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DEC 12 1979

C. A. ALLEN, Branch Manager
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PRELIMINARY DRAFT

SUMMARY

RAFT RIVER GROUNDWATER AND GEOTHERMAL COMPUTER MODEL

THE JOB

The job required utilizing an existing two-dimensional computer program to model quasi-transients of mass transport (mixing only), temperature, and hydraulic head in a vertical cross-section of the Raft River Geothermal Area. The results were contour plots of temperature, pressure, and concentration for multiple runs using different model designs and input parameters projected to 1, 5, 10, 30, 50 and 100 years. The computer work was satisfactorily performed by Intera Environmental Consultants of Houston, Texas.

INITIAL INPUT DATA

The original data package given to Intera is shown in Appendix A. The cross section was placed on a line across the resource area shown as $A\text{-}A^1$ on the map in Figure 1. Two deep geothermal injection wells were projected on this line (RRGI-4 and RRGI-6), as well as several intermediate and shallow wells. The depths and open hole portions of each well were graphically illustrated on a two-dimensional cross section of the area.

Temperature contours were made on the cross section from temperature log control points. These control points are somewhat sparce. Bottom hole temperatures were used from the monitor wells, while shut-in temperature logs were used from RRGP-1 and RRGI-7 and projected onto the plan view.

The original hydraulic conductivities given were taken from a variety of sources as well as interpolated from various non-quantitive indicators. The value for zone 1 is from a transmissivity calculated by equations for

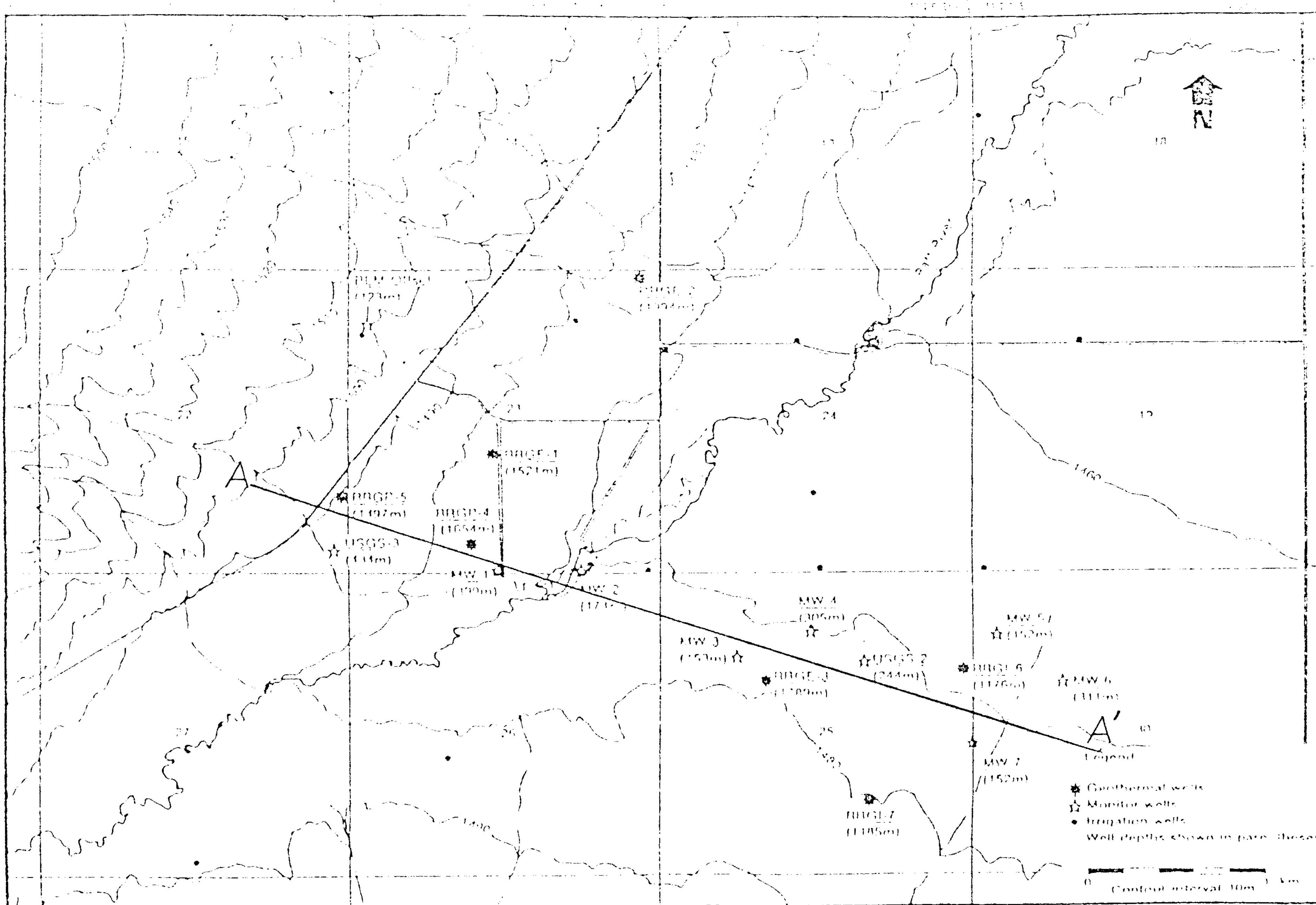

FIGURE 1

RAFT RIVER GEOTHERMAL AND MONITOR WELLS
WITH MODEL CROSS SECTION A-A[1]

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a leaky aquifer from pump test "A" in Morrilla and Ralston (1975). Zone 2 is given a low hydraulic conductivity due to the apparent confining nature of this aquitard. Slug tests conducted on two 300 meter monitor wells by Don Callan and Julie Martinez of EG&G Idaho, led to calculations for hydraulic conductivity that were consistent with the value interpolated for that zone. The value for zone 3 was calculated from the results of an injection test at RRGI-6. The use of this data for zone 3 is based on the concept that most of the injected fluid at RRGI-6 enters the formation within 150 feet of the casing terminus, as evidenced by flowmeter logs run during injection.

Zones 4 and 5 were given hydraulic conductivities that seem consistent with injectibility and response patterns seen in observation wells. Zone 6 was added later to simulate the strong response of MW-4 to injection at RRGI-6, and was given the same transmissive value as Zone 5.

The thicknesses of the zones were based on lithology logs, flowmeter logs, and driller's logs. The contacts are certainly gradational, and the nature of the aquifer formation is lensy, with interfingering facies. The contacts are shown as horizontal and uniform for simplicity, but do not represent the true case. This slight discrepancy is not considered significant to the results.

Four types of water quality are shown for the area, based primarily on total dissolved solids. The contours are based on scattered, relatively sparce control points, modified to follow temperature contours somewhat. The water chemistry control points were determined by samples from all of the geothermal and monitor wells representing a deep, and an intermediate zone (Allen, 1979).

The piezometric surface was sketched from current well head pressures and depths to water, however, these values are questionable due to the erratic effects of irrigation pumping. This contour was later modified to fit the apparent thermal cycle.

Porosity for the various zones was assumed to be 15% for zones 1 and 3; 5% for zone 2, and 10% for zone 4.

MODIFICATIONS

Following the initial computer runs, the results were evaluated.

Test runs were made using different input values to determine the sensitivity of the model.

It was decided that the hydraulics around RRGI-4 and RRGI-6 could be verified by duplicating actual pump tests with the model and comparing results.

The results of this comparison indicated that the addition of a zone 6 was necessary. This zone has the same hydraulic conductivity as zone 5, and provides the conduit for communication between MW-4 and RRGI-6. It was determined, however, that the vertical to horizontal conductivity ratio in different zones required modification. A Kv to Kh ratio of 1:1 for zone 5, 1:40 for zone 6, and 1:400 for all other zones provides the best fit for duplication of pump test results.

It was determined that four new cases to be run would provide maximum information on the behavior of the system. These new cases are as follows:

Case A: Zones 1-6 present Kv:Kh = 1:10 for zones 1-4, 1:1 for zone 5, 1:40 for zone 6. Injection at RRGI-4 and RRGI-6 at 1200 gpm, 2000 ppm, 140^{O}F. I, and I_Z pumping at 200 gpm.

Case B: Same as above, with Kv:Kh at 1:400 for zones 1-4.

Case C: Same as case B, with only RRGI-6 as injection well.

Case D: Same as case C with the addition of a zone 7, that extends zones 5 and 6 to zone 1.

Following presentation of all of the results to EG&G, a consultation with the environmental officer and hydrogeologists, lead to the addition of other cases. These cases were:

Case E: 2200 gpm injected into RRGI-6, with all other conditions the same as Case B.

Case F: The addition of a theoretical well (RRGI-9) between zones 5 and 6. This well is open to formation throughout zone 3. 400 gpm injected into RRGI-9 and 1800 gpm injected into RRGI-6. All other conditions the same as Case B.

Case G: The lower boundary of zone 2 is brought up to 800 feet and zones 5 and 6 are extended to 600 feet. 2200 gpm is injected into RRGI-6. All other conditions as above.

An excess of funds for the project led to addition of the following runs: the first two to continue assessment of environmental impact, and the last to perhaps determine groundwater hydraulics.

Case P: Inject 2200 gpm into RRGI-9 that is open throughout zone 3. Zone 7 is present. All else the same as Case B.

Case Q: As above without zone 7.

Case R: Eliminate zone 6 and truncate zone 2 at location I-1. Inject 400 gpm into RRGI-4 and 1800 gpm into RRGI-6.

Case S: Inject 2200 gpm in RRGI-9. Observation well 0-1 near RRGI-4 has a total depth of 4400 feet and is open from 4000 to 4400 feet. All else as in Case B.

THE INTERA MODEL

The model consists of systems of finite-difference numerical expressions of the partial differential equations describing

1. single phase flow in the aquifers
2. energy transport by convection and conduction

3. compositional changes in the aquifer fluid.

The model can be used for numerical simulation of

1. waste disposal operations
2. fresh water storage in saline aquifers
3. hot water storage in underground aquifers
4. salt water intrusion into the groundwater system
5. interpretation of the aquifer and tracer test results, and other hydrology-related problems.

The physical system that we are studying should satisfy:

1. conservation of total liquid mass
2. conservation of energy
3. conservation of the mass of a specific contaminant dissolved in the injection and/or resident fluid.

The assumptions of the INTERA model;

1. 3-D transient, flow can be described by Darcy's law
2. $\rho=\rho(P, T, C)$

   $\mu = (T, C)$
3. Aquifer properties (like porosity, permeability, aquifer thickness and elevation) can be specified for each block in the model.
4. Hydrodynamic dispersion tensor is described as a linear function of fluid velocity.
5. $\rho = \rho_0 \quad \frac{\partial \rho}{\partial c}_{c = o} \quad C + \left.\frac{\partial \rho}{\partial T}\right|_{T_0} (T-T_0) + \left.\frac{\partial \rho}{\partial P}\right|_{P = P_0} (P-P_0)$
6. The energy equation can be described as "enthalpy in - enthalpy out = change in internal energy in the system." The kinetic and potential energy term are ignored.

The parameters used include a thermal conductivity of 30 m/btu, and a thermal expansion factor of $2.26 \times 10^{-4}/^{o}F$. A dispersivity factor is a second-order correct method that characterizes transport heterogeniety and is related to grid-block size. The longitudinal vector of this parameter is 600 feet, and the transverse is 200 feet. The rock compressibility used was 4×10^{-6}/psi; a common value for poorly consolidated sediments.

Density and viscosity are considered to be functions of temperature only. 30 x 14 grid blocks were used.

Free surface is unimportant and the side boundaries of the model are considered hydrostatic.

RESULTS

Table 1 shows generalized maximum concentrations and temperatures for each case at land surface. Cases H through O correspond to Cases 1 through 8 of the original data input.

Case B represents the best characteristics for matching pump test data, and the highest confidence is in those results.

All cases which include zone 7 represent "worst case" examples.

The model seems to be insensitive to alteration in thickness of zone 2, and most other variables except the addition of zone 7.

Appendix B shows results of original runs before modification.

SUMMARY OF RESULTS

Case	Zones	K	Injection	T_{1max}	C_{1max}
A	I, II, III, IV, V, VI	$K_H = 10*K_V$	RRGI-4 (1200 gpm) RRGI-6 (1200 gpm)	163°F (100 yrs)	3805 ppm (50 yrs)
B	I, II, III, IV, V, VI	$K_H = 400*K_V$	RRGI-4 (1200 gpm) RRGI-6 (1200 gpm)	148°F (50 yrs)	2619 ppm (100 yrs)
C	I, II, III, IV, V, VI	"	RRGI-6 (1200 gpm)	145°F (50 yrs)	2196 ppm (100 yrs)
D	I, II, III, IV, V, VI, VII	"	RRGI-6 (1200 gpm)	184°F (100 yrs)	6117 ppm (50 yrs)
E	I, II, III, IV, V, VI	"	RRGI-6 (2200 gpm)	147°F (50 yrs)	2673 ppm (100 yrs)
F	I, II, III, IV, V, VI	"	RRGI-6 (1800 gpm) RRGI-9 (400 gpm)	147°F (50 yrs)	2641 ppm (100 yrs)
G	I, II, III, IV, V, VI	"	RRGI-6 (2200 gpm)	145°F (50 yrs)	2567 ppm (100 yrs)

$K_V = K_H$ (V) (See attached figure.)

$K_H = 40*K_V$ (VI)

$\Theta = 0.15$ (I and III)

$\Theta = 0.05$ (II)

$\Theta = 0.10$ (IV)

Injection 2000 ppm, 140°F

$K_H(V) = 3.12$ ft/day

TABLE 1

intera

SUMMARY OF RESULTS (Continued)

	Case	Zones	K	Injection	T_{1max}	C_{1max}
(1)	H	I, II, III, IV	$K_H = K_V$	RRGI-4 (1000 gpm) RRGI-6 (1000 gpm) (No pumping)	176°F (100 yrs)	4429 ppm (30 yrs)
(3)	I	I, II, III, IV	$K_H = K_V$	RRGI-4 (1000 gpm) RRGI-6 (1000 gpm) (With pumping)	181°F (100 yrs)	4587 ppm (30 yrs)
(4)	J	I, II, III, IV	$K_H = 10*K_V$	RRGI-4 (1000 gpm) RRGI-6 (1000 gpm) (With pumping)	175°F (50 yrs)	4362 ppm (30 yrs)
(2)	K	I, II, III, IV	$K_H = 10*K_V$	RRGI-4 (1000 gpm) RRGI-6 (1000 gpm) (Without pumping)	169°F (50 yrs)	4149 ppm (30 yrs)
(5)	L	I, II, III, IV, V	$K_H = K_V$	RRGI-4 (1000 gpm) RRGI-6 (1000 gpm) (Without pumping)	176°F (100 yrs)	4465 ppm (30 yrs)
(7)	M	I, II, III, IV, V	$K_H = K_V$	RRGI-4 (1000 gpm) RRGI-6 (1000 gpm) (With pumping)	178°F (100 yrs)	4632 ppm (30 yrs)
(6)	N	I, II, III, IV, V	$K_H = 10*K_V$	"	175°F (100 yrs)	4396 ppm (30 yrs)
(8)	O	I, II, III, IV, V	$K_H = 10*K_V$ (K(V) = 0.1*Original)	"	175°F (100 yrs)	4260 ppm (30 yrs)

K(V) = 0.312 ft/day
(See attached figure.)

TABLE 1 (continued)

APPENDIX A
INPUT DATA

The job requires utilizing existing two-dimensional computer programs to model quasi-transients of mass transport (mixing only), temperature, and hydraulic head in a vertical cross-section of the Raft River Geothermal Area in Idaho. The model must account for radial type flow from pumping/injection wells so as not to distort flow paths. It is desired to have multiple runs utilizing different model designs and/or input parameters. The results should be contour plots of chemical species, temperature, and hydraulic head with the initial input data and projections after 1, 5, 10, 30, 50, and 100 years. No interpretation of the data or output is necessary.

The basic model showing all five of the optional zones is described in Figure 1. Note that the "horizontal discontinuity" in zone 4 represents a 1100-ft gap in depth. This is only for ease of presentation. The model should be continuous.

The wells shown are our control points. The hatched portion of a well is that part which is open to the formation. The distance between wells is shown at the top of Figure 1. The thickness of each zone can be determined by the scale on the left. The initial parameters of initial water quality, temperature, and hydraulic head are found in Figure 2 and Table I, Figure 3, and Figure 4, respectively. The additional input parameters, such as hydraulic conductivities and pump/injection rates, are given in Table II.

It is desired to run several cases as described in Table III.

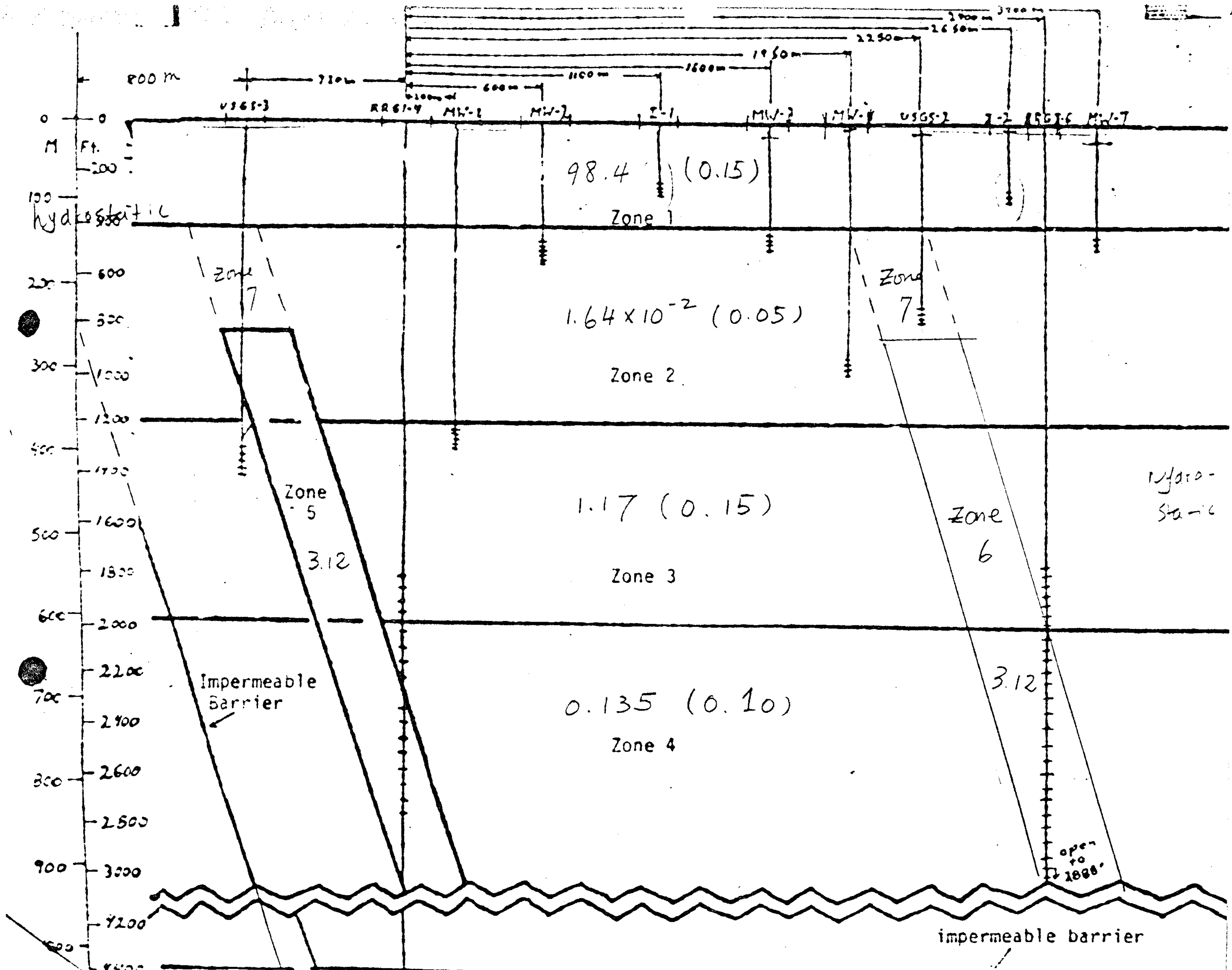

Figure 1 Permeable Zones

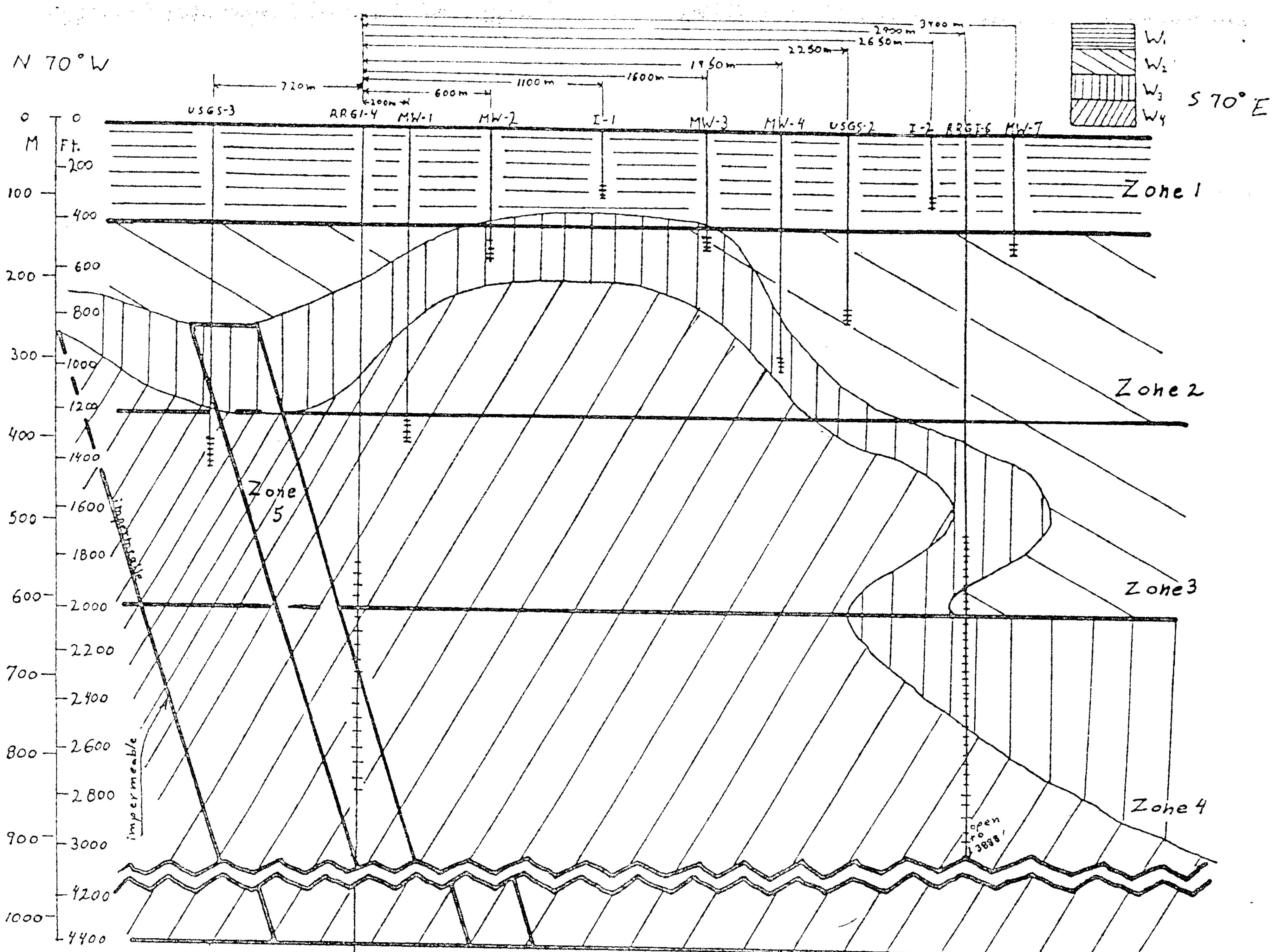

Figure 2 Water Quality

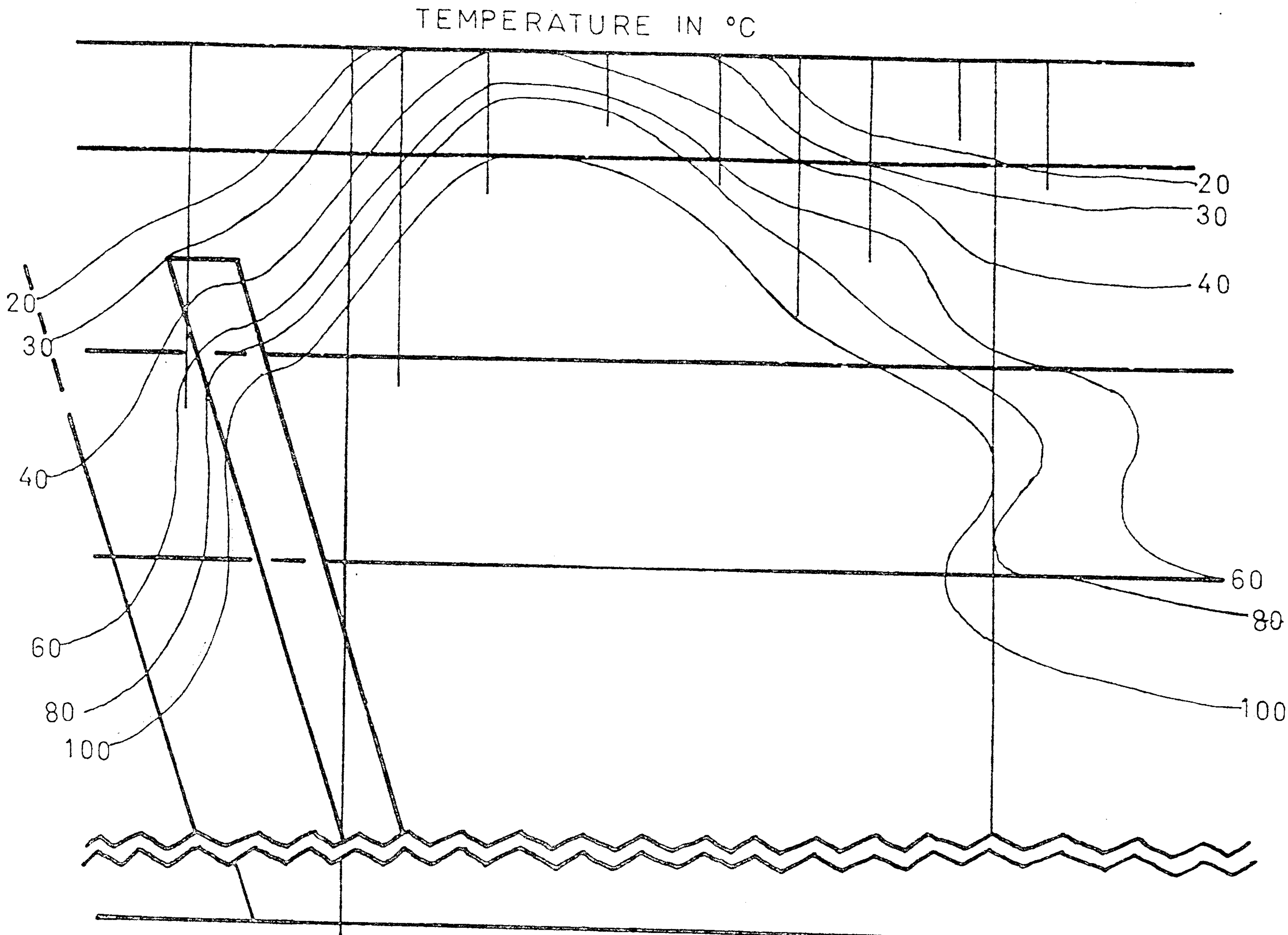

Figure 3

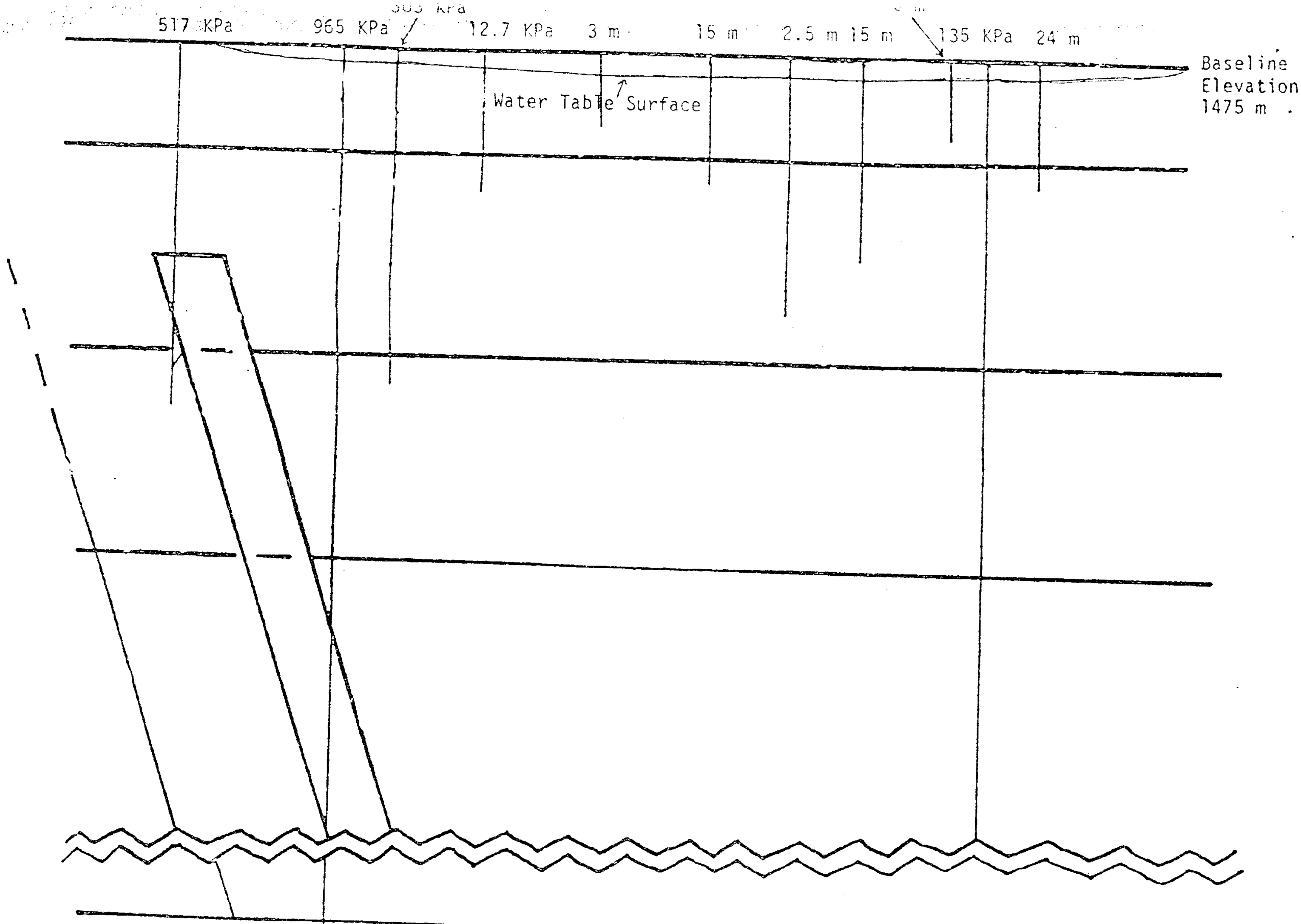

Figure 4 Depth to Water or Wellhead Pressure

TABLE I

Piezometric Surface

Well	DTW	WHP	Well	DTW	WHP
MW-4	2.5 m		RRGI-4		965 KPa
MW-3	15 m		MW-7	24 m	
MW-1		303 KPa	I-2	6 m	
MW-2		127 KPa	USGS-2	15 m	
I-1	3 m		USGS-3		517 KPa
			RRGI-6		135 KPa

Water Quality: (ppm)

	Cl	F	Na	Ca	K	Sr	TDS
W_1	267	0.43	200	75	8	0.45	1180
W_2	551	6.37	682	93.9	54	3.10	2322
W_3	2150	5.34	1323	150	34	1.95	4208
W_4	7306	4.3	2145	205	30	7.5	6460

TABLE II

Horizontal Hydraulic Conductivity:	
Zone 1	3.47×10^{-4} m/s
Zone 2	5.79×10^{-8} m/s
Zone 3	4.13×10^{-6} m/s
Zone 4	4.78×10^{-7} m/s
Zone 5	1.10×10^{-6} m/s
Injection Rate:	
Q_I	63.1 l/s (1000 gpm) per well
Production Rate:	
Q_P	12.6 l/s (200 gpm) from each well
Injection Temperature:	
140°F (60°C)	
Injection Wells:	
RRGI-4	
RRGI-6	
Production Wells:	
I_1	
I_2	

TABLE III

Case	Zones	Injection/Pumping	Hydraulic Conductivity
1	1,2,3,4	Injection only	Horizontal = Vertical
2	1,2,3,4	Injection only	Horizontal = 10 x Vertical
3	1,2,3,4	Injection & Pumping	Horizontal = Vertical
4	1,2,3,4	Injection & Pumping	Horizontal = 10 x Vertical
5	1,2,3,4,5	Injection only	Horizontal = Vertical
6	1,2,3,4,5*	Injection only	Horizontal = 10 x Vertical
7	1,2,3,4,5	Injection & Pumping	Horizontal = Vertical
8	1,2,3,4,5	Injection & Pumping	Horizontal = 10 x Vertical
9	1,2,3,4,5*a)	Injection only	Horizontal = 10 x Vertical
10	1,2,3,4,5*a)	Injection & Pumping	Horizontal = 10 x Vertical
11	1,2,3,4,5*b)	Injection only	Horizontal = 10 x Vertical
12	1,2,3,4,5*c)	Injection & Pumping	Horizontal = 10 x Vertical
13	1,2,3,4,5*d)	Injection only	Horizontal = 10 x Vertical
14	1,2,3,4,5*e)	Injection & Pumping	Horizontal = 10 x Vertical

5* Zone 5 always has horizontal = vertical permeability.

a) Remove the impermeability boundary in lower left portion and extend to infinity (no boundaries).

b) Increase permeability in Zone 3 by 10X from original.

c) Decrease permeability in Zone 3 by 10X from original.

d) Increase permeability in Zone 5 by 10X from original.

e) Decrease permeability in Zone 5 by 10X from original.

SUMMARY OF RESULTS

CASE	T_{MAX} (AT ZONE 1)		C_{MAX} (AT ZONE 1)		T_P, C_P (I1) 100 YRS	T_P, C_P (I2) 100 YRS
1	176°F	(100 YRS)	4429 PPM	(30 YRS)	N/A	N/A
2	169°F	(50 YRS)	4149	(30 YRS)	N/A	N/A
3	181°F	(100 YRS)	4587	(30 YRS)	172°F, 3600 PPM	117°F, 2000 PPM
4	175°F	(100 YRS)	4362	(30 YRS)	163°F, 3500 PPM	98°F, 1900 PPM
5	176°F	(100 YRS)	4465	(30 YRS)	N/A	N/A
6	169°F	(100 YRS)	4196	(30 YRS)	N/A	N/A
7	178°F	(100 YRS)	4632	(30 YRS)	173°F, 3500 PPM	120°F, 1900 PPM
8	175°F	(100 YRS)	4396	(30 YRS)	163°F, 3600 PPM	98°F, 1900 PPM
11	166°F	(50 YRS)	3858	(30 YRS)	N/A	N/A
12	175°F	(100 YRS)	4496	(50 YRS)	161°F, 4100 PPM	96°F, 2300 PPM
13	170°F	(100 YRS)	4389	(30 YRS)	N/A	N/A
14	175°F	(100 YRS)	4260	(30 YRS)	163°F, 3400 PPM	98°F, 1900 PPM

$T_{INITIAL} = 100°F$, $C_{INITIAL} = 1180$ PPM

APPENDIX B

INITIAL RESULTS BEFORE MODIFICATION