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from the reuse of this water for irrigation or creation of fish or wildlife habitat. Future studies are aimed at further quantifying the treatment capability and the biomass production potential of biological systems using geothermal water. By providing an environmentally sound alternative to injection or a way to improve fluid quality prior to injection, the competitive economic position of geothermal commercialization may be enhanced.

Acknowledgments

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Raft River wellfield testing and analysis

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The objective of the Raft River Geosciences Program is to develop an understanding of a typical fracture-controlled, liquid-dominated, moderate-temperature hydrothermal system.

The Raft River geothermal field includes five deep geothermal exploratory/production wells and two intermediate-depth injection wells drilled between 1975 and 1978. Groundwater, petroleum, and high-temperature geothermal equipment and techniques were used to test the wells. A more detailed interpretation of the data is provided in the *Raft River Geoscience Case Study* [1] published in September 1981. The geoscientific data presented in the case study suggest that the Raft River thermal production reservoir is: (a) controlled largely by fractures found at the contact between the metamorphic rock sequence and the Salt Lake Formation at the base of listric normal faulting of the Bridge and Horse Well Fault zones [2]; (b) anisotropic, with the major axis of hydraulic conductivity coincident to the Bridge Fault Zone; (c) hydraulically connected to the shallow thermal fluids (based upon both geochemistry and pressure response); and (d) controlled by a mixture of diluted meteoric water recharging from the northwest and a saline chloride water entering from the southwest [2].

The testing procedures and an overview of the expected performance of the Raft River wellfield during plant operation are presented in this paper.

Testing Procedures

Four well-testing procedures were used to evaluate the seven geothermal wells. The method selected for each well was dependent on the primary test objective and availability of pumps and instrumentation. The four procedures employed were: (1) artesian flow and air-lift tests during and shortly after drilling; (2) short duration (less than five days) constant rate and variable-head artesian flow tests following drilling; (3) a series of pulse discharge and injection tests of short duration (less than five days), with constant rate and variable head; and (4) pumping and injection tests of up to 30 days duration using permanently installed pumps. In addition, well-interference data was collected and analyzed for all tests that were at least three days in duration.

The reservoir data obtained from the testing procedures often required evaluation of fracture flow, a controversial issue in both the petroleum and groundwater industries. The recommended analytical techniques vary from using the standard Theis assumptions and equations for an anisotropic permeable medium [3] to computer simulations of block responses [4]. The latter technique suggests that use of the Theis solution in analyzing pump-test data from fractured reservoirs can yield grossly erroneous values of reservoir parameters.

Based on the field experience at Raft River, an empirical technique was developed that has resulted in an accurate method of predicting well drawdown, even with apparent "leaky" hydrologic boundary conditions, commingling effects of multiple aquifers, well losses, borehole fluid-density effects, and wellbore storage effects. This technique was developed as a result of many pump tests conducted over a wide range of discharge rates, such that it is possible to define well drawdown

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without any recourse to a strictly theoretical approach. The discharge rate (Q) divided by the straight-line slope of the data over one log cycle (s_{10}) on a semilogarithmic plot of drawdown-versus-time has been used. The values of Q/s_{10} are not reservoir parameters, but do allow prediction of well drawdown and allow for comparison between wells in a reservoir if adjusted for fluid viscosity.

Wellhead temperatures at the production wells are measured by platinum resistance thermometers and calibrated mercury thermometers. The wellhead temperatures recorded for the production wells range from 113°C, at RRGP-4, to 144°C at RRGE-3 (Table 1).

Table 1. Raft River Wellhead Temperatures

RRGE-1	137°C (279°F)
RRGE-2	138°C (281°F)
RRGE-3	144°C (291°F)
RRGP-4	113°C (235°F)
RRGP-5	129°C (264°F)

Wellfield Testing

RRGE-1. Five well tests have been conducted at this well since November 1975, including pulse testing, pump testing, and artesian flow testing. These tests ranged in duration from 8 hours to 500 hours, at discharge rates from 1.7 L/s to about 76 L/s.

Additional well tests are planned for this well to supplement the existing data. It is estimated that the well will produce a sustained artesian flow of approximately 13 L/s for a three-year period. An estimation of well discharge-versus-wellbore drawdown from static conditions is given in Figure 1.

RRGE-2. Fourteen reservoir tests have been conducted on this well since September 1975. Eight have been artesian flow tests and six have been pump tests. The artesian flow tests were generally conducted for a 24-hour period with a flow of about 17 L/s while the pump tests ranged in duration from 12 to 500 hours with flows from 15.8 L/s to 46.7 L/s.

The estimated production rate of well RRGE-2 is 22 L/s. Figure 2 shows the predicted drawdowns at a range of flow rates. These have been calculated under assumptions regarding use, wellhead pressures, and boundary conditions. Given these assumptions, the available drawdown would be utilized after three years of 85% sustained use at 22 L/s.

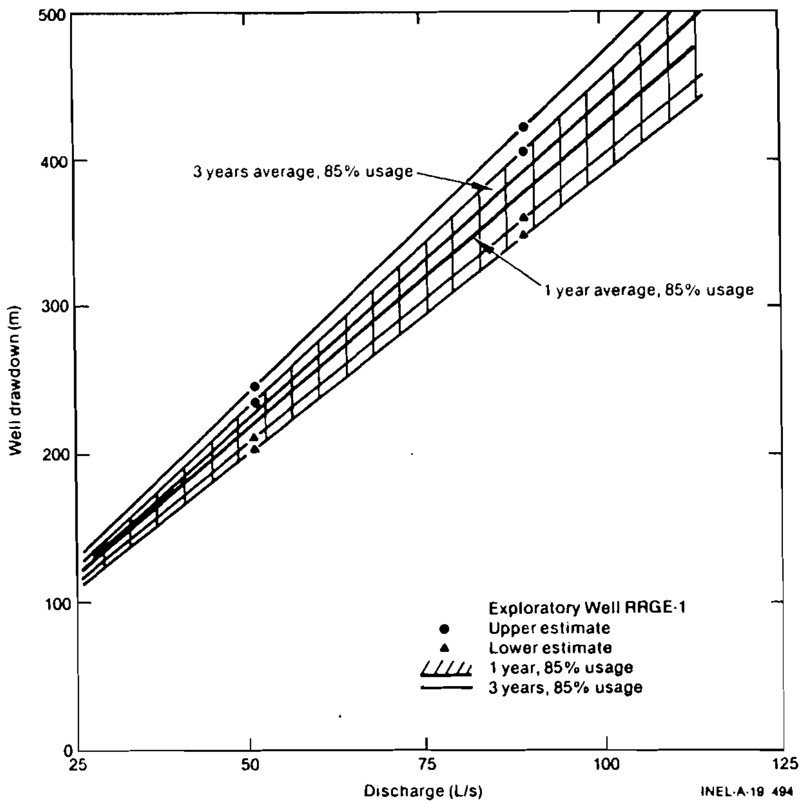

Figure 1. Expected drawdown versus flow rate at exploratory well RRGE-1 (not including interference effects; see reference 2).

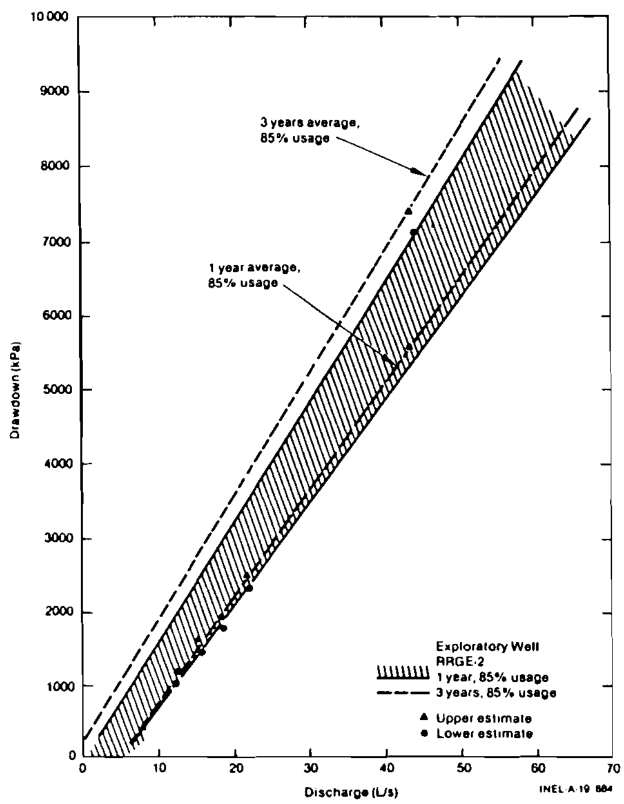

Figure 2. Expected drawdown versus flow rate at exploratory well RRGE-2 (not including interference effects; see reference 2).

RRGE-3. There have been 11 well-performance tests conducted on this well. Most of these were pumping tests with an average discharge of 42 L/s with test durations ranging from 24 to 800 hours.

The probable maximum sustained artesian flow capability of RRGE-3 is 12 to 13 L/s. The available artesian drawdown would be exhausted after three years of 85% sustained use at 12 to 13 L/s. An estimation of well discharge-versus-wellbore drawdown from static conditions is plotted in Figure 3.

RRGP-4. The Raft River well designated RRGP-4 was originally constructed and tested as an injection well. As such, the well carried the designation of RRGI-4. During the year following May 1977, when RRGI-4 was completed, a number of artesian flow and injection tests were conducted. The results of these tests were inconclusive.

The well was deepened in 1979 and the construction modified to create a fourth production well (RRGP-4). In conjunction with deepening the well, a hydro-fracturing effort was initiated [2]. The only test conducted after the stimulation process that exceeded 24 hours was designed to evaluate the results of the hydraulic fracturing. The well was not produced at a constant rate, and there are no tests at RRGP-4 that can be used to evaluate reservoir characteristics. The test did show a five-fold increase over the pre-stimulation flow rate, although it is still a subcommercial rate for production purposes.

RRGP-5. This well was initially completed in July 1978 at a total depth of 1493 m. After about nine months of testing, a decision was made to attempt to stimulate the well by hydraulic-fracturing [2]. Post-stimulation testing indicates that the well is still developing. "Frac" sand from the stimulation effort was produced during the post-stimulation test which resulted in destruction of the pump before reservoir evaluation tests were completed. A sand extractor might be utilized in conjunction with production from the well if another pump is installed. The extraction is believed capable of removing about 95% of the sand.

RRGI-6 and -7. At each of these wells, 5 well tests have been conducted for which data are suitable for analysis. Both injection and recovery data were collected for these tests. The predicted wellhead buildup for RRGI-6 and -7 is illustrated by Figures 4 and 5, respectively. Figure 4 reflects projections from four injection tests of RRGI-6, and has been adjusted for an injection-fluid temperature of 66°C. Figure 5 shows the projected pressure buildup at RRGI-7 as a function of injection rate and fluid temperature of 66°C.

Both of these wells are injecting into multiple zones. RRGI-6 is primarily fracture-controlled, while RRGI-7 appears to be subject to intergranular control with limited fractures. Until October 1981, all of the injection tests had utilized fluids of approximately 120°C. The October-November 1981 fluid-injection temperatures during start-

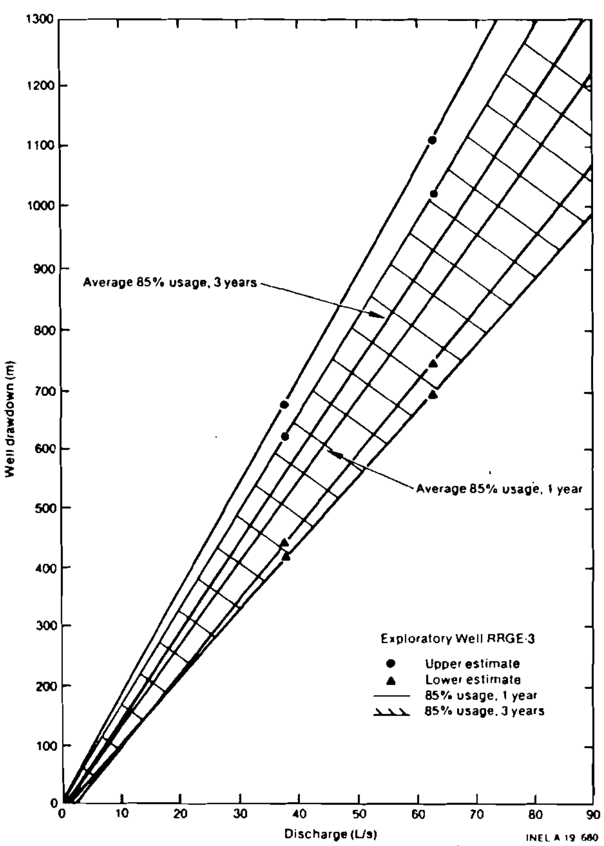

Figure 3. Expected drawdown versus flow rate at exploratory well RRGE-3 (not including interference effects; see reference 2).

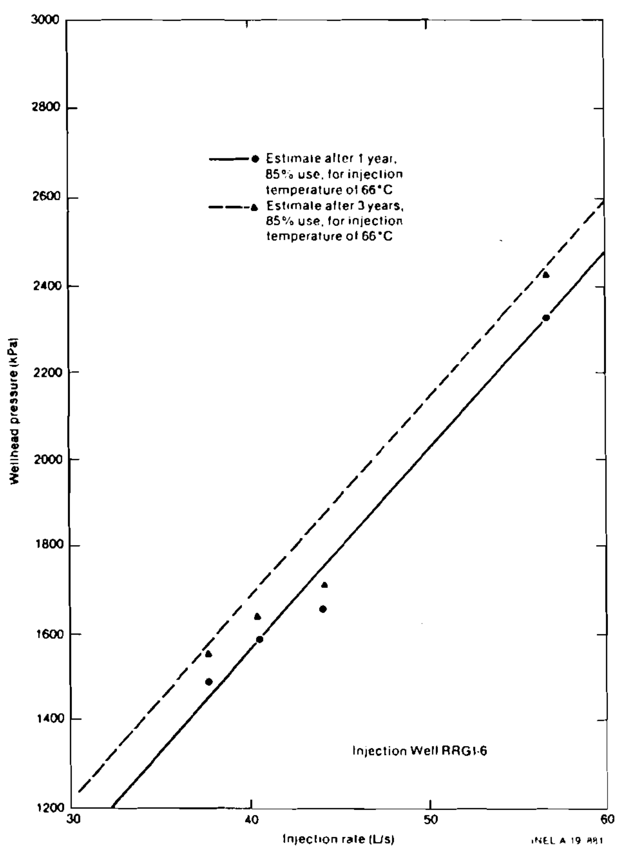

Figure 4. Predicted pressure buildup versus injection rate for injection well RRGI-6 (see reference 2).

up operations ranged from 21°C to 133°C. The results of these tests have not been fully analyzed, although it is clear that a steady-state condition was not obtained at either wellhead. RRGI-7 demonstrated a marked improvement in injectivity since prior testing, conceivably due to pump-induced water-hammer effects or thermal shock.

A discussion of the injection wells at RRGI-6 and -7 in operation during plant start-up at Raft River in October 1981 will be presented later in 1982 [5].

Analysis of Well Productivity

Productivity curves were plotted for each of the exploratory and production wells. Data from wells RRGP-4 and -5 show that RRGP-4 will not produce the necessary flow needed from a production well and data collected at RRGP-5 indicate that it is potentially a good well if the sand utilized in the hydraulic fracturing effort can be removed before damaging the pump. However, the data from RRGE-1 and -3 do not appear to reflect a constant specific capacity. The observed specific capacities for these wells at low discharge rates are considerably higher than at high discharge rates. When the 24-hour productivity curves are generated for these wells, the curves are quadratic in

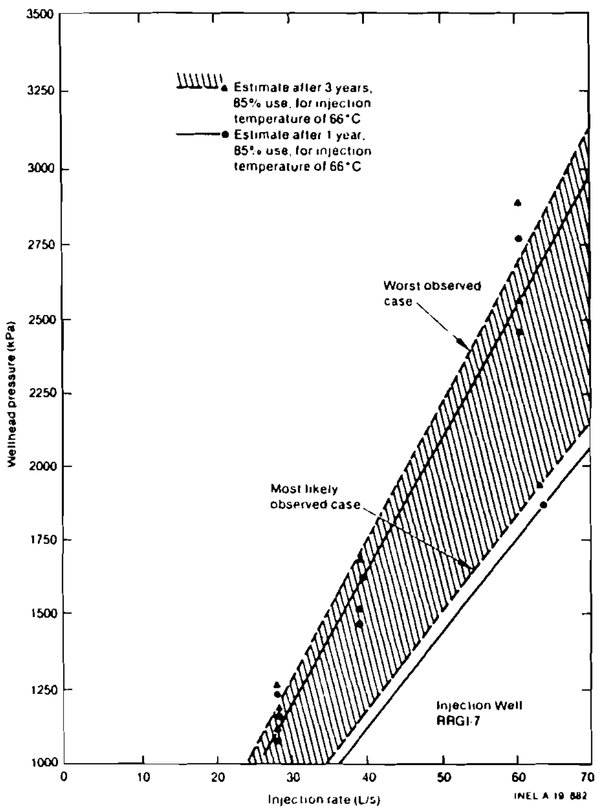

Figure 5. Predicted pressure buildup versus injection rate for injection well RRGI-7 (see reference 2).

form, rather than linear (Figure 6). The quadratic form is believed to be a function of the fractured nature of the reservoir [1].

Further data analysis of these and other curves may result in a better understanding of a fracture-controlled reservoir and greatly improve the ability to predict reservoir behavior.

Conclusion

The Raft River wellfield has the capability of supplying the necessary flow to operate the 5 MW(e) facility. RRGE-1, -2, and -3 will be utilized for production purposes and RRGI-6 and -7 will serve as the injection wells. RRGP-4 remains unproductive for plant operation, and RRGP-5 is continuing to develop.

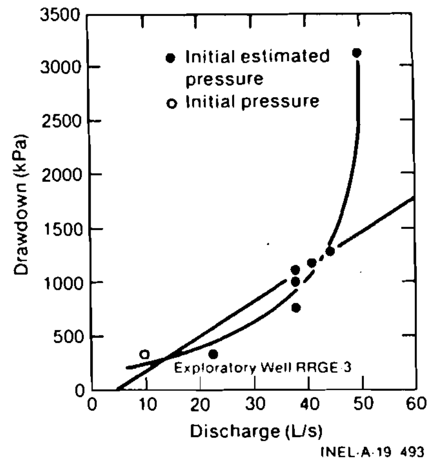

Figure 6. Productivity curve of 24-hour data well RRGE-3.

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