considered. To do this, some assumptions must be made. For injection influence, the distance between RRGE-3 and the injection wells is taken to be 762 m (2,500 ft). In addition, the average kh between the two is assumed to be 75,000 millidarcy-ft (T = 4904 gpd/ft) and the reservoir temperature is assumed to be 93°C (200°F). Storage is assumed to be 5×10^{-4}. If all 158 l/s (2,500 gpm) from plant production were injected into RRGI-6 and RRGI-7, the expected buildup at RRGE-3 would be 1241 kPa (180 psi) after five years.

Drawdown due to production in the vicinity of RRGE-1 can be estimated in the same manner. Production in the vicinity of RRGE-1 is assumed to be 132 l/s (2,100 gpm).

The remaining 25 l/s (400 gpm) would be expected to come from RRGE-3. Additionally, the distance between RRGE-3 and the production wells in the vicinity of RRGE-1 was estimated to be 1859 m (6,100 ft). Reservoir parameters between RRGE-3 and the production wells are assumed to be kh = 75,000 millidarcy-ft (T = 6,299 gpd/ft), reservoir temperature =

121°C (250°F). Storage is assumed to be 5×10^{-4}. With these constraints, drawdown at RRGE-3 due to production in the vicinity of RRGE-1 of 132 l/s (2,100 gpm) would be 945 kPa (137 psi). Based on these data, the net performance of RRGE-3 would then be approximately 32 l/s (500 gpm), with its present pump setting at 236 m (773 ft) below land surface. This is presented graphically in Figure 11.

4. RRGE-3 Injectability

Predictions at present for the injection capacity for RRGE-3 to accept water are at best nebulous. They are based solely on production tests and may be subject to change. The method by which injectability was predicted is shown graphically in Figures 12 and 13.

Shown in Figure 12 are idealized production trends, inverted, for a series of tests performed at RRGE-3. They assume no boundary effects over a 5-year period. The lines were extrapolated for five years, at which point the 5-year pressure buildup intercept was chosen. These points were in turn plotted as a function of injection rate for both 66°C (150°F) and 143°C (290°F) water, Figure 13. Two straight lines are generated; the area between conceivably representative of the expected injection pressure for a given injection rate. The data in Figure 13 is also corrected for wellbore density effects, as well as influence due to production and injection elsewhere in the field, as described in the previous section.

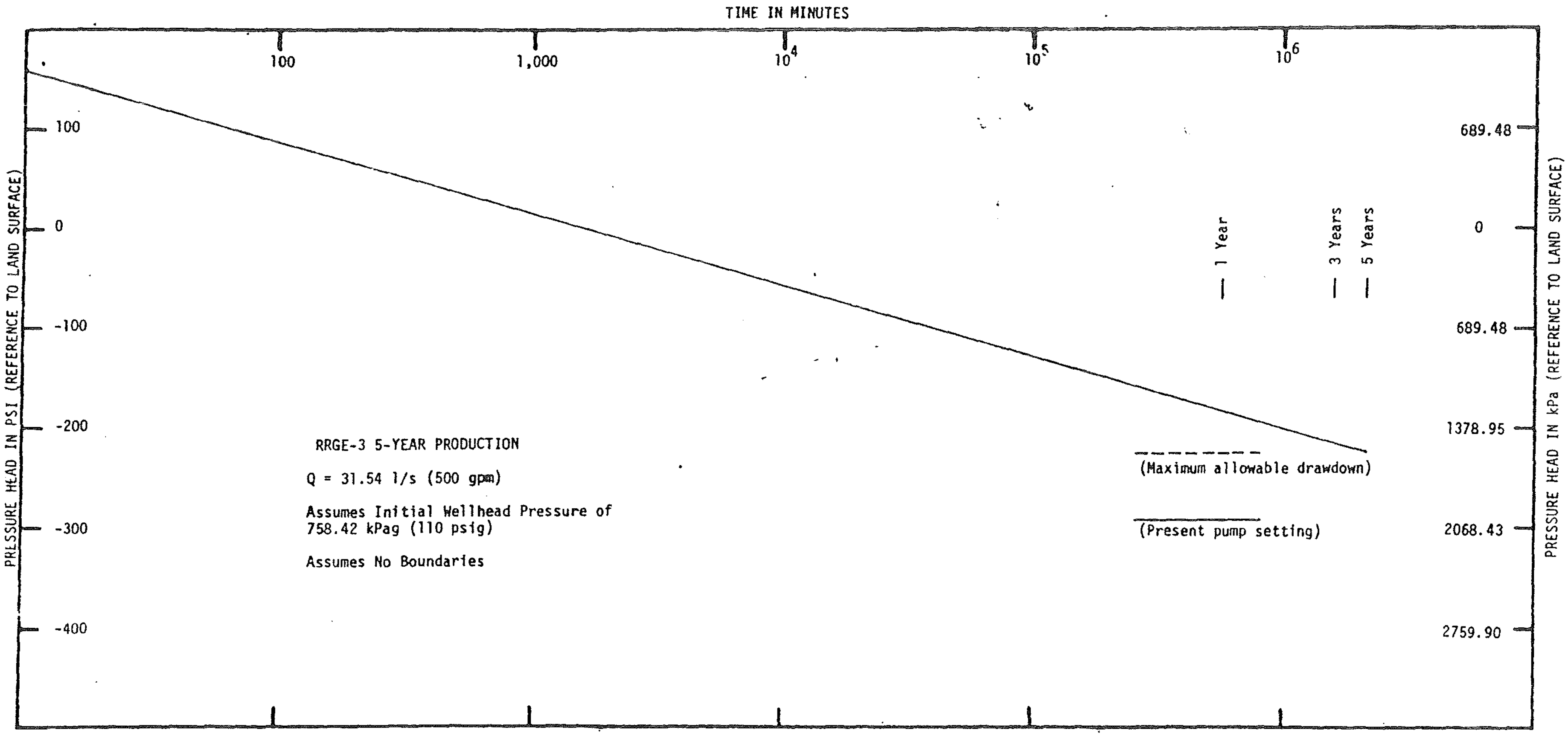
TIME IN MINUTES
100
1,000
10^4
10^5
10^6
PRESSURE HEAD IN PSI (REFERENCE TO LAND SURFACE)
100
0
-100
-200
-300
-400
PRESSURE HEAD IN kPa (REFERENCE TO LAND SURFACE)
689.48
0
689.48
1378.95
2068.43
2759.90
1 Year
3 Years
5 Years
RRGE-3 5-YEAR PRODUCTION
Q = 31.54 l/s (500 gpm)
Assumes Initial Wellhead Pressure of 758.42 kPag (110 psig)
Assumes No Boundaries
(Maximum allowable drawdown)
(Present pump setting)

FIGURE 11

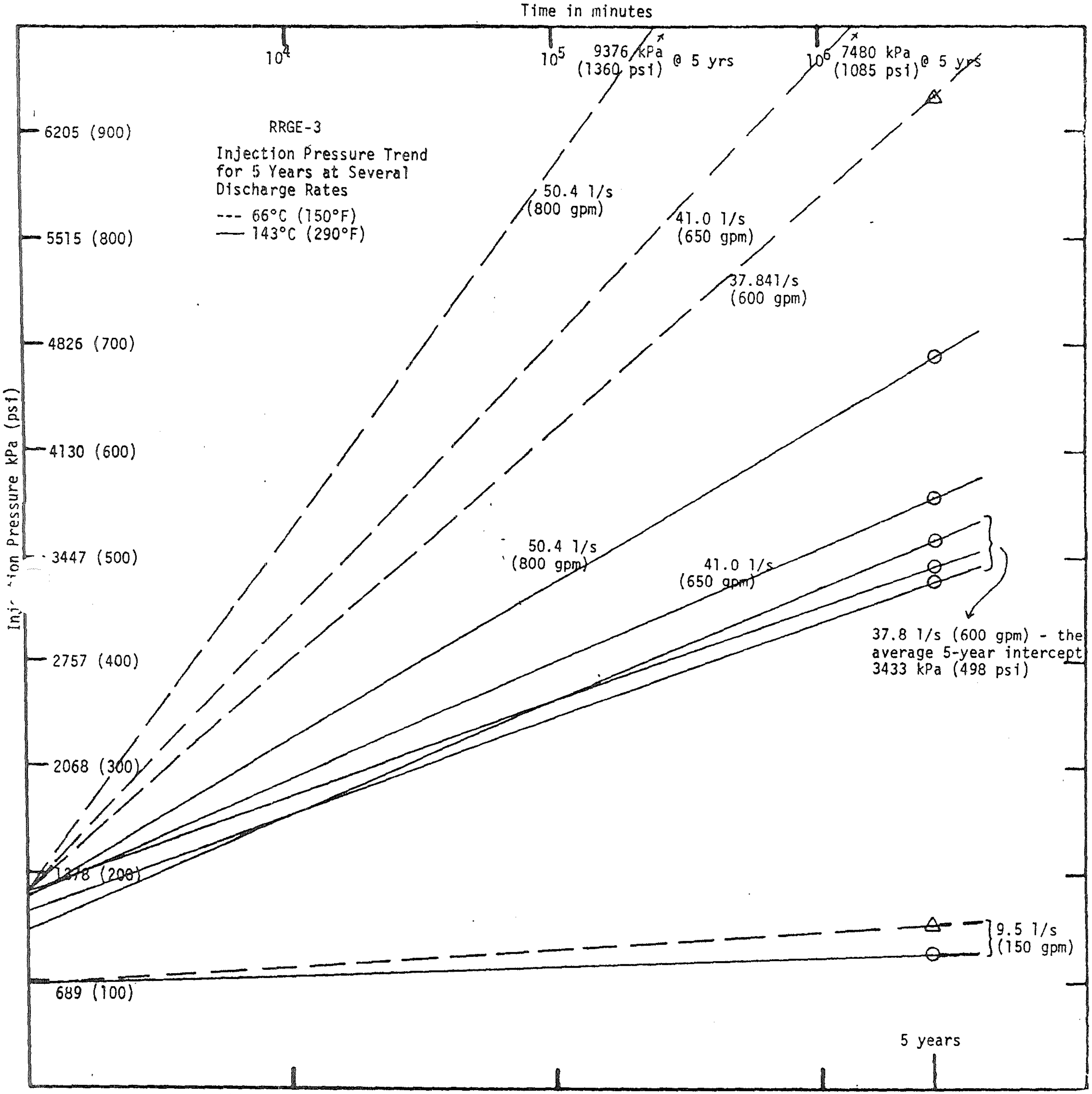
Time in minutes
10^4
10^5
10^6
9376 kPa (1360 psi) @ 5 yrs
7480 kPa (1085 psi) @ 5 yrs
RRGE-3
Injection Pressure Trend for 5 Years at Several Discharge Rates
--- 66°C (150°F)
— 143°C (290°F)
Inj- -ion Pressure kPa (psi)
6205 (900)
5515 (800)
4826 (700)
4130 (600)
3447 (500)
2757 (400)
2068 (300)
1378 (200)
689 (100)
50.4 l/s (800 gpm)
41.0 l/s (650 gpm)
37.84 l/s (600 gpm)
50.4 l/s (800 gpm)
41.0 l/s (650 gpm)
37.8 l/s (600 gpm) - the average 5-year intercept 3433 kPa (498 psi)
9.5 l/s (150 gpm)
5 years

FIGURE 12

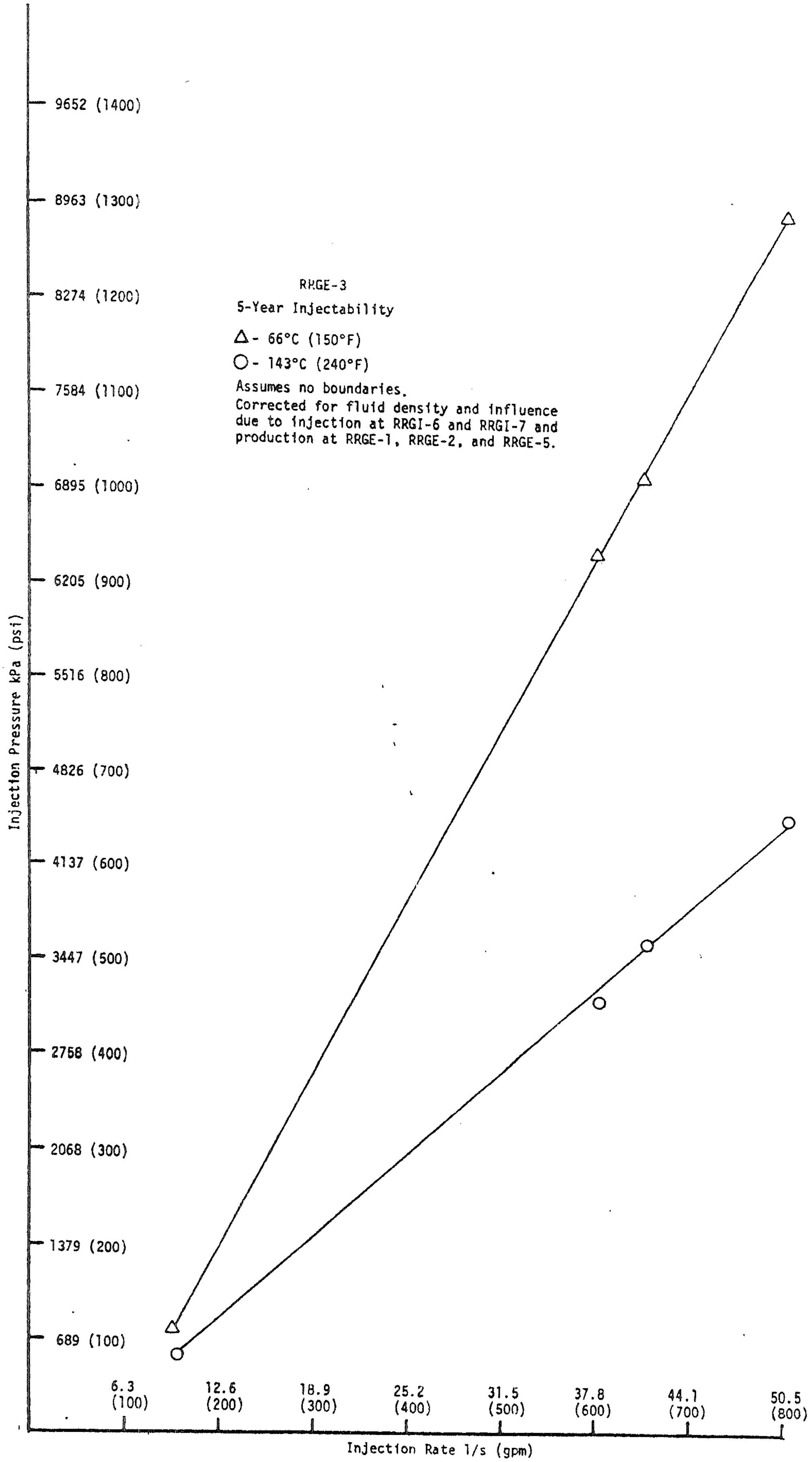
RRGE-3
5-Year Injectability
△ - 66°C (150°F)
○ - 143°C (240°F)
Assumes no boundaries.
Corrected for fluid density and influence due to injection at RRGI-6 and RRGI-7 and production at RRGE-1, RRGE-2, and RRGE-5.
Injection Pressure kPa (psi)
9652 (1400)
8963 (1300)
8274 (1200)
7584 (1100)
6895 (1000)
6205 (900)
5516 (800)
4826 (700)
4137 (600)
3447 (500)
2758 (400)
2068 (300)
1379 (200)
689 (100)
6.3 (100)
12.6 (200)
18.9 (300)
25.2 (400)
31.5 (500)
37.8 (600)
44.1 (700)
50.5 (800)
Injection Rate l/s (gpm)

FIGURE 13

V. CONCLUSIONS

1. RRGE-3 is capable of producing 32 l/s (500 gpm), if production in the vicinity of RRGE-1 is 126 l/s (2,000 gpm) and if injection of 157.70 l/s (2,500 gpm) into RRGI-6 and RRGI-7 is 158 l/s (2,500 gpm).

2. A non-ideal recharge boundary is detected at RRGE-3 between 4,500 minutes and 5,000 minutes, with its source most likely in the vicinity of RRGE-1.

3. Injection of power plant fluids into RRGE-3 in its present configuration appears impracticable.

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2. T. N. Narasimhan and P. A. Witherspoon, "Reservoir Evaluation Tests on RRGI-1 and RRGE-2, Raft River Geothermal Project, Idaho," Lawrence Berkeley Laboratory, University of California, Berkeley, 1975.