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EVALUATION OF IRRIGATION MANAGEMENT PROCEDURES FOR GEOTHERMAL EFFLUENT

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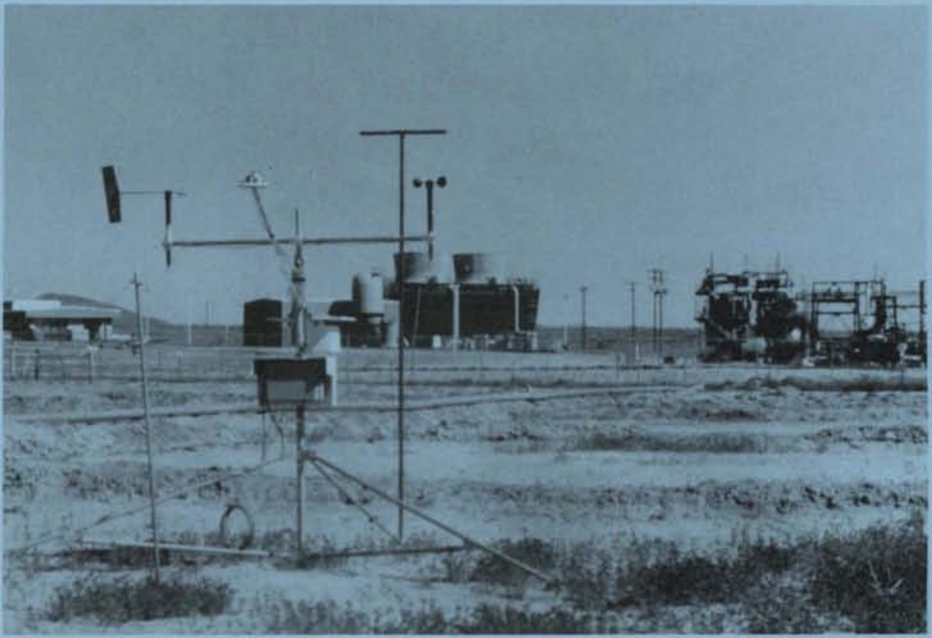

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by

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ABSTRACT

An investigation was conducted to determine the feasibility of geothermal power plant effluent disposal by surface irrigation and the resulting impact on the shallow aquifer. The study was conducted at the Raft River Experimental Geothermal Power Plant site near Malta, Idaho and at the Snake River Conservation Research Center with soils and effluent obtained from the geothermal power plant site. The conclusions of the investigation were:

1. Salinity hazard to the shallow aquifer is minimized by high-rate irrigation of previously irrigated lands due to the high amounts of soluble salts found in the native soils.
2. Irrigation disposal of effluent will cause little if any fluoride contamination of the shallow aquifer.
3. The irrigation method best suited for disposal is surface irrigation with borders. The irrigation system will experience problems with cold weather operation. Crop emérgence will be hindered by border irrigation.
4. Recommended cropping systems on disposal lands are grain and forage crops, providing the portion harvested did not have contact with the effluent.
5. Two mechanisms in the soil were apparently removing fluoride from the effluent. One mechanism was identified (fluorite precipitation) and one was not. Further study is needed to determine the other mechanism.

EVALUATION OF IRRIGATION MANAGEMENT PROCEDURES FOR GEOTHERMAL EFFLUENT

INTRODUCTION

The purpose of this investigation was to determine the feasibility of utilizing surface irrigation for disposal of geothermal power plant effluent and the potential impact on the shallow ground-water system. The impact was evaluated with regard to the current aquifer uses for irrigation, domestic, and livestock supplies. The following four disposal schemes were considered as alternatives to deep well injection into the geothermal system:

1) injection into the shallow ground-water system,
2) year-around irrigation of alfalfa on land not previously irrigated,
3) year-around irrigation of alfalfa on land previously irrigated, and
4) year-around irrigation of range land.

Field studies were conducted at the Raft River Experimental Geothermal Power Plant (RGP) located at the south end of the Raft River valley near the Idaho-Utah border (figure 1). Greenhouse studies were conducted at Kimberly, Idaho using soils and geothermal waters obtained from the RGP site.

CLIMATE AND SOILS

The Raft River valley is bounded by the Sublett and Black Pine mountains on the east, the Cotteral and Jim Sage mountains on the west, and the Raft River mountains to the south. The valley gently slopes toward the Snake River Plain to the north.

Soils in this area are deep (over 1 m (40 in)), somewhat poorly

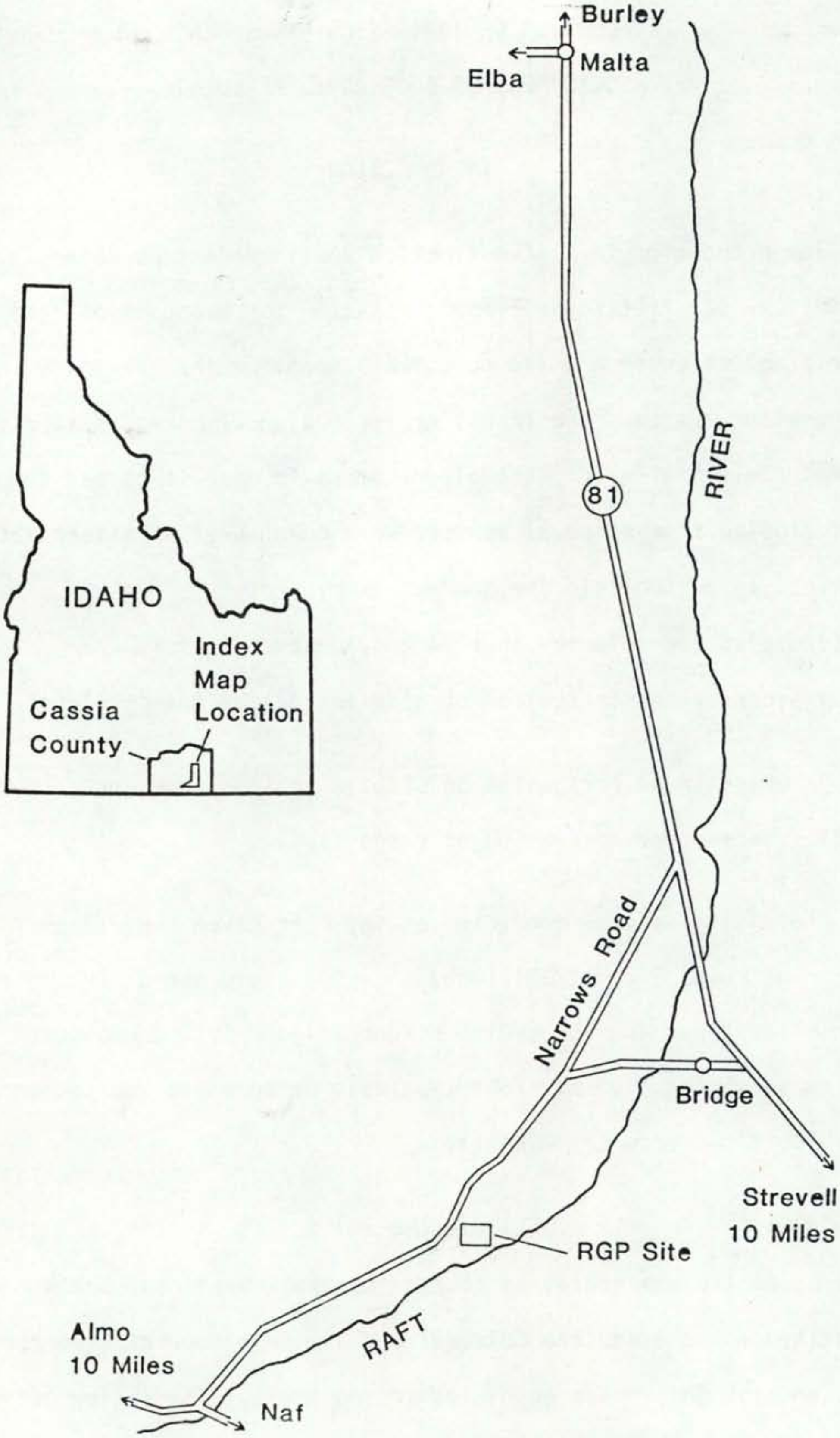

Figure 1. Location of study area.

to moderately well drained, level to gently sloping (0-4 percent) and have a slight salinity to severe saline-alkali condition. The field and greenhouse studies were conducted on a Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids) found at the RGP site. A gravelly or cemented layer was found at 5 to 6 meters (16 to 20 feet).

The climate at the RGP site is arid with moderately cold winters and dry, moderately hot summers. The mean annual precipitation for the valley is 283 mm (11.2 inches) (19 years of record) and the average monthly distribution is shown in figure 2. The mean maximum and minimum monthly temperatures are shown in figure 3 (19 years of record). The average growing season is 93 days and the average daily wind speed is 8 km per hour (5 mph).

GEOHYDROLOGY

The Raft River valley is a downwarped basin filled with sediments. The uppermost alluvial deposits are underlain by sediment of the Raft Formation which are in turn underlain by sediments of the Salt Lake Formation (Dolenc and others, 1981, p. 6). The general stratigaphy is shown is figure 4. A geologic map of the area is presented by Nace and others (1961, plate 1).

The combined alluvium, Raft Formation, and upper unit of the Salt Lake Formation constitute the main water-bearing units of the Raft River basin (Walker and others, 1970, p. 31). This aquifer is unconfined in most areas and is underlain by one or more deeper, confined aquifers. Underlying all the aquifers is a geothermal reservoir. The relationship among the several aquifers is poorly known but it is inferred that piezometric head generally increases

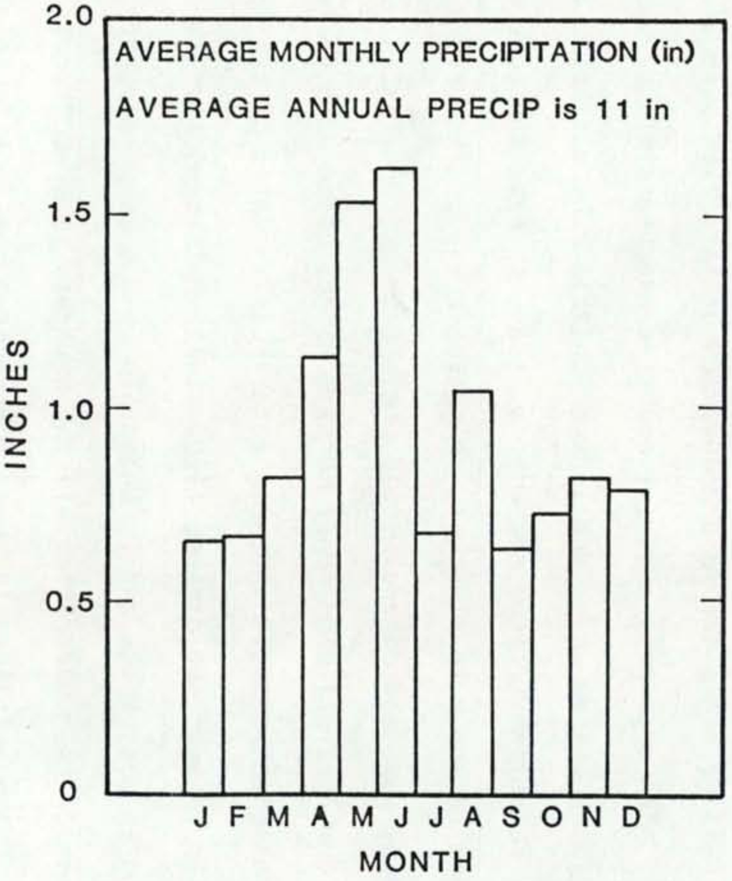

Figure 2. Average monthly precipitation. Raft River, Idaho.

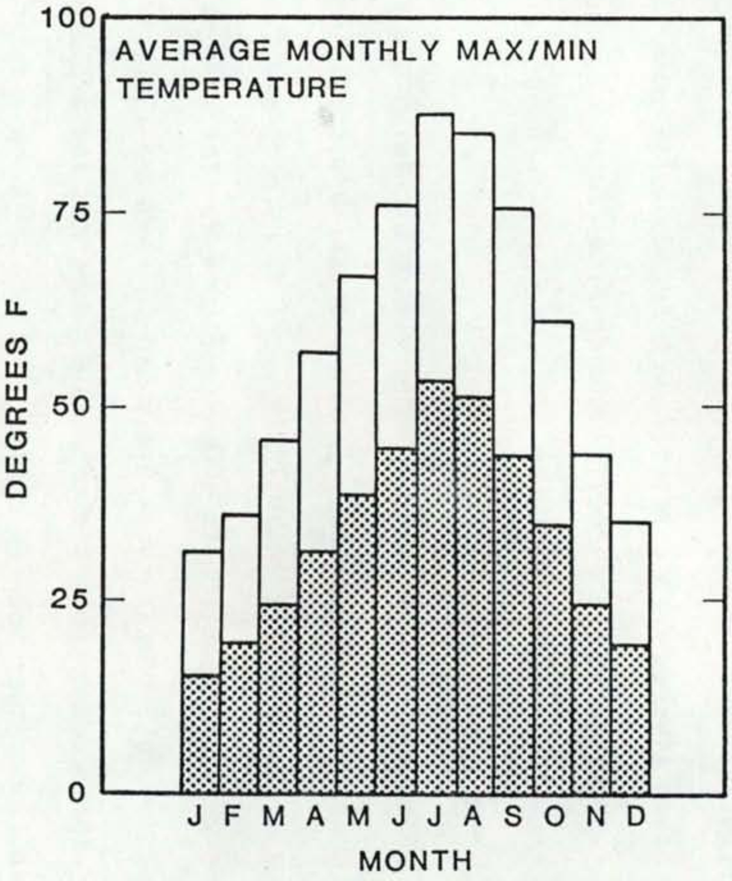

Figure 3. Average monthly maximum and minimum temperature - Raft River, Idaho.

ERA	FORMATION OR DEPOSIT	MAXIMUM THICKNESS IN FEET	PART OF FORMATION OR DEPOSIT SERVING AS AQUIFER
CENOZOIC	Alluvium, fan deposits, landslides, and glacial outwash	250	Surficial sheets of alluvium and fan materials
	Basalt of the Snake River Group	>400	Joints and cracks, and interflow brecciated zones
	Raft Formation	1,000	Sand and gravel in alluvium and lake beds
	Salt Lake Formation (upper unit)	500	Silty sand and tuff
	Salt Lake Formation (middle unit)	500	Fractures
	Salt Lake Formation (lower unit)	1,700	Sand, tuff, and sandstone
PALEOZOIC AND MESOZOIC	Granitoid rocks of the Cassia batholith of Cretaceous(?) age		Fractures
	Phosphoria Formation of Permian age	700	Not determined
	Wells Formation of Pennysilvanian age	2,900	Not determined
	Limestone of	>1,400	Not determined
	Undifferentiated sedimentary and metamorphic rocks of Cambrian age	10,000	Fractures
	Undifferentiated rocks of Precambrian age	10,000	Fractures

Figure 4. Correlation of chronologic, stratigraphic, and hydrologic units in Raft River basin (after Walker and others, 1970, p. 24).

with increasing depth. Each of the aquifers in the southern Raft River basin is recharged, at least in part, by upward leakage from underlying aquifers (Nichols, 1979, p. 7).

The shallow water table aquifer is recharged by underflow from the surrounding mountains, by upward leakage from deeper aquifers, and in places by losses from the Raft River. The aquifer discharges by underflow to the Snake River Plain, by irrigation pumping, by consumption by phreatic vegetation, and in places by losses to the Raft River. Nichols (1979, p. 74) found that there was no significant line or point source of upward leakage, but rather it occurred over large areas through thick confining layers of low hydraulic conductivity.

Water-table elevation altitudes have been mapped by Nace and others (1961, plate 5), Walker and others (1970, figure 14), and changes were reported by Nichols (1979, figure 6). A more detailed map of water levels in the vicinity of the RGP site is presented in figure 5. The map was constructed from water levels reported in driller's logs, measurements made in 1980 and 1981 by the Idaho Department of Water Resources, and maps of previous investigators (Nace and others, 1961; Walker and others, 1970; and Nichols, 1979).

The saturated thickness of several water-bearing deposits was mapped by Walker and others, (1970, figure 8). Nichols (1979, p. 8) assumed the unconfined aquifer included the combined thickness of alluvium, basalt, and the Raft Formation. Thicknesses mapped by Nichols (1979, figure 3) show the unconfined aquifer near the RGP to be about 120 meters (400 feet) thick. The unconfined aquifer becomes progressively thicker down the valley to the north.

Hydraulic conductivity and transmissivity have been estimated by

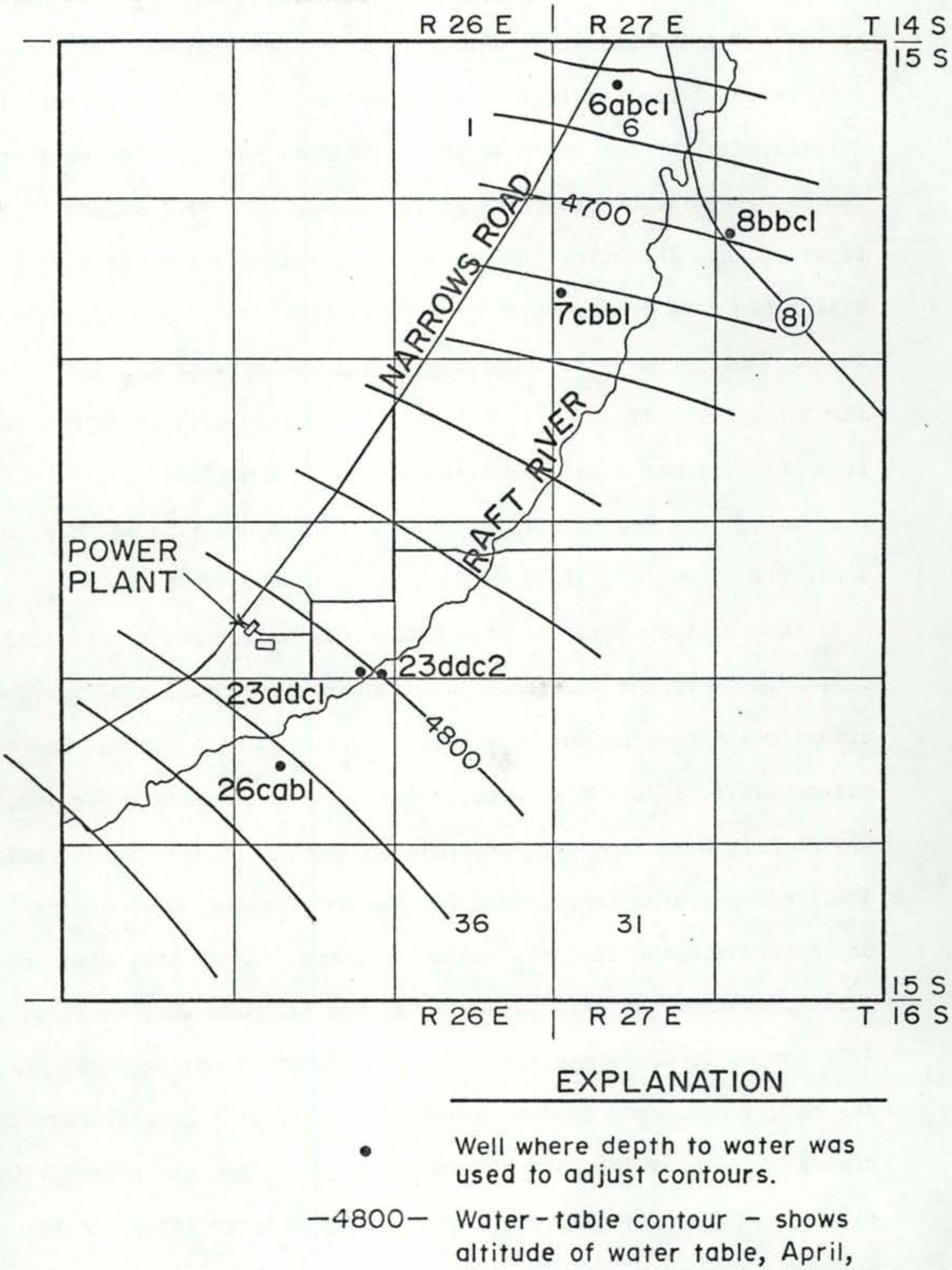

Figure 5. Water table contours, Raft River Geothermal Project area, April 1981.

several investigators. The results of their findings are summarized by Nichols (1979, p. 10). The upper 15 meters (50 feet) to 61 meters (200 feet) of aquifer in the Raft River valley may have a hydraulic conductivity as high as 40 meters (130 feet) per day. Below these depths hydraulic conductivity may be as low as 2 to 3 meters (5 to 10 feet) per day (Nichols, 1979, p.12). Estimated transmissivity values determined from ground-water flow model application are about 372 to 464 m^2 (4000 to 4990 ft^2) per day in the vicinity of RGP site (Nichols, 1979, figure 8). A hydraulic conductivity of 40 m (130 feet) per day and a saturated thickness of 61 m (200 feet) is equivalent to a transmissivity of 2400 m^2 (26,000 ft^2) per day, many times the value determined by Nichols' ground-water flow model.

Several investigators have mapped concentrations of chemical constituents of the aquifer. The procedure is complicated by variations occurring not only areally but also with depth. Walker and others (1970, figure 23) mapped water quality parameters for the entire Raft River valley. Dolenc and others (1981) presented maps for the immediate area surrounding the RGP showing the areal distribution of temperature and specific conductance and the vertical distribution of temperature, specific conductance, and fluoride concentration (figures 6, 7, 8, 9, and 10). Higher concentrations near the RGP are the result of upward leakage along the faults at a greater rate than occurs throughout the rest of the aquifer. Dolenc and others (1981, p. 128) concluded that leakage of geothermal water into the shallow aquifer may originate from two separate faults thereby explaining the variation in concentrations of chemical constituents at the different monitoring wells.

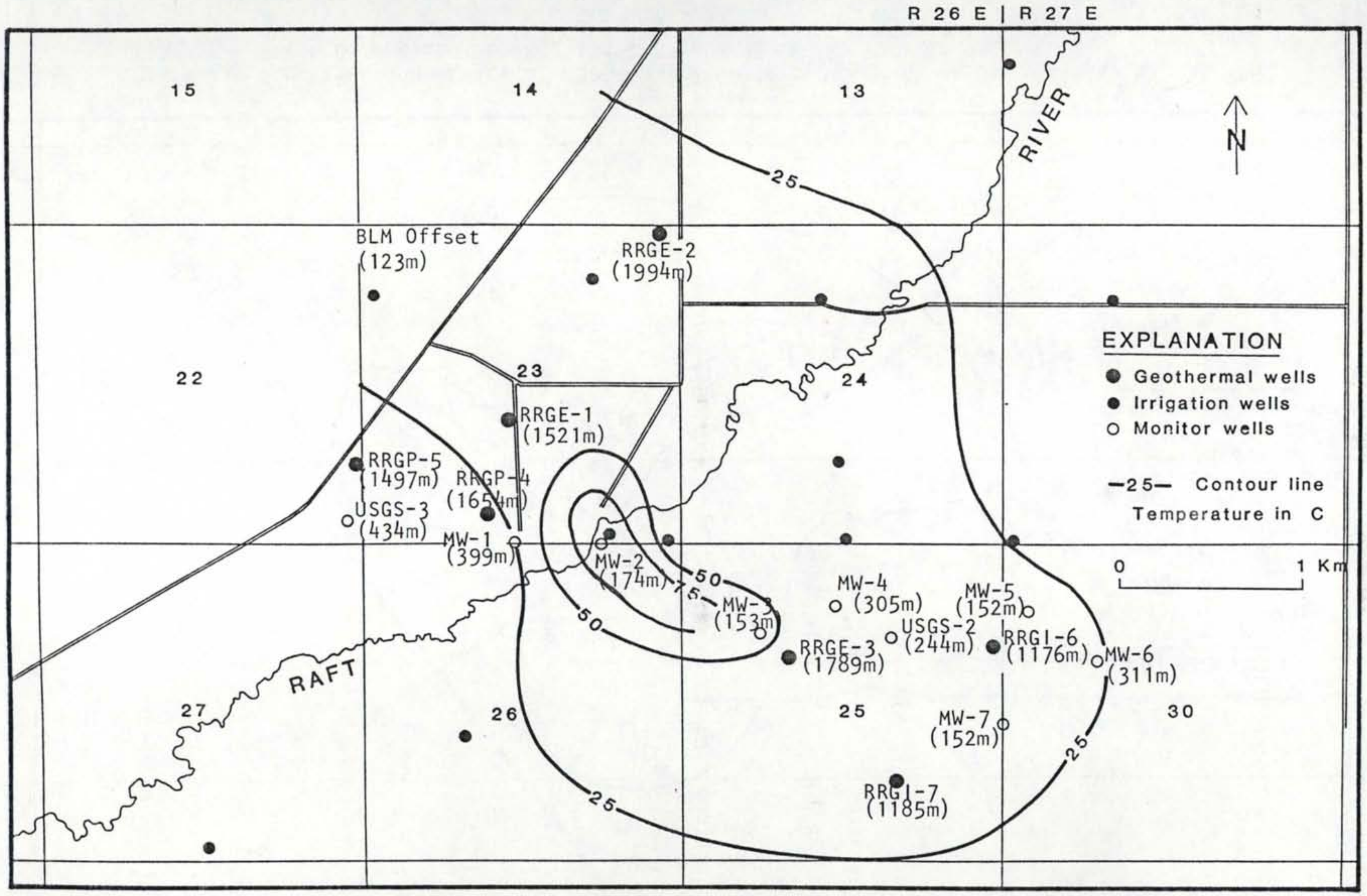

Figure 6. Temperature of shallow (<200m) ground water in the vicinity of the RGP (from Dolenc and others, 1981, figure 99).

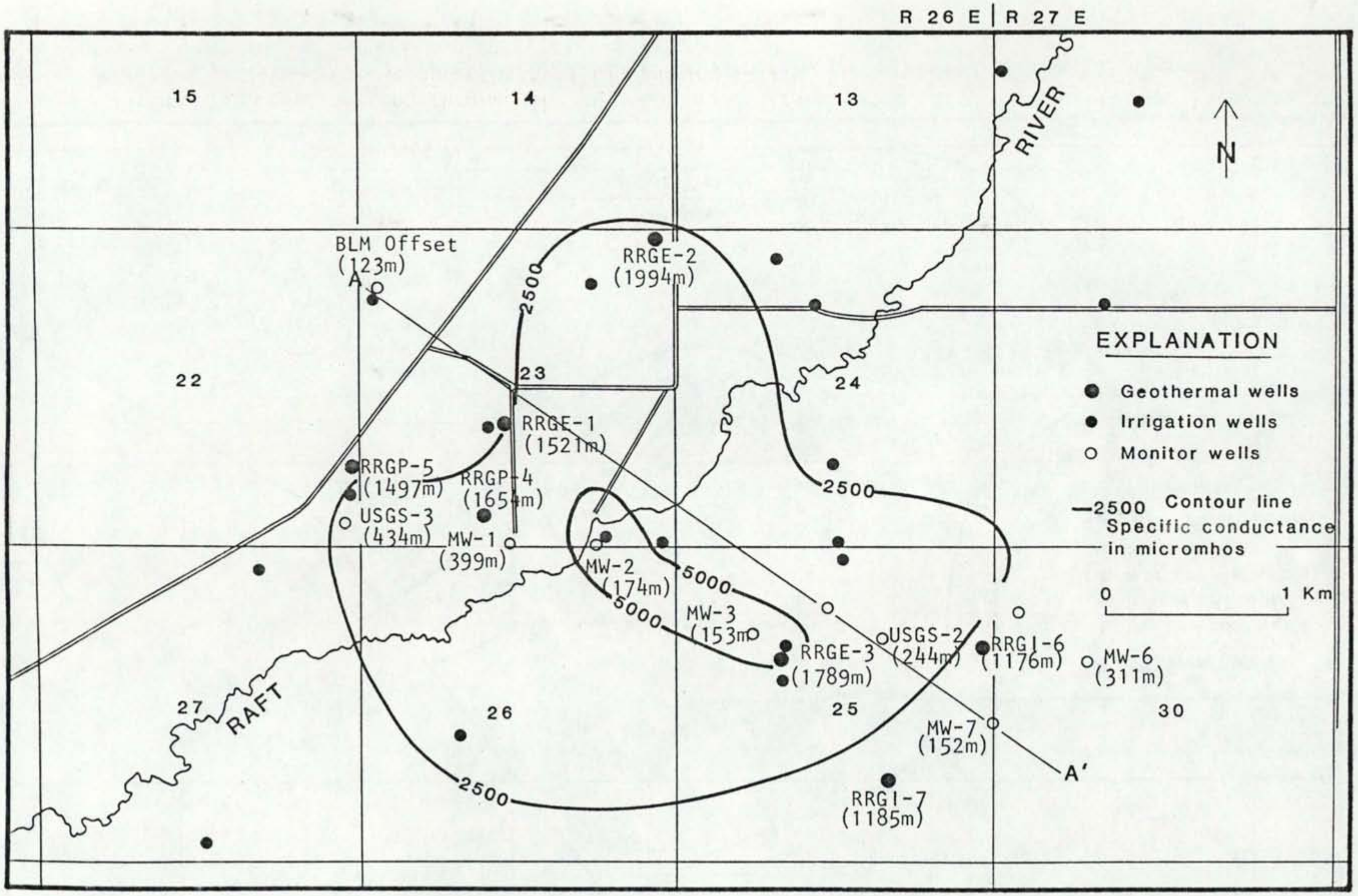

Figure 7. Specific conductance of shallow (<200m) ground water in the vicinity of the RGP (from Dolenc and others, 1981, figure 98).

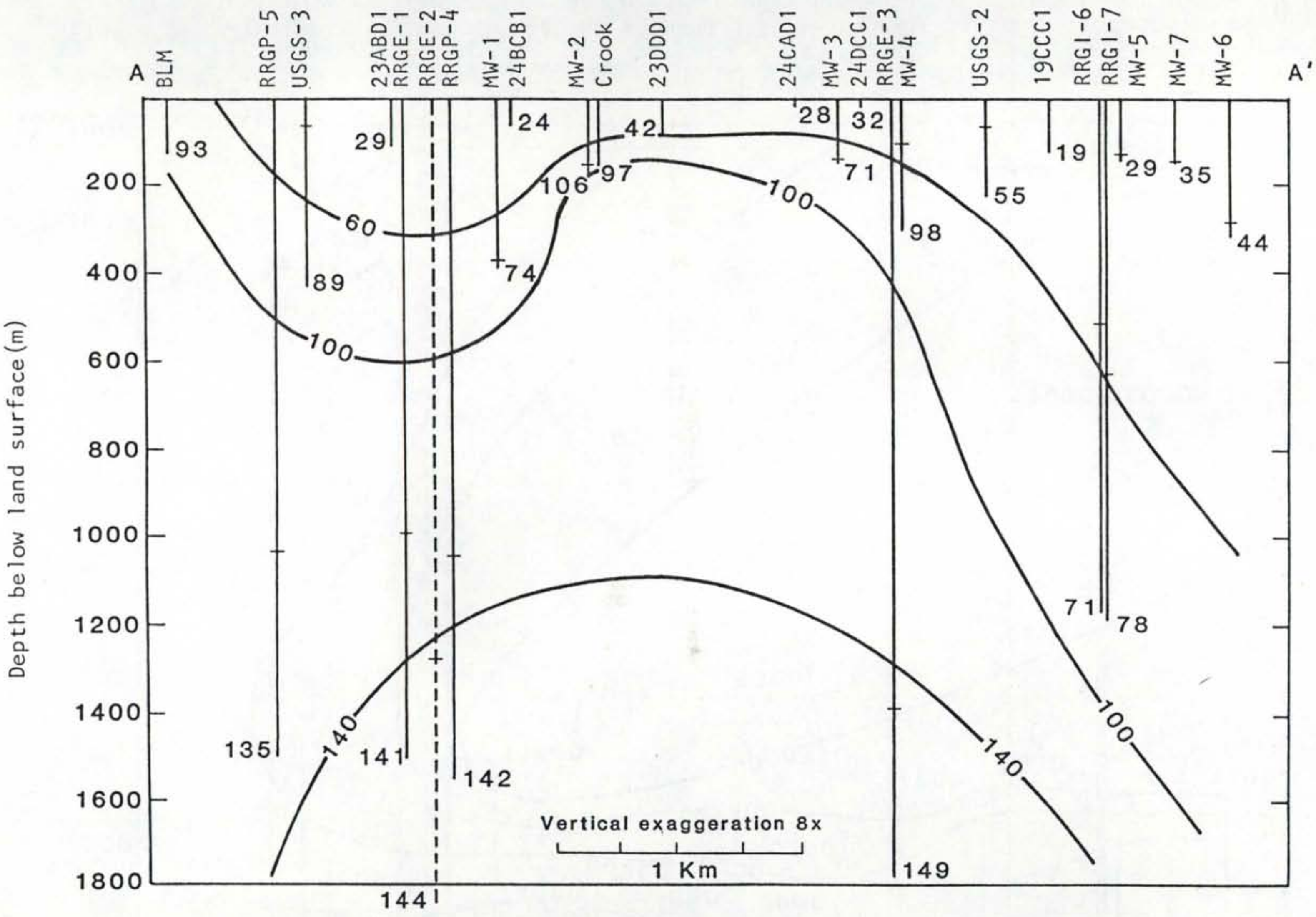

Figure 8. Cross section through the RGP showing distribution of temperature of ground water (from Dolenc and others, 1981, figure 101).

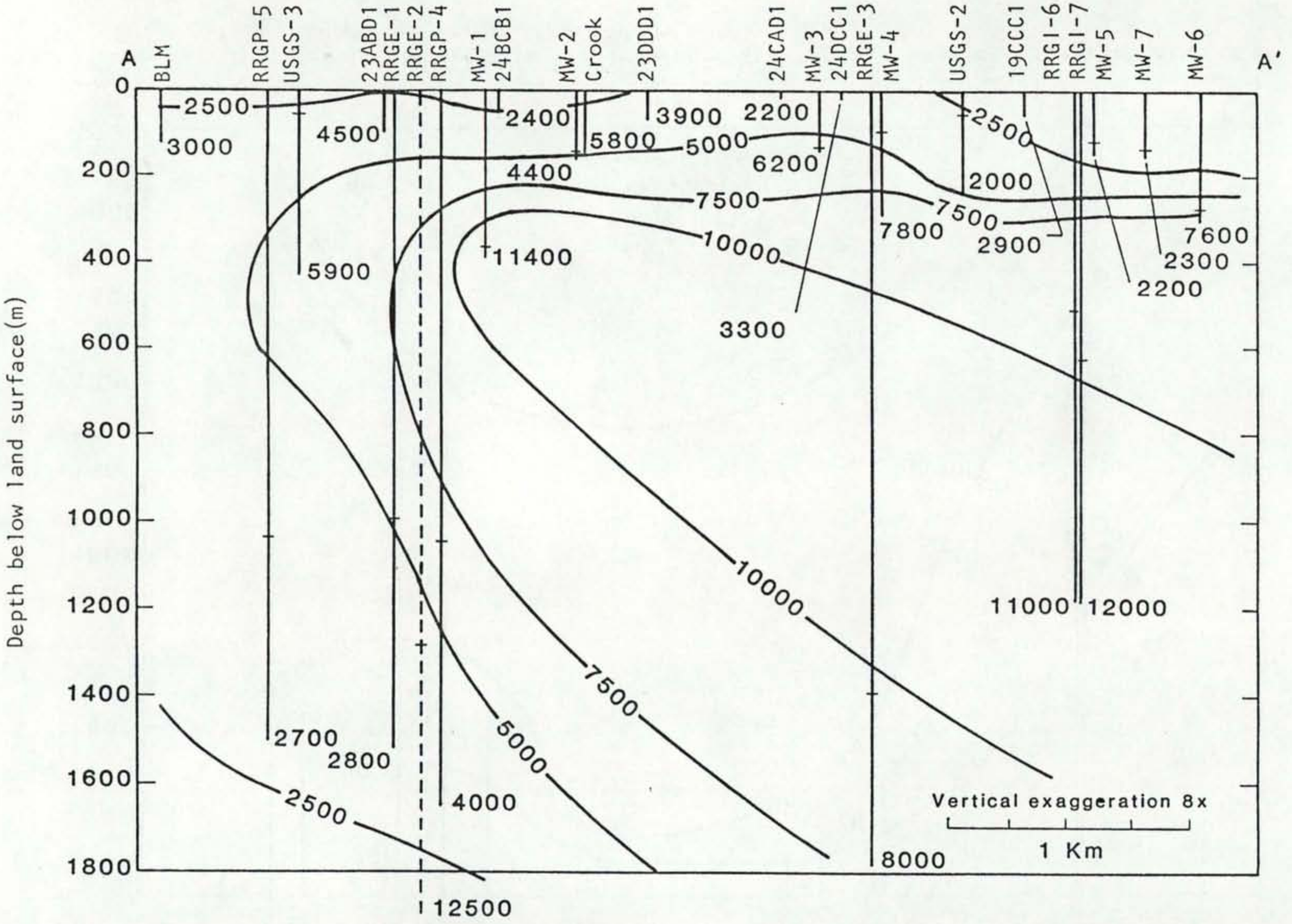

Figure 9. Cross section through the RGP showing distribution of specific conductance of ground water (from Dolenc and others, 1981, figure 100).

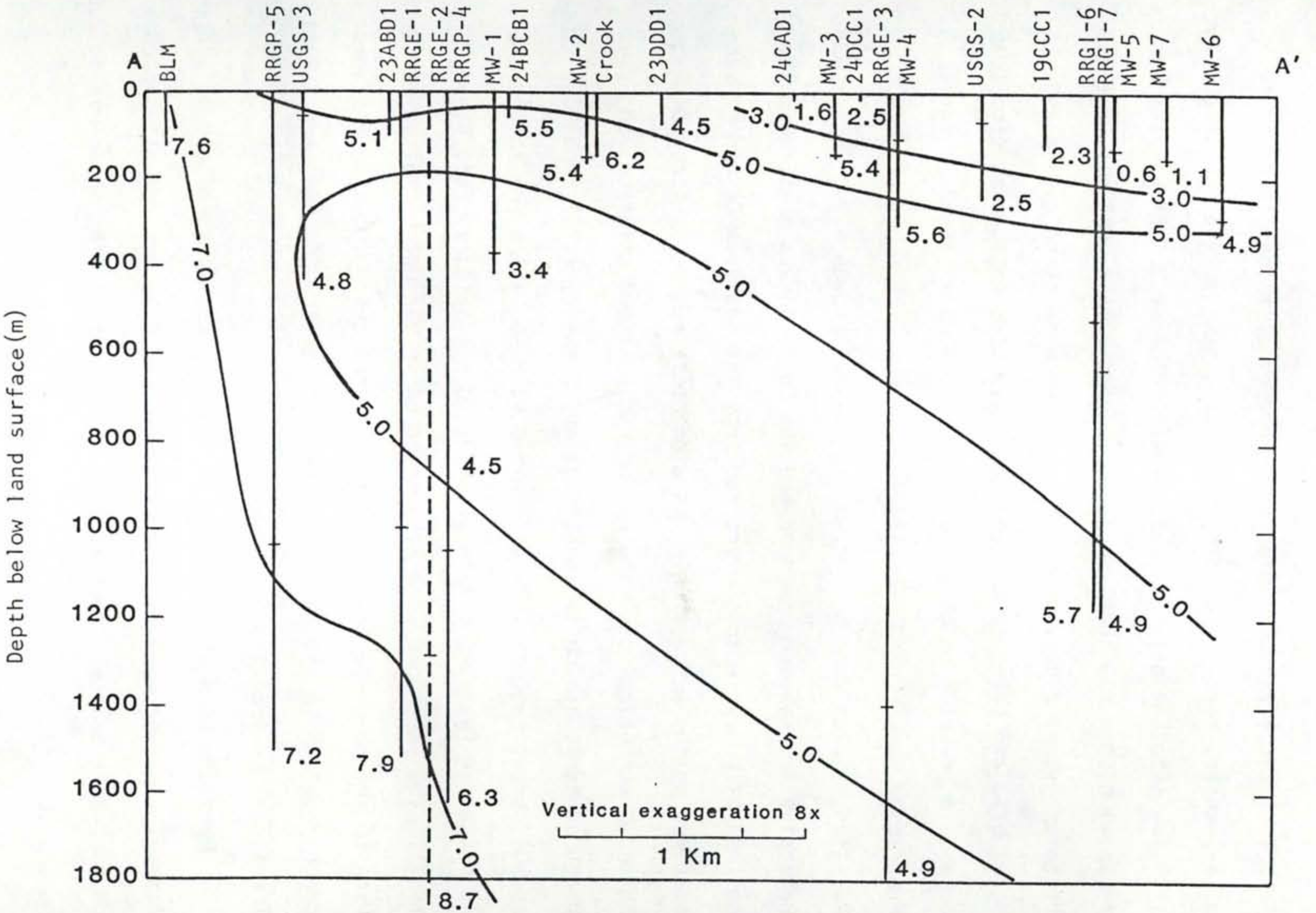

Figure 10. Cross section through the RGP showing distribution of fluoride in ground water, (from Dolenc and others, 1981, figure 104)

SOILS

This study was conducted on a Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids) site next to the RGP site (figure 1). The site had not previously been irrigated. Soil samples were taken at 0.25 m (.8 feet) depth increments with a .075 m (.25 feet) diameter bucket auger. Eight auger holes were taken over a 2 ha (5 acre) area and moisture contents were measured on samples from four holes. A gravelly or cemented layer at 5 to 6 m (16 to 20 feet) restricted deeper hand sampling.

The samples were air dried and passed through a 2.0 mm sieve. Saturated pastes were prepared and the paste pH was measured. The soil solutions were then extracted from the pastes. Ca and Mg were measured on the extract using an atomic adsorption spectrophotometer. Na and K concentrations were determined by flame emission, SO_4 was measured turbochemically (Tabatabai and Bremner, 1970), and CO_3, HCO_3, and Cl concentrations were determined by H_2SO_4 titration followed by Ag titration in the presence of $KCrO_4$ (U.S. Salinity Lab. Staff, 1954). The same ions were also measured in the geothermal well water used in the power plant. Table 1 lists the average cation and anion concentrations in the saturation extract and the EC, SAR, and ESP of three sampled profiles on the site.

Particle size distribution in the soil was measured and moisture retention curves were made from saturation, 0.2, 5.0, and 15 bar data on duplicate samples taken at 0.25 m (.8 feet) depth increments to 2.0 meters (6.5 feet).

The soil profile native salt concentration was calculated on the air dry basis from the individual ion concentrations in each 0.25 m

Table 1. Chemical analyses of non-irrigated Freedom silt-loam soil at RGP.

Depth (cm)	Cations(mg/1)				Anions(mg/1)			EC	SAR	ESP
	Ca	Mg	Na	K	SO	HCO_3	CO_3	mmho/cm	meq/l	
0-25	0.8	0.50	18.6	1.40	0.73	9.99	6.51	1.95	213.0	41.0
25-50	1.0	0.23	133.7	4.27	21.33	11.22	9.30	13.11	419.0	59.0
50-75	3.3	1.27	378.3	8.83	52.67	7.39	5.86	33.86	391.0	63.0
75-100	6.0	4.03	436.7	8.67	62.67	6.38	2.60	37.52	273.6	61.0
100-125	6.9	4.69	393.3	6.57	58.0	6.60	1.30	34.53	264.9	61.0
125-150	12.3	7.34	375.0	5.40	53.33	3.74	2.80	34.01	215.0	60.0
150-175	15.7	8.20	378.2	4.97	60.67	5.20	0.65	34.68	185.7	55.0
175-200	20.9	9.47	396.7	4.87	62.33	3.58	1.30	36.68	165.9	52.0

(.8 feet) depth increment and the native salt load was calculated assuming a uniform profile bulk density of 1.3 g/cm^3 (81 lbs/ft^3) (Robbins, 1977). Table 2 shows the average total salt concentrations in the profile to 5.0 m depth and the accumulated total salt load in the profile. There are 531 t/ha (237 ton/acre) of total salt in the 5.0 m profile. The various cation ratios and anion ratios were calculated for the soil and the water on a weight basis (Table 3).

WATER QUALITY

For the purpose of this study it is assumed that the chemical characteristics of the geothermal water will not be altered within the power plant and that geothermal effluent will have characteristics (except temperature) identical to the plant influent. It is further assumed that the geothermal influent will be a mixture of water originating from any of 4 RGP wells. Since the mixing ratios are unknown, it is assumed that equal amounts will be used from each of the wells. The chemical characteristics of the water from the wells (Dolenc and others, 1981) and the average values are shown in table 4.

Introduction of geothermal effluent into the shallow aquifer may present two ground-water quality problems. The total dissolved salts in the effluent may increase as the effluent percolates through the vadose zone, resulting in an increase in the salinity of the ground water immediately beneath and down-gradient of the disposal site. The fluoride concentration of the geothermal water (7.2 mg/l, average) exceeds drinking standards (table 5) and may present a health hazard to people and livestock down-gradient of the disposal area.

Table 2. Total salts in the surface 5 m of Freedom silt loam soil, Raft River Geothermal Project.

Depth m	----ppm----	-------- metric ton/ha-------	
	mean	mean	cumulative
0 - .25	1200 ± 900	4 ± 2	4
0.25 - 0.50	4500 ± 900	15 ± 3	19
0.50 - 0.75	6500 ± 1200	22 ± 4	41
0.75 - 1.00	7000 ± 600	23 ± 2	64
1.00 - 1.25	7200 ± 500	24 ± 2	88
1.25 - 1.50	7300 ± 1300	24 ± 4	112
1.50 - 1.75	7600 ± 2100	25 ± 7	137
1.75 - 2.00	8400 ± 2400	28 ± 8	165
2.00 - 2.25	8300 ± 1200	28 ± 4	193
2.25 - 2.50	8700 ± 1500	29 ± 5	222
2.50 - 2.75	9500 ± 2200	32 ± 7	254
2.75 - 3.00	9300 ± 1500	31 ± 5	285
3.00 - 3.25	9900 ± 1700	33 ± 6	318
3.25 - 3.50	9100 ± 1200	30 ± 4	348
3.50 - 3.75	8600 ± 900	20 ± 3	377
3.75 - 4.00	8800 ± 2500	29 ± 8	406
4.00 - 4.25	8500 ± 1500	28 ± 5	434
4.25 - 4.50	10000 ± 1600	33 ± 5	467
4.50 - 4.75	9700 ± 800	32 ± 3	499
4.75 - 5.00	9600 ± 900	32 ± 3	531

Table 3. Cation and anion percentages in the native soil profile and in the geothermal power plant waste water on a weight basis.

	Cations				Anions		
	Ca	Mg	Na	K	Cl	SO_4	HCO_3
Soil	Percent						
0-1 m	3	1	93	3	72	21	6
1-5 m	9	3	86	2	75	23	2
Water	10	<.1	83	7	85	9	6

Table 4. Water quality characteristics of selected geothermal production wells, Raft River Geothermal Project [1]

Parameter	RRGE-1	RRGE-2	RRGE-3	RRGE-5	Average
Temp. °C	141	144	149	135	142
Sp.Cond.(Mmhos/cm)	2800	2500	8000	2700	4000
pH (mg/l)	7.3	7.1	6.9	7.5	7.2
Ca^{+2}(mg/l)	56	42	224	41	91
Mg^{+2}(mg/l)	0.6	0.1	0.5	0.1	0.3
Sr^{+2}(mg/l)	1.4	1.2	5.2	1.2	2.2
Na^{+}(mg/l)	455	441	1194	484	643
K^{+}(mg/l)	34	38	105	31	52
Li^{+}(mg/l)	1.6	1.1	3.1	1.6	1.8
HCO_3^{-}(mg/l)	41	41	44	35	40
SO_4^{-2}(mg/l)	36	53	60	40	47
CL^{-}(mg/l)	776	708	2260	800	1140
F^{-}(mg/l)	7.9	8.7	4.9	7.2	7.2
Si_2(mg/l)	121	131	158	133	136

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[1] Data from Dolenc and others, 1981, p. 119.

Table 5. Maximum levels for fluoride, 1975 interim drinking water standards[1/]

Annual Average Maximum Daily Air Temperature (°F)	Level (mg/l)
53.7 and below	2.4
53.8 - 58.3	2.2
58.4 - 63.8	2.0
63.9 - 70.6	1.8
70.7 - 79.2	1.6
79.3 - 90.5	1.4

[1/] Taken from Clark, Viessman, and Hammer, 1977, p.268.

FLUORIDE MOVEMENT

Most geothermal waters in the western United States contain more fluoride (F_2) than currently allowed by drinking water standards. The maximum allowable concentration is from 1.4 to 2.4 ppm F, depending on the average maximum daily temperature (Kubota et al., 1982). Concern for shallow aquifer contamination by irrigation disposal of high F geothermal power plant waste water prompted this investigation of high F water-soil chemistry interactions. Considerable data are available on F adsorption by neutral and acid soils, but limited information is available for calcareous and alkali soils. Gupta, et al., (1981) have shown that the higher the pH, the lower the F adsorption capacity of several soils. Since most arid area soils contain soluble calcium salts, the precipitation of F as fluorite (CaF_2) becomes a possible mechanism for F removal from soil solution when high F water is used for irrigation. The RGP waste water is near saturation with respect to fluorite, and if Ca and F concentration in solution were to be increased by evaporative concentration, fluorite would be expected to precipitate.

The solution ion activity product (IAP) is a measure of the tendency for a solute to precipitate from solution. When the log IAP for fluorite, which is calculated as Ca activity times F activity squared, exceeds -9.4, fluorite can start to precipitate. Figure 11 shows the relation of -log IAP for fluorite to the leaching fraction for irrigation with RGP waste water with chemical composition as shown in table 6. The leaching fraction is that fraction of the applied irrigation water that leaches below the root zone, the remainder being evaporated from soil solution or the crop surface. From figure 11,

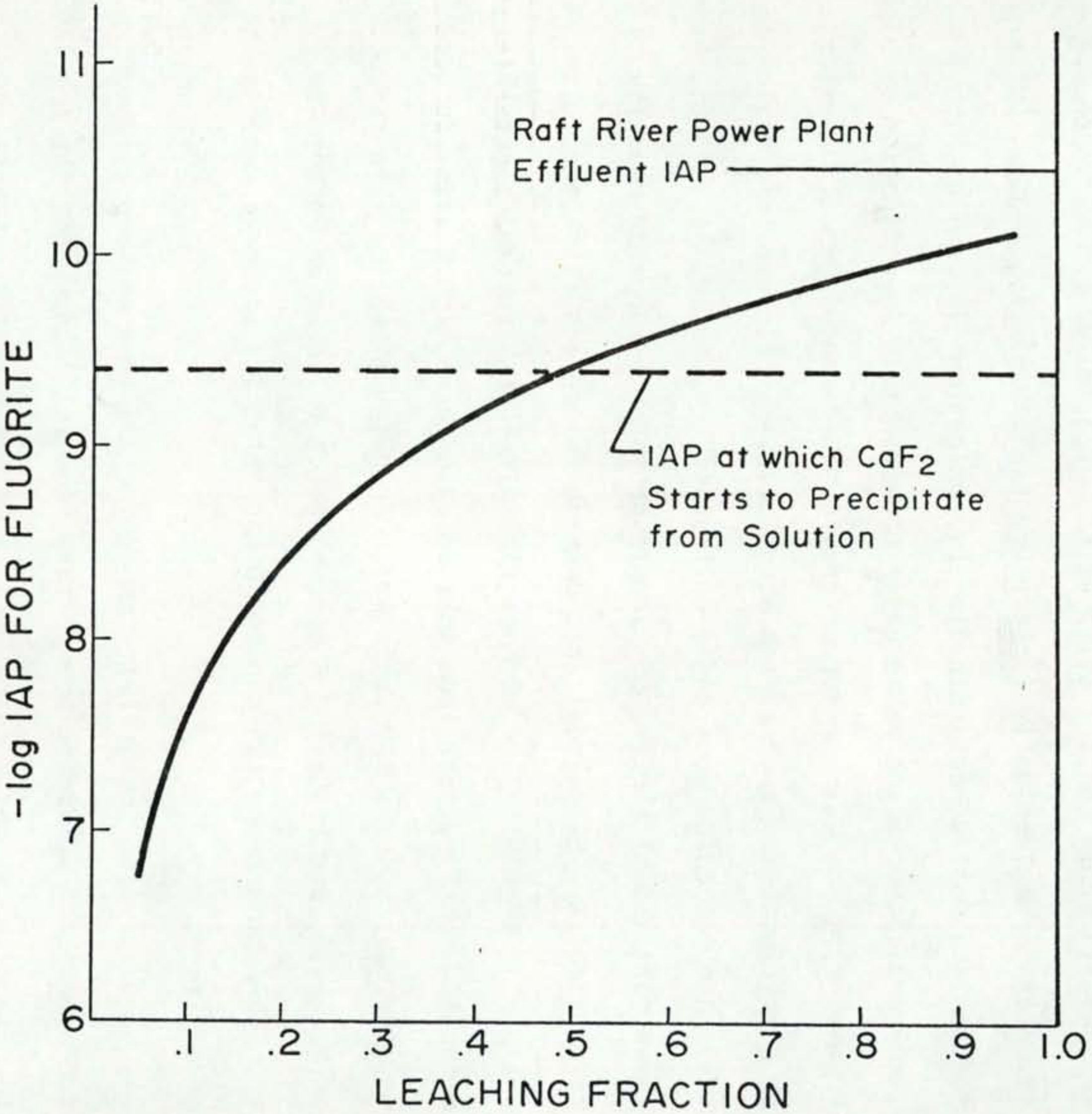

Figure 11. Ion Activity Product (IAP) and Leaching Fraction Relationships - RGP power plant effluent.

Table 6. Chemical composition of geothermal effluent.

Date	Ca	Mg	Na	SO_4	HCO_3	F	pH	EC	log IAP fluorite
	meg/l					mg l		dS/m	
2/03/81	2.7	.03	19	1.3	1.0	7.0	7.3	2.6	-10.2
4/24/81	2.7	.02	20	1.3	1.5	7.4	7.5	2.5	-10.2
6/12/81	2.7	.02	19	1.4	0.9	7.2	7.3	2.7	-10.2
8/12/81	2.7	.03	24	1.5	1.1	7.3	7.2	2.7	-10.2
4/15/82	2.3	.01	22	1.1	1.5	7.0	7.2	2.7	-10.2

Table 7. Lysimeter water and F mass balance data.

	1/3 leaching fraction		1/2 leaching fraction	
	Lys. A	Lys. B	Lys. A	Lys. B
Water applied (l)	875	963	640	560
Water applied (cm)	1225	1348	894	784
Total leachate (l)	259	292	96	85
Total leachate (cm)	360	409	134	120
Leaching fraction	0.30	0.30	0.15	0.15
Evapotranspiration (l)	616	671	598	475
Evapotranspiration (cm)	862	939	837	665
Leachate pore volume	7.0	7.9	2.6	2.3
Total applied F (g)	6.35	6.99	5.04	4.07
Total leached F (g)	0.18	0.13	0.04	0.03
Retained F (g)	6.17	6.86	5.00	4.04
Percent F retained (g)	97.2	98.1	99.2	99.3

fluorite precipitation should start once half of the applied water is used by the growing crop. To examine this hypothesis, a lysimeter study using RGP soils was conducted at the Snake River Conservation Research Center at Kimberly, Idaho. Deep percolation solution from lysimeters irrigated at 0.3 and 0.5 leaching fractions with geothermal water were analyzed for F and common soluble salt ions normally found in arid region soils. The lysimeter soils had been irrigated for 20 months. The water and fluoride balance (table 7) shows that over 97 percent of the applied F was retained by the soil and the log IAP for this percolate was in the -11 to -14 range. This indicates that a mechanism other than fluorite precipitation was controlling the final F concentration in the percolate solutions.

The lysimeter soils were then sampled in 0.1 m (0.3 feet) depth increments. Soil solution extracts (50% water by weight) were made and analyzed for Ca, Mg, N_2, KCl, HCO_3, and F. Electrical conductivity (EC) and pH were also measured.

The water extractable F concentration (figure 12) increased in the upper profile as more water and F were applied and the concentration peak was deeper as the water application depth increased. Even though high F concentrations were measured in the upper root zone, the F was being taken out of solution and was not moving to the bottom or out of the soil profile.

To determine if fluorite was precipitating, the IAP was calculated from the soil solution data. When the log IAP is greater than -9.4, the system is supersaturated with fluorite and it should precipitate (figure 13). If fluorite precipitation is the only mechanism removing F from solution, the F concentration (figure 12) and the log IAP (figure 13) would increase to the saturation value and

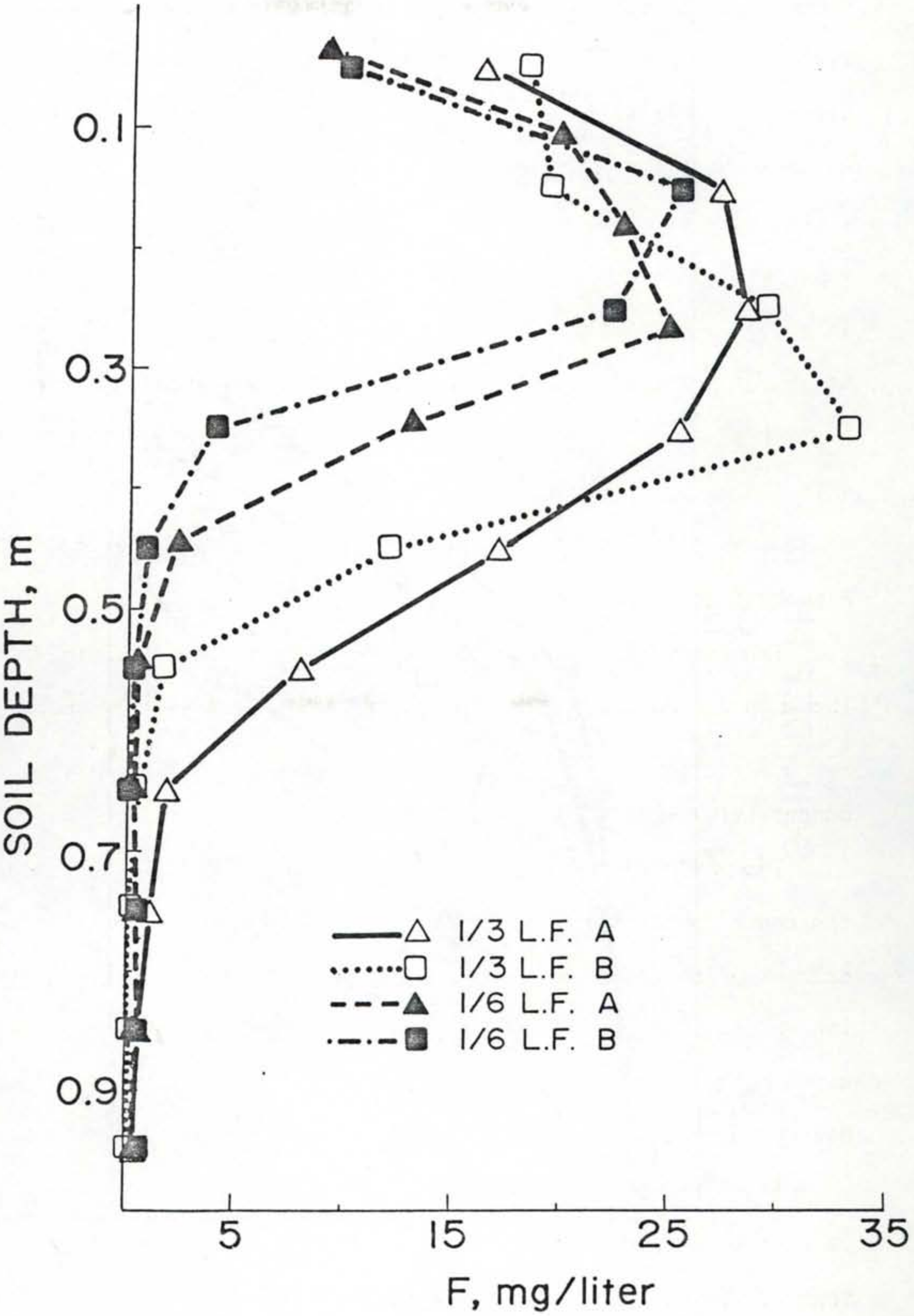

Figure 12. Extractable fluoride distribution with depth in Lysimeters with two leaching fractions.

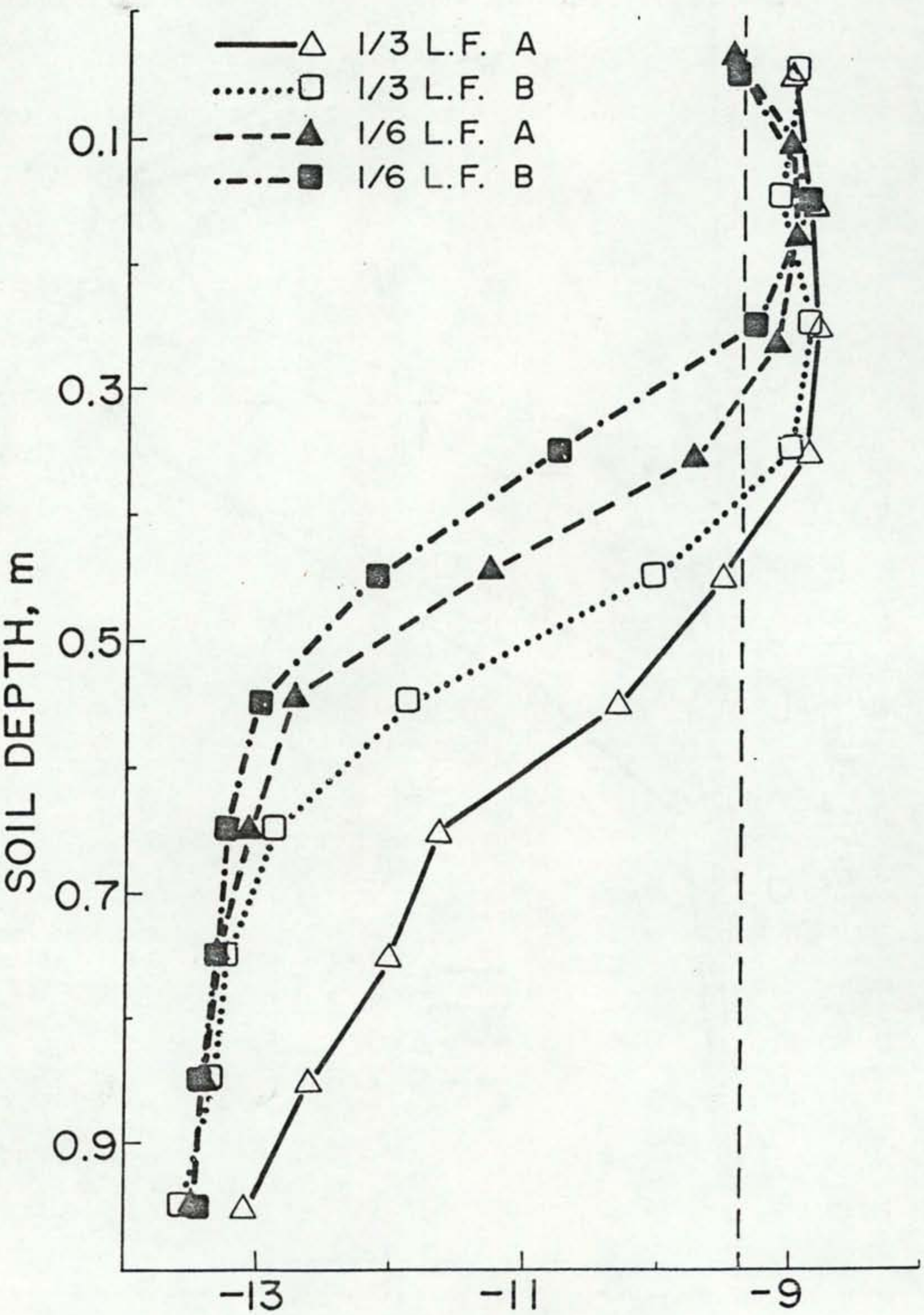

Figure 13. Log Fluorite IAP distribution with depth in lysimeters with two leaching fractions.

then remain somewhat constant with depth as more water is applied. However, below the 0.5 meter depth both values drop sharply. This indicates that as the high F water is applied to the soil, F is adsorbed until the adsorption mechanism is saturated and the F concentration in solution increases until fluorite precipitation starts (that portion of the profile where the log IAP is greater than -9.4). From these data it appears that two mechanisms are removing F from solution, one which has been identified (fluorite precipitation) and one which has not. Further study is needed to determine the initiating mechanism and the F adsorption capacity of these soils.

IRRIGATION WITH GEOTHERMAL EFFLUENT

The primary purpose for considering the use of irrigation for disposal of geothermal effluent is to reduce the amount of effluent and associated ions reaching the shallow cold water aquifer. The soil profile acts as a cation exchange column allowing removal by concentration and then precipitation of certain chemicals found in the effluent and soil. Crops rely on the soil profile for mechanical support, nutrients, and water. Use of soil water by plants and evaporation from the soil surface increases the chemical concentrations allowing precipitation. Because this soil is high in NaCl, the soluble salts will eventually reach the water table if water is applied over a long enough time.

Crop Selection

Crops which might be considered for irrigation using geothermal effluent are limited by climate, soil type, and chemical characteristics of the effluent. Potential toxic chemical uptake of specific plants also limits the selection. The short 93 day growing season with some night-time frosts and the 2000 degree-days available during the season limit the potential crops to those listed in table 8. Since chemical uptake by plants is not well defined, crop selection is based on the potential chemical contamination of the harvestable portion and intended uses.

Crops currently grown in the southern portion of the Raft River Valley consist of alfalfa, grain (barley and wheat), and potatoes. Although sugar beets are considered to be a major crop in the valley, they are not grown in the southern section due to freezing nights encountered during the spring which kill young seedlings. The major portion of the area is devoted to range pasture. These crops have different tolerances to soil salinity conditions. Table 8 shows the tolerance to salinity and the effect of salinity on yields of these crops.

Assuming the RGP management would not be involved in a farming operation, the growing and harvest of the crops irrigated with RGP effluent would be the responsibility of local farmers. The types of crops available for production on effluent disposal lands could well be limited to those already in production in the area.

Irrigation Methods

Several application methods of irrigation water are currently practiced in the western United States. Sprinkler, trickle, furrow, borders, and flooding are applicable under specific conditions; however, the predominant methods practiced in the Raft River Valley are sprinkler and furrow irrigation. Topography in the area adjacent to the RGP site limits the potential methods to sprinkler, graded furrow, or graded borders. Even though trickle is topographically

Table 8. Salinity effects on potential crops for irrigation using RGP effluent (from Bresler, McNeal, and Carter, 1982, tables 16, 17, 18).

Crop	Salinity Threshold EC_e	% Productivity decrease per mmho/cm increase	Relative Productivity % at selected EC_e, mmho/cm						
			2	4	6	8	10	12	14
Alfalfa	2.0	7.3	100	85	71	56	42	27	12
Barley	8.0	5.0	100	100	100	100	90	80	70
Potatoes	1.7	12.0	96	72	48	24	0	0	0
Sugarbeets	7.0	5.9	100	100	100	94	82	71	59
Wheat	6.0	7.1	100	100	100	86	71	57	43
Wheatgrass, tall	7.5	4.2	100	100	100	98	89	81	73

acceptable, the primary purpose is water conservation contrary to the disposal objective of this project.

Sprinkling of geothermal effluent has potential problems with regard to water quality. The effluent chemical concentrations will be raised by evaporation between the time the effluent is discharged by the sprinkler and the time it strikes the soil surface and/or plant surface. Some of the chemicals will remain on the vegetation due to evaporation and adsorption, thereby potentially increasing concentrations to toxic levels on the foliage, such as fluoride on forage surface, thus causing a problem with feeding the hay or pasture to livestock (Kubota, et al., 1982).

Sprinkler application is also limited by freezing conditions. Under full production, a geothermal power plant would produce effluent 24 hours per day, 365 days per year. During the winter months, the system would be in operation with mean air temperatures of $-7.2^{\circ}C$ ($17^{\circ}F$) (record low temperatures of $-33^{\circ}C$ ($-28^{\circ}F$)). Problems could be encountered with frozen or broken pipes in the distribution system and ice accumulation around sprinkler heads. With sprinkler application systems, land selection would not be limited to gentle slopes; however, the crop production would be limited to seed crops. Use of this method would not be applicable to rangeland, due to possible chemical residues left on the vegetation.

Furrow and border irrigation methods, which are surface application procedures, do not have the same water quality constraints as sprinkler. The effluent will have limited contact with vegatation using these methods, although root systems of the plants would still be in contact with the chemicals found in the effluent. Chemical uptake into the plant will not cause problems with forage or grain crops.

Depending on the design of the distribution system, winter operation of a surface application system may be as complex as that of a sprinkler system. Open ditches and control structures would need to be designed for ice loading.

Surface runoff from graded furrow or graded border irrigation systems would be a potential problem. Provisions would be required to recycle or contain the runoff. Irrigation with border systems can cause scalding of small, young plants which are submerged or nearly submerged by irrigation. Once the plants have grown enough to stand above the effluent, scalding may not be detrimental to the crop.

Furrow and border irrigation would be restricted to lands having slopes less than 4% and runoff would need to be controlled and recycled. Most crops are compatable with surface irrigation methods except crops whose roots are harvested for consumption.

Irrigation Plot Studies at RGP

A 3.4 ha (8.3 acre) area of native land south of the RGP site was used for studying irrigation management practices using geothermal effluent. The study area consisted of a 15 m (50 ft) border strip surrounding 27, 15 m x 15 m (50 ft x 50 ft) plots. The perimeter along the plots was irrigated using furrow techniques and the internal plots were irrigated using level border methods. The source of geothermal water was from production wells and from well number 4. Before plot preparation, the area was irrigated using sprinkler techniques with geothermal waters initially cooled by a holding pond. Climatic data were collected during the study using a portable weather station for estimation of evapotranspiration rates (ET).

Evapotranspiration

Using data collected from the weather-station, potential ET was computed using energy balance techniques described by Wright (1982). The calculated peak 5 day potential ET rate was approximately 9.5 mm/day (.37 inches/day) during the summer and approximately .8 mm/day (.03 inches/day) during the winter. The calculated potential ET for the study area as a function of time is shown in figure 14. The ET rate for a specific crop is dependent on the potential ET, the crop grown, and the stage of growth of the crop. The crop coefficients for calculation of the crop's ET are shown in figure 15 for Kimberly, Idaho. The potential ET rates of Kimberly, Idaho are similar to those for the RGP site as shown in figure 16.

Crops

The plot perimeter was planted to alfalfa/grass mixture to reduce desert dry air effects on the plots. Two-thirds of the plots were planted to alfalfa and one-third of the plots were planted to crested wheat grass. These crops were selected for their tolerance to salinity and high consumptive use of water.

One-half of the alfalfa plots were treated with calcium chloride to evaluate the effect on infiltration rates.

Water Balance

The 27 plots were irrigated from April, 1981 to September, 1982. The water balance considered only the water applied and the water evaporated, assuming any excess resulted in deep percolation. Precipitation on the plots was measured using a weighing precipitation gage, and the geothermal effluent application was measured with a propeller type flow meter.

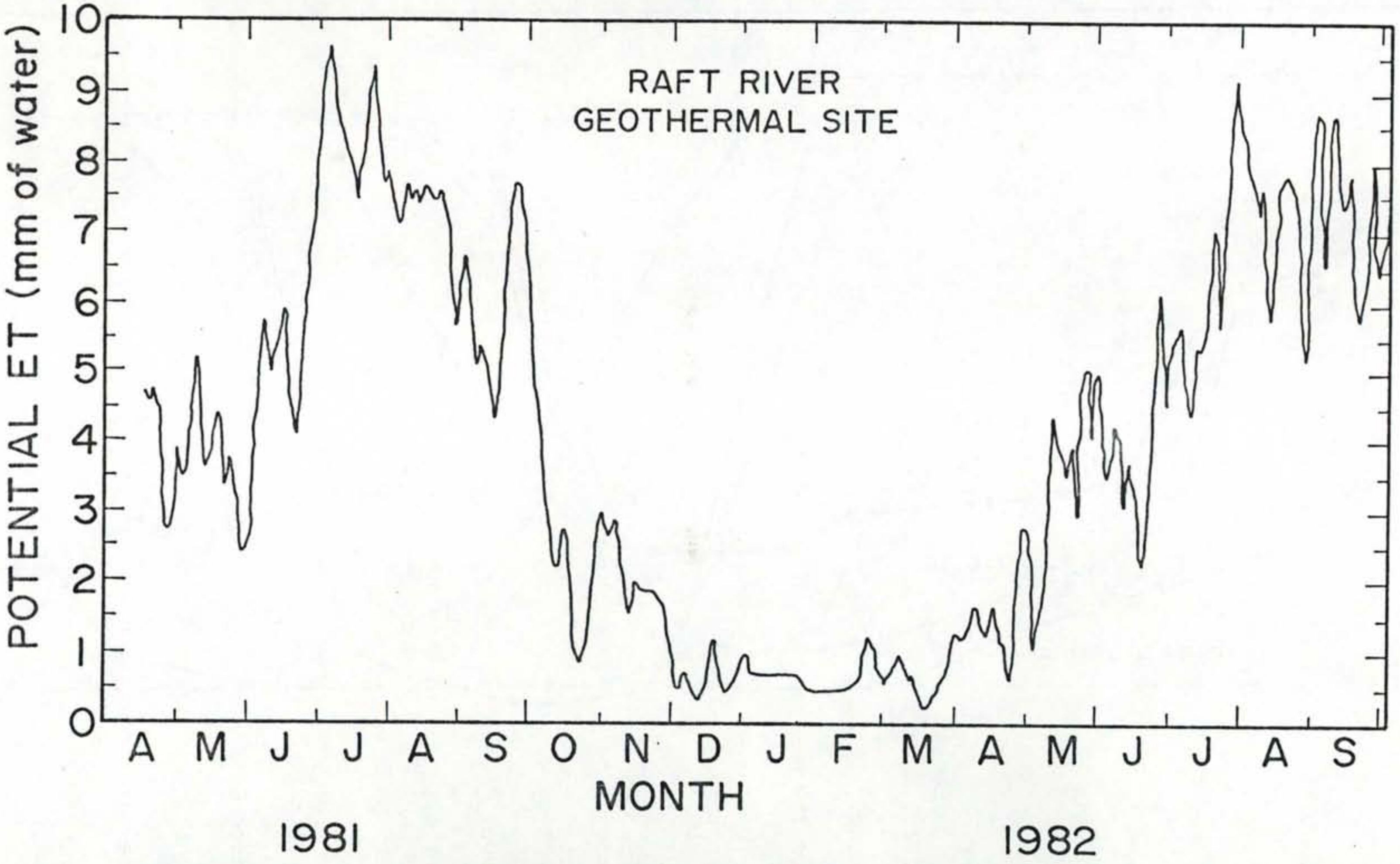

Figure 14. Potential evapotranspiration, Raft River Geothermal Project, 1981-82.

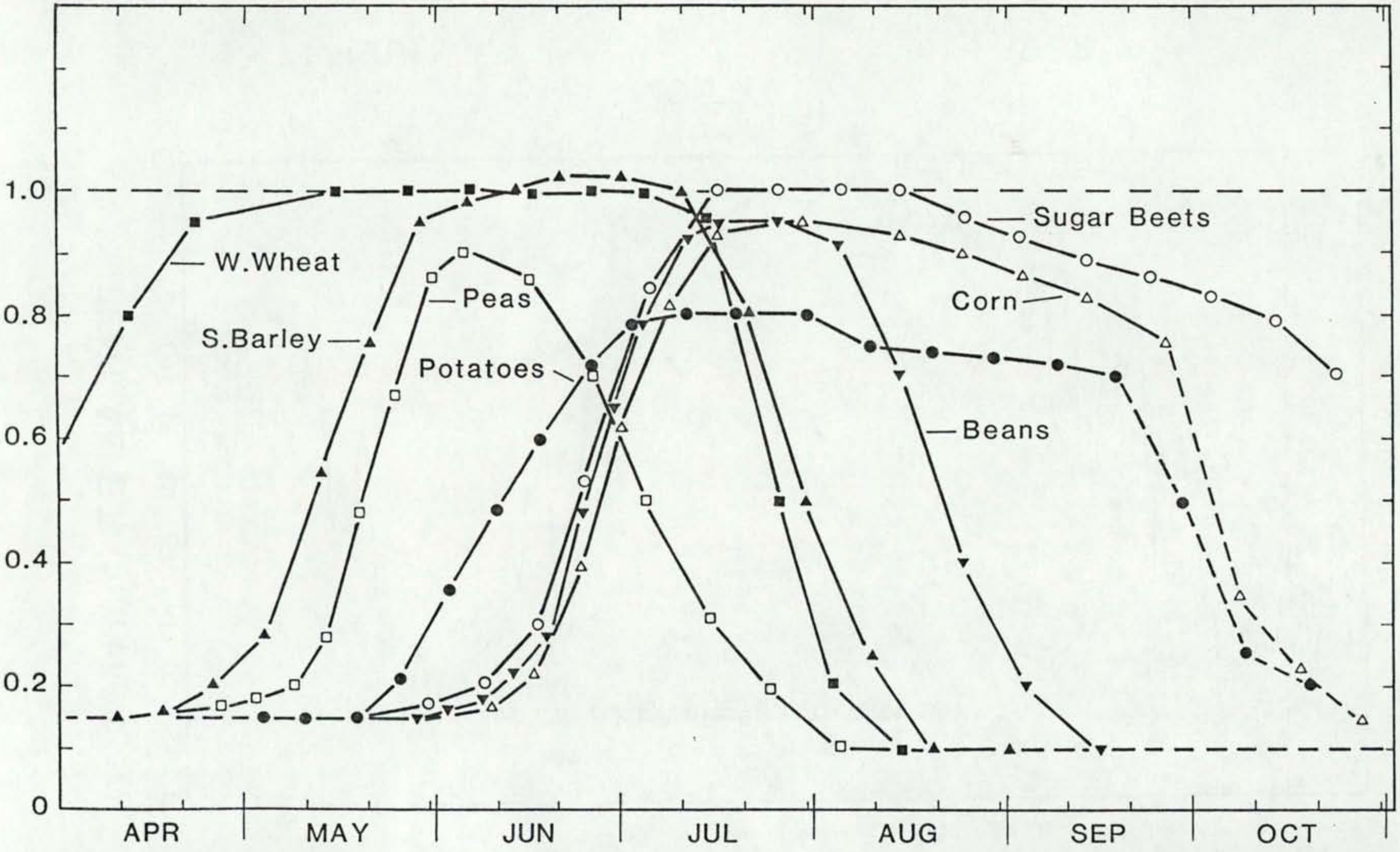

Figure 15. Variations of alfalfa based crop coefficients over the growing season (from Wright, 1982).

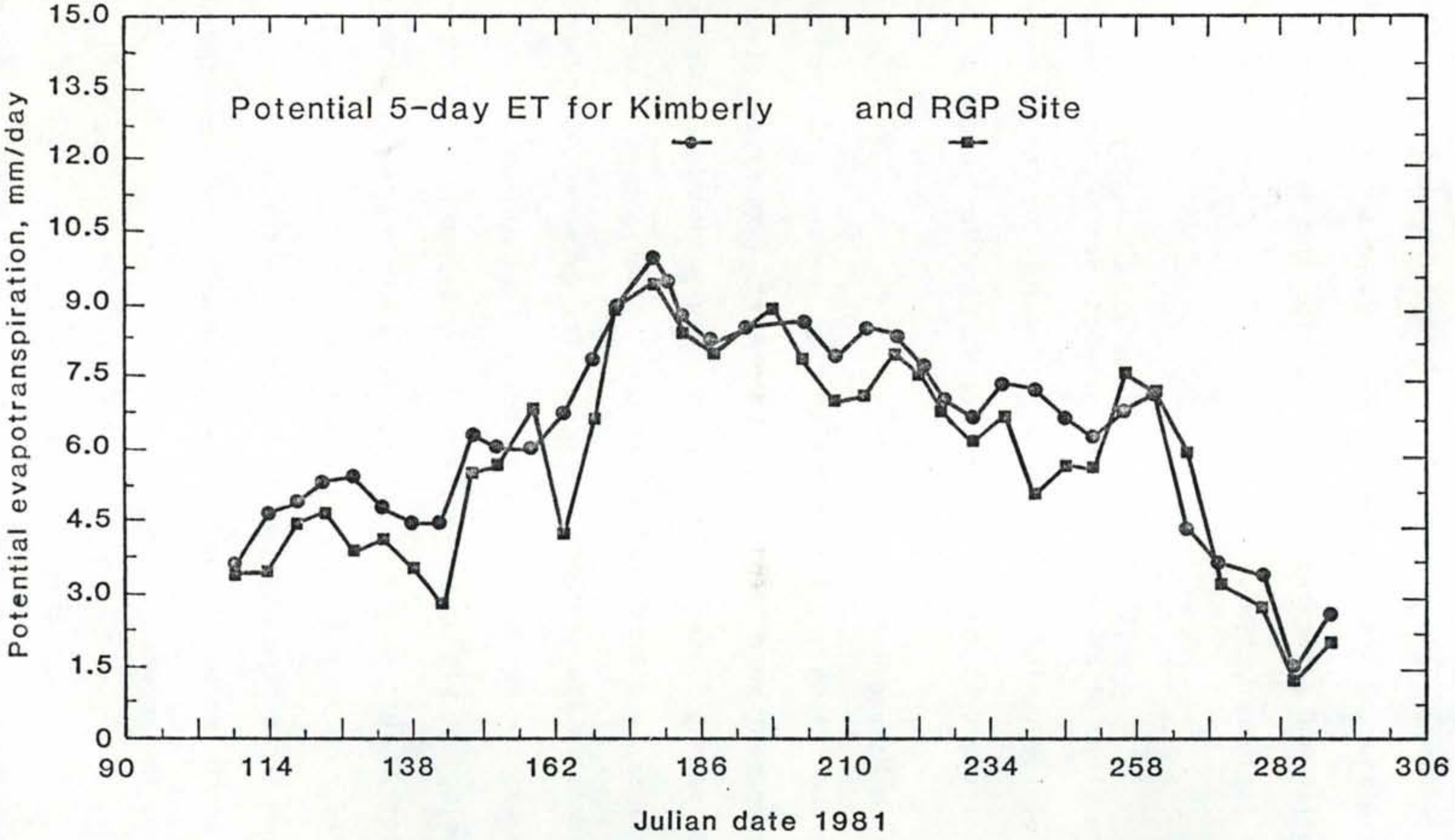

Figure 16. Comparison of estimated potential 5-day evapotranspiration at Kimberly, ID and Raft River Geothermal Project.

During the study period, 414.7 mm (16.32 inches) of precipitation was measured at the RGP site and the estimated potential ET was 2100 mm (83 inches). Each plot received different amounts of effluent to achieve different leaching rates. Table 9 shows the crop, water application and water use for each plot for the period April, 1981 through September, 1982.

Crop Yields

The yield of dry matter from the plots was measured during the summer of 1982. The yields were approximately 9 t/ha (4 tons/acre) for alfalfa and 11 t/ha (5 tons/acre) for the tall wheat grass.

Irrigation Management Problems

In conducting the irrigation studies, several problems associated with management were identified. Crop establishment was severely impacted on the border systems. The seeds germinated, however, the young plants/seedlings died. This problem was probably due to submergence in the geothermal effluent for extended periods. The problem was not encountered on furrow irrigated areas.

During the winter months, the soil was frozen to depths of .68 m (2.2 feet). This amount of frost would require careful management of the irrigation during the winter months.

When irrigating with sprinklers, the electrical conductivity was raised approximately 2.0 mmhos due to evaporation before the water contacted the ground surface.

EFFECTS OF EFFLUENT DISPOSAL

The impact of effluent disposal on the water-table aquifer is dependent on the location and area of the disposal site, the

Table 9. Water balance summary for RGP Plots (April 1981 - September 1982).

Plot	Crop	Geothermal Effluent Application (mm)	Total[1] Water Applied	ET			Excess Application (mm)	L.F.
				Crop	Soil	Plot[2]		
				(mm)				
A-1	AL	1610.7	2065.1	1431	928.5	985.5	1079.6	.5
A-2	AL	766.4	1220.4	1439	937.9	1079.7	140.7	.1
A-3	AL	1720.7	2101.6	1434	924.3	1009.8	1268.9	.6
A-4	AL	1432.8	1886.4	1436	910.7	983.1	903.3	.5
A-5	AL	1293.2	1747.1	1437	887.9	950.7	796.4	.4
A-6	AL	1439.8	1893.5	1432	898.9	971.8	921.7	.5
A-7	AL	1402.4	1856.9	1430	895.8	981.8	875.1	.4
A-8	AL	1368.7	1822.3	1436	919.2	962.1	860.2	.4
A-9	AL	1544.8	1998.6	1434	922.3	981.1	1017.5	.5
B-1	AL	1595.8	2049.3	1437	942.2	1207.5	841.8	.4
B-2	AL	1538.5	1992.4	1365	884.8	966.6	1025.8	.5
B-3	AL	1529.1	1983.1	1443	951.2	1220.0	763.1	.4
B-4	AL	954.9	1408.6	1438	928.6	1242.4	166.2	.1
B-5	AL	1372.5	1826.6	1439	936.1	1188.7	637.9	.3
B-6	AL	1415.8	1945.4	1439	933.5	1285.1	660.3	.3
B-7	AL	1453.1	1907.5	1437	954.0	1225.0	682.5	.3
B-8	AL	1592.5	2071.7	1438	951.6	1211.0	860.7	.4
B-9	AL	1535.2	1989.3	1437	950.4	1196.3	793.0	.4
C-1	GR	1530.7	1984.2	1325	946.	1283.1	701.1	.3
C-2	GR	1878.5	2332.2	1325	948.9	1251.5	1080.7	.4
C-3	GR	1521.0	1974.6	1332	968.6	1196.5	778.1	.4
C-4	GR	1754.6	2208.7	1328	955.2	1285.9	922.8	.4
C-5	GR	1887.8	2342.0	1331	958.9	1289.1	1052.9	.4
C-6	GR	1641.7	2095.7	1321	947.4	1205.5	890.2	.4
C-7	GR	1616.7	2070.4	1325	948.7	1241.9	828.5	.4
C-8	GR	1766.7	2220.9	1330	943.9	1199.0	1021.9	.4
C-9	GR	1715.2	2169.5	1433	943.8	1348.7	820.8	.4

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[1] Includes precipitation and carry-over soil moisture.

[2] Crop stands were incomplete in some plots and the A plots were bare during 1982.

ground-water flow rate beneath the site, natural ground-water quality, soil type and depth, and aquifer characteristics. These factors are not only important directly beneath the disposal site but also at all points down gradient.

The effects of disposal may best be evaluated relative to the naturally occurring effects of upward leakage along the faults. Nichols (1979, p. 44) found no significant line or point sources of vertical recharge when analyzed on a flow basis. The water-table contours presented in this or any previous publication do not indicate any large source of vertical recharge near RGP. Temperature and chemical characteristics of the ground water (figures 6 through 10); however, are more sensitive to geothermal recharge and indicate that upward leakage is greater near the power plant than in the rest of the Raft River valley.

The amount of geothermal recharge in the area of the power plant can be roughly estimated based on temperature or chemical changes that occur as the shallow ground water flows through the area. This determination requires estimates of the shallow ground-water flow rate, the water characteristics up-gradient and within the mixing zone, and the corresponding characteristics of the geothermal water.

The analysis was based on ground-water temperature data which was more consistent and available than chemical data. It is assumed that the shallow ground water has a temperature of 10°C before mixing with the geothermal leakage, and a temperature of 25°C after mixing (figure 6). An aquifer section 2 miles wide, shown in figure 17, was assumed to represent shallow ground water flow at the given temperatures. Geothermal leakage was assumed to have a temperature at 140°C. Based on these assumptions of temperature, the calculated upward leakage

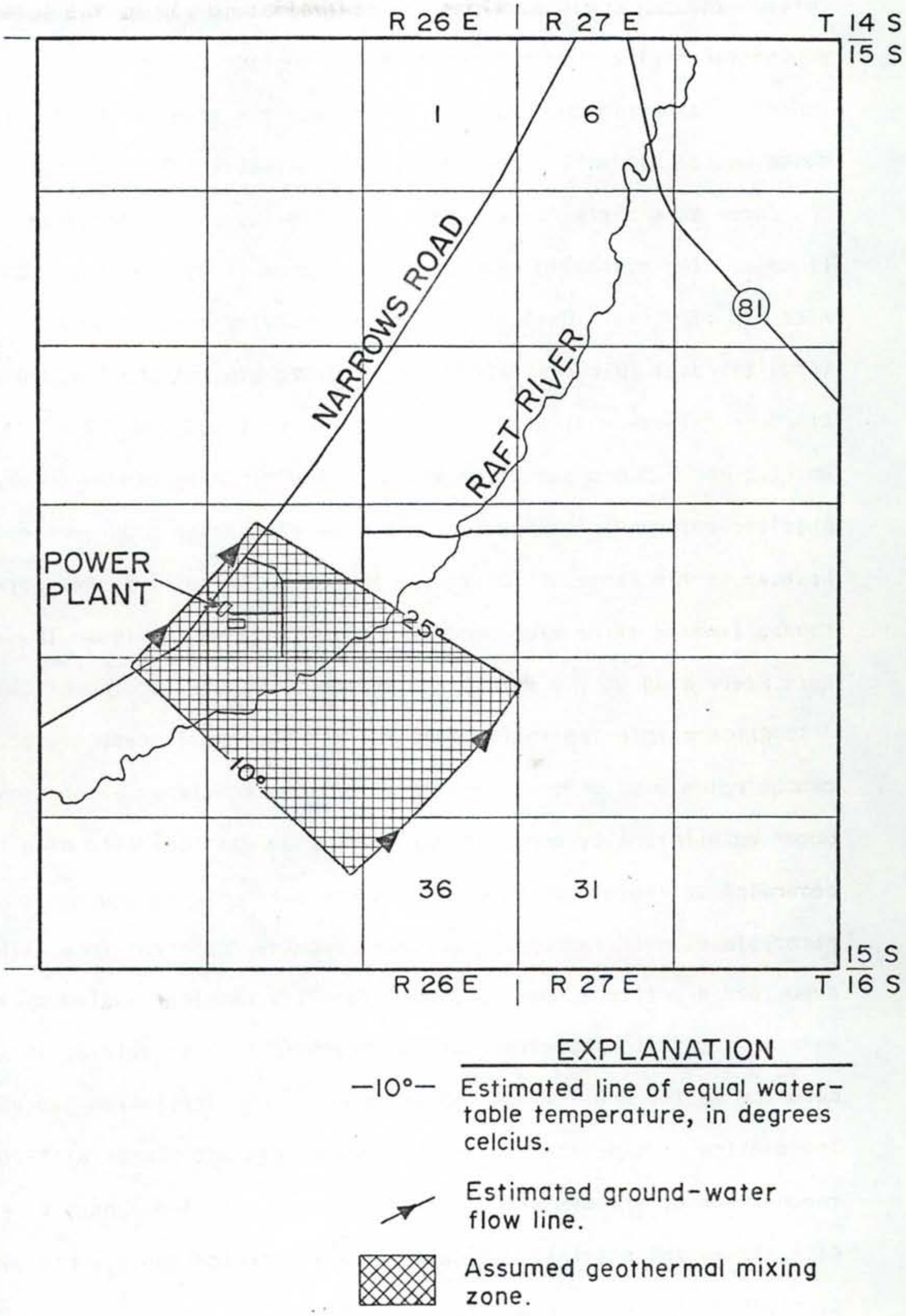

Figure 17. Simplified geohydrologic system for estimating geothermal leakage into shallow aquifer - Raft River Geothermal Project.

between the two cross sections was equivalent to 13% of the lateral ground-water flow into the hypothetical section.

The lateral ground-water flow through the area can be estimated based on the hydraulic gradient and transmissivity in the area, and can serve as a basis for estimation of the amount of geothermal leakage. The hydraulic gradient in the area (figure 5) is about 4.7 m/km (25 ft/mile). Estimates of transmissivity range from 418 m^2/day (4500 ft^2/day) (Nichols, 1979, figure 9) to 2400 m^2/day (26,000 ft^2/day). These estimates yield flow rates of .02 and .13 m^3/sec per km (1.3 and 7.5 cfs per mile) width in the vicinity of the power plant. Geothermal leakage determined as 13% of the ground-water flow is then in the range of .01 to .06 m^3/sec (0.34 to 1.95 cfs) within the 3.22 km (2 mile) wide band of aquifer defined in figure 16.

Evaluation of the effects of effluent disposal are complicated by dispersion within the shallow aquifer and by erratic natural variation of concentrations of contaminants within the aquifer. Dispersion will occur both laterally and vertically from the disposal site at a rate dependent on the structure of the water-bearing formation. Stratification in the upper sediment deposits, apparent from lithology reported in drillers logs, probably inhibits vertical mixing of the aquifer. Erratic reportings of concentrations of soluble salts and fluoride in the shallow aquifer are affected by irrigation and upward leakage from the geothermal aquifer and create additional difficulties in analysis of effects of disposal. With the limited amount of known data, it is not possible to quantitatively predict the effects of disposal on the shallow aquifer.

The effects of injection into the shallow aquifer depend on the number and locations of injection wells and the interval open to the aquifer. The effluent plume may disperse in a somewhat irregular pattern down gradient of the disposal area in response to variations in the aquifer formation and locations of recharge and discharge zones. Stratification may restrict vertical dispersion, consequently the depth of effluent release is important. Assuming injection occurs over the entire aquifer thickness and at multiple points across the 3 km (2 mile) cross section previously described; then the general effects may be expected to be several times more apparent than the effects of geothermal leakage illustrated in figures 7, 8, 10. No quantitative estimate of the effects can be made.

Irrigation using the geothermal effluent will alter the chemical characteristics and quantities of effluent reaching the aquifer. These changes are affected by two basic factors considered in the following analyses. These factors are the effluent application rates and the previous land use.

Irrigation application rates dictate the size of disposal area required. Irrigating alfalfa year-round at the maximum potential evapotranspiration rate of 9 mm/day (0.4 inches/day) results in an annual application of 3.28 m (10.8 feet). Therefore, 149 ha (368 acres) would be required to dispose of the 4.9×10^6 m^3 (4000 acre-feet) of effluent generated annually. Average annual alfalfa evapotranspiration is about 749 mm (29.5 inches) resulting in about 2.5 m (8.3 feet) of deep percolation per year. This is equivalent to a leaching fraction of 0.77. Normal leaching fractions on irrigated lands are estimated to be 0.1 to 0.2.

Irrigation on previously irrigated land will impact the shallow aquifer less than bringing new land under irrigation. Native soluble salts will be leached from the soil profile as the initial surge of excess irrigation water percolates through the soil. Previous research has shown that 300 mm (11.8 inches) of moisture passing any given depth in the soil profile is sufficient to remove native soluble salts above that point (Carter and Robbins, 1978). Assuming an unsaturated soil thickness of 12 m (40 feet), and assuming the concentration of soluble salts throughout the profile remains the same as in the upper 4.6 m (15 feet) of soil, then the native profile above the water table contains about 1277 t/ha (570 tons/acre) of soluble salts. Previous irrigation for many years has probably leached most of the soluble salts from the profile.

Irrigation with geothermal effluent on previously irrigated land will contribute soluble salts to the aquifer at approximately the same rate as applied in the effluent. Significant amounts of salt will neither be deposited in nor removed from the soil profile. The soluble salts contributed to the aquifer under these conditions would be about 11,800 t/year (13,000 tons/year) or 78.4 t/ha/yr (35 tons/acre/yr). The soluble salt concentration of percolate entering the aquifer should be about 3100 ppm. Although concentrations of salt are greater due to evapotranspiration, the total salt loading to the aquifer is the same as achieved by injection. The effects on the aquifer will differ from injection since the effects of the leachate will be concentrated at the top of the aquifer. Vertical mixing is dependent on properties of the aquifer and cannot be accurately predicted with available data.

The effects of salinity on the aquifer will be much greater if irrigation disposal is conducted on land not previously irrigated. Large quantities of native salt would be leached from the soil profile into the aquifer in addition to salts applied in the effluent.

Assuming 1277 t/ha (570 tons/acre) of native soluble salts exist in the soil profile above the aquifer, and that 149 ha (368 acres) are irrigated, then nearly 190,500 metric tonnes (210,000 tons) of native salt will be leached from the soil profile. This is equivalent to the salts applied in 16 years of effluent disposal at a constant rate of .16 m^3/sec (5.5 cfs).

The time required to leach the native soluble salts from the soil profile is dependent on application rate. Assuming that the 12 meter (39 ft) deep vadose zone has a volumetric water holding capacity of 17%, and that 300 mm (11.8 inches) of water percolating through the profile are sufficient to remove nearly all soluble salts; then, 2.4 m (7.8 ft) of deep percolation is sufficient to leach nearly all soluble salts from the soil profile into the aquifer. Since 2.5 m (8.3 ft) of percolation result from one year of application at the prescribed rate, it is estimated that about one year of application is sufficient to leach most of the native soluble salts into the shallow aquifer.

Low rate effluent irrigation of range land will eventually result in leaching large quantities of native salts into the aquifer. To maintain vegetative growth, an accumulation of soluble salts in the root zone must be prevented by leaching. After some unknown amount of time the leachate will enter the aquifer transporting large quantities of native and applied salts. It is unknown what leaching rates would be required and consequently it is not possible to estimate the effects of application.

Fluoride applied in effluent will be at least partially removed in the soil profile before reaching the aquifer. The extent of removal has been indicated as being initially greater than 90% (Tracy and others, 1984). It is unknown what total loading the soil will withstand before concentrations increase in the leachate.

CONCLUSIONS

It is difficult to quantitatively evaluate the chemical response of the aquifer to salts applied in the effluent and leached from the soil profile. Estimates of upward leakage from the geothermal system in the vicinity of the RGP suggest that the proposed disposal rate of .16 m^3/sec (5.5 cfs) of effluent presents a significant hazard relative to the natural geothermal leakage. The salt introduced by injection or high rate irrigation of previously irrigated lands, however, is probably insignificant relative to the amounts of native soluble salts leached into the aquifer from the thousands of acres of land currently irrigated in the Raft River valley. Salinity hazard is minimized by disposing of effluent by means of direct injection or by high-rate irrigation of previously irrigated lands. It should be remembered that any new land brought under irrigation, regardless of water source, will contribute 1300 t/ha of salt to the shallow aquifer. Moving non-geothermal water from previously irrigated land to new land will also have this same salt loading effect.

Fluoride concentrations of the shallow aquifer may be locally affected by effluent disposal. Direct well injection is likely to cause the greatest increases in fluoride concentration. Irrigation disposal techniques will cause less and possibly no measurable increase in the fluoride content of the shallow aquifer.

If disposal is to be achieved by one of the methods evaluated (based on impact to the shallow aquifer) it is recommended that disposal be by means of high rate application to previously irrigated land. High rate irrigation minimizes the fluoride and salinity impacts upon the shallow aquifer.

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