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1981 Annual Report

An Analysis of the Response of the Raft River Geothermal Site Monitor Wells

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ABSTRACT

A groundwater monitoring program has been established on the Raft River Geothermal Site since 1978. The objective of this program is to document possible impacts that may be caused by geothermal production and injection on the shallow aquifers used for culinary and irrigation purposes. This annual progress report summarizes data from 12 monitor wells during 1981. These data are compared with long-term trends and are correlated with seasonal patterns, irrigation water use and geothermal production and testing. These results provide a basis for predicting long-term impacts of sustained geothermal production and testing. To date, there has been no effect on the water quality of the shallow aquifers.

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INTRODUCTION

This report summarizes the results of the continuing groundwater monitoring program at the Raft River Geothermal Facility. The facility is located in south-central Idaho on the Raft River Known Geothermal Resource Area (KGRA). Preliminary geological and geophysical research conducted in southern Idaho by the U.S. Geological Survey (USGS) in 1973 and 1974 indicated the presence of a geothermal resource in the southern portion of Raft River Valley. Geochemical calculations using shallow aquifer data estimated the temperature of this resource to be 150°C. A cooperative venture was initiated in 1974 between the U.S. Department of Energy (DOE), the Raft River Rural Electric Cooperative (RRREC) and the Idaho Department of Water Resources (IDWR) to investigate the potential of electrical generation using this moderate temperature geothermal resource. The resulting DOE Raft River Geothermal Facility is operated by EG&G Idaho, Inc. Following completion of DOE research and development, the plant may be transferred to a private utility for continued operation.

The major feature of the facility is a binary pilot plant with a nominal gross rating of 5MW(e) when supplied by geothermal fluid of 143°C or greater. The fluid temperature, quantity and disposal capacity needed to operate the plant is provided by an integrated network of supply wells and injection wells. This network is comprised of three main production wells [Raft River Geothermal Exploratory (RRGE) wells RRGE-1, RRGE-2 and RRGE-3], one backup production well [Raft River Geothermal Production (RRGP) well RRGP-5], two injection wells [Raft River Geothermal Injection

(RRGI) wells RRGI-6 and RRGI-7] and one well (RRGI-4) which was initially tested as an injection well and later deepened and completed as a production well (RRGP-4). The flow from RRGP-4 is too low to justify pipeline construction and consequently does not contribute any water for power plant use. During normal plant operation, RRGE-1, RRGE-2 and RRGE-3 are pumped to produce the 150 l/sec required to operate the plant. Geothermal fluid is disposed by injecting into RRGI-6 and RRGI-7 at a rate of 120 l/sec and wellhead pressures of 2400 kPa to 2800 kPa. The remainder of the fluid produced is consumed in the plant cooling cycle. Dolenc et al., (1981) provides a detailed description of the Raft River supply and injection system.

MONITOR WELL PROGRAM

In 1963, the IDWR declared the Raft River Basin a Critical Groundwater Area and restrained further ground water development. Therefore, with the inception of the Raft River geothermal program, concerns were identified pertaining to protection of the quality and quantity of the limited water supply in this region. Modeling of the shallow aquifers by the USGS indicated that it would take 100 years before projected rates of geothermal production would affect the irrigation and culinary water supply in the valley (Nichols 1979). However, little is known of interactions between the shallow and intermediate depth aquifers. Concern exists that high pressure injection at 1200 m into intermediate depth aquifers could adversely affect nearby irrigation wells in the shallow aquifer. A ground water monitoring program was established by the DOE to assess this concern.

Ground water monitoring was initiated in 1974. This effort consisted of semi-annual chemical sampling of 22 irrigation wells near the Raft River geothermal development area. This program yielded some useful baseline data; however, several problems were inherent. For example, access to the water pumped from the wells is limited to the irrigation season (April through September). The wells are not all consistently used, thus some wells that were sampled one season could not be sampled the next. In addition, information on well construction, completion and production is often unreliable or not available.

Due to these problems, a joint decision was reached in 1976 between the IDWR and the DOE to establish a series of monitor wells near the geothermal site. These wells were to be located and designed to provide data necessary for evaluating and predicting the impact of geothermal development on the shallow aquifer system. The wells were established during 1978 and were drilled so two different depths of the shallow, irrigation aquifer could be monitored. Currently, seven monitor wells are established. These wells (MW-1 to MW-7), in conjunction with data collected from two USGS exploratory wells (USGS-2, USGS-3), a BLM geothermal well and two additional wells (Pit Well-3 and Pit Well-5), form the nucleus of the injection monitoring program. Figure 1 illustrates the location of the production and injection wells and each well in the monitor network. Information on the completion characteristics of the monitor wells (Spencer and Callen 1980) is presented in Table 1.

Each of the monitor wells is equipped with either a digiquartz pressure transducer or a Stevens water level recorder. These instruments provide continuous records of fluctuations in the potentiometric water surface in each well.

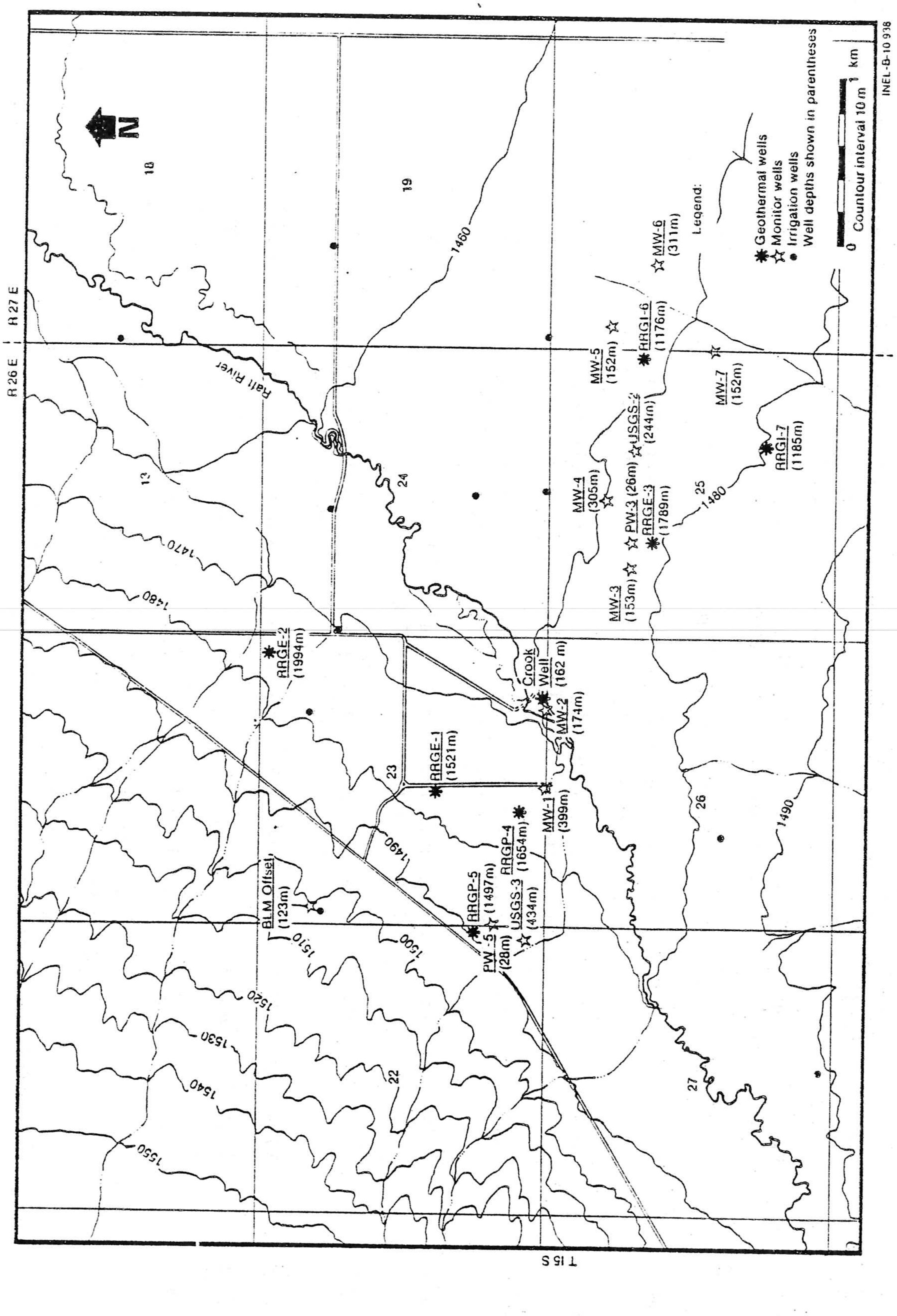

Figure 1. Location and depth of Raft River geothermal and monitor wells

TABLE 1. MONITOR WELL COMPLETION INFORMATION

	Elevation (m)	Well Depth (m)	Casing	Perforations	Surface Temperature (°C)	Bottom Hole Temperature (°C)
MW-1	1475	399	25 cm diameter: 0 m-37 m 15 cm diameter: 37 m-369 m	None	80	--
MW-2	--	174	20 cm diameter: 0 m-166 m	154 m-166 m	58	106
MW-3	1472	153	30 cm diameter: 0 m-61 m 20 cm diameter: 61 m-153 m	50 slots between 140 m and 153 m	24	71
MW-4	1468	305	25 cm diameter: 0 m-171 m 20 cm diameter: 171 m-254 m	105 slots between 225 m and 254 m	20	97
MW-5	1466	152	30 cm diameter: 0 m-61 m 20 cm diameter: 61 m-136 m	54 slots between 124 m and 136	13	28
MW-6	1469	305	25 cm diameter: 0 m-46 m 15 cm diameter: 46 m-274 m	None	11	44
MW-7	1474	152	30 cm diameter: 0 m-61 m 20 cm diameter: 61 m-152 m	50 slots between 140 m and 152 m	20	35
USGS-2	1473	241	10 cm diameter: 0 m-64 m	None	28	59
USGS-3	1486	434	10 cm diameter: 0 m-60 m	None	77	89
PW-3	--	28	10 cm diameter: 0 m-17 m	None	--	--
PW-5	--	26	15 cm diameter: 0 m-17 m 10 cm diameter: 17 m-26 m	17 m-26m	--	--
BLM-Offset	1500	98	Not available --	--	95	--

GEOLOGY AND HYDROGEOLOGY

The southern Raft River Valley is a complex structural basin surrounded on three sides by mountain ranges (Figure 2). The Black Pine Mountains bound the east side of the basin. They are comprised primarily of Late Paleozoic marine sediments with minor Tertiary and Quaternary volcanic and alluvial sediments. Structurally the range exhibits high angle normal faulting superimposed on folds and low-angle thrust faults associated with Laramide tectonism. The Raft River Range bounding the south end of the valley formed in the Pliocene as a doubly plunging east-trending anticline (Compton et al., 1977). The autochthonous core of the range, Precambrian Adamellite, is mantled by two major allochthonous sheets of Precambrian, Paleozoic and Triassic rocks that were displaced many kilometers over low-angle faults. Strata from both the autochthon and part of the Precambrian allochthon form the basement complex in the Raft River basin. The Jim Sage Mountains bounding the west side of the valley are a tilted block (Anderson 1931). The range is comprised of the Tertiary Salt Lake Formation capped in places by rhyolite flows. The east side of the range is bounded by listric normal faults that significantly affect the geothermal resource. The Raft River enters the basin from the southwest and flows north to its confluence with the Snake River.

The stratigraphy in the basin consists of recent alluvium and colluvium, the Pleistocene Raft Formation and the Tertiary Salt Lake Formation (Figure 3). These sediments unconformably overlie the assemblage

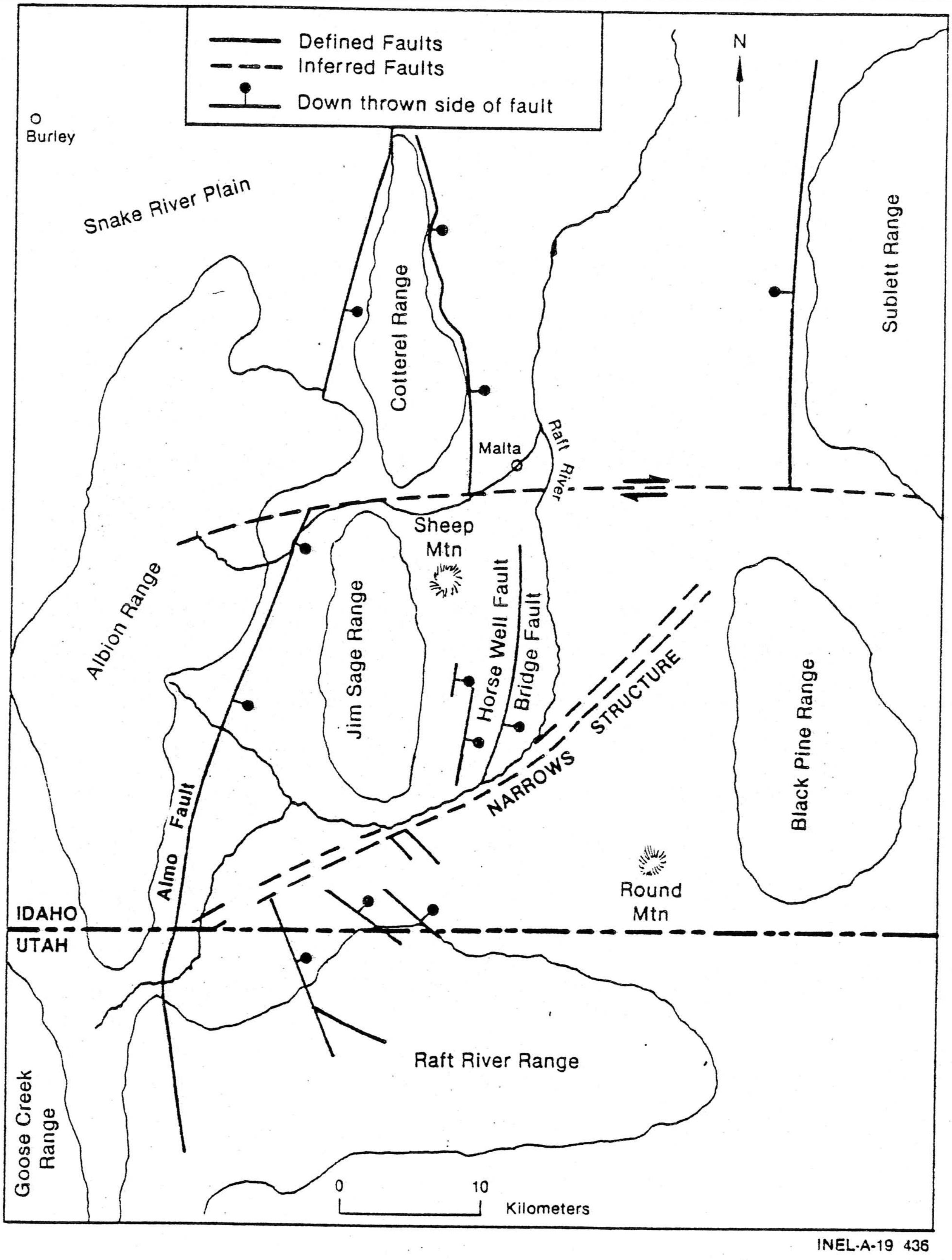

Figure 2. Major structural features of the Raft River Valley. The DOE geothermal facility is located about 23 km south-southwest of Malta, Idaho.

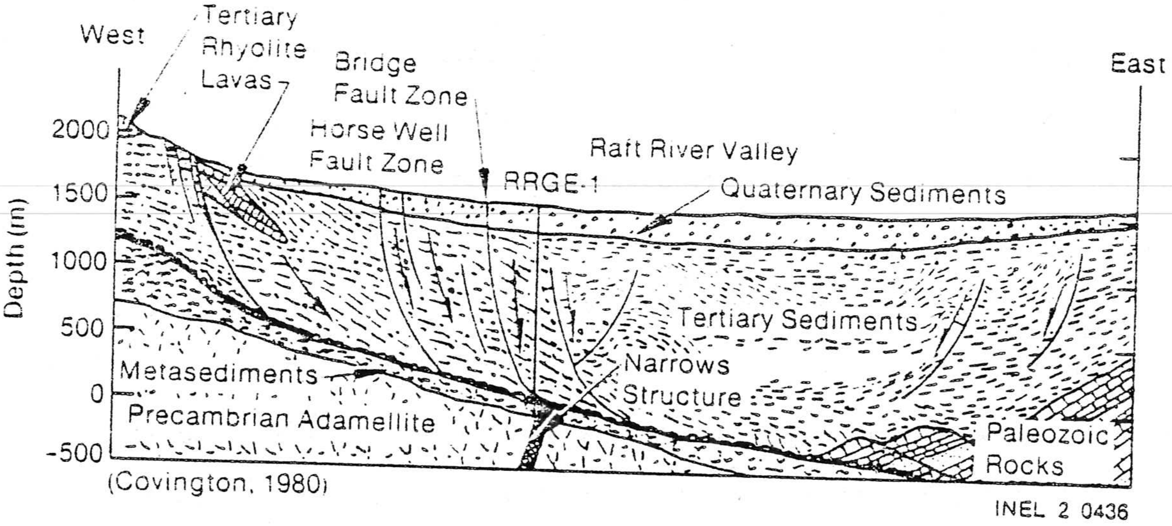

Figure 3. Geologic cross-section of the Raft River Valley

of Precambrian metasediments and Adamellite which characterize the Raft River Range. The Raft Formation, a fluvial and alluvial deposit up to 300 meters thick, consists of quartz sand and silt, unconsolidated tuff and rhyolite gravel, and quartz sand and quartz silt. The sediments originated in the surrounding mountain ranges and are poorly sorted and angular. Correlation of the Raft Formation between wells is not feasible due to the lenticular nature of deposition. The Salt Lake Formation is a lacustrine deposit up to 1600 meters thick. The division between Tertiary and Quaternary sediments is not always definitive, but is usually based on the relative abundance of volcanic material which is greater in the lacustrine deposit. The Salt Lake Formation primarily consists of thin-bedded to massive light green tuffaceous siltstone and sandstone with minor conglomerate (Devine and Bonnichsen, 1979). The primary rock types in the formation are shale, siltstone, sandstone and tuff. Provenance studies indicate the sediments originated primarily in the surrounding mountain ranges. Generally, the sediments are poorly consolidated. Deformational structures in the Salt Lake Formation include microfaults, breccias, convolute laminations and ball and pillow structures. These features indicate rapid deposition and deformation of water-saturated sediments, possibly caused by slumps and turbidity currents (Devine and Bonnichsen, 1979).

The Precambrian metamorphic sequence, from youngest to oldest, is comprised of the Quartzite of Yost, the Schist of the Upper Narrows, the Elba Quartzite and the Older Schist. Both the Quartzite of Yost and the Older Schist are absent in wells RRGE-1 and RRGE-2. This absence is possibly due to low-angle thrust faulting that characterizes the Raft River Range. Precambrian Adamellite basement rock is thought to be partially older than the metasediments, and partially remobilized and intruded (Williams, 1976).

The geologic structure of the Raft River Basin has been studied extensively using geophysical methods, surface mapping, and aerial photography. The eastern boundary of the basin is formed by the downwarped flank of the Black Pine Mountains with secondary normal faulting. The western boundary of the basin is downdropped along a series of listric normal faults called the Horse Well fault and the Bridge Fault (Figure 2). The Bridge Fault strikes north-south, extending from the south end of the Jim Sage Mountains to the east side of Sheep Mountain. The fault plane has a 60-80° dip at the surface, flattening as it decends to parallel the metasediments (Figure 3). Numerous vertical fractures extend into the basin sediments from the faults (Covington, 1980). A northeast trending structural lineament extends across the valley from the south end of the Jim Sage Mountains. This poorly defined structure called the Narrows Zone, is possibly a basement shear related to the Humboldt Zone of northern Nevada (Mabey, et al., 1978).

The geothermal resource from which fluids are withdrawn in the Raft River Valley occurs in the zone of intersection between the Bridge Fault and the Narrows Structure. Hydrothermal water rises at this intersection and spreads into the Salt Lake Formation along porous zones in the sediments and along soft-sediment fractures. Hydrothermal alteration in the Salt Lake Formation and the Raft Formation has resulted in replacement of primary calcite by silica, fracture filling by calcite, clay mineral alteration, and emplacement of secondary minerals (Ackerman, 1979). Hydrothermal alteration is most prevalent in the deeper sediments where calcite fills fractures and silica forms a "caprock" above the geothermal reservoir (Covington, 1980). Static water levels in the thermal reservoir are about 100 m above the land surface. Because the hydraulic gradient is diverted upward (head increases with depth), some shallow and intermediate aquifers are recharged in part by upward leakage from deeper aquifers. This is evidenced by the shallow hot wells in the basin.

Groundwater in the basin occurs in both confined and unconfined conditions in the Raft Formation and the Salt Lake Formation. Most aquifers below 300 m are confined. Local precipitation and infiltration of surface water and irrigation runoff recharge the shallow aquifers in the Raft Formation and the Salt Lake Formation. The rate of the ground water withdrawal for irrigation within the basin has increased substantially for the last 30 years. Most of the valleys irrigation wells are concentrated within 3 km of the Raft River. Ground water level declines along the river have been the most severe. An estimated total of more than 0.6 km^3 of ground water was removed from the basin's aquifer storage by the end of the 1966 irrigation season (Walker et al, 1970). A ground water decline of more than 15 m has occured in the agricultural region north of Malta since 1952. A 6 m decline has been observed near the geothermal site (Nichols 1979). These declines are due to irrigation water withdrawal and are not associated with Raft River geothermal development. Almost all the surface water of the river is diverted for irrigation. As a result, the Raft River flow rate during the irrigation season is totally dissipated by the time it reaches Malta.

GENERAL GROUND WATER TRENDS

Ground water level changes are characterized by a long-term trend and by annual seasonal fluctuations. The local shallow aquifers within the Raft River Basin exhibit a declining long-term trend due to extensive irrigation pumping (Nichols 1979). Data collected from monitor wells MW-3, MW-5, MW-6, MW-7, PW-3 and USGS-2 exhibit a declining trend in the long-term ground water level records, indicating a close relation with the irrigation aquifers. Monitor wells MW-2 and MW-4 also show some response to irrigation aquifer use, however these trends are often masked by the response to injection. Monitor wells MW-1, USGS-3 and BLM-offset do not exhibit seasonal trends and appear to have little or no connection with the irrigation aquifers.

A distinctive seasonal ground water level fluctuation is found in most of the monitor wells. Historically, the seasonal water level reaches its peak at the end of April. At this time recharge from snowmelt and rainfall starts to decrease and pumping of water used for irrigation begins. Consequently, the ground water levels decline through the end of September. A water level rise begins in October and continues until the end of April, thus completing the cycle. The seasonal fluctuations observed in the individual monitor wells are listed in Table 2. The variation in seasonal fluctuations can in most cases be used as an indication of the extent of recharge associated with precipitation.

TABLE 2. MAGNITUDE OF SEASONAL WATER FLUCTUATION IN THE MONITOR WELLS

	Seasonal Fluctuation (m)		
Well Number	1979	1980	1981
MW-1	--	1.98	0.63
MW-2	--	2.48	3.38
MW-3	2.44	1.83	2.90
MW-4	3.05	2.10	2.53
MW-5	5.98	4.76	5.61
MW-6	2.84	2.04	2.83
MW-7	2.74	2.16	2.71
USGS-2	2.33	3.08	4.05
USGS-3	1.16	1.68	0.91
PW-3	--	5.73	6.49
PW-5	--	0.79	0.60
BLM-Offset	0.37	0.42	0.23

WATER CHEMISTRY

Samples for chemical analyses were collected from the monitor wells three times during 1981. The MW-1, MW-2, USGS-3, and Crook thermal wells have potentiometric heads above the land surface. Samples from these wells were collected from the artesian flow. The remaining monitor wells were sampled using submersible pumps. Wells were generally cleared of one wellbore volume before samples were collected. Table 5 contains a list of chemical analyses performed during 1981.

Differences in water quality between the various wells can generally be explained on the basis of depth and location within the geothermal field. Specific conductance is a good indicator of general water quality because it is closely related to the total dissolved solids in water. Therefore, this parameter is useful for comparing gross differences in water quality (Figure 4). The deepest monitor well, MW-1, has the highest specific conductance and appears to be located in a low permeability area of a relatively hot and shallow portion of the geothermal reservoir. The low circulation rate of fluid in the zone monitored by MW-1 and the relatively high temperatures probably account for the high specific conductance. The chemical character of MW-1 is similar to the chemical character of water encountered in RRGI-6 and RRGI-7. Despite this chemical similarity, there appears to be no direct hydraulic connection between MW-1 and the injection wells.

TABLE 3. CHEMICAL ANALYSES OF THE RAFT RIVER VALLEY MONITOR WELLS DATA RECORDED IN mg/1 UNLESS OTHERWISE STATED

	MW-1			MW-2			MW-3	
Analysis	04/01/81	06/10/81	11/17/81	03/31/81	06/10/81	11/16/81	04/02/81	11/17/81
F	1.5	2.9	3.0	2.8	5.4	5.6	2.6	5.6
Cl	3620	3970	3620	1660	1760	1640	2400	2596
SO_4	76	77	85	51	58	60	45	56
HCO_3	28	29	49	34	38	54	56	68
Ca	235	200	271	135	110	155	185	220
Mg	0.37	0.29	0.31	0.40	0.36	0.34	0.45	3.7
Na	2088	2460	1950	929	960	1000	1300	1680
K	42	26	30	34	23	24	49	54
SiO_2	96	78	81	88	83	90	107	121
Alkalinity ($CaCO_3$)	25	24	30	30	31	36	45	50
Conductivity µmhos/cm	11200	11200	11100	6000	5500	5490	7000	7030
Hardness ($CaCO_3$)	520	510	690	310	290	390	440	560
TDS	--	--	4815	--	--	2194	--	3292
pH	7.60	7.60	7.63	7.23	7.30	7.41	7.43	7.37
Temperature (°C)	80	79	81	66	68	70	--	49

TABLE 3. (continued)

	MW-4		MW-5	MW-6		MW-7			BLM	
Analysis	04/02/81	06/09/81	04/01/81	04/01/81	06/09/81	04/01/82	06/10/81	11/17/81	03/31/81	06/10/81
F	2.6	4.9	0.8	2.3	4.2	0.9	1.1	1.3	3.4	6.8
Cl	2500	2580	600	2700	2960	680	652	580	880	950
SO_4	58	55	35	82	76	51	31	30	60	56
HCO_3	38	45	122	55	55	129	130	137	50	52
Ca	172	150	122	235	190	120	120	133	71	58
Mg	0.55	0.43	0.31	0.21	1.9	--	18	18	0.22	0.26
Na	1429	1500	234	1586	1620	281	350	310	495	560
K	43	30	17	82	56	22	14	15	27	19
SiO_2	94	85	47	122	85	49	43	47	101	79
Alkalinity ($CaCO_3$)	30	37	100	45	45	105	105	114	40	43
Conductivity µmhos/cm	7350	7900	2050	8200	8700	2350	2400	2310	2950	3200
Hardness ($CaCO_3$)	390	370	370	560	550	330	340	430	130	125
TDS	--	--	--	--	--	--	--	974	--	--
pH	7.83	7.90	7.27	7.45	7.70	7.15	7.50	7.37	8.10	7.40
Temperature (°C)	34	42	26	34	34	31	31	32	93	92

TABLE 3. (continued)

Analysis	CROOK			USGS-1			USGS-3		
	03/31/81	06/10/81	11/16/81	03/31/81	06/10/81	11/16/81	03/31/81	06/10/81	11/16/81
F	3.0	5.6	6.1	2.1	3.9	4.2	0.9	3.3	1.9
Cl	1900	2010	1760	680	650	716	660	600	385
SO_4	69	66	61	70	63	81	38	68	35
HCO_3	44	37	49	115	125	127	124	155	146
Ca	150	130	168	90	85	107	128	105	101
Mg	0.43	0.36	0.41	11	8.8	9.8	24	13	10.5
Na	1032	1070	980	294	400	370	249	350	202
K	33	28	31	12	10.5	0.6	17	8	9.6
SiO_2	109	89	100	68	59	75	64	47	58
Alkalinity ($CaCO_3$)	35	30	37	95	100	105	100	125	126
Conductivity µmhos/cm	6000	6100	6390	2250	2500	2460	2050	2300	1480
Hardness ($CaCO_3$)	330	320	430	210	220	290	360	280	300
TDS	--	--	2510	--	--	1040	--	--	653
pH	8.15	7.90	8.01	7.43	7.50	7.44	7.36	7.50	7.49
Temperature (°C)	95	96	97	29	32	32	31	30	30

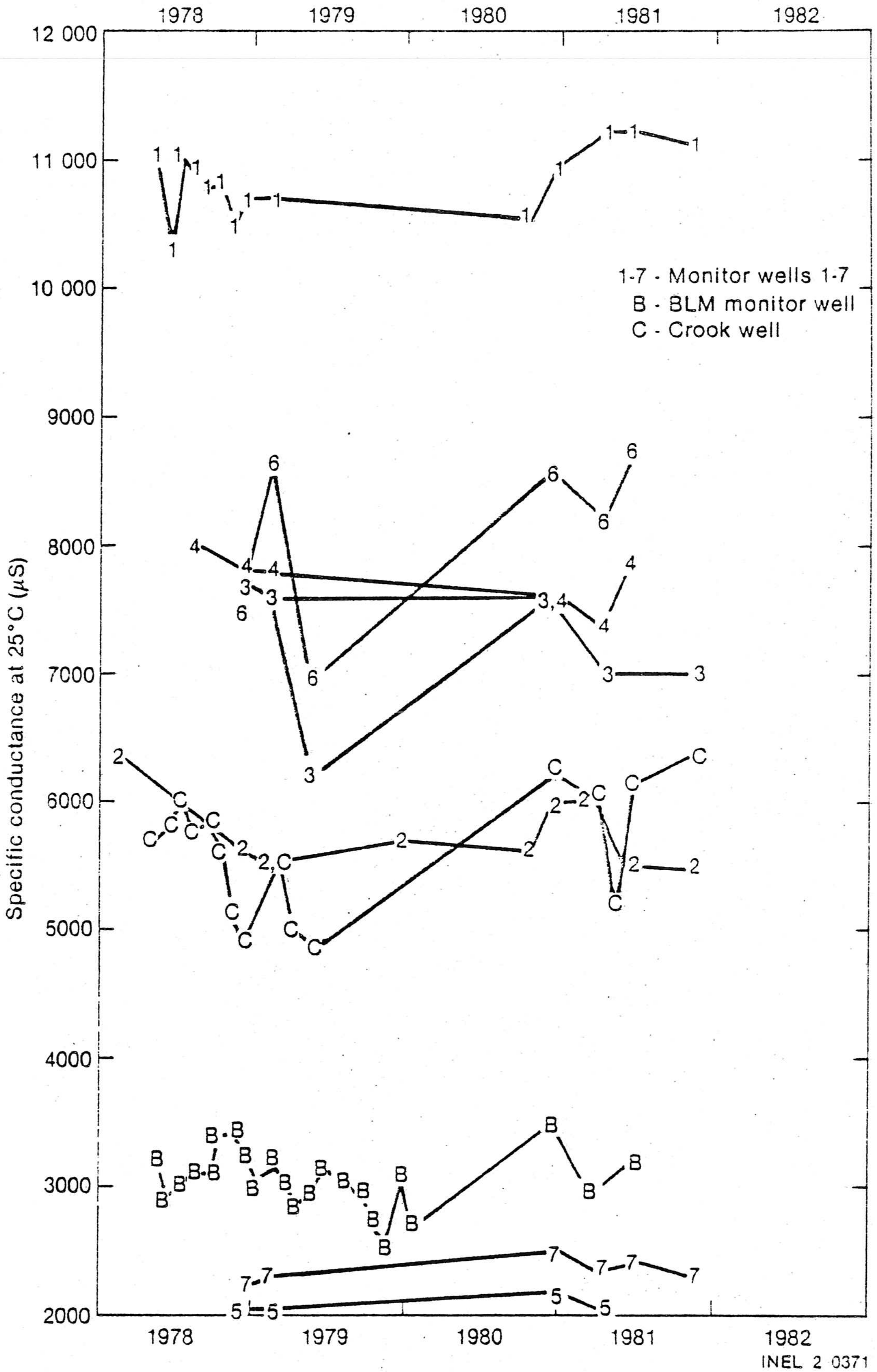

Figure 4. Specific conductance of water samples collected from selected wells at the Raft River Geothermal Site

The similarity of specific conductance between MW-3, MW-4, and MW-6 is in sharp contrast to their very different response to irrigation pumping and injection. MW-3 is shallower (153 m) than either MW-4 (305 m) or MW-6 (311 m) and would normally be expected to have a specific conductance similar to MW-5, which is at the same depth as MW-3. The abnormally high specific conductance at MW-3 may be due to a high rate of leakage from the underlying intermediate zone possibly due to faulting of an aquitard between the intermediate and shallow aquifers. The specific conductance of MW-4 and MW-6 are probably representitive of the specific conductance of the intermediate aquifer between 300 m and 400 m.

Monitor well MW-2 and the Crook well are close together and completed at approximately the same depth. As expected, the water chemistry in the two wells is similar. These wells produce unusually hot water for their depth. They appear to be closely associated with a large subsurface geothermal discharge; probably occurring via faults. The BLM well is northwest of the geothermal field, and although it has a relatively low specific conductance is 95°C at the surface. The difference in chemistry between the BLM and Crook thermal wells is possibly due to the wells obtaining fluids from different geothermal systems or from different portions of the same geothermal system. Monitor well MW-5 and MW-7 are both located to the southeast of the developed geothermal field and probably monitor the shallow aquifer. The water chemistry in this shallower zone (150 m) is much better than in the intermediate aquifer.

Most of the wells appear to exhibit some variation in chemical concentrations with time. This is probably caused by changes in sampling methods and analytical errors rather than because of any changes in ground water chemistry. None of the monitor wells show a significant upward or downward trend in water quality compared to the short term fluctuations in specific conductance. Thus, it appears that geothermal testing has had no appreciable effect on the chemical quality of the water.

PRODUCTION-INJECTION TESTING

The production-injection system was originally designed to dispose of geothermal fluid that had been used for power generation by directly pumping it via a pressurized pipeline into the injection wells. The rationale for this closed system design was to:

1. minimize cooling of the geothermal fluid prior to injection;
2. reduce the possibility of particulate formation;
3. prevent consumptive water loss via evaporation.

Several operational difficulties were associated with the closed system. The major source of problems was the need to precisely integrate the flow between production and injection wells. A malfunction within the network often necessitated a shut down of the entire operation. These time consuming shut downs were compounded by the occasional failures of the submersible production pumps. The operational life of these pumps was often limited to days or sometimes only minutes.

In 1981 the closed injection system was modified so that the disposed fluid flowed directly into an open pond. This allowed independent operation of the production and injection systems. The cooled water (30°C) did not cause a decrease in fluid injectivity. Suspended particulates did not increase to a level that would decrease injectivity. Also, the submersible geothermal pumps were replaced by line-shaft geothermal pumps. These pumps have performed satisfactorily since their installation in July, 1981.

The production-injection activity in 1981 is presented in Table 3. Major tests of previous years are listed in Table 4. For greater detail on past production and injection tests see Dolenc et al. (1981).

TABLE 4. PRODUCTION AND INJECTION TESTS DURING 1981

	INJECTION WELLS				PRODUCTION			
Date	Well Number	Duration (hours)	Rate (L/sec)	Remarks	Well Number	Duration (hours)	Rate (L/sec)	Remarks
2/4 - 2/17	RRGI-6	55	16 to 30	cold water direct injection 4-9.5 hours/day				
2/19 - 2/25	RRGI-7	27	25 to 28	cold water direct 2 to 7 hours a day				
3/9	RRGI-7	7	42	cold water direct injection	RRGE-3	7	44	Stopped due to pump failure
3/12 - 3/15	RRGI-7	100	40-44	hot water direct injection	RRGE-5	102	41-44	Stopped due to pump failure
3/19 - 3/30	RRGI-7	240	39-43	hot water direct injection	RRGE-5	240	41-44	
5/27 - 6/1	RRGI-7	24	25 to 28	cold water direct injection 2 to 8 hours a day				
8/20	RRGI-6	7	53-73	hot water direct injection	RRGE-3	7	28	
8/20	RRGI-7	2	20-41	hot water direct injection				
10/19	RRGI-7	10	57-85	as of 10/19, fluid disposal procedure changed from a closed, direct injection to disposal in reserve ponds at RRGI-6 and RRGI-7 prior to injection				
10/20 - 10/23					RRGE-2 RRGE-1	63 75	50 63	
10/21 - 10/23	RRGI-6	50	61-63					
10/21 - 10/23	RRGI-7	50	61-66					
10/27 - 11/3	RRGI-7	104	61-66		RRGI-1	100	63	
10/27 - 11/3	RRGI-6	75	61-63		RRGI-2 RRGI-3	52 56	50 35-41	

TABLE 5. MAJOR (80 HOUR) PRODUCTION AND INJECTION TESTS FROM 1978 THROUGH 1980

	INJECTION				PRODUCTION			
Date	Well Number	Duration (hours)	Rate (L/sec)	Remarks	Well Number	Duration (hours)	Rate (L/sec)	Remarks
1980								
5/14-6/17					RRGE-3	823	44	
5/14-6/12	RRGI-6	700	44	hot water direct injection				
6/12-6/17	RRGI-7	122	44					
8/20-9/10					RRGE-2	475	57	
8/20-8/28	RRGI-6	190	57	hot water direct injection				
8/28-9/10	RRGI-7	285	57					
1979								
3/20-4/10	RRGI-6	504	39	hot water direct injection	RRGE-2	504	39	
5/16-6/6	RRGI-6	483	40	hot water direct injection	RRGE-5	483	40	
8/11-8/15	RRGI-7	96	63	hot water direct injection	RRGE-2	96	28	
10/15-10/18	RRGI-7	80	63	hot water direct injection	RRGE-1	80	63	
1978								
5/30-6/9	RRGI-4	221	45	hot water direct injection	RRGE-2	221	45	

MONITOR WELL RESPONSE

The following text describes and analyzes ground water responses at each of the wells used to monitor the affects of Raft River geothermal development. Both a 1981 and a long term hydrograph containing all available data for each of the monitor wells are illustrated in Appendix 1 (Figures A-1--A-24). The results of the monitor well responses are presented in three seperate sections. Each of the three sections is characterized by a distinct hydrograph pattern. Monitor wells MW-5, PW-3, MW-3, MW-6, MW-7, USGS-2 and PW-5 represent a gradient in shallow aquifer response from those strongly affected by irrigation withdrawal to those which primarily only reflect the affects of natural recharge. The second population discussed (MW-2 and MW-4) is believed to monitor water level trends in the intermediate aquifer near the injection wells. The water level response in these wells is affected by both injection and irrigation. A third population, composed of MW-1, USGS-3 and the BLM-Offset, monitors water level trends in the intermediate aquifer near the Bridge Fault System. The water level in these wells is unaffected by irrigation pumping withdrawals. These population categorizations are admittedly qualitative, nevertheless three distinctive patterns are present. The correlation of the water level trends will be quantified in the summary monitor well report to be published in September 1982.

Wells Primarily Affected by Irrigation and Seasonal Recharge

Monitor Well-5 (MW-5)

Wellhead Elevation--1475 m

Bottom-hole Elevation--1314 m

Slotted Casing--1405 m to 1330 m

Open Borehole--1330 m to 1314 m

MW-3, MW-4, MW-5, MW-6 and MW-7 were all located to monitor the effects of injection into RRGI-6 and RRGI-7. Of all these wells, MW-5 exhibits the most dramatic response to seasonal changes and irrigation pumping. It is also apparent that MW-5 clearly responds to several individual irrigation wells. This is evident by the magnitude of responses seen in the 1981 hydrograph. From the recovery slopes seen throughout the summer, it appears possible that at least three irrigation wells affect the water level at MW-5. The sharp drop in the spring and the sharp rise in the fall coincides with the beginning and end of the irrigation season in the valley. The small peaks throughout the summer reflect the signature of various irrigation wells that had been turned off.

The 1981 hydrograph pattern is consistent with observations of previous years. The net water level at MW-5 continues to drop each year. This trend is consistent with the regional ground water declines due to irrigation. MW-5 shows an indirect response to RRGI-6 injection. This response is a slight, sudden decrease in water level which corresponds closely to the beginning of the RRGI-6 injection tests. At termination of the injection test the curve recovers to its original pattern.

Pit Well-3 (PW-3)

Wellhead Elevation--1470 m

Bottom-hole Elevation--1442 m

Open Borehole--1453 m to 1442 m

PW-3 shows responses similar to MW-3 and MW-5. All three of these wells show the strong affects of irrigation pumping. MW-5 is farthest east and closest to the major irrigation activity, hence it shows the most response to irrigation pumping. PW-3 is about 1.4 km west of MW-5 and MW-3 is about 0.4 km west of PW-3. MW-3 shows the least response to pumping and PW-3 shows a response intermediate between the MW-5 and MW-3. The general trend of seasonal drawdown associated with irrigation is noted by the rapid drawdown at the beginning of irrigation pumping and the rapid recovery when the irrigation pumps are turned off in the autumn. The small peaks noted throughout the summer are attributed to brief interuptions in nearby irrigation pumping.

The long-term pattern follows the same general trends as seen in 1981. As with MW-3 there is no noticable response to injection. MW-5, the other well similar to PW-3 and MW-3 is much closer to the RRGI-6 injection site and does exhibit an indirect injection response.

Monitor Well-3 (MW-3)

Wellhead Elevation--1472 m

Bottom-hole Elevation--1319 m

Slotted Casing--1332 m to 1319 m

The water level fluctuations in MW-3 follows the typical seasonal trend. As in prior years, the 1981 ground water level rises and declines in a very uniform manner. The onset of the downward and upward ground water trends is directly associated with the irrigation season.

Deviations in the steady ground water level decline are noted during the summer of each of the three years for which data are available. This pattern is typical of aquifers that are used for irrigation. Temporary level or short upswing periods are probably assocated with a change in irrigation pumping. This would occur, for example, during the first and second alfalfa cuttings when irrigation is temporarily halted. Since the temporary deviations from the downward summer pattern occur in June (first cutting) and August (second cutting) these data seem to confirm an irrigation tie to alfalfa production. Water level fluctuations in MW-3 do not show any indication of connection with the injection zone.

Monitor Well-6 (MW-6)

Wellhead Elevation--1469 m

Bottom-hole Elevation--1164 m

Open Borehole--1195 m to 1164 m

The 1981 ground water level at MW-6 illustrates an overriding seasonal pattern typical for the region. Also MW-6 is most responsive to the indirect effects of injection at RRGI-6. The water level increases from the beginning of the year until the onset of the irrigation system at the beginning of May. A steady decline occurs throughout the irrigation season followed by recovery beginning in October. The two noticable declines that occur in late October and early November are due to slight aquifer deformation caused by injection at RRGI-6. Similar declines in February and September also occur, but the magnitude of the drop is far less due to shorter duration tests or lower rates of injection.

MW-6 is the same depth as MW-4 and is located closer to RRGI-6. However, this monitor well does not respond in a similar manner to injection into RRGI-6 as does MW-4. This is a clear example suggesting that fractures are an important mechanism controlling aquifer communication. Both MW-4 and MW-6 are hydraulically connected to the irrigation system. However, MW-4 also responds directly and strongly to injection, while MW-6 shows only a small indirect affect that implies aquifer deformation. The magnitude of water level fluctuation is similar for each of the years during which the well was monitored. The data also indicate an overall declining trend. This is consistent with the overall valley trend and is expected since it is apparent that this well is so closely connected with the irrigation aquifers.

Monitor Well-7 (MW-7)

Wellhead Elevation--1474 m
Bottom-hole Elevation--1322 m
Slotted Casing--1334 m to 1322 m

The 1981 water level fluctuation at MW-7 follows a seasonal trend. Minor increases in the water level during the summer downward trend are due to irrigation pumps being temporarily shutdown. These small increases correspond to responses seen at MW-5 and to a lesser extent at Pit Well-3. The smaller magnitude of rises at MW-7, compared to MW-5, indicate that MW-7 is further removed than MW-5 from the irrigation pumping. The decline noted in the general upward trend during late October and early November are associated with aquifer deformation as noted earlier.

The long term trend confirms the observations noted in 1981. A "step function" decline is noted during injection tests to RRGI-6. MW-7 also shows response to irrigation activities. This response corresponds to the pattern at MW-5 but is of smaller magnitude.

USGS-2

Wellhead Elevation--1473 m

Bottom-hole Elevation--1232 m

Open Borehole--1409 m to 1232 m

The 1981 data from USGS-2 are only partially available, however the trend seems to follow the long-term pattern established for the well. Since data were first collected in 1976, there has been a steady declining trend resulting in a total drop of 1.5 meters. The pattern of the well reflects the effects of seasonal irrigation pumping and natural recharge. The pattern is consistent with other wells monitoring the shallow aquifer such as MW-3, MW-5, MW-6, MW-7, and PW-3. Evidence of deformation associated with injection into RRGI-6 is seen as a slight decrease in the ground water level.

Pit Well-5 (PW-5)

Wellhead Elevation--1490 m

Bottom-hole Elevation--1464 m

Slotted Casing--1473 m to 1464 m

The smooth seasonal water level trend observed in this well is atypical of any other monitor well in the network. The pattern suggests that the aquifer sampled by this well is not detectably affected by either irrigation or by geothermal injection or pumping. Rather, the pattern reflects what should be expected in a natural, undisturbed ground water system. A steady rise in the water level begins in mid-November and continues until mid-June. This rise coincides with the period of natural recharge for the region. As the recharge effects of snowmelt and precipitation cease, the ground water level begins to decline. This decline is sustained through the typically low precipitation months of summer and early autumn. This decline ends when autumn precipitation increases.

This pattern observed in 1981 is consistent with earlier records from this well. The water level lows of 1979, 1980 and 1981 remain fairly constant indicating that the water table is perhaps remaining at the same level, rather than declining as is the case with most monitor wells that communicate with the irrigation aquifers. The lower 1981 peak is probably the result of lower regional recharge from precipitation and snowmelt.

Wells Primarily Affected by Injection, Irrigation and Seasonal Recharge

Monitor Well-2 (MW-2)

Wellhead Elevation--1474 m
Bottom-hole Elevation--1300 m
Slotted Casing--1320 m to 1308 m
Open Borehole--1308 m to 1300 m

MW-2 was drilled near the Crook geothermal well to monitor the effects of pumping and injection on the Crook well and shallow irrigation and domestic wells. The Crook well was previously used to supply geothermal water (average temperature 96°C) for greenhouse heating. Greenhouse operation ceased in November, 1980. The well has been allowed to flow artesian since. MW-2 appears to have a direct connection with the Crook well aquifer. This communication is so strong that MW-2 responds exactly to any variations in the Crook well operation. This is in contrast to MW-1 which responds more weakly to Crook well operation. Such deviations in response between MW-1 and MW-2 are expected since the 174 m deep MW-2 is 200 m from the 126 m deep Crook well, while MW-1 is 399 m deep and is about 800 m from the Crook well.

Unlike MW-1, MW-2 shows some response to seasonal ground water drawdown. A slight downward pressure trend is apparent from early May through September, followed by a gradual recovery in the autumn. This seasonal pattern is characteristic of most of the monitor well trends and is associated with natural seasonal recharge and with pumping of water for irrigation throughout the valley. The two brief pump tests of the Crook well during 1981 resulted in immediate and very rapid wellhead pressure drops at MW-2. When the pump tests were terminated, the recovery was likewise very rapid. The two rises in water level in August are due to declines in irrigation pumping. This is supported by comparing this period with the potentiometric heads at MW-5 (MW-5 is the most responsive of the monitor wells to irrigation pumping).

The long-term wellhead pressure trend at MW-2 is almost completely dictated by the Crook well operation. The time of greatest need for greenhouse heating is during the cooler seasons. Consequently, the period from October 1979 through March 1980 was the period of greatest Crook well pumping and the lowest wellhead pressures at MW-2. Each sharp decline in wellhead pressure at MW-2 can be correlated to increased pumping activity at the Crook well.

Monitor Well-4 (MW-4)

Wellhead Elevation--1468 m
Bottom-hole Elevation--1163 m
Slotted Casing--1243 m to 1214 m
Open Borehole--1214 m to 1163 m

In general, the 1981 hydrograph for MW-4 follows the typical seasonal pattern of drawdown during the summer followed by recovery at the end of the irrigation season. Data are not available from April because the digiquartz pressure transducer installed at the well malfunctioned. Exceptions to normal seasonal variation are directly correlated to injection tests at RRGI-6. During each RRGI-6 test, an increase in water level is recorded. The magnitude of the increase is related to the injection rate and duration of the test. In February the water level rise was small. This was probably because this 55 hour test was injecting at rates of only 16 l/sec to 30 l/sec. The August water level increase is also small because while the injection rate was higher (53 l/sec to

73 l/sec) the duration of the test was only 7 hours. The RRGI-6 injection tests in late October and early November were both of longer duration (50 hours and 75 hours) and had a high injection rate averaging about 63 l/sec. Both these tests resulted in a rapid rise in the monitor well water level.

The water level rises associated with RRGI-6 injection tests in 1981 are consistent with responses observed in previous years. This indicates that relatively direct aquifer communication exists between RRGI-6 and MW-4. Seasonal trends are not evident during 1979 and 1980. In fact, there appears to be a net ground water level increase over this period. This response and that of MW-2 is in contrast to most of the other monitor wells which show a steady declining trend. This can be explained in that the RRGI-6 injection operations during both 1979 and 1980 occurred during the season when water level drawdown due to irrigation begins. The effects of these long term, high volume injection tests appear to counter the impacts of seasonal drawdown by increasing the potentiometric surface. After these tests there was a rapid drawdown until the irrigation pumps were turned off at the end of September. At this point the normal autumn recharge began. The steady general rise that is apparent from 1979 through the spring of 1981 is attributable to a seasonal water level decline that is less than the increase due to the injection. Thus fall recharge began at a higher ground water level than in the previous year. This results in a general upward trend. Very little injection at RRGI-6 occurs in 1981, consequently the water level follows the normal seasonal pattern. Thus, it appears that sustained injection to RRGI-6 results in a potentiometric head increase in the intermediate aquifer, resulting in a significant increase in the water level of MW-4. The significance of this projected response as a potentially degrading factor to shallow water quality is difficult to quantify. If long-term injection to RRGI-6 occurs, it would be expected that poor quality fluids in the injection zone would move up into the shallower aquifers. It is important to note, however, that the undisturbed water-bearing zones intercepted by MW-4 initially contained water of poor quality, presumably because natural communication with the injection zone has existed historically.

Intermediate Aquifer Wells Unaffected by Irrigation and Seasonal Trends

Monitor Well-1 (MW-1)

Wellhead Elevation--1475 m
Bottom-hole Elevation--1076 m
Open Borehole--1106 m to 1076 m

MW-1 was drilled near RRGI-4 for the purpose of monitoring the impacts of injection tests on local irrigation and domestic wells. Comparisons of well locations and well logs with known fault systems indicate that USGS-3 and RRGI-4 probably penetrate the same fracture system, while MW-1 penetrates unfractured rock adjacent to the fracture system (Niemi and Nelson 1978). The chemical characteristics of MW-1 indicate direct hydraulic connection with the geothermal system. This connection is indicated by water chemistry (Figure 4; Table 5) and a wellhead discharge temperature of 80°C. In 1981, the wellhead pressure remained fairly constant with a calendar year high of 316 kPa (absolute) occurring on 5 April and low of 209 kPa (absolute) occurring on 12 October. The minor fluctuations of wellhead pressure in MW-1 observed in 1981 are attributable to atmospheric pressure changes.

The wellhead pressure at MW-1 has remained fairly constant since pumping of the Crook Well and RRGP-4 has ceased. Throughout the autumn and winter of 1979 and the spring of 1980, wellhead pressure remained fairly constant, averaging about 308 kPa. In June of 1980 a drop in wellhead pressure of 17 kPa began. This drop correlates with pumping at RRGP-4 to fill the reserve pond with water to be used for irrigation studies. After RRGP-4 pumping ceased, the wellhead pressure increased by late October to its previous average of about 309 kPa. Shortly after this, pumping of the Crook well ceased. This prompted the average wellhead pressure to increase to about 312 kPa. The erratic wellhead pressure pattern in the spring of 1979 is due to flow tests conducted at MW-1. The limited data from 1978 show recovery at MW-1 after a flow test of that well. This was followed by a very rapid increase in wellhead pressure of 34 kPa associated with the injection test at RRGI-4. Partial recovery data indicate a rapid decline of this pressure increase following termination of the injection test.

USGS-3

Wellhead Elevation--1486 m
Bottom-hole Elevation--1052 m
Open Borehole--1426 m to 1052 m

Monitor well baseline data from USGS-3 are available since 1976. The ground water level changes are irregular and do not follow a seasonal pattern. In 1981, the ground water level remained fairly constant.

The long term data indicate that the aquifer monitored by USGS-3 has a good hydraulic connection to the geothermal system and is strongly related to activity at RRGP-4. The distinctive wellhead pressure rises, particularly the increase beginning 28 May, 1978, are tied to injection tests into RRGI-4 well. Sharp decreases in the water level may be associated with artesian flows of RRGP-4, although accurate records of when the well was allowed to flow are not available. Wellhead pressure data indicate the probability of direct communication with the geothermal reservoir affected by RRGP-4. The monitor well zone seems to be isolated from the aquifers used for irrigation.

BLM-Offset Well

Wellhead Elevation--1500 m
Bottom-hole Elevation--1402 m
Casing--?

The potentiometric head trend of the BLM-Offset well is typical of an aquifer that is essentially hydrologically isolated from the shallow aquifers used for irrigation. The 1981 hydrograph exhibits very little fluctuation in the potentiometric head. The only response to Raft River Geothermal production and testing occurs during late October and early November. During this period the potentiometric head increased. This increase is more likely a response to production, rather than injection, due to the proximity of the production wells compared to injection wells. This increase could be caused by a potentiometric head decline due to pumping and induced aquifer compaction of the overlying intermediate aquifer. A similar phenomenon was noted in some of the monitor wells near the injection wells.

The lack of drawdown in the BLM-Offset well during pumping suggests that the production wells have a poor, if any, hydraulic connection with the system monitored by the BLM-Offset well. The long-term trends from 1978 to 1981 exhibit little change except during the 1978 injection test into RRGI-4 and the drop in 1980 possibly due to flowing RRGP-4.

DISCUSSION

The hydrologic system of the Raft River Valley shallow ground water zone (0-300 m depth) consists of several localized, interconnected aquifers. An intermediate aquifer exists throughout the geothermal area between depths of 300 m to 600 m. The hydraulic communication between these aquifers and the geothermal production and injection aquifers are complex. This communication appears to be affected by both horizontal and vertical fracture systems.

Several basic aquifer systems have been confirmed by water chemistry data. Differences in monitor well water quality are associated with the depth and location of the well. None of the monitor wells currently show changes in water chemistry associated with the affects of geothermal injection. Fluid movement is much slower than pressure movement, therefore many years of pressure change would be expected to precede a detectable change in water quality. To date, only MW-2 and MW-4 show a direct pressure response associated with injection. While no decrease in water quality has yet been identified at this well, poor quality fluids can be expected to move up into the shallower aquifers from the injection zone. It is important to note, however, that the undisturbed water-bearing zones intercepted by MW-4 initially contained poor quality water, presumably because natural communication with the intermediate aquifer injection zone receiving fluid from RRGI-6 has existed historically (Spencer and Callen 1980).

There are different types of ground water level fluctuations in response to injection. One type of response is reflected as a measurable decline in water level that closely corresponds to the beginning and end of injection into RRGI-6. This response is evident at MW-5, MW-6 and MW-7 and the BLM-Offset well. The relative amplitude of the response appears to be related to the barometric efficiency in each well. This response is probably due to elastic deformation of the aquifer matrix. The fact that the deformation remains constant during injection implies that distortion does not increase with the duration of the injection test, and may be primarily dependent on the amount of injection pressure buildup. The magnitude of the pressure distortion is not great and therefore does not represent a serious environmental concern. If injection continued at a constant rate over a long period of time, the cone of deformation would be expected to decay and water levels would return to pre-test trends.

The other type of response to injection is represented by water level rise during the injection pumping. This type of response was observed only at MW-2 and MW-4. The injection pressure buildup in the intermediate aquifer apparently extends away from RRGI-6. The extent of the pressure changes is probably affected by fracture systems within the aquifer.

A comprehensive, detailed analysis of the monitor well network will be completed in September 1982. That report will be published as Volume 2 of the Raft River Environmental Summary.

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APPENDIX I

The following tables exhibit all the available data for each of the wells used in the Raft River monitor well network. A 1981 and a long-term hydrograph is illustrated for each monitor well.

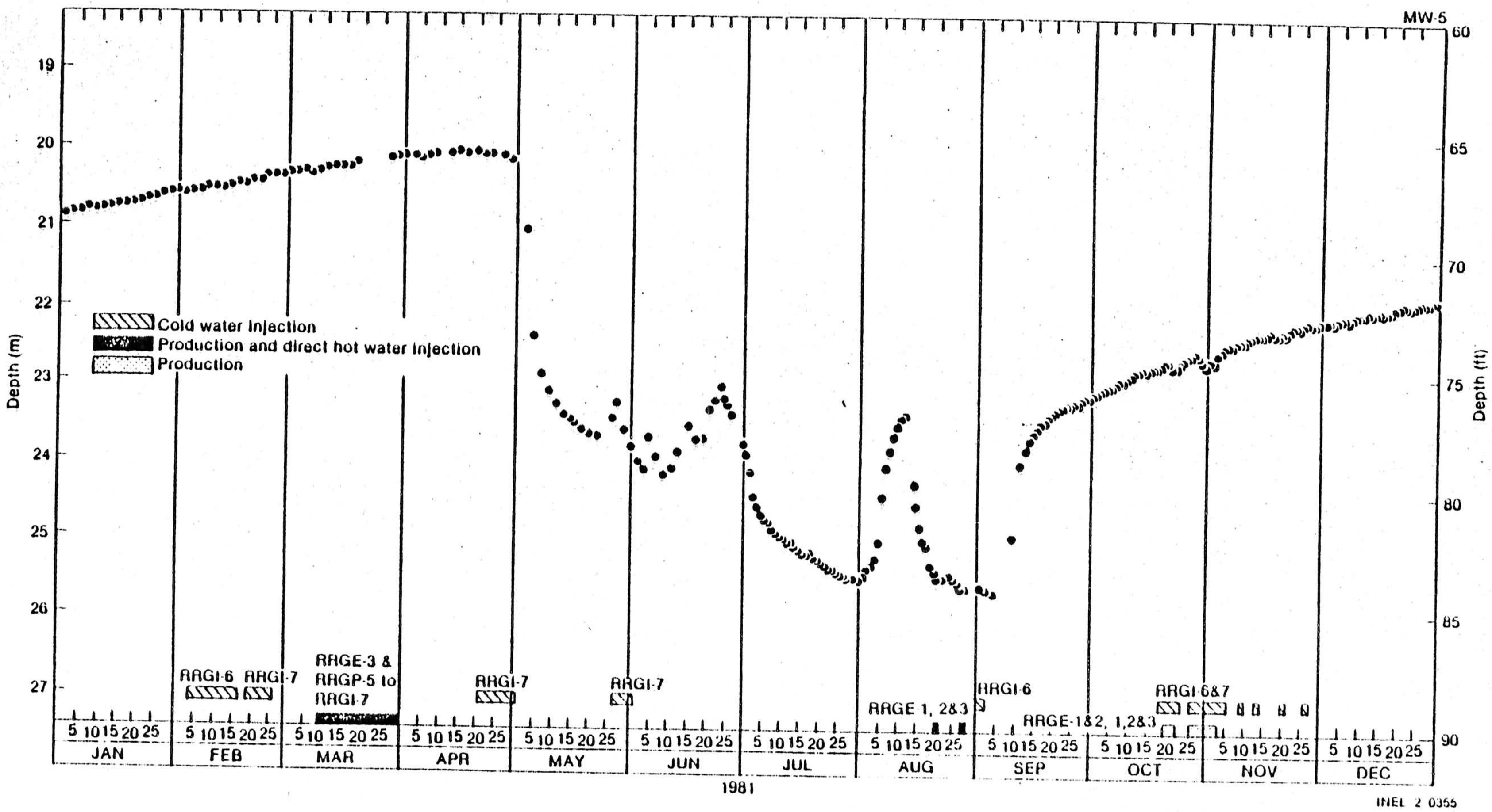

Figure A-1. MW-5 hydrograph for 1981. Casing is slotted from 124 m to 136 m. The well is not cased from 136 m to the bottom-hole depth of 152 m.

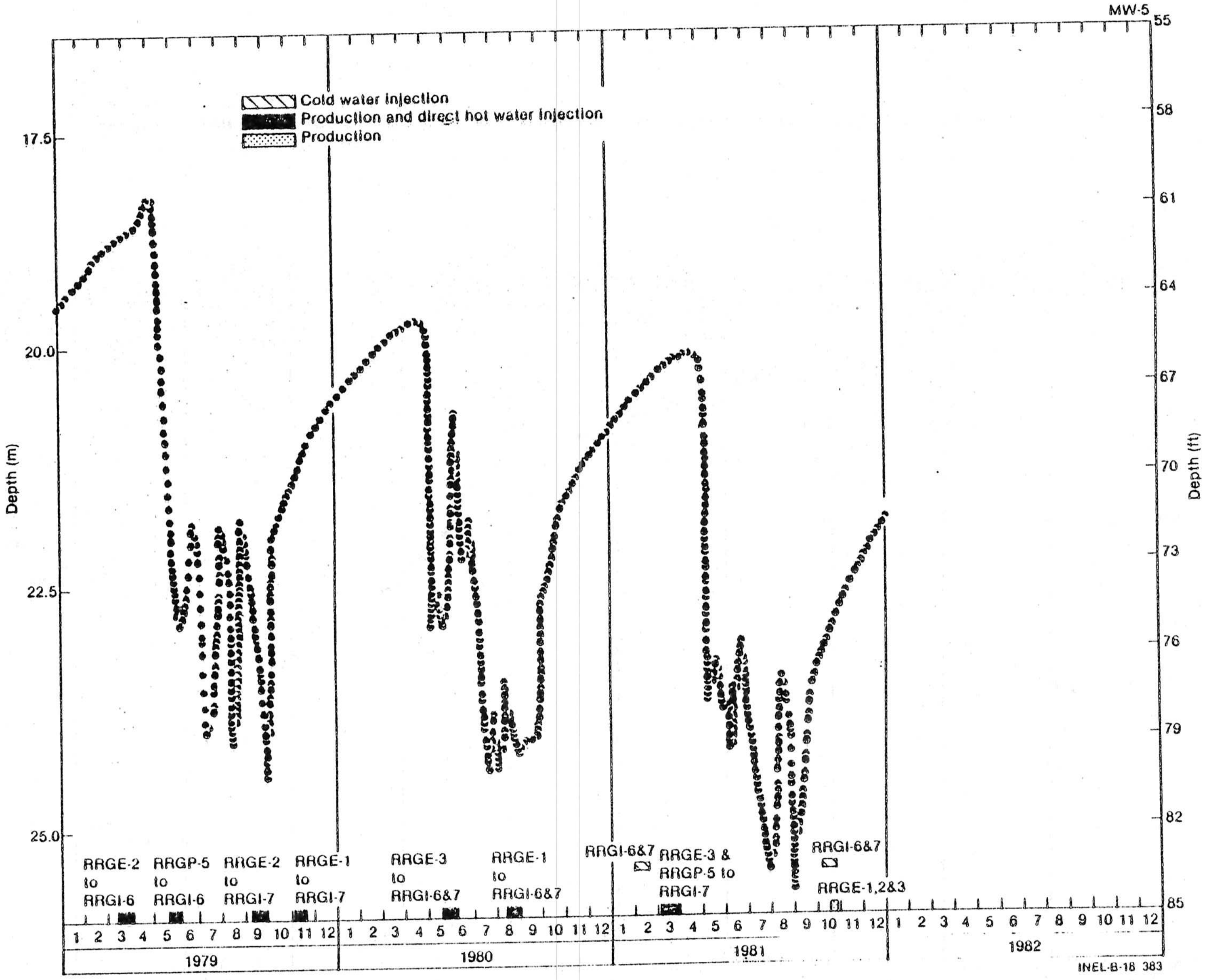

Figure A-2. MW-5 long-term hydrograph. Casing is slotted from 124 m to 136 m. The well is incased from 136 m to the bottom-hole depth of 152 m.

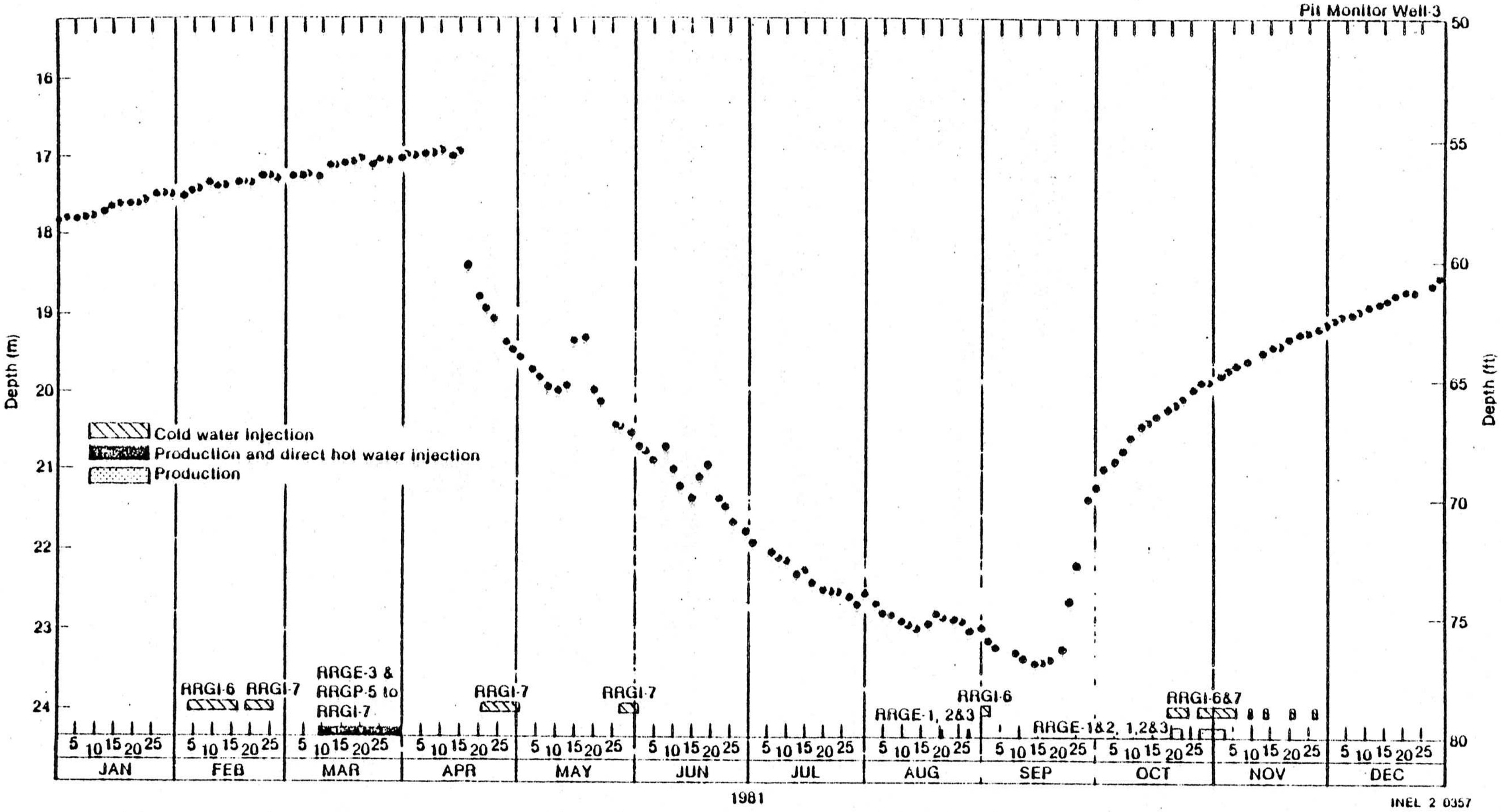

Figure A-3. PW-3 hydrograph for 1981. The well is not cased from approximately 17 m to the bottom-hole depth of 28 m.

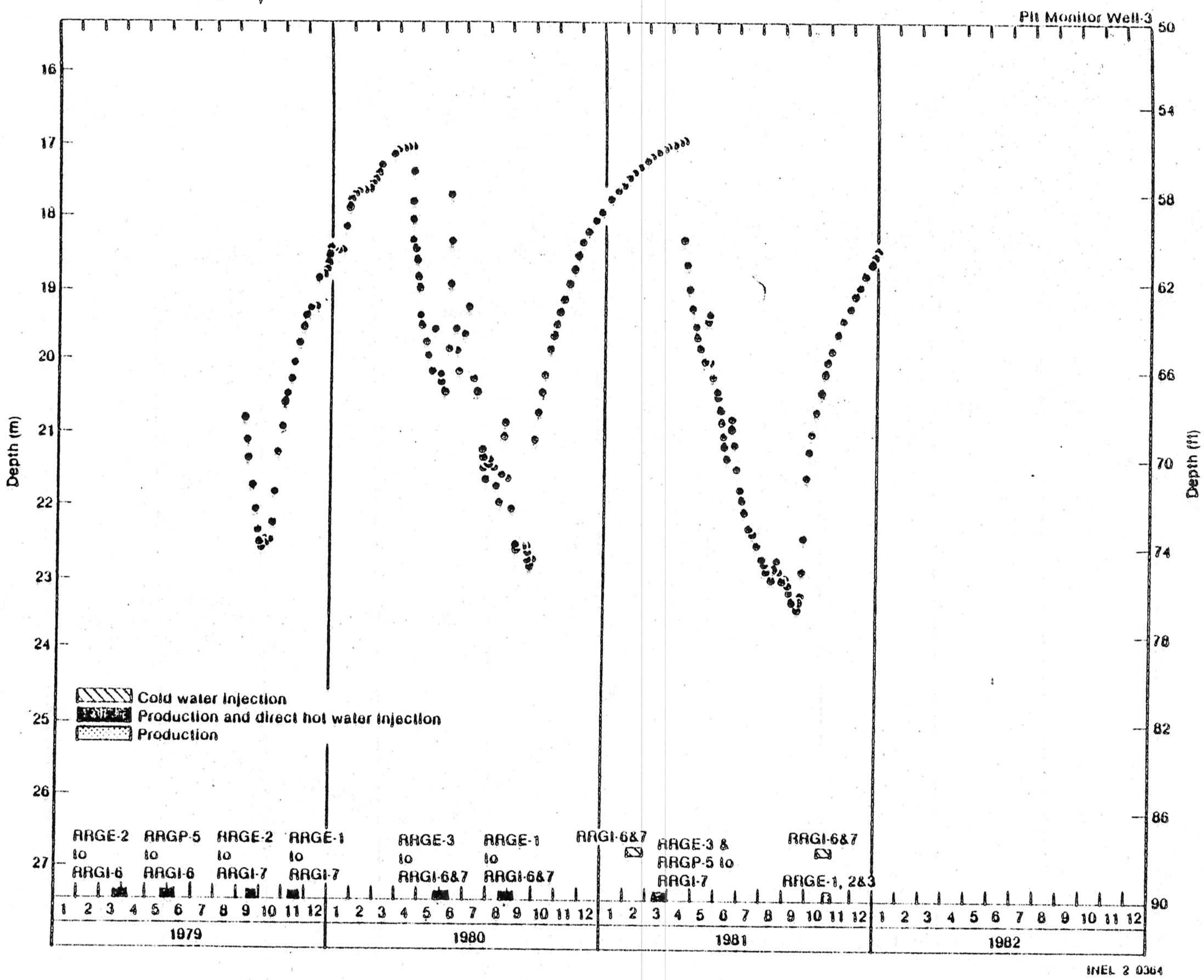

Figure A-4. PW-3 long-term hydrograph. The well is not cased from approximately 17 m to the bottom-hole depth of 28 m.

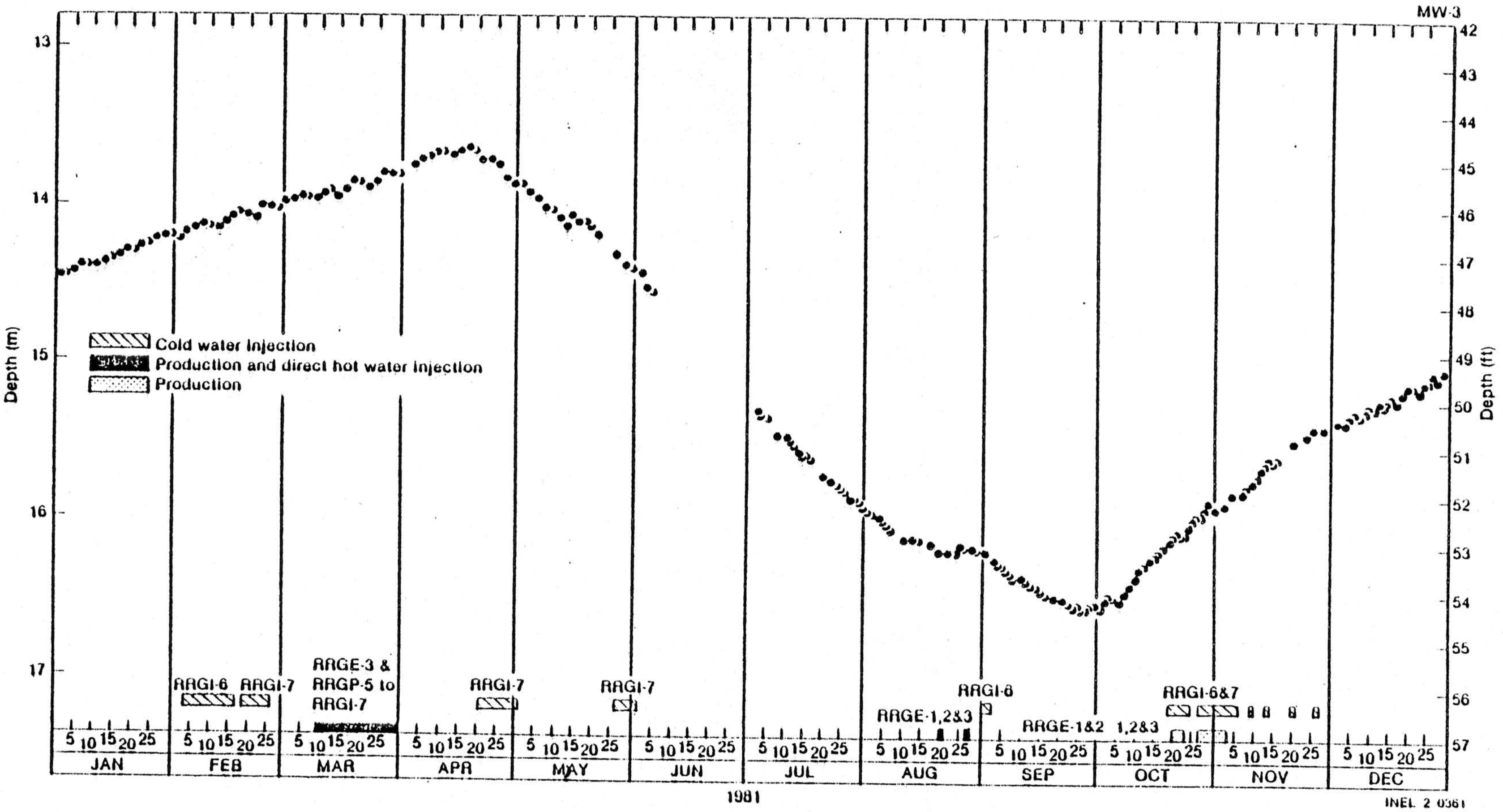

Figure A-5. MW-3 hydrograph for 1981. Casing is slotted from 140 m to the bottom-hole depth of 153 m.

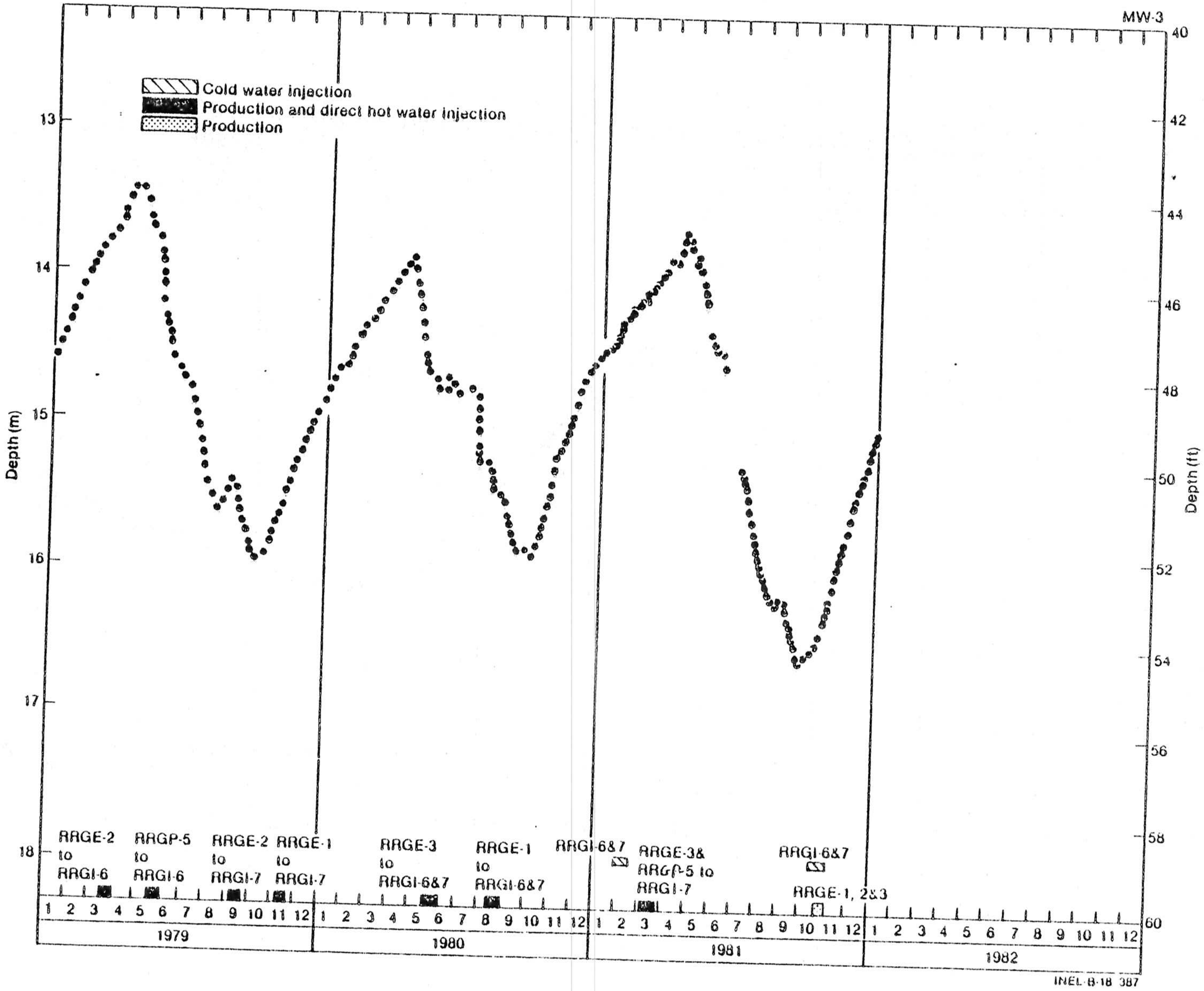

Figure A-6. MW-3 long-term hydrograph. Casing is slotted from 140 m to the bottom-hole depth of 153 m.

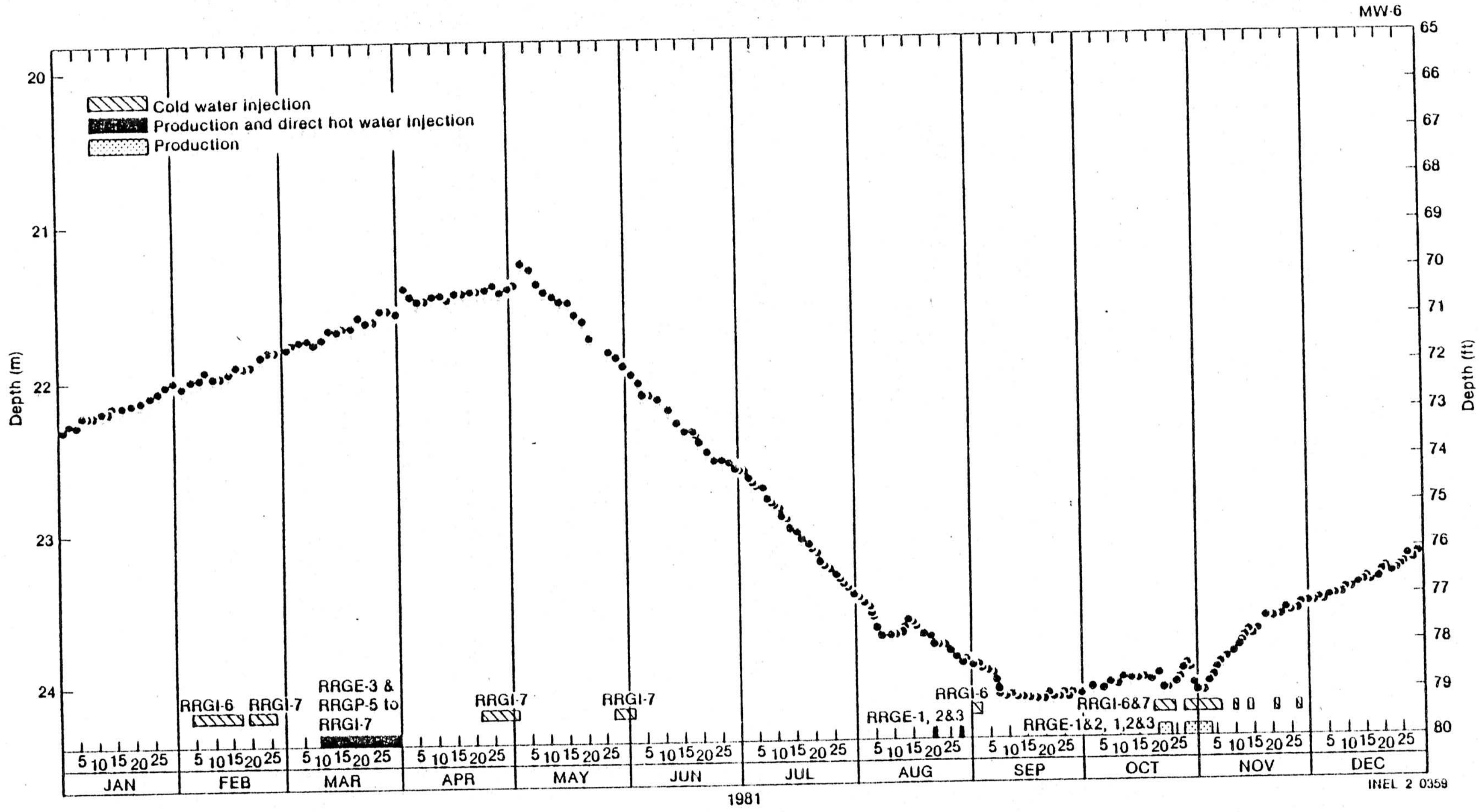

Figure A-7. MW-6 hydrograph for 1981. The well is not cased from 274 m to the bottom-hole depth of 305 m.

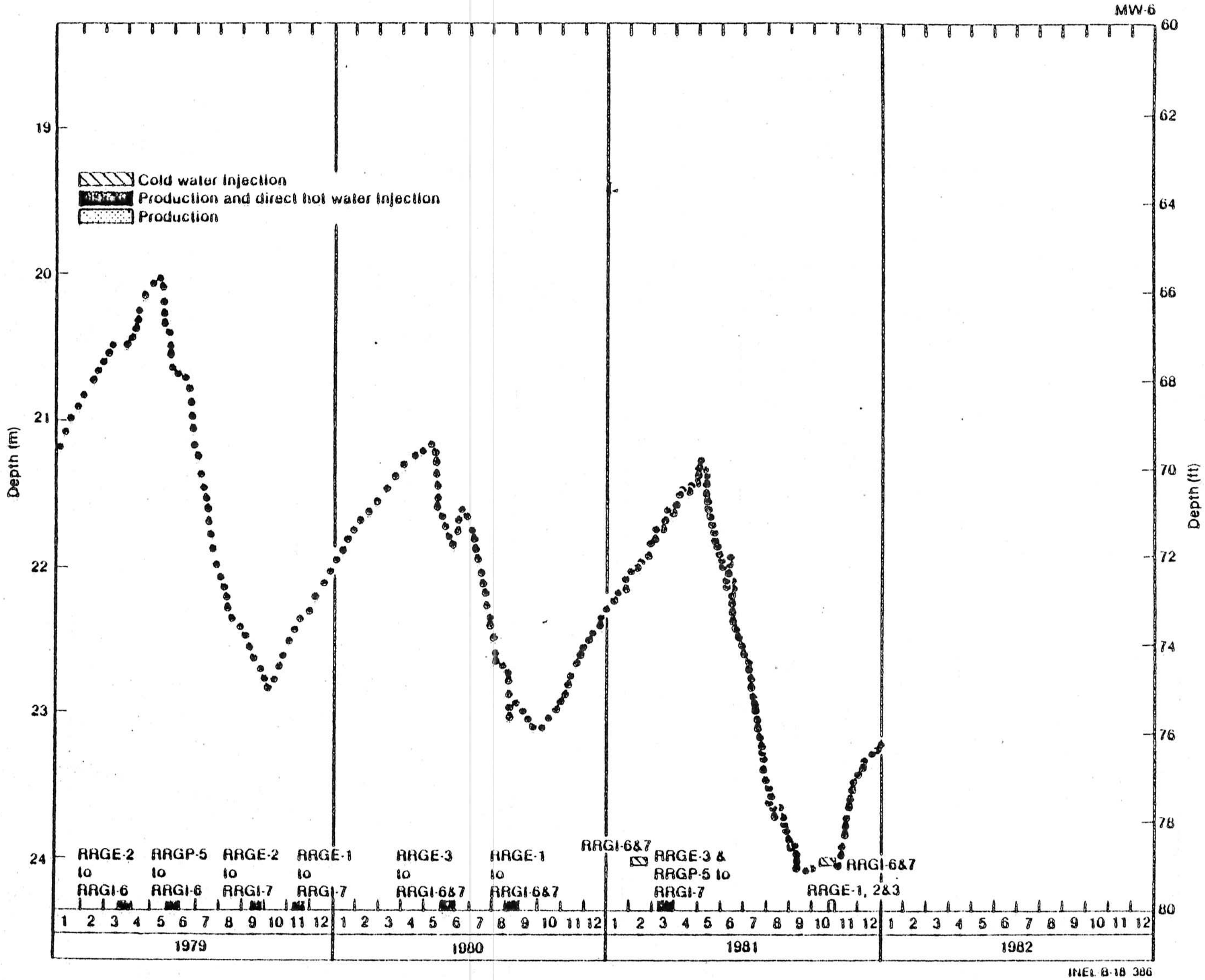

Figure A-8. MW-6 long-term hydrograph. The well is not cased from 274 m to the bottom-hole depth of 305 m.

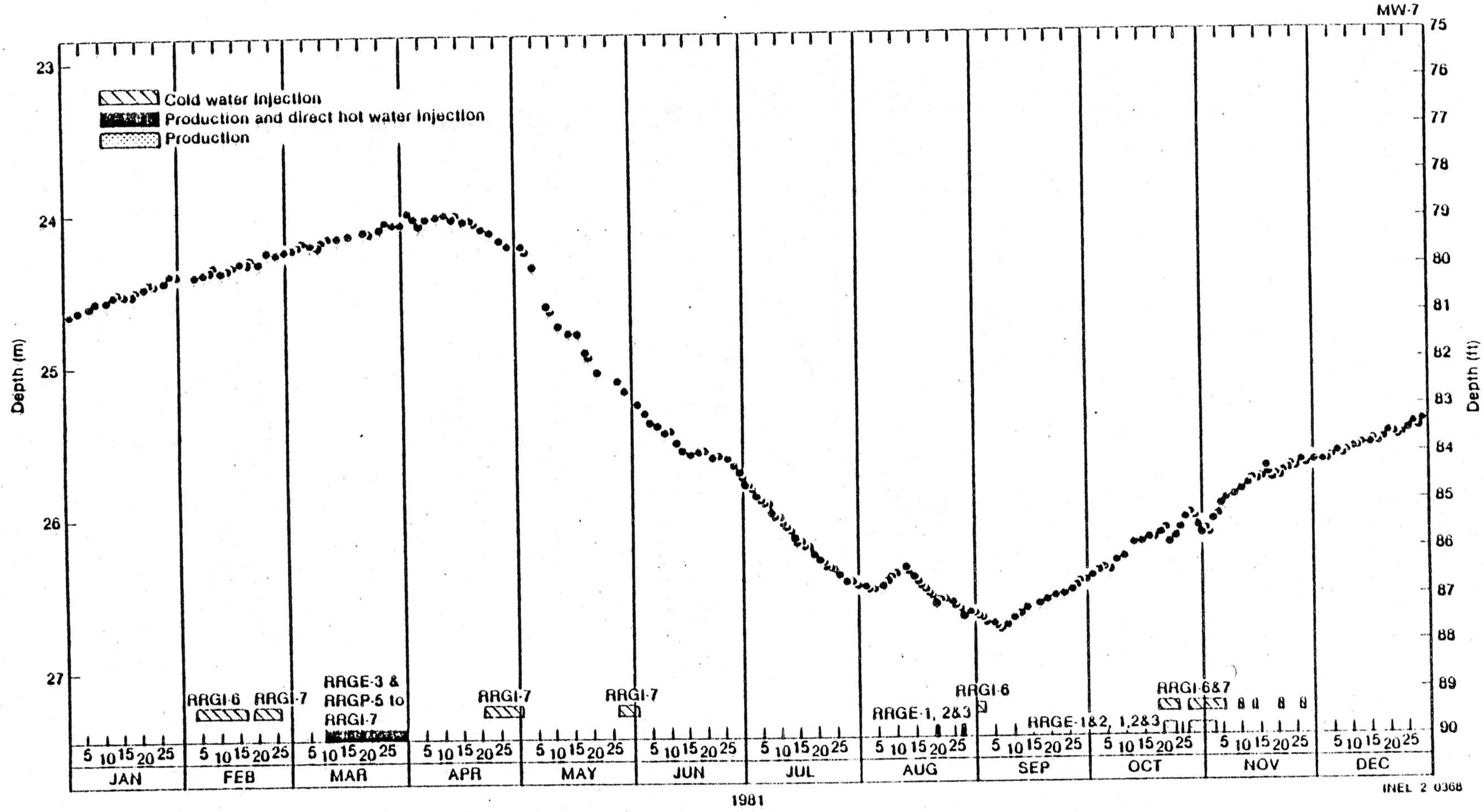

Figure A-9. MW-7 hydrograph for 1981. Casing is slotted from 140 m to the bottom-hole depth of 152 m.

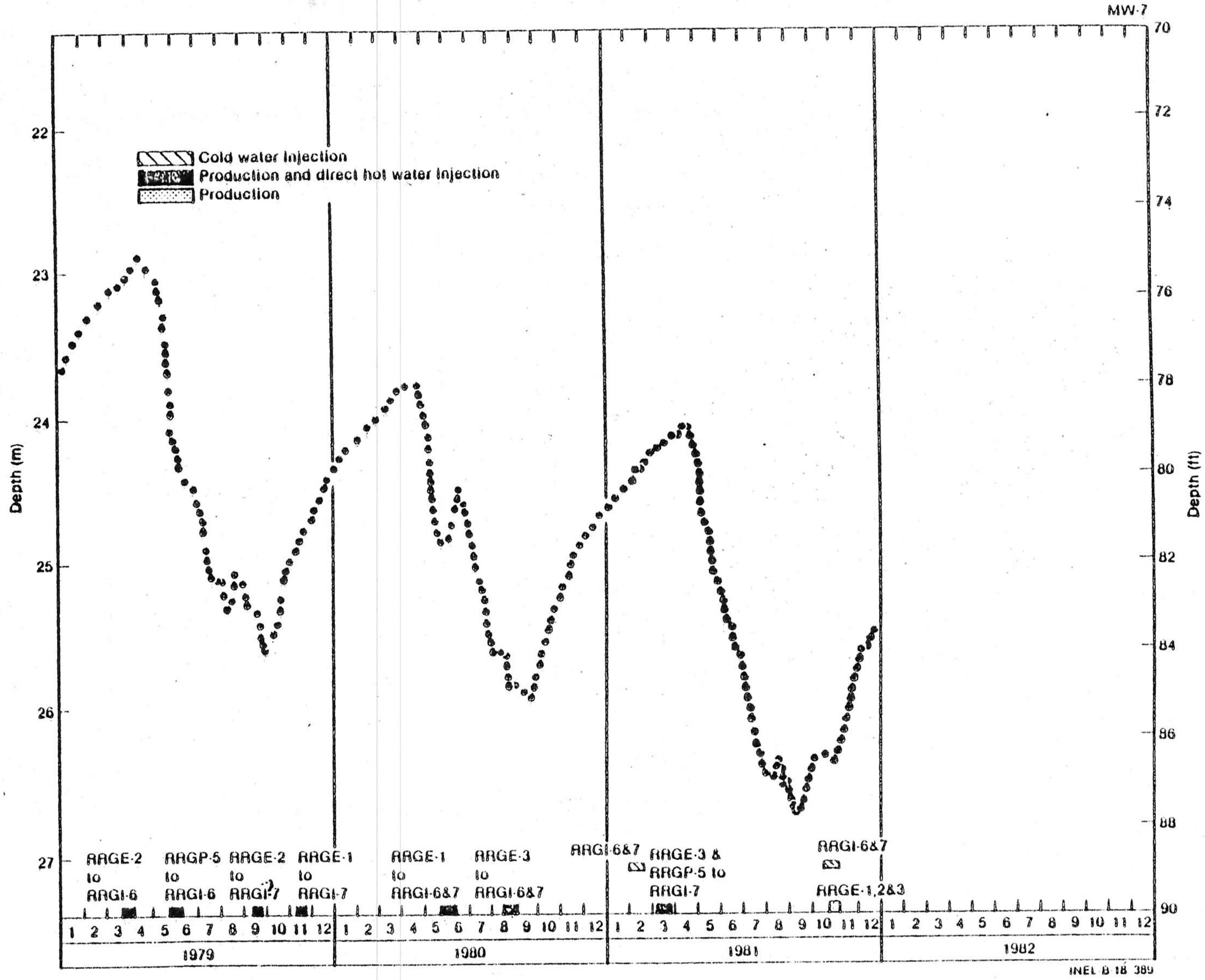

Figure A-10. MW-7 long-term hydrograph. Casing is slotted from 140 m to the bottom-hole depth of 152 m.

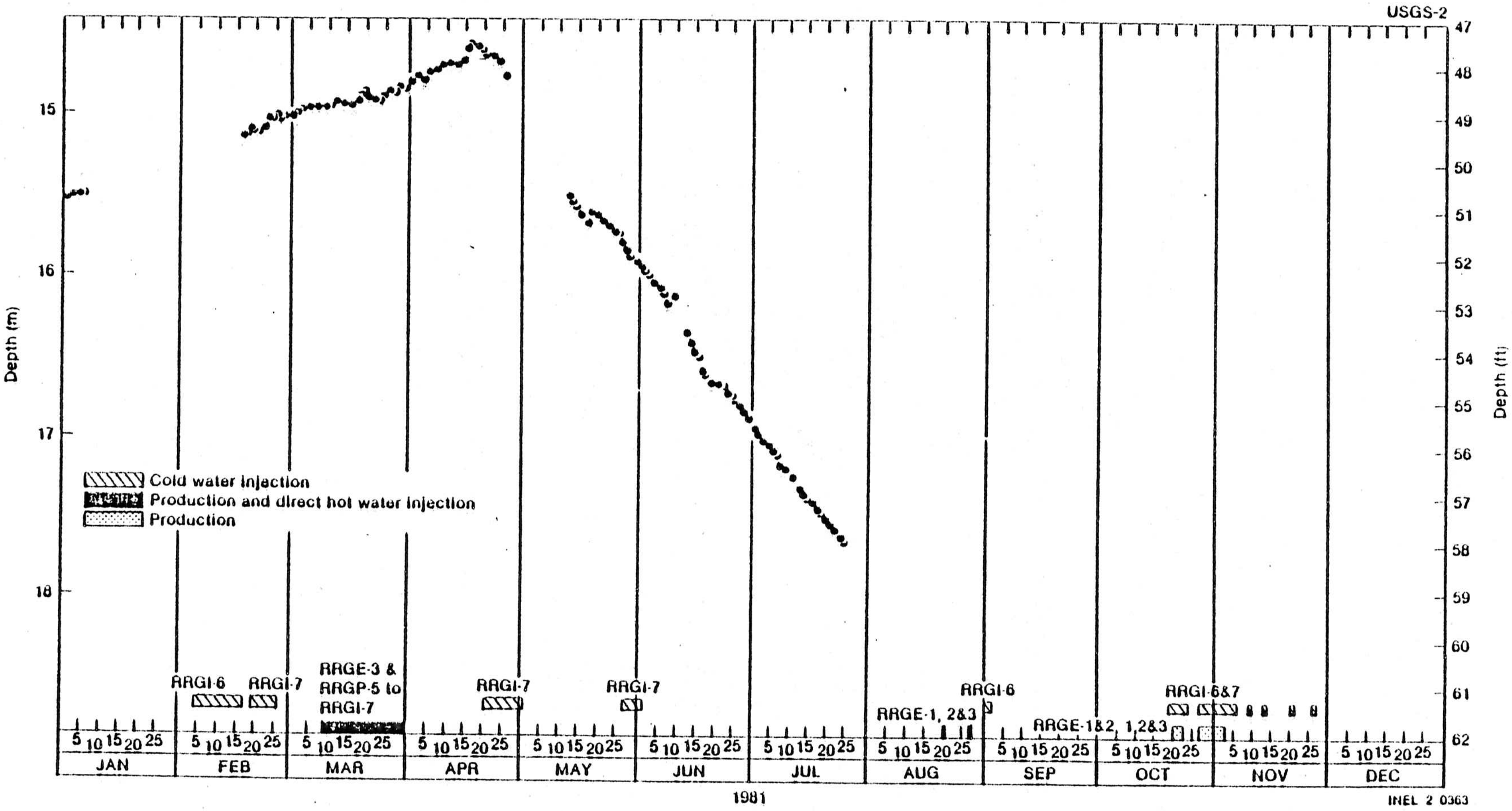

Figure A -11. USGS-2 hydrograph for 1981. The well is not cased from 64 m to the bottom-hole depth of 241 m.

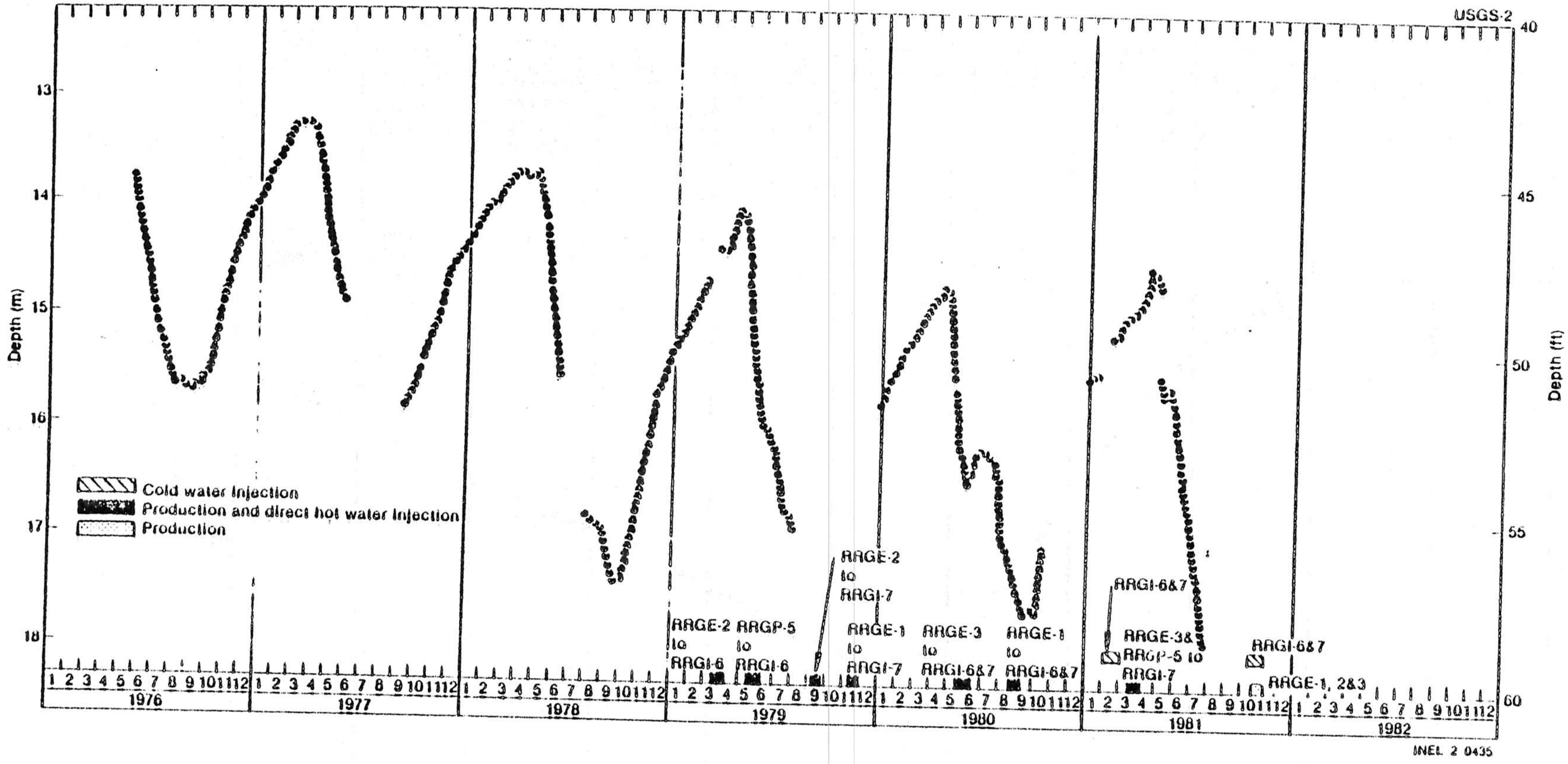

Figure A-12. USGS-2 long-term hydrograph. The well is not cased from 64 m to the bottom-hole depth of 241 m.

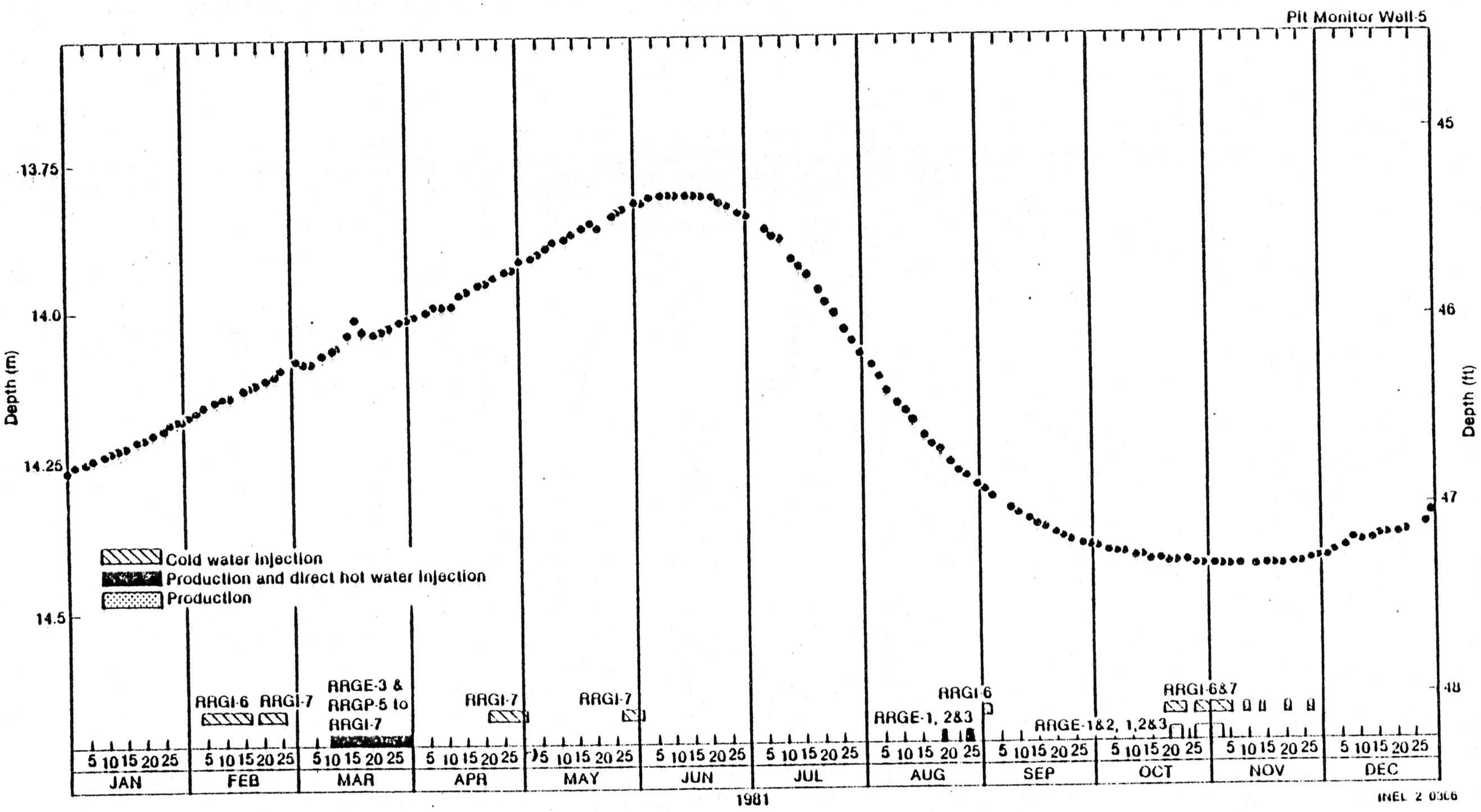

Figure A-13. PW-5 hydrograph for 1981. Casing is slotted from 17 m to the bottom-hole depth of 26 m.

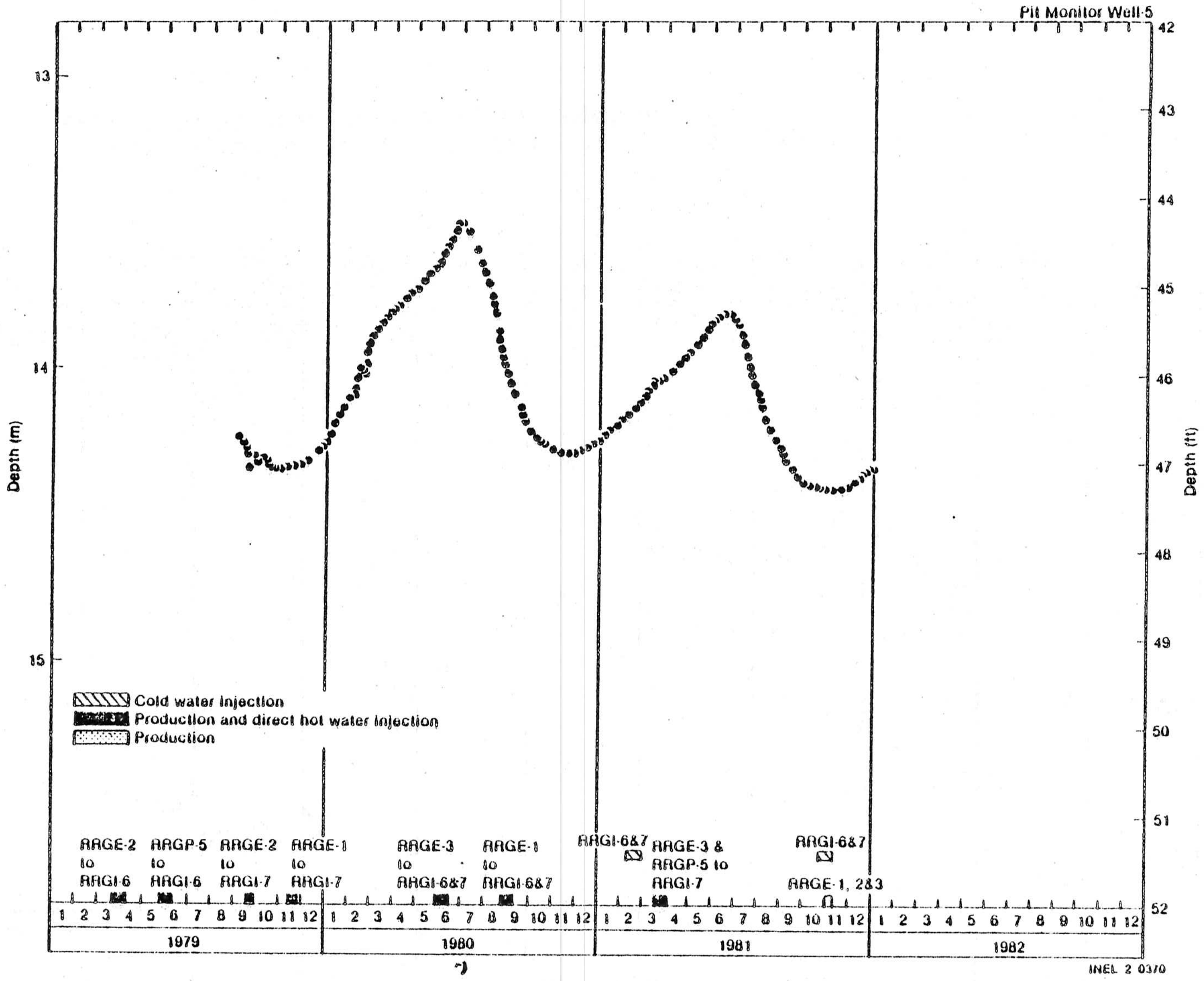

Figure A-14. PW-5 long-term hydrograph. Casing is slotted from 17 m to the bottom-hole depth of 26 m.

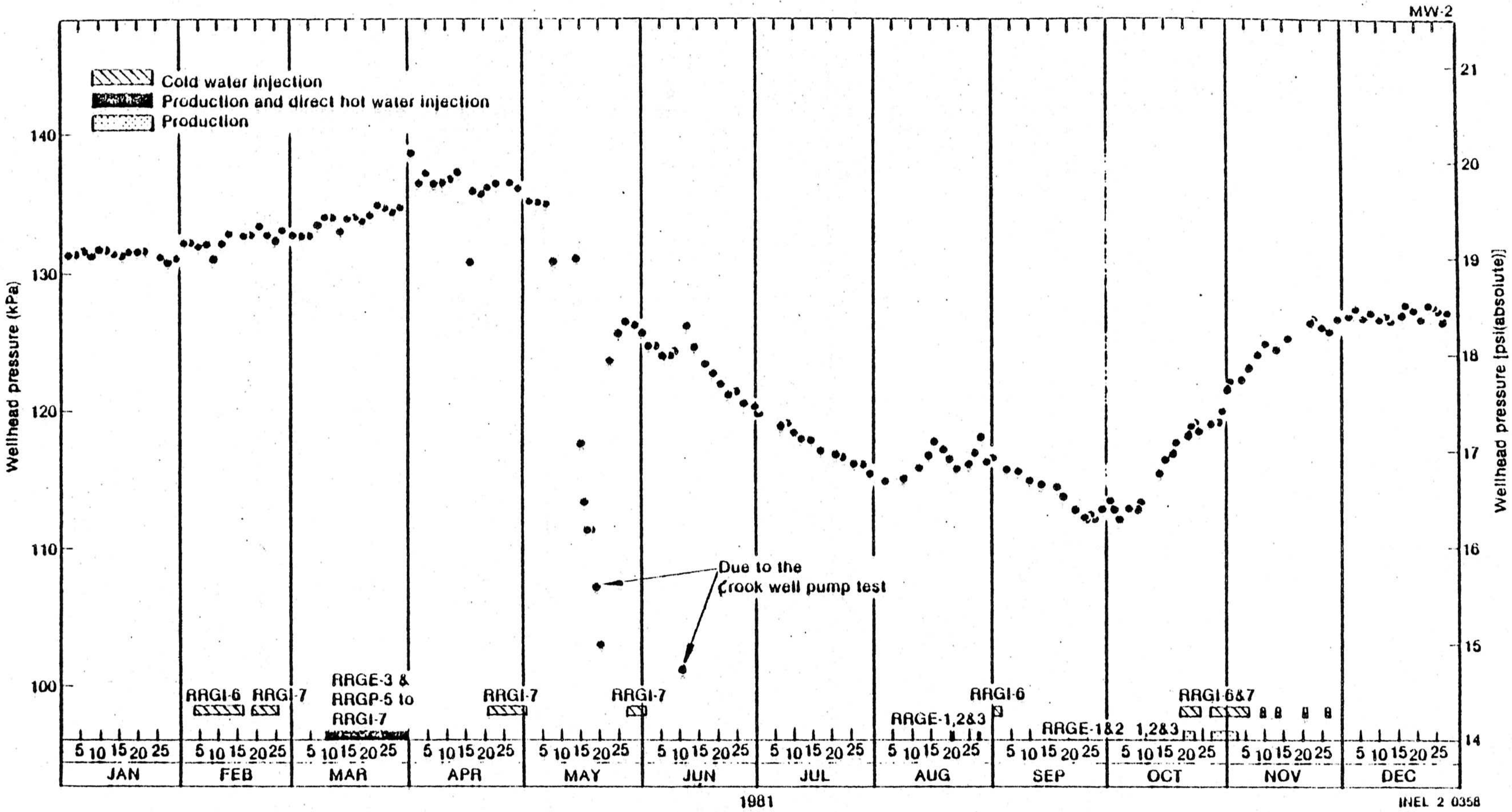

Figure A-15. MW-2 hydrograph for 1981. Casing is slotted from 154 m to 166 m. The well is not cased from 166 m to the bottom-hole depth of 174 m.

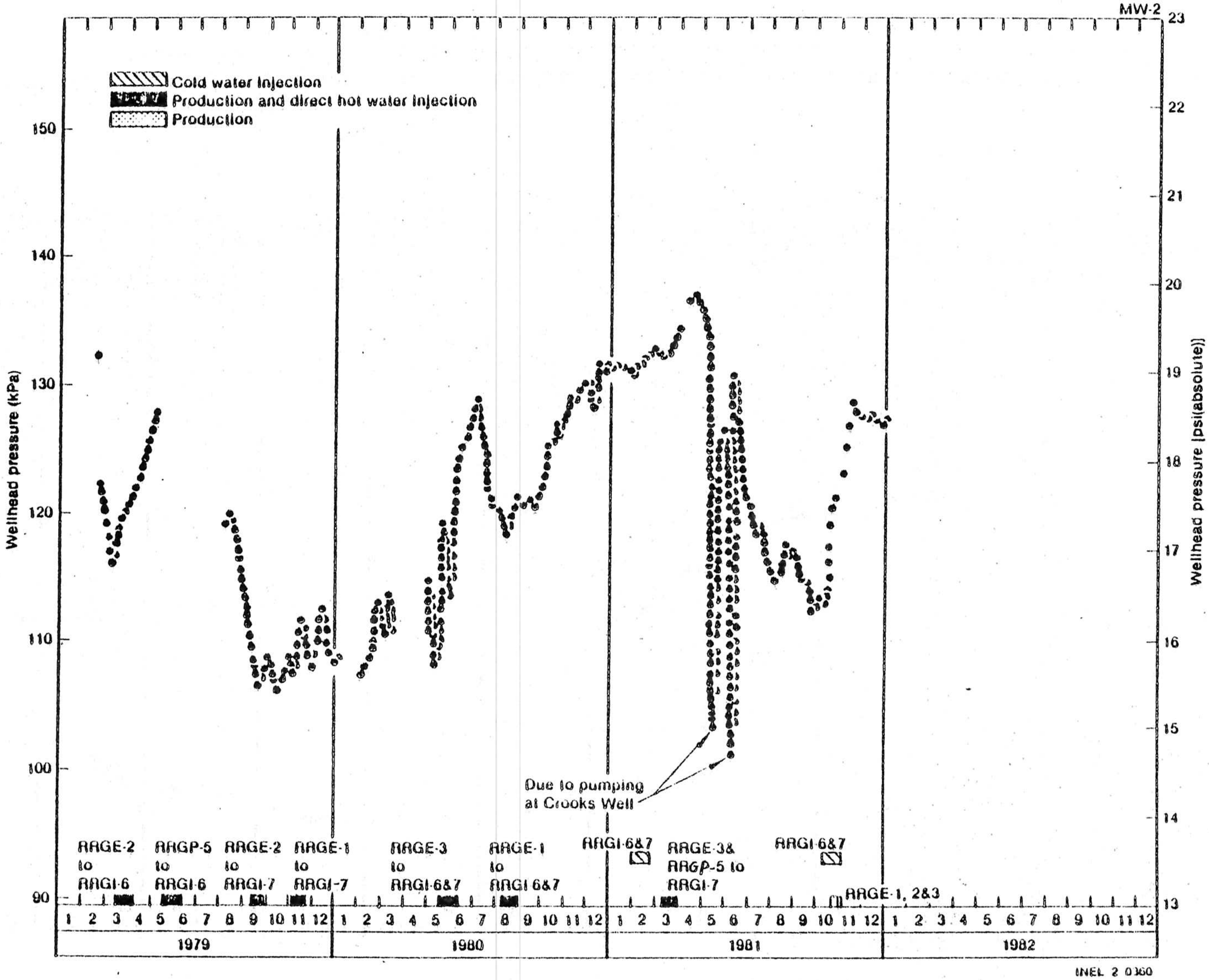

Figure A-16. MW-2 long-term hydrograph. Casing is slotted from 154 m to 166 m. The well is not cased from 166 m to the bottom-hole depth of 174 m.

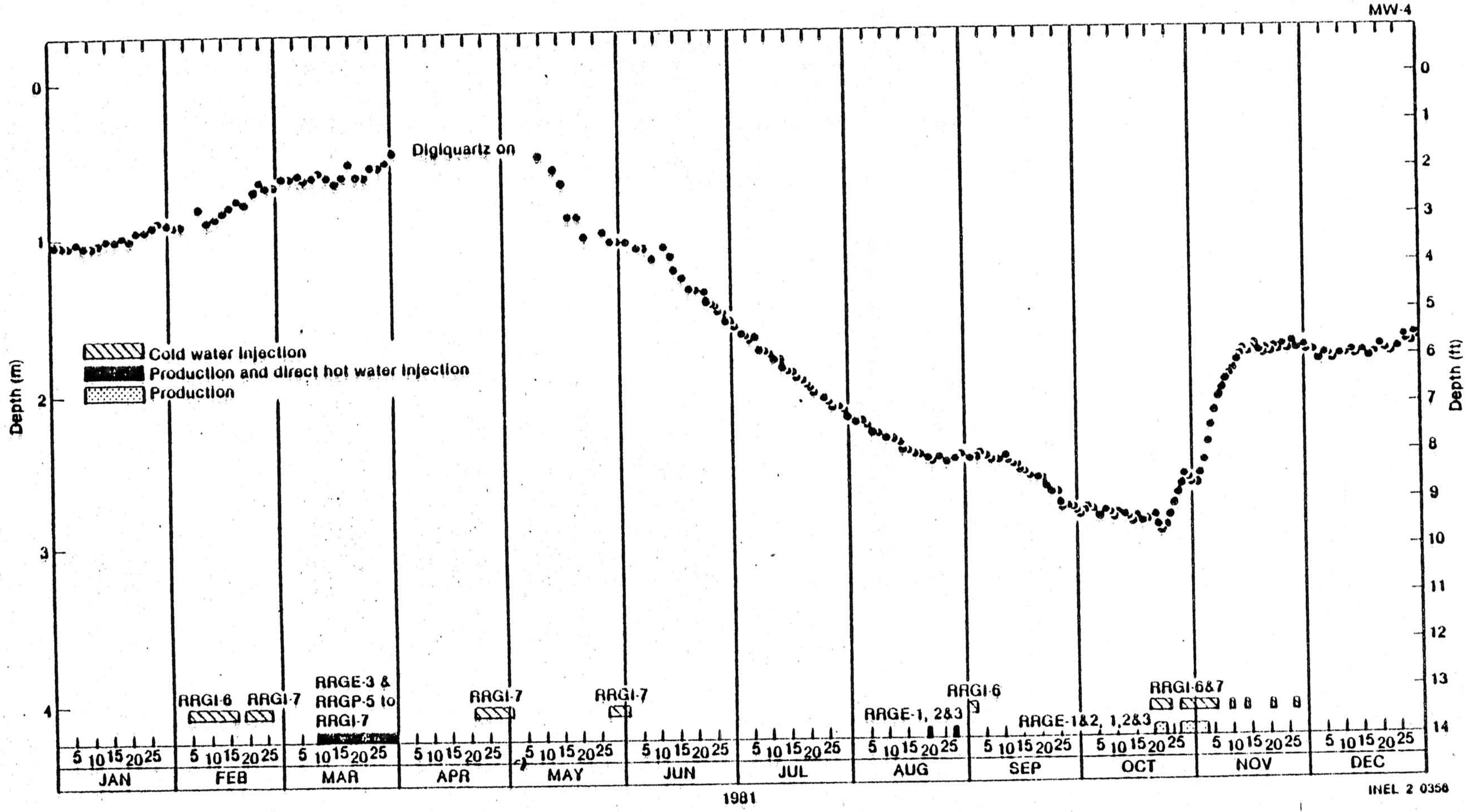

Figure A-17. MW-4 hydrograph for 1981. Casing is slotted from 171 m to 254 m. The well is not cased from 254 m to the bottom-hole depth of 305 m.

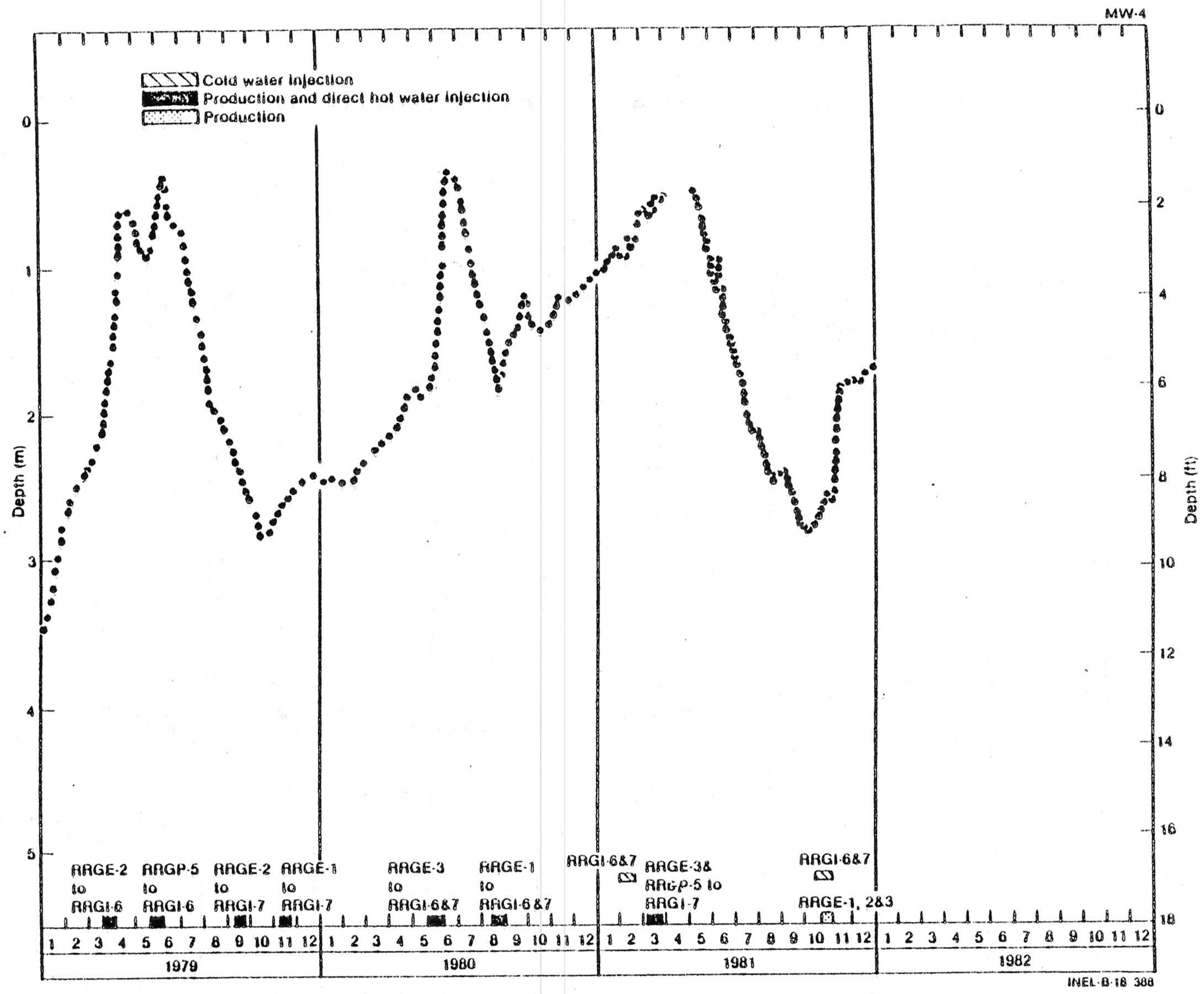

Figure A-18. MW-4 long-term hydrograph. Casing is slotted from 171 m to 254 m. The well is not cased from 254 m to the bottom-hole depth of 305 m.

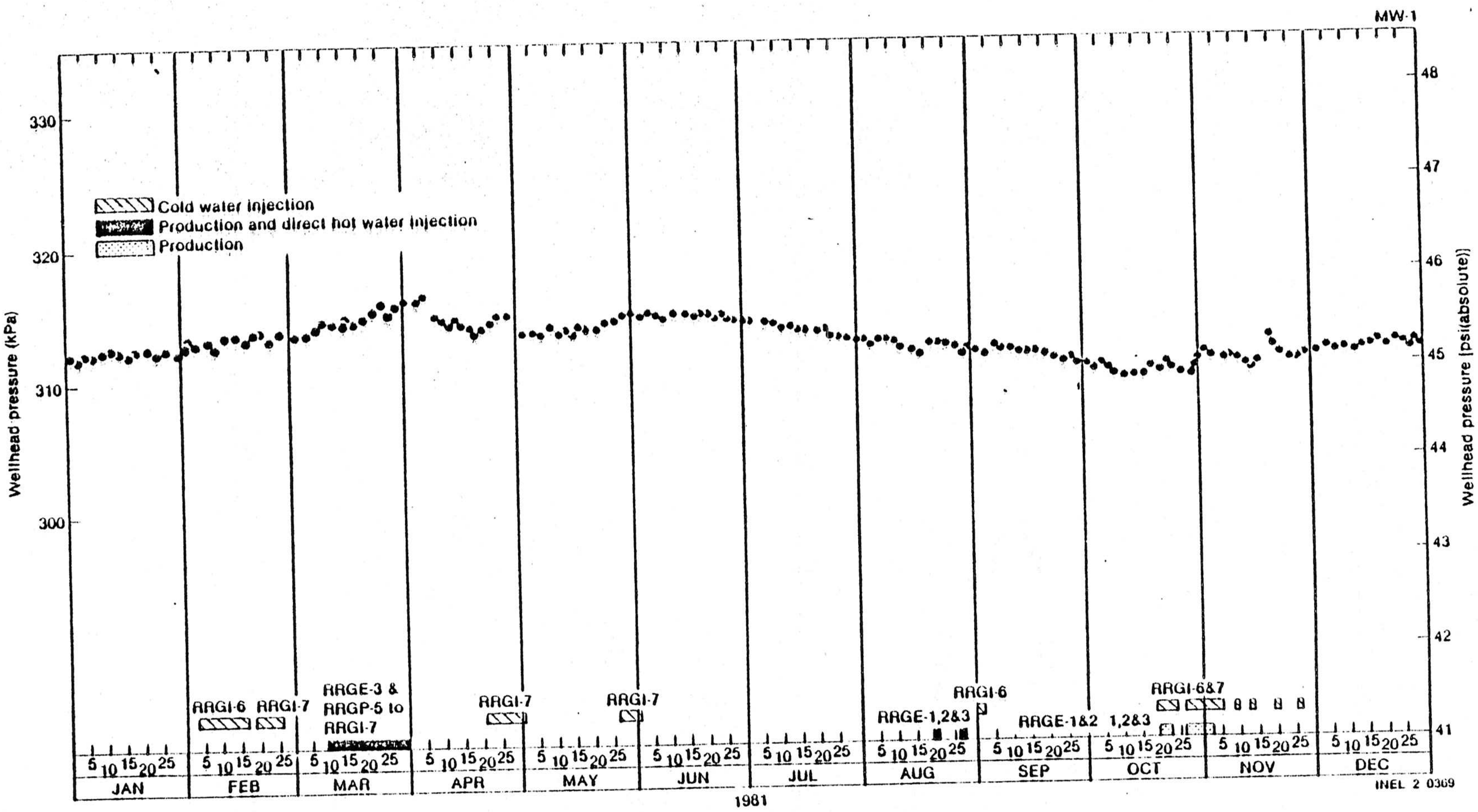

Figure A-19. MW-1 hydrograph for 1981. The well is not cased from 369 m to 399 m.

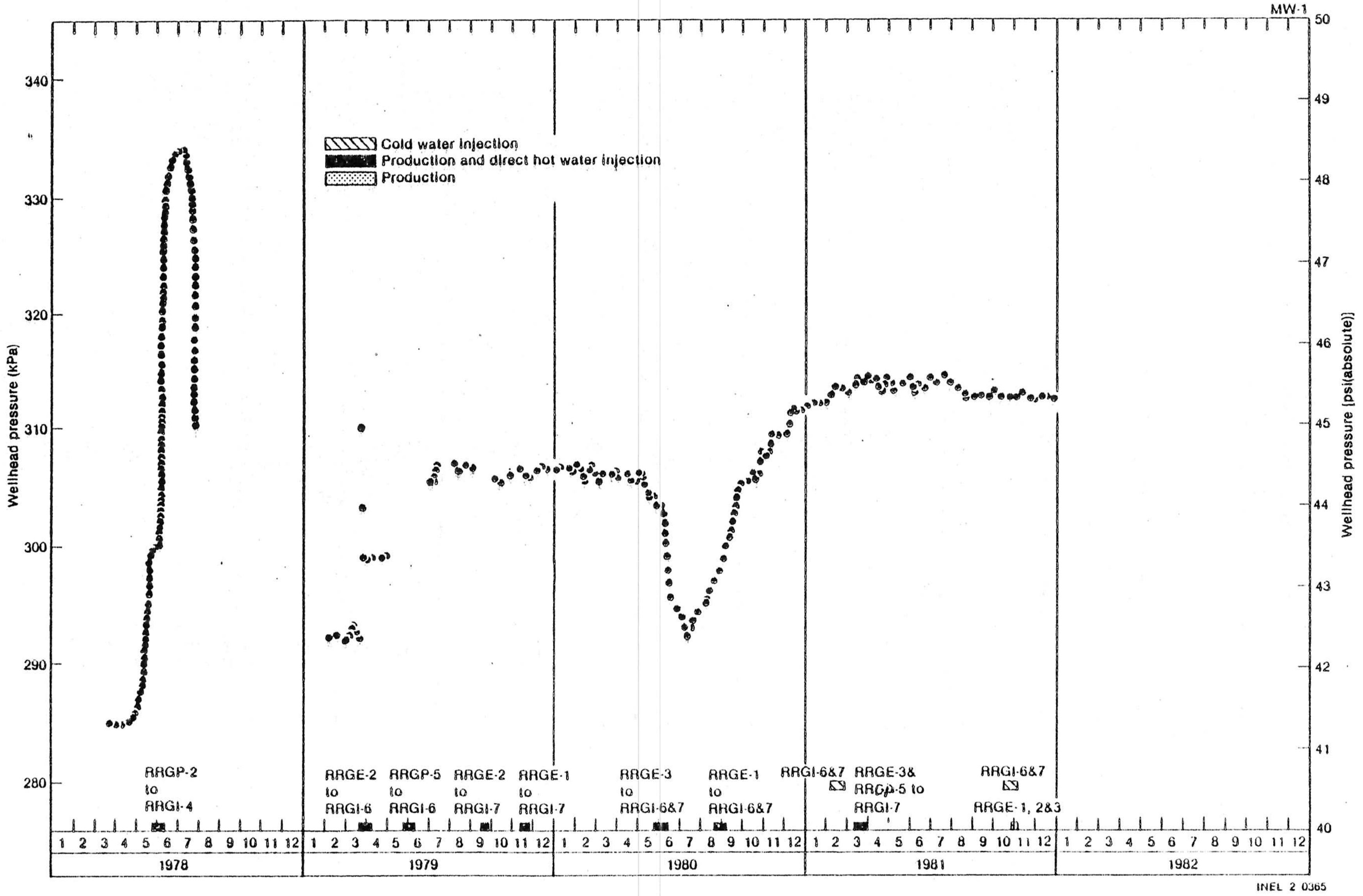

Figure A-20. MW-1 long-term hydrograph. The well is not cased from 369 to 399 m.

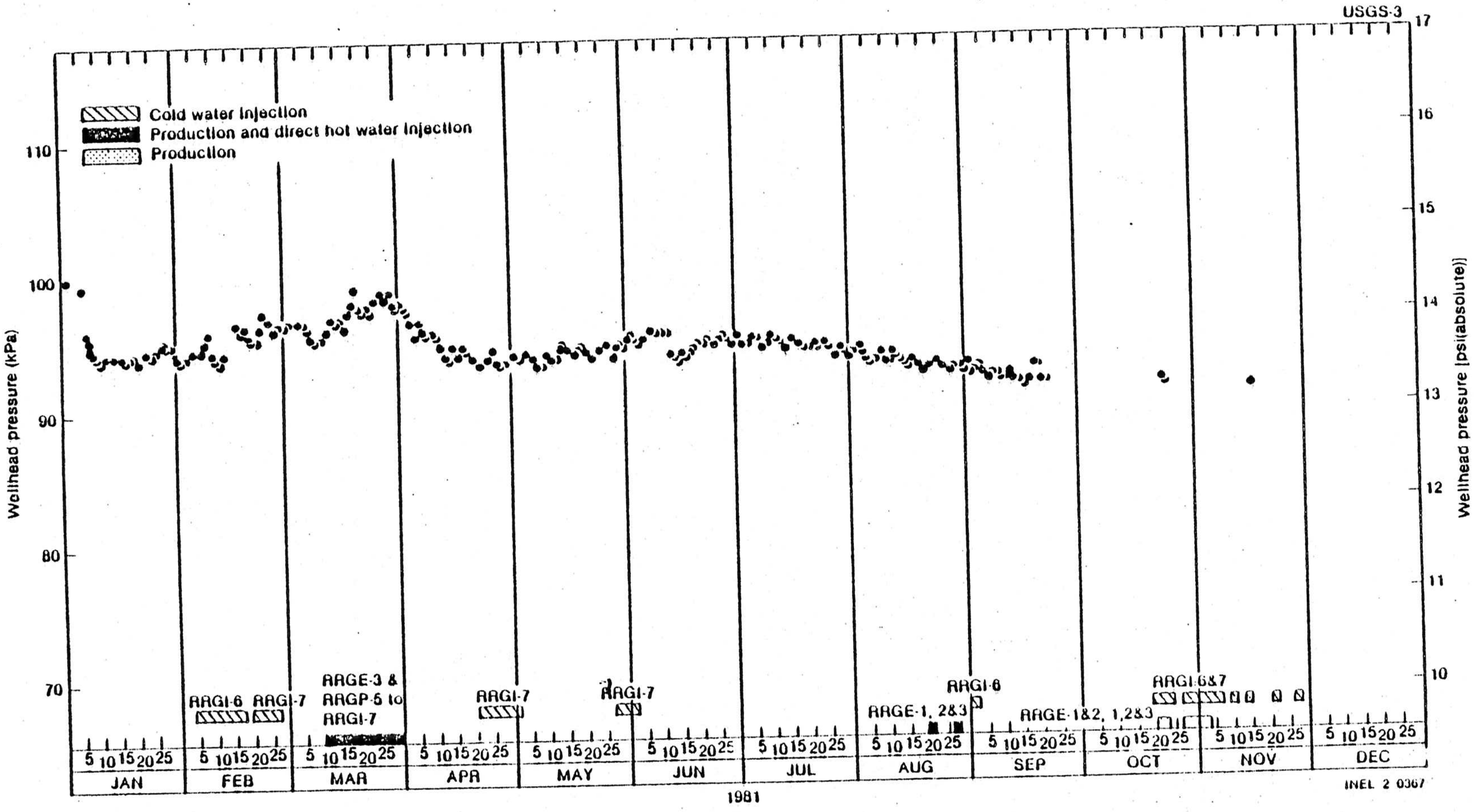

Figure A-21. USGS-3 hydrograph for 1981. The well is not cased from 60 m to 434 m.

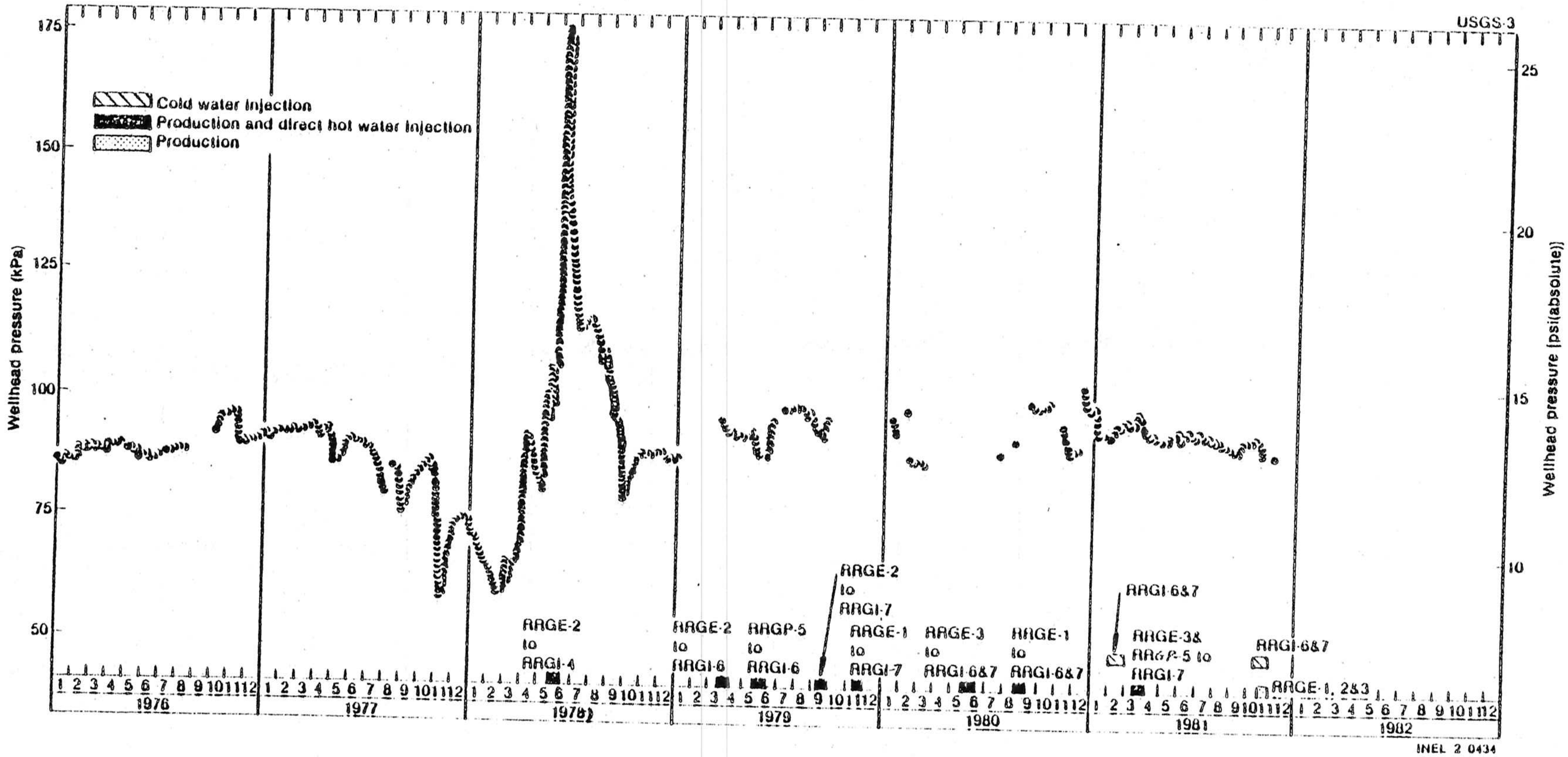

Figure A-22. USGS-3 long-term hydrograph. The well is not cased from 60 m to 434 m.

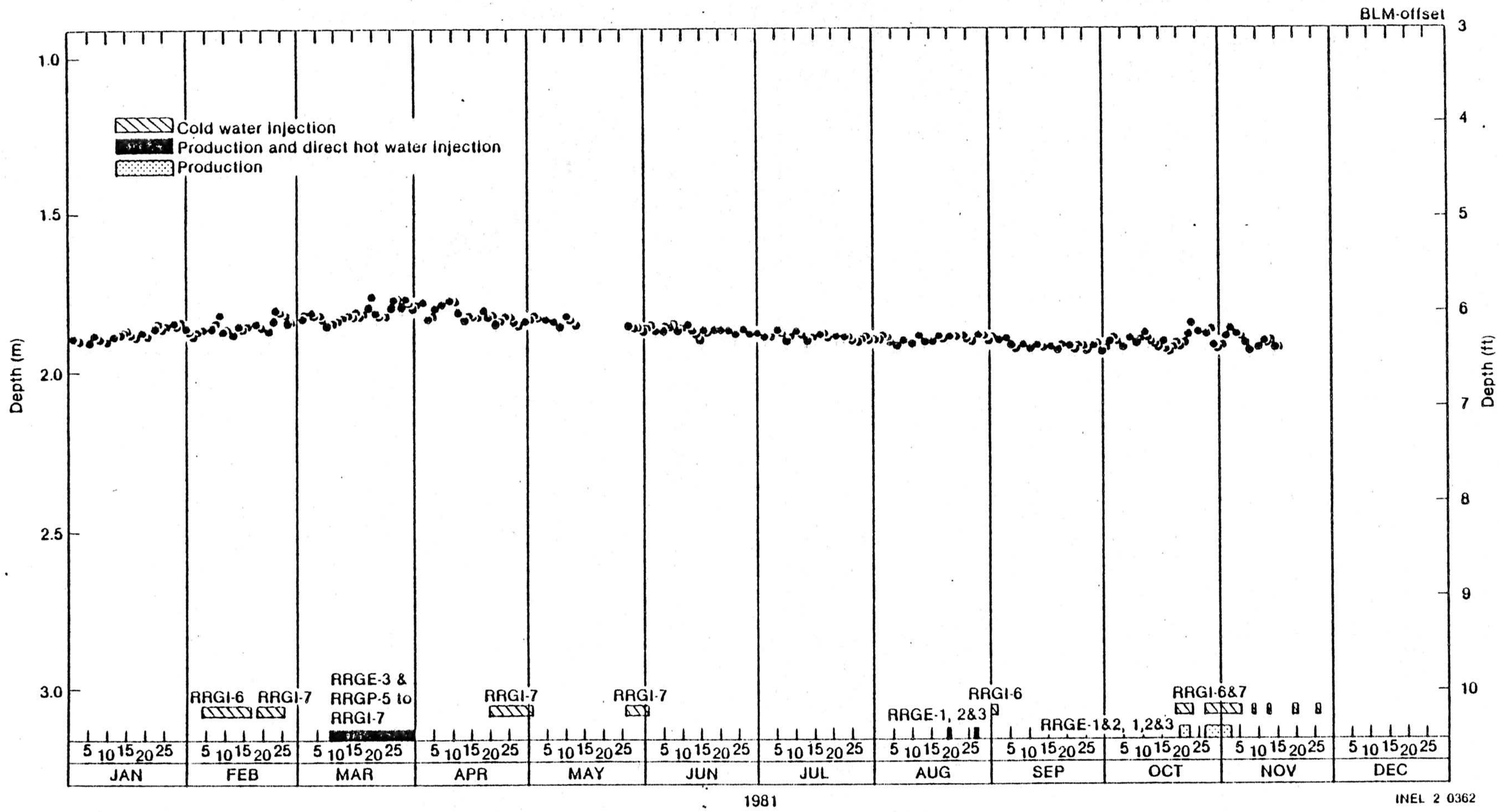

Figure A-23. BLM-offset well hydrograph for 1981. The well depth is 98 m. Casing information is not available.

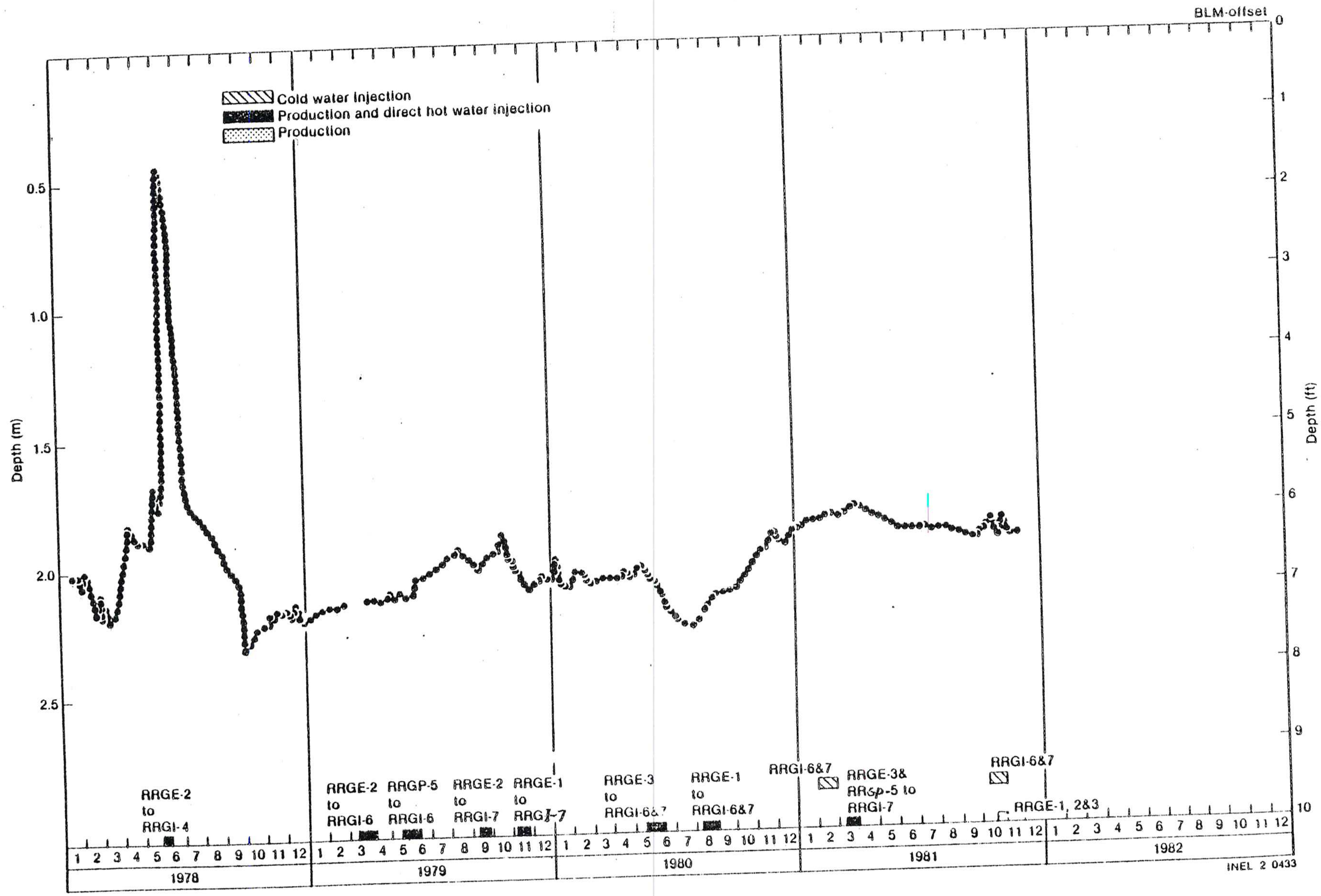

Figure A-24. BLM-offset well long-term hydrograph. The well depth is 98 m. Casing information is not available.