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MONITOR WELL RESPONSES AT THE RAFT RIVER, IDAHO, GEOTHERMAL SITE

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ABSTRACT

Effects of geothermal fluid production and injection on overlying ground-water aquifers have been studied at the Raft River Geothermal Site in southcentral Idaho. Data collected from 13 monitor wells indicate a complex fractured and porous media controlled ground-water flow system affected by natural recharge and discharge, irrigation withdrawal, and geothermal withdrawal and injection. The monitor wells are completed in aquifers and aquitards overlying the principal geothermal aquifers. Potentiometric heads and water quality are significantly affected by natural upward geothermal leakage via faults and matrix seepage. No significant change in water quality data has been observed, but potentiometric head changes resulted due to geothermal resource testing and utilization.

Long-term hydrographs for the wells exhibit three distinct patterns, with superimposed responses due to geothermal pumping and injection. Well hydrographs typical of the Shallow aquifer exhibit effects of natural recharge and irrigation withdrawals. For selected wells, pressure declines due to injection and pressure buildup associated with pumping are observed. The latter effect is presumably due to the elastic deformation of geologic material overlying the stressed aquifers. A second distinct pattern occurs in two wells believed to be hydraulically connected to the underlying Intermediate aquifer via faults. These wells exhibit marked buildup effects due to injection as well as responses typical of the Shallow aquifer. The third pattern is demonstrated by three monitor wells near the principal production wells. This group of wells exhibits no seasonal potentiometric head fluctuations. Fluctuations which do occur are due to injection and pumpage. The three distinct hydrograph patterns are composites of the potentiometric head responses occurring in the various aquifers underlying the Raft River Site.

INTRODUCTION

The Raft River Known Geothermal Resources Area (KGRA) is located in the Raft River Valley in southcentral Idaho (Figure 1). The Raft River Geothermal Site is located near the south extremity of the KGRA. Exploration and development of the geothermal reservoir was performed between 1973 and 1978 (Dolenc et al., 1981). The development includes five deep geothermal production wells--RRGE-1, RRGE-2, RRGE-3C, RRGP-4B, and RRGP-5B, and two intermediate depth injection wells--RRGI-6 and RRGI-7 (Figure 2, Table 1). These wells are designed as a geothermal fluid supply and injection system for the U.S. Department of Energy (DOE) sponsored research program for utilization of a moderate temperature (136°C) geothermal fluid for electric power generation (Bliem et al., 1983).

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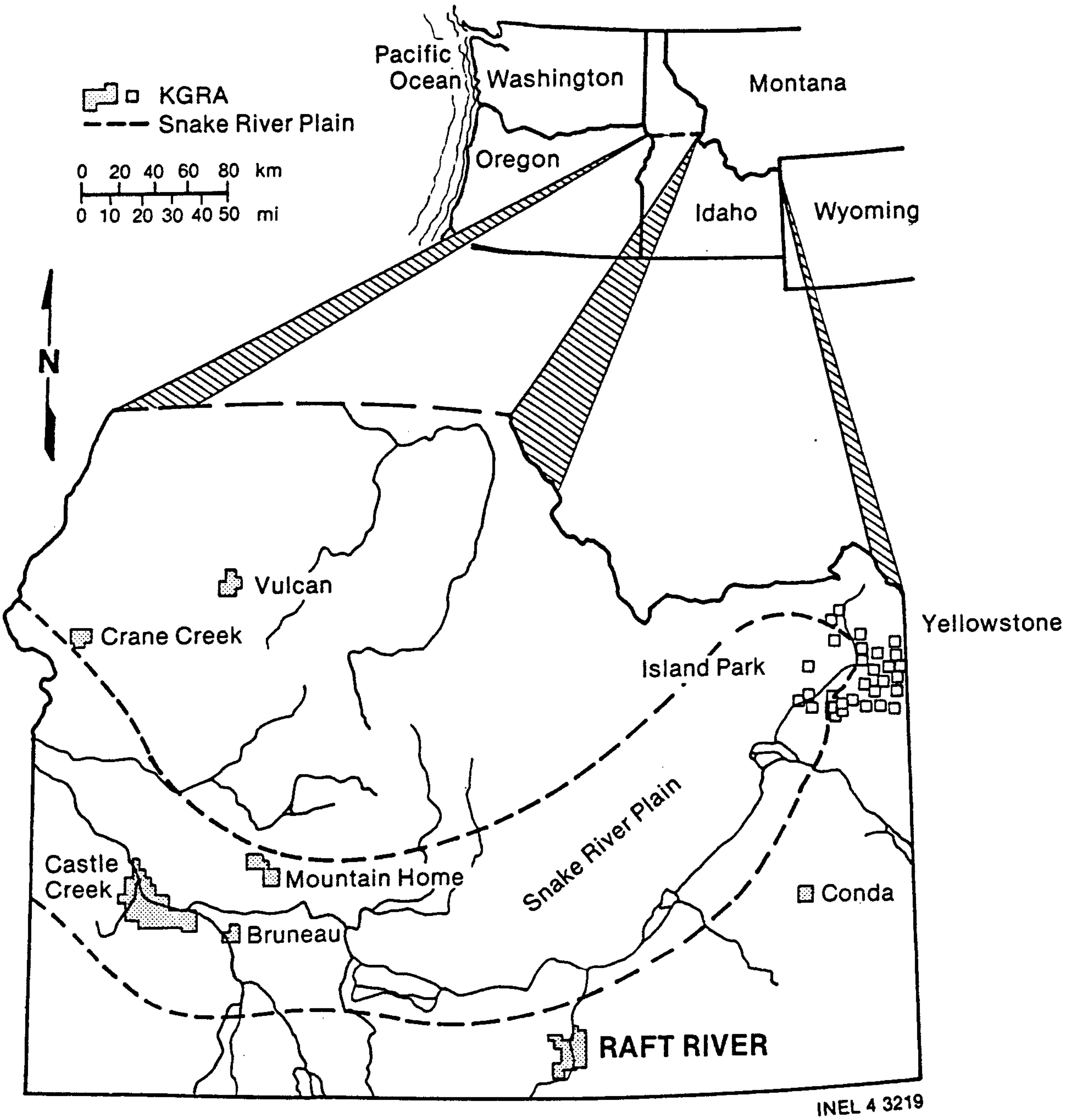

Figure 1. Location of Raft River KGRA.

The ground-water resources of the Raft River Valley are the primary source of irrigation and domestic water. In 1963, the Idaho Department of Water Resources declared the Raft River Basin a critical ground-water area because of declining potentiometric heads in the Shallow aquifer resulting from excessive irrigation withdrawals (Allman et al., 1982). The monitoring program addresses both potential irrigation and domestic water quality degradation and potential water table changes that could result due to development of the geothermal resource.

Table 1. Selected Physical and Chemical Data from Wells

Well	Depth (m)	Casing[a] Depth (m)	Maximum Borehole Temperature (°C)	Specific[b] Conductance µs	Chemical Cocentrations mg/L		
					Na^+	Cl^-	F^-
Geothermal							
RRGE-1*	1521	1105	141	2160	376	623	8.9
RRGE-2*	1994	1289	144	2160	336	592	8.7
RRGE-3*	1803	1293	149	8000	1194	2260	4.9
RRGI-4**	861	555	---	7450	1525	2580	4.5
RRGP-4B*	1555	1049	142	4050	725	1660	6.3
RRGP-5B*	1497	1034	135	2700	484	800	7.2
RRGP-6**	1176	509	107	10800	2200	2640	5.7
RRGI-7**	1185	623	122	12000	2200	4000	4.9
Monitor							
MW-1	399	369	--	11400	2200	3680	3.4
MW-2	174	164	106	5500	1000	1740	5.4
MW-3	153	140	71	6200	1400	2460	5.4
MW-4	305	225	97	7800	1520	2610	5.6
MW-5	152	124	28	2200	280	610	0.6
MW-6	311	274	44	7600	1570	2770	4.9
MW-7	152	140	34	2300	333	650	1.1
PW-3	26	17	--	---	---	---	---
PW-5	27	9	--	---	---	---	---
USGS Monitor							
USGS-2	244	64	59	1960	370	520	2.5
USGS-3	434	60	89	5900	1270	2040	4.8
BLM-	123	--	--	---	---	---	---
Other							
BLM	123	--	93[c]	3000	577	890	7.6
CROCK	165	45	97[c]	5800	1020	1750	6.2

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a. Depth to bottom of casing or to first perforations.
b. Lowest specific conductance data.
c. Temperature measured at surface.
* Production Well
** Injection Well

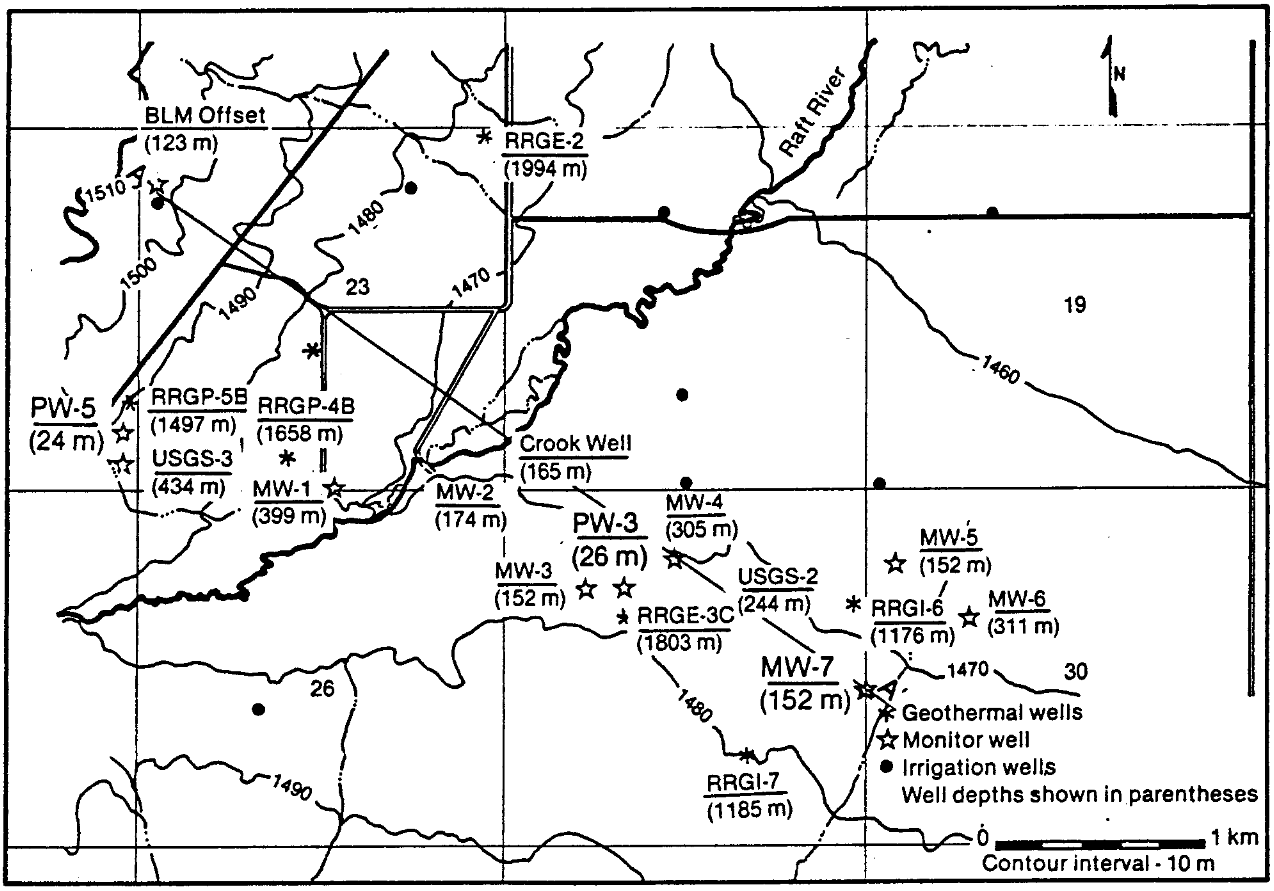

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Figure 2. Location map; wells and A-A' cross section.

Geology

The Raft River Basin is located on the northern edge of the Basin-and-Range physiographic province. The basin is north-south trending and structurally downwarped (Figure 3). The bounding mountain ranges differ stratigraphically being composed of (a) primarily Paleozoic limestones (Black Pine Range), (b) Precambrian gneiss mantled by allochthonous Paleozoic sediments and metamorphosed sediments (Raft River Range), and (c) Tertiary rhyolites and tuffaceous sediments (Jim Sage Range). The basin fill, consisting of poorly consolidated Tertiary sediments derived from the surrounding mountain ranges, is approximately 1,300-1,600 m thick. The upper 300 m are lenticular Quartenary deposits of alluvial, fluvial, and loessal origin. This is called the Raft Formation. The lower portion of the basin fill consists of sand, silt, minor conglomerate and tuff of the Tertiary Salt Lake Formation. This formation directly overlies a series of Precambrian metasediments capping a quartz monzonite basement that is partially remobilized and intruded (Williams et al., 1976).

The principal structural features of the Raft River Valley are the Bridge and Horse Well faults, and the Narrows Structure (Figure 4). The Bridge and Horse Well faults are normal listric faults flattening to

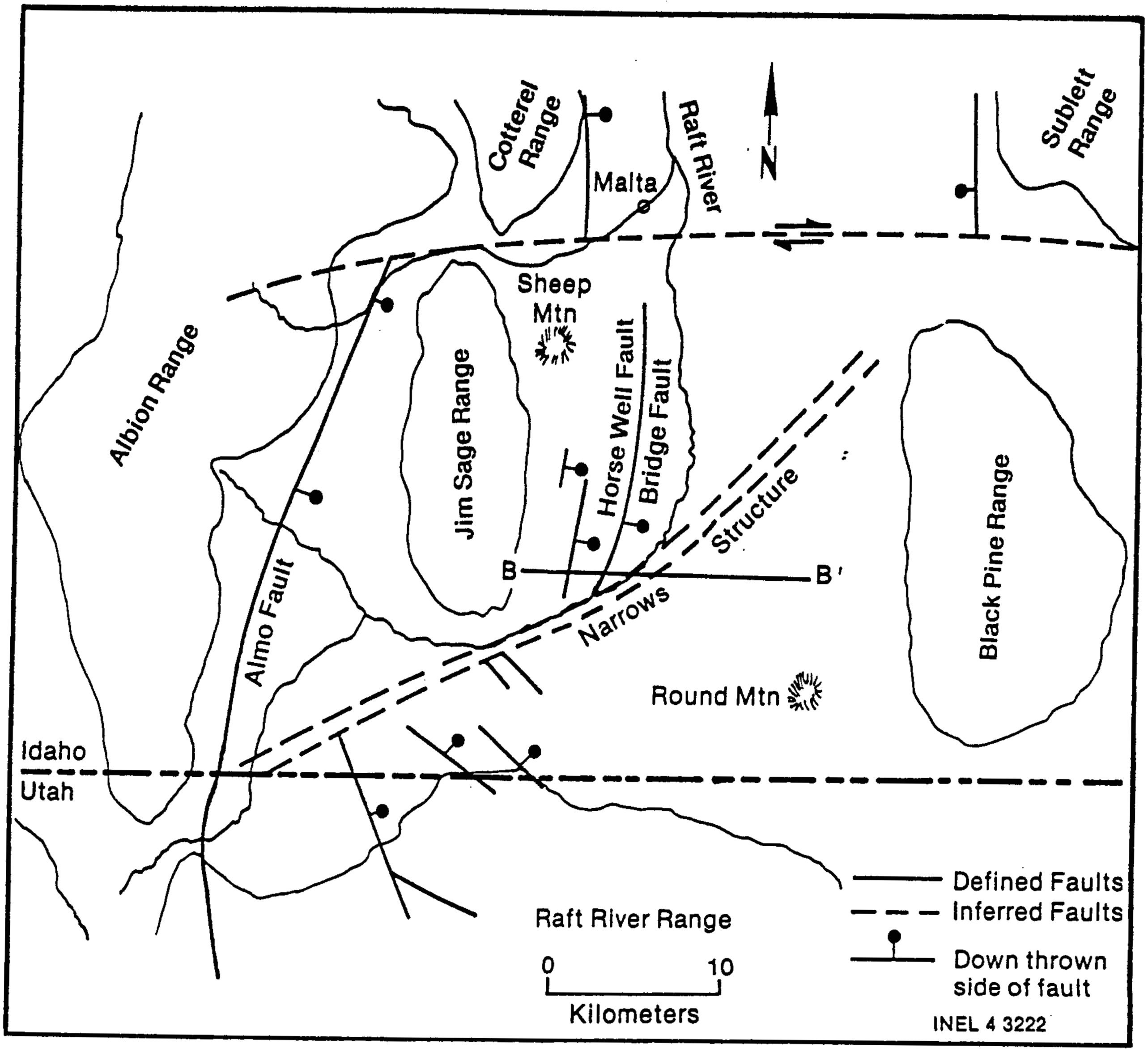

Figure 3. Raft River Valley and major structural features adjoining the valley.

parallel the metasediments at depth and perhaps penetrating into the metasediments and ademellite. The Narrows structure is believed to be a basement shear defined principally by anomalous geophysical surveys. Apparent low-angle faults in the metasediments on the east flank of the Jim Sage Range are major geothermal aquifers. The Bridge and Horse Well faults are also important geothermal aquifers; importance of the Narrows structure on the geothermal system has not been determined. The hydrologic charcteristics of the production wells are controlled by these permeable fault systems.

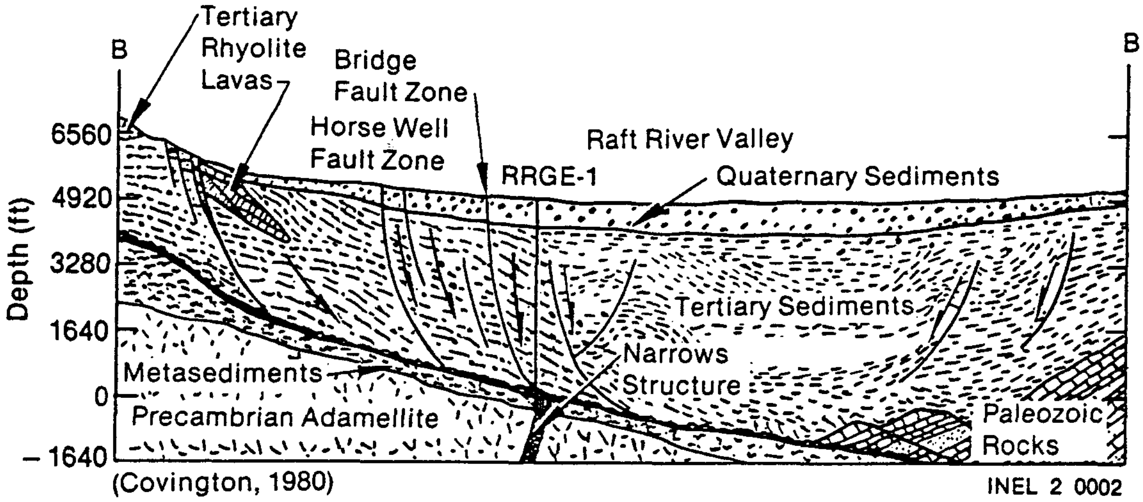

Figure 4. A recent interpretation of geologic structure.

Hydrogology

The ground-water flow system at the Raft River Basin is complex because of many permeable faults and lithostratigraphic aquifers and aquitards. The geologic strata have been classified into six hydrologic aquifer/aquitard units (Allman et al., 1982). Figure 5 is a cross-section of A-A' in Figure 2 indicating the conceptual ground-water flow system. These six units include: 1) the Shallow aquifer, 2) the Upper aquitard, 3) the Lower aquitard, 4) the Intermediate aquifer, 5) the Geothermal aquitard/aquifer, and 6) the Metamorphic and Basement geothermal aquifer.

The Shallow aquifer which is used as a source for domestic and irrigation water is a permeable unit extending to a depth of approximately 180 meters. The Upper aquitard extends from approximately 180 to 335 m and appears to be less permeable than the Shallow aquifer. The Lower aquitard which extends from 335 to 450 m has a distinctly lower vertical permeability than the Upper aquitard due to a greater tuff content. The Intermediate aquifer consists of highly transmissive sands and gravels extending from 450 m to 580 m. The Geothermal aquitard/aquifer extends from 580 m to the base of the Salt Lake Formation and contains several aquifers with both matrix and fracture type permeabilities. The lowermost hydrologic unit is a fracture dominated geothermal reservoir principally within the metasediments and, to a lesser extent, the adamellite basement. The lower hydrologic units have higher potentiometric heads than the overlying units, thereby creating the potential for upward leakage. Nearly all irrigation and monitor wells at the Raft River Site show thermal and chemical evidence of upward leakage from the geothermal resource. It was the known hydrologic connection between the geothermal system and the Shallow aquifer that prompted governmental regulatory agencies to insist on a ground-water monitoring program.

MONITOR WELLS

A total of 12 wells were monitored for potentiometric heads, 10 wells for water quality, and one flowing well for both discharge rate and water

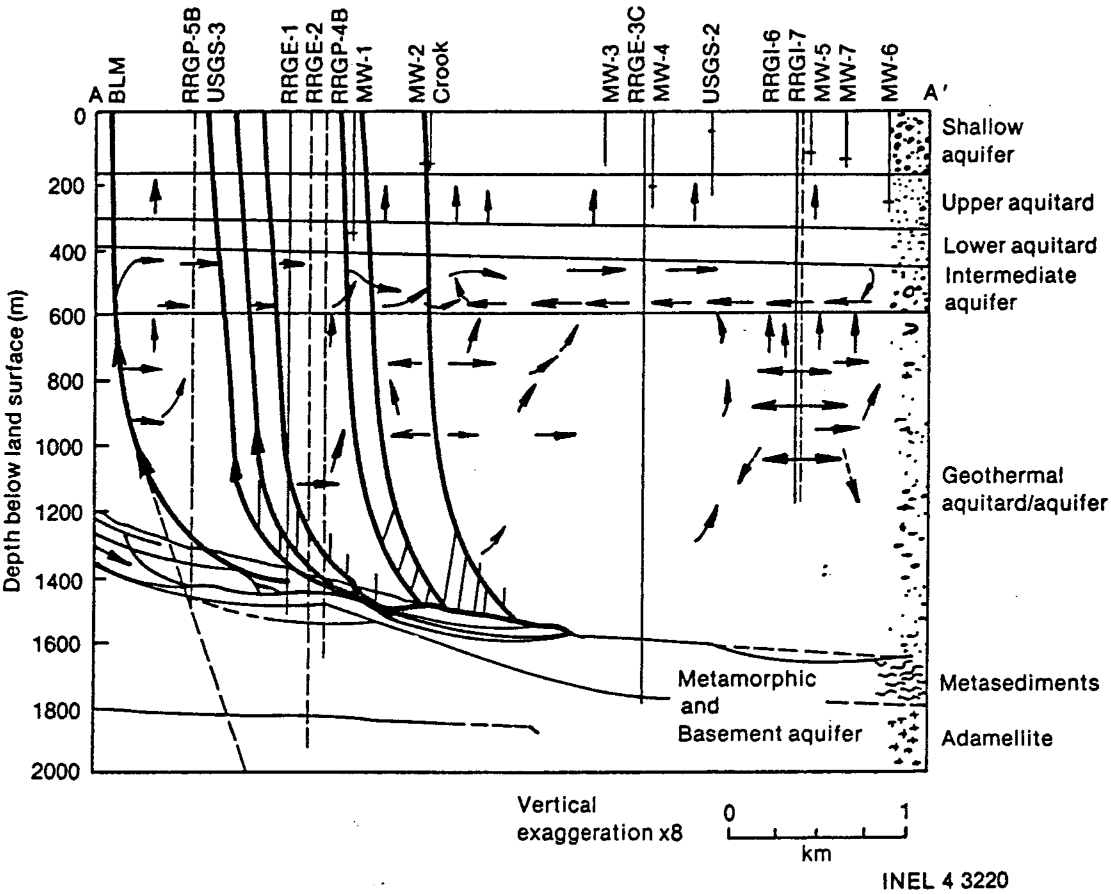

Figure 5. Conceptual groundwater flow system.

quality. The United States Geological Survey (USGS) initiated periodic water sampling in three wells in 1974 (Table 1) with reasonably complete continouous potentiometric head data available beginning in 1976. The DOE established a monitoring program by drilling 11 wells beginning in 1977 with completion in 1978. The DOE wells range from 26 to 399 m in depth. Potentiometric head data were collected for 9 of these wells until 1982, with water quality data being collected until 1981.

Water Quality

The best quality water in the geothermal flow system occurs in the metasediments at wells RRGE-1, RRGE-2, and RRGP-5B (Table 1). Figure 5 indicates an upward flow component from the Metamorphic and Basement aquifers toward the land surface. The greater the residence time in the flow system, generally the poorer the water quality that can be expected. The poorest quality water sampled was at RRGI-7 near the top of the Geothermal aquitard/aquifer where the specific conductance was 12000 µS. The Intermediate aquifer probably results in some dilution and mixing of fluids originating in the Geothermal aquitard/aquifer. However, poor quality water occurs in the overlying Upper and Lower aquitard such as at MW-4 and MW-6 which have a specific conductance of 7800 and 7600 µS, respectively (Table 1). Significant dilution occurs in the Shallow aquifer due to local recharge and the higher flow velocities, principally lateral; resulting from aquifers with higher transmissivities and probably higher lateral hydraulic gradients than those at depth. Wells of similar depth have significantly different water quality because of spatial heterogeneous dilution that occurs in the Shallow aquifer. Monitor wells 3 and 5 (MW-3 and MW-5), with a specific conductance of 6200 and 2200 µS, respectively (Table 1), provide examples of this heterogeneous spatial dilution. The wide variation in water quality of the ground waters at the site has significantly aided the delineation of the flow system and the interpretation of monitor well hydrographs.

The quality of the water produced by wells RRGE-1, RRGE-2, and RRGP-5B (Table 1) is a sodium-chloride type. This is very similar to local irrigation and domestic wells water, except for signiciantly higher fluoride concentrations which are approximately 8.3 mg/L in the geothermal fluid. An exception is RRGE-3 fluid, which has a lower fluoride concentration but a much higher specific conductance than the fluid produced by the other production wells. Because the power plant effluent was unacceptable for irrigation, injection was necessary. The effluent was injected into aquifers containing fluids with a high specific conductance, 10800 and 12000 µS for RRGI-6 and RRGI-7 respectively (Table 1). Thus, when injecting, a high specific conductance fluid would be displaced by a lower specific conductance fluid. The monitor wells were established primarily to determine the flow paths by which the displaced fluids could enter the Shallow aquifer. Monitoring water quality by periodic sampling continued in excess of four years. No significant changes were observed in the quality of water obtained from the monitor wells. With more continuous injection, water quality changes can be expected to occur because of ground-water flow system alterations that will result as indicated by short-term changes observed in the potentiometric heads.

Potentiometric Heads

The monitor wells at the Raft River Site are completed in the Shallow aquifer, the Upper and Lower aquitard, and the Intermediate aquifer. Due to the fault-controlled nature of the hydrologic system, wells stratigraphically completed in overlying hydrologic units often monitor some portion of the potentiometric head changes occurring in deeper aquifers with higher potentiometric heads. There appear to be three basic patterns in the long-term hydrographs. One typical pattern develops in the Shallow aquifer, and the Upper and Lower aquitards where seasonal recharge and irrigation responses dominate. Figure 6 (Allman et al., 1982) is a hydrograph for MW-7; it exhibits this pattern, typical for PW-3, MW-3, -5, -6, -7, USGS-2, and to a lesser extent, PW-5, which appears to be only slightly affected by irrigation withdrawals. Figure 6 also indicates the geothermal test pumpage and injection volumes via a bar graph. Irrigation pumpage, which usually begins in April and ends in September-October, results in generally declining potentiometric heads for this period. Potentiometric heads increase during the remainder of the year due to recovery from pumping and recharge from infiltration of local precipitation and surface waters. There has been no clearly discernible adverse impact of injection or pumping on the Shallow aquifer system monitored by these seven wells.

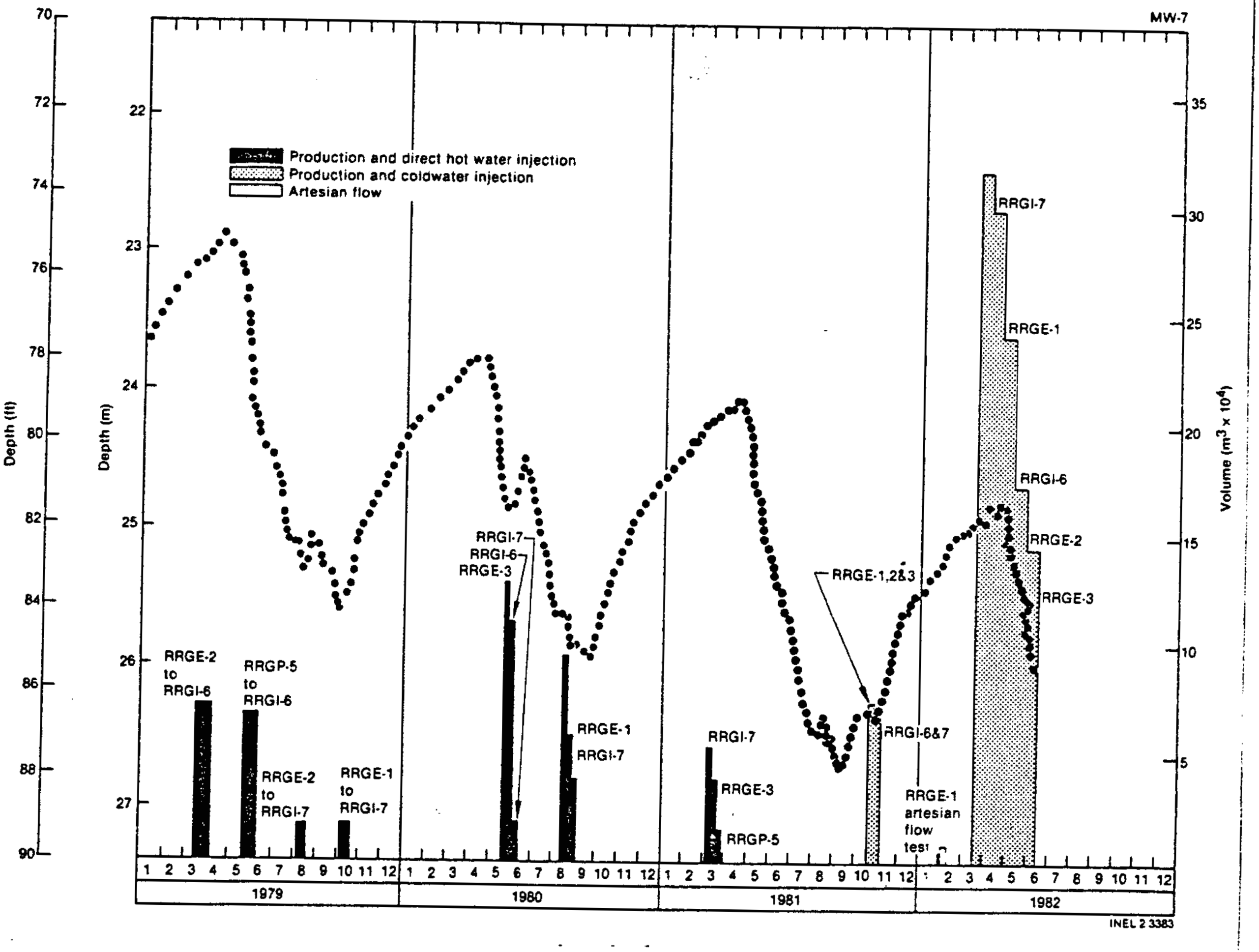

Figure 6. MW-7 Long-term hydrograph.

However, there are some short-term potentiometric head responses to injection and pumping in the Shallow aquifer and the Upper and Lower aquitard monitor wells that are somewhat unexpected. When injecting, a potentiometric head buildup can normally be expected. However, the potentiometric head rapidly declined in MW-6 at the beginning of injection into RRGI-6 (Figure 7) and remained suppressed below the background trend for the entire 21-day test. Unusually high wellhead injection pressures of 1100 kPa occurred while injecting at 39 l/s (Spencer et al., 1980). When injection ceased, wellhead pressures in MW-6 returned to the background trend. This response, which was observed in MW-3, -4, -5, -6, -7 and PW-3, is believed to result from elastic dilation of the strata overlying the injection zones. This potentiometric head decline was not observed when injecting into RRGI-7, probably because the injection zone for RRGI-7 is deeper than that for RRGI-6. In a similar manner, PW-5 appears to have a potentiometric head buildup when pumping RRGP-5B at 40 l/s. Surveys while pumping and injecting have detected no changes in wellhead elevations. Both vertical and lateral deformations of the strata overlying the injection zones are probably very small and would require a special monitoring program to detect physical deformation. This potentiometric head response in a Shallow aquifer due to injection and pumping in deep aquifers (below 500 m) with large wellhead pressure buildup and drawdown

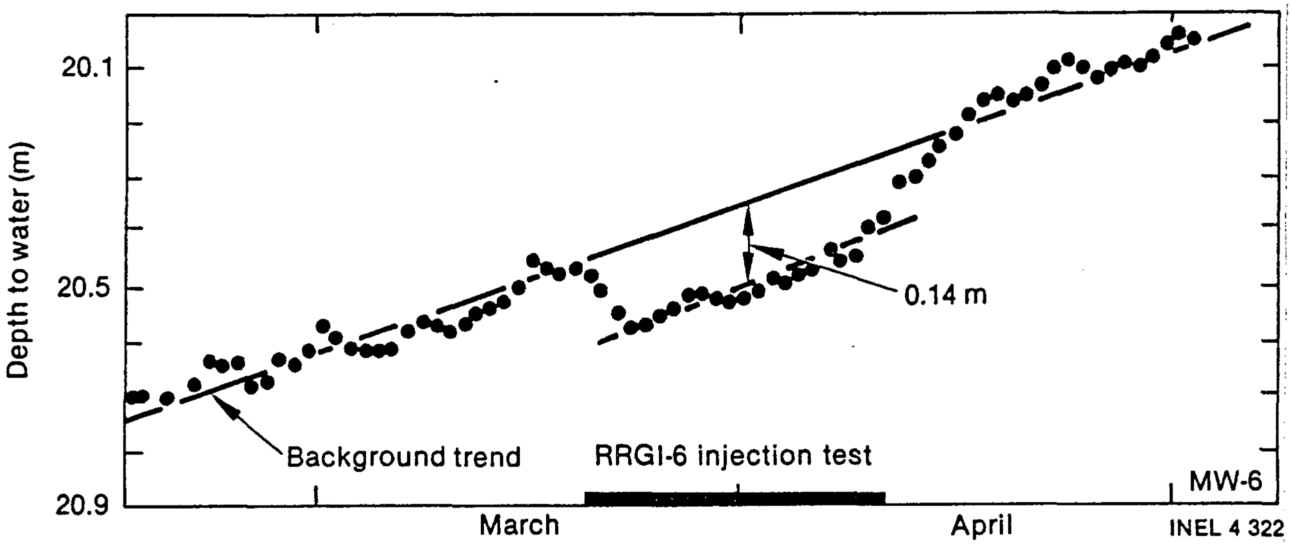

Figure 7. Potenitiometric head response in MW-6 during injection into RRGI-6.

may prove to be a valuable reconnaissance technique for siting deeper, more costly permanent monitor wells.

A second typical long-term hydrograph pattern occurs in MW-2 and MW-4 (Allman et al., 1982) (Figure 8). These wells, although completed above the Intermediate aquifer, are believed to have hydrographs somewhat indicative of those in the Intermediate aquifer because of the presence of permeable faults. Monitor well 2 is open to the Shallow aquifer while MW-4 is open to the Upper aquitard. The potentiometric head in MW-4 initially declines due to injection into RRGI-6, but, approximately 4 days after initiating injection, the potentiometric head in MW-4 begins to increase. Responses to injection into RRGI-6 occurred in March and May 1979, May 1980, October 1981, and March to June 1982 (Figure 8). The effects of injection apparently mask the effects of irrigation withdrawals in 1979 and 1980. However, in 1981, MW-4 appears to respond to irrigation withdrawals when much less total fluid was injected into RRGI-6 than in 1979 and 1980. The Crook well near MW-2 ceased operations in November 1980. This resulted in additional potentiometric head buildup at MW-2 and, to a lesser extent, at MW-4. Thus, MW-4 and MW-2 respond to both injection into RRGI-6, the cessation of withdrawals from the Crook well, and to local irrigation well withdrawals from the Shallow aquifer.

The third typical long-term hydrograph patterns occurs in MW-1, USGS-3 (Figure 9), and the BLM offset well (Allman et al., 1982). The potentiometric head changes in 1977 are irregular, in part, due to many small tests not indicated on Figure 9. The seasonal pattern in the hydrographs typical of the Shallow aquifer is not observed in MW-1, USGS-3 and BLM offset. These wells are believed to have a good hydraulic connection with (a) the Intermediate aquifer near RRGE-1, RRGP-5, and RRGE-2, (b) the geothermal system affected by production from RRGE-3C, (c) the hydraulic system affected by injection into RRGI-4; and (d) the hydraulic system affected by injection into RRGI-7 and, to a lesser extent, RRGI-6. None of the potentiometric heads in the monitor wells declined due

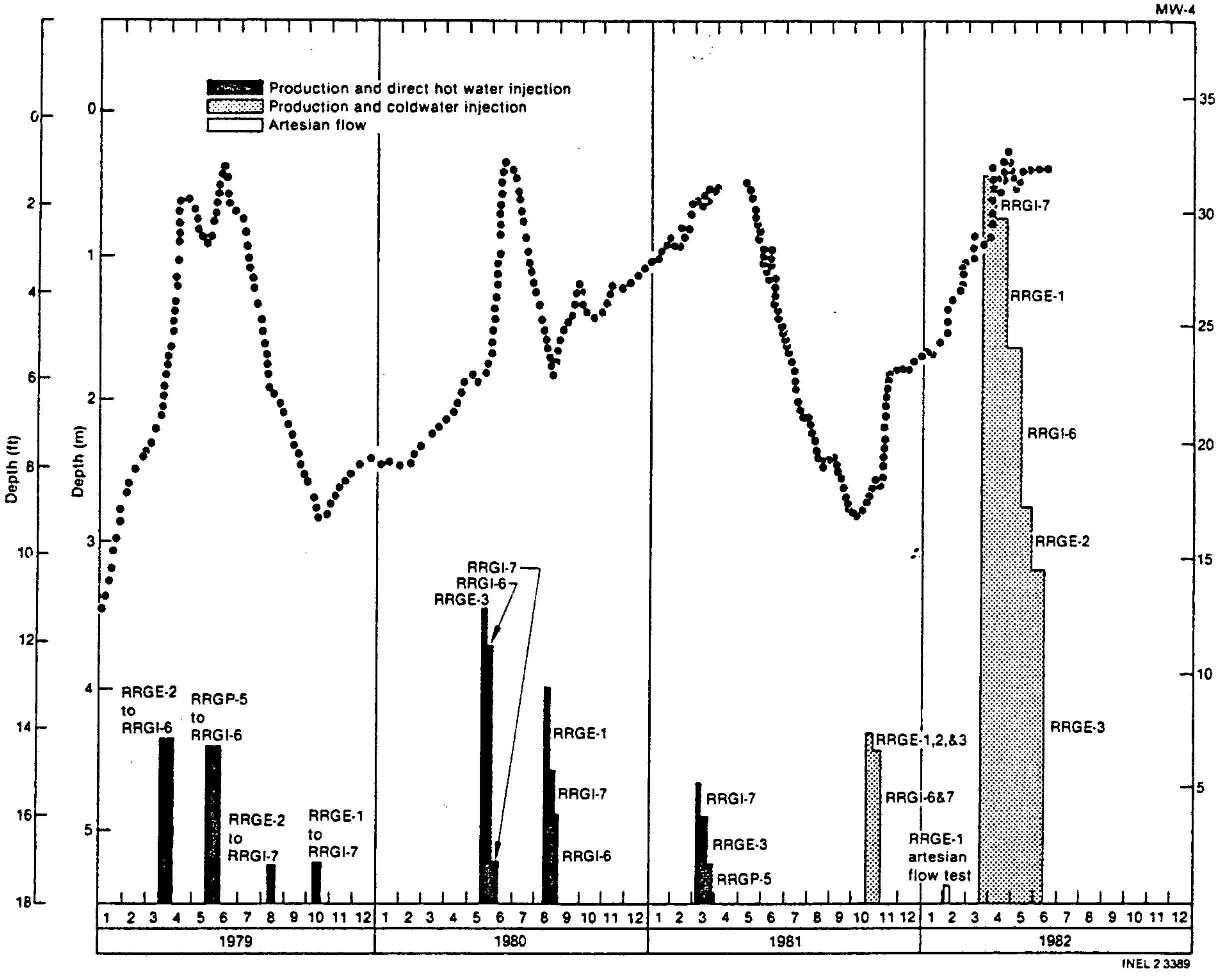

Figure 8. MW-4 Long-term hydrograph.

to production from RRGE-1, RRGE-2, or RRGP-4B. The pressure buildup in 1978 is related to injection into RRGI-4, with the abrupt drawdowns in 1977 related to artesian discharge from RRGI-4. After modifying the well construction of RRGI-4 to RRGP-4B by casing-off the upper aquifer and deepening the well, monitor wells do not exhibit any obvious hydraulic effects due to withdrawals from RRGP-4B either before or after hydraulic fracturing. The pump test at RRGP-5B in May 1979, resulted in interference effects at USGS-3 but not at MW-1 or the BLM offset. Pumping of RRGE-3C in May 1980 had noticeable interference effects on MW-1, and the BLM offset, but probably not on USGS-3. The BLM offset responds to injection into RRGI-7 and, to lesser extent, RRGI-6. Monitor well 1 appears to respond more to injection into RRGI-6 than RRGI-7. It is uncertain whether or not injection into RRGI-6 or RRGI-7 affects USGS-3. Thus, although the basic long-term hydrographs are similar for MW-1, USGS-3, and the BLM offset, there are different interference effects from production and injection of geothermal fluids.

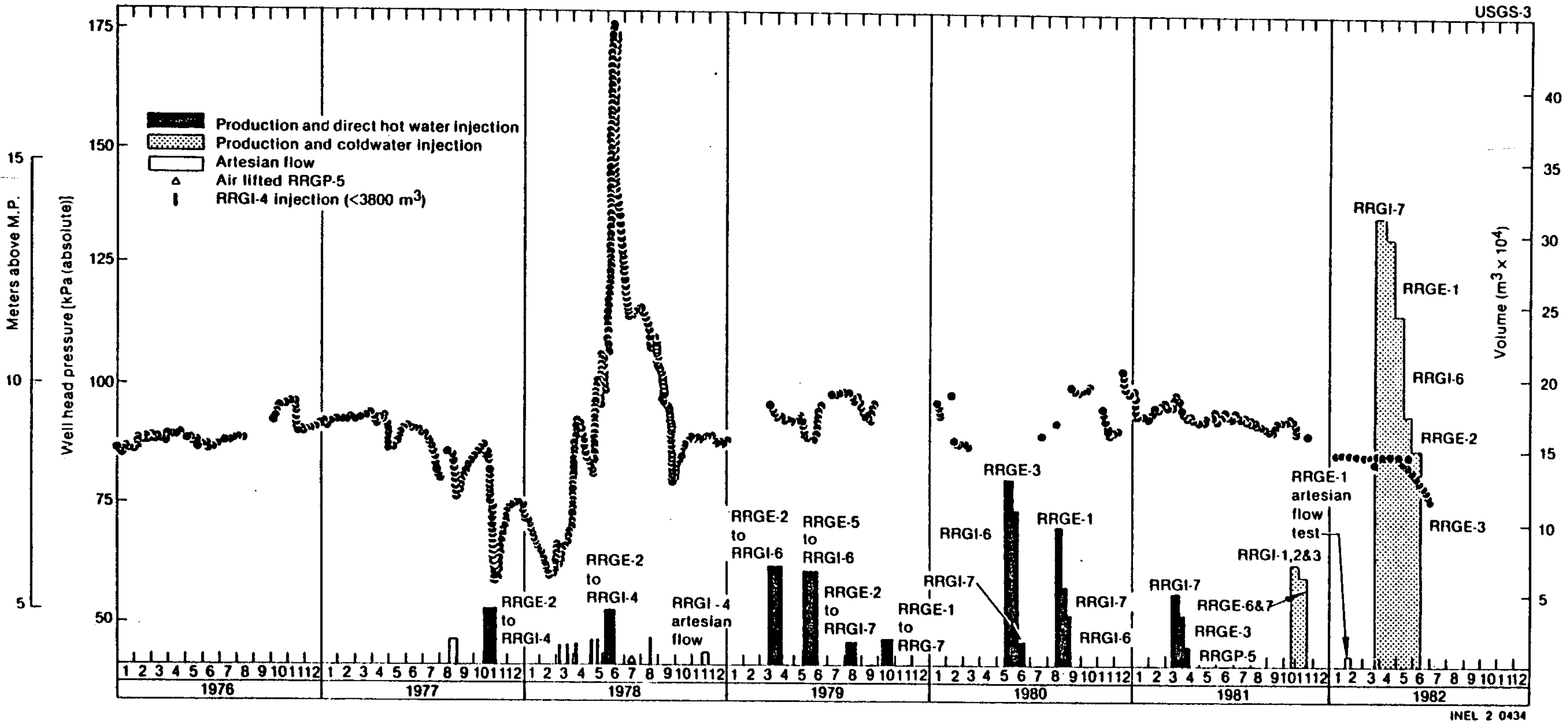

Figure 9. USGS-3 Long-term hydrograph.

CONCLUSIONS

The monitor well program provided the data base for the following conclusions:

1. The monitor well program at the Raft River Site provided valuable hydrologic and water quality data that permits at least a preliminary determination of a conceptual ground-water flow system.
2. The geothermal system monitored is fractured-flow controlled to a large extent. This complicates hydrograph and water quality interpretations since fault controlled aquifers can penetrate several lithostratigraphic aquifers.
3. Hydrologic responses due to injection include potentiometric head declines, presumably due to the elastic dilation of aquifers overlying the injection zones.
4. Conventional initial pressure buildup and falloff were observed in selected wells when injecting and pumping.
5. No water quality changes were observed in any monitor wells.
6. Three long-term potentiometric head patterns were observed: (a) the Shallow aquifer, and the Upper and Lower aquitard are dominated by irrigation pumpage and seasonal recharge, (b) the Shallow aquifer and the Lower aquitard are affected by injection into RRGI-6 where permeable fractures extend upward from the Intermediate aquifer, and (c) the Intermediate aquifer and Geothermal aquifer/aquitard near the production wells are affected by injection and production.

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