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GEOLOGICAL SURVEY

APPRAISAL OF POTENTIAL FOR INJECTION-WELL RECHARGE OF THE HUECO BOLSON WITH TREATED SEWAGE EFFLUENT-- PRELIMINARY STUDY OF THE NORTHEAST EL PASO AREA, TEXAS

By Sergio Garza, Edwin P. Weeks, and Donald E. White

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the Texas Department of Water Resources

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METRIC CONVERSIONS

Most units of measurements used in this report are inch-pound units. For those readers interested in using the metric system, the inch-pound units may be converted to metric units by the following factors:

From	Multiply by	To obtain
acre-foot	1233	cubic meter
acre-foot per year	1233	cubic meter per year
foot	0.3048	meter
foot per day	0.3048	meter per day
foot per mile	0.189	meter per kilometer
foot per year	0.3048	meter per year
gallon per minute	0.06309	liter per second
mile	1.609	kilometer
square mile	2.590	square kilometer

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PRELIMINARY STUDY OF THE NORTHEAST EL PASO AREA, TEXAS

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ABSTRACT

The U.S. Geological Survey, in cooperation with the City of El Paso and the Texas Department of Water Resources, made a preliminary study of specific factors related to recharging the Hueco bolson in the northeast El Paso area with treated sewage effluent. The city is interested in the location and spacing of injection wells relative to (1) maintaining the injected effluent in the aquifer for a predetermined amount of time (residence time) before it is pumped out, (2) recovery by pumping of as much of the injected effluent as possible, and (3) the long-term effects of injection on water-level declines.

A two-dimensional digital-computer model was developed to project short-term hydraulic gradients under various conditions of pumping and injection. A corresponding range of interstitial velocities (294-773 feet per year) was estimated by assuming idealized piston-type flow. These velocities may be used to plan the location and spacing of production and injection wells under assumed time factors related to the required residence time for the injected water.

The injection sites were selected near a proposed sewage-treatment facility in an area that will allow flexibility in the locations of the production and injection wells. Maximum 20-year declines of about 35 feet were projected for areas several miles west and southwest of the facility under anticipated injection and pumping rates.

The proposed injection water will require strict water-quality controls, which may involve chlorination and the removal of suspended solids. Mixing of the proposed injection water with the native ground water probably will not clog the aquifer by mineral precipitation. The relatively large concentrations of sodium in the injection water may reduce the hydraulic conductivity of the clay layers in the aquifer, but the permeable sands should not be seriously affected. Plans for an artificial-recharge program need to include an experimental installation to evaluate the system under field conditions.

INTRODUCTION

The Water Utilities and Public Service Board of the city of El Paso requested the U.S. Geological Survey, in cooperation with the Texas Department of Water Resources, to study some specific factors related to recharging the Hueco bolson in the northeast El Paso area with treated sewage effluent. Specifically, the city is interested in the location and spacing of injection wells related to (1) maintaining the injected effluent in the aquifer for a predetermined period of time (required residence time) before it is pumped out for use, (2) recovery by pumping of as much of the injected effluent as possible, and (3) the long-term effects of injection on water-level declines.

A digital-computer model was developed from the regional digital model of the Hueco bolson (Meyer, 1976) to provide information related to the following:

(1) Location and spacing of injection and production wells to give the injected water a predetermined residence time within the aquifer as required by the U.S. Environmental Protection Agency;

(2) potentiometric-head declines as a result of projected long-term pumping and injection; and

(3) location of injection and production sites relative to the greatest potential for recovery of the injected water.

The physical and chemical properties of the injected water were considered with respect to problems associated with well-bore and formation clogging. The design and completion of the injection wells were considered in relation to problems of well development, air entrainment, and anticipated injection rates. The quality of injection water was examined in relation to its compatibility with the aquifer materials and with the native ground water.

THEORETICAL MODEL PROJECTIONS

The digital-computer model developed for this study is a part of the regional digital model developed for simulating ground-water pumping from the Hueco bolson in Texas, New Mexico, and Mexico (Meyer, 1976). The basis for the model is a finite-difference model developed by the U.S. Geological Survey for aquifer simulation in two dimensions (Trescott, Pinder, and Larson, 1976). The location and extent of the modeled area, the grid system, the existing wells, and the site of the proposed sewage-treatment plant and oxidation ponds (source of injection water) are shown on plate 1.

The modeled area was divided into discrete units (nodes) by a rectangular grid network of 27 rows and 30 columns with variable spacing ranging from 0.25 to 2 miles. The two outside rows (1 and 27) and the two outside columns (1 and 30), which represent no-flow boundaries around the borders of the rectangular model, are not shown on plate 1. The hydrologic properties within each node were assumed to be constant, and potentiometric head in the model was simulated at the center of each node. Water-table conditions were simulated in the modeled area, which is part of the mesa area described by Meyer (1976, p. 6). The aquifer thickness within the modeled area varies between 0 to almost 1,000 feet; the average is about 400 feet. Values of hydraulic conductivity range between 0 and about 100 feet per day; the average is about 44 feet per day. Values ranging between 0.15 and 0.22 were used for specific yield in model simulations; the average was about 0.2. The values of these hydrologic properties were based on those values used by Meyer (1976), who derived them from average results of aquifer-test data plus adjustments through model calibrations.

The four boundaries imposed on the rectangular model were no-flow or impermeable boundaries, which were required around the border of the model as a computational expediency. The western no-flow boundary was the only one representing a physical boundary, the Franklin Mountains to the west. The north, east, and south boundaries were located far enough from the area of interest (center of the model) so that their effect during most simulations was minimal. The effect of these latter artificial boundaries were checked during long-term simulations. The 20-year simulations appear to be affected somewhat. However, for purposes of most of the theoretical projections in this study, the model size appears to be adequate.

One-Year Simulations

The purpose of the 1-year simulations in this study was to determine head gradients under various conditions of pumping and injection, so that the rates of movement in the interstices of the bolson deposits could be estimated. These estimates of interstitial velocity may be used to determine the location of injection wells, relative to production wells, for the purpose of retaining the injected water within the bolson aquifer for a predetermined period of time.

The following equation is a form of the basic Darcy equation used in this study to estimate average interstitial velocity:

$$v = 0.0691\ K\ I/p \qquad (1)$$

where v = average interstitial velocity, in feet per year;

K = hydraulic conductivity, in feet per day;

I = hydraulic-head gradient, in feet per mile; and

p = effective porosity (percent, as fraction).

Velocities derived from this equation reflect an idealized piston-type flow, and hydrodynamic dispersion caused by the unknown degree of heterogeneity of the bolson material is not represented. A study of the effects of the heterogenous bolson deposits is beyond the scope of this report.

The conditions of the 1-year (360-day) well-injection simulations in an area that is 1 to 2 miles northwest of the proposed sewage-treatment plant and oxidation ponds (plate 1) are summarized in table 1. The annual well-field pumping rates used in the simulations represent either the 1977 rate (28,550 acre-feet per year) or twice the 1977 rate (57,100 acre-feet per year). The existing wells (plate 1) compose the well field, and the existing potentiometric head was that at the end of 1977. Injection was simulated at one, two, and six nodes and the rates varied between 500 and 6,000 gallons per minute (800 to 9,700 acre-feet per year) for each node. Node 16-15 for example, is the intersection of row 16 and column 15 in the grid network (plate 1). A potentiometric-head rise or decline at either or both observation nodes 16-23 and 20-23 is shown in table 1 following a simulated period of 360 days. The potentiometric-head differences at these nodes, which are also injection sites, do not include any head losses related to the frictional effects around the well bore.

Table 1.--One-year well-injection simulations

Simulation number	Well-field pumping rate (acre-feet/ year)	Injection sites		Injection rate (gallons/ minute)		Simulated head rises(+) and declines(-) (feet)		Simulated conditions between observation node and production well	
		Number	Nodes (row-column)	Per node	Total	Observation node 16-23	Observation node 20-23	Gradient (feet/mile)	Average interstitial velocity (feet/year)
1	28,550	6	16-15, 16-19, 16-23	500	3,000	+2.4		17	294
			20-15, 20-19, 20-23				+1.4	15	223
2	57,100	6	16-15, 16-19, 16-23	500	3,000	-.3		24	415
			20-15, 20-19, 20-23				-2.4	18	267
3	28,550	6	16-15, 16-19, 16-23	1,000	6,000	+8.3		20	345
			20-15, 20-19, 20-23				+6.9	19	282
4	57,100	6	16-15, 16-19, 16-23	1,000	6,000	+5.6		26	449
			20-15, 20-19, 20-23				+3.0	22	327
5	28,550	2	16-23	1,500	3,000	+10.2		26	449
			20-23				+8.2	22	327
6	57,100	2	16-23	1,500	3,000	+7.5		33	570
			20-23				+4.5	26	386
7	28,550	2	16-23	3,000	6,000	+23.5		37	639
			20-23				+20.3	33	490
8	57,100	2	16-23	3,000	6,000	+20.8		44	760
			20-23				+16.6	37	550
9	28,550	1	20-23	3,000	3,000		+16.4	30	446
10	57,100	1	20-23	3,000	3,000		+12.7	34	505
11	28,550	1	20-23	6,000	6,000		+36.1	48	713
12	57,100	1	20-23	6,000	6,000		+32.5	52	773

Hydraulic gradients (feet per mile) at the end of each simulation were computed between each observation node (16-23 and 20-23) and the nearest production well southwest of the observation node (plate 1). The regional direction of ground-water movement in the area is generally southwesterly, and the computed gradients for the conditions indicated result in the maximum or near maximum gradients in the vicinity of each observation node. The velocity equation above is used with hydraulic conductivity values of 50 feet per day (node 16-23) and 43 feet per day (node 20-23) and an effective porosity of 20 percent to compute the average interstitial velocity for each simulation shown in table 1.

The conditions indicated in simulation number 8 (table 1), for example, result in computed gradients of 44 and 37 feet per mile at nodes 16-23 and 20-23, respectively. The respective average interstitial velocities would be 760 and 550 feet per year. The nearest production wells southwest of the centers of nodes 16-23 and 20-23 are 0.7 and 0.87 mile, respectively (plate 1).

With the assumption that piston-type flow prevails, and with the indicated conditions of simulation 8 (plate 1), water injected at the center of node 16-23 will remain underground for nearly 5 years before it is pumped out through the nearest production well. Water injected at the center of node 20-23 will have a residence time of more than 8 years. With the conditions indicated in simulation 12, the injected water will have a residence time of nearly 6 years. These examples illustrate estimates of residence time for the one- and two-node simulations, which reflect the relatively large interstitial velocities for the simulations given in table 1.

The city of El Paso has indicated the need for criteria to space and locate production and injection wells because of regulations related to maintaining the injected treated sewage effluent in the aquifer for a predetermined period of time (required residence time). Estimates of residence times, such as in the preceding simulations, may be used with required residence times to obtain residence-time factors that could be used as the criteria sought by the city. For example, if the required residence time is 1 year, approximate residence-time factors of 5 and 8 may be obtained under the conditions illustrated for each respective node, 16-23 and 20-23, in simulation 8.

The residence-time factor is defined here as the ratio of residence time computed under piston-type flow conditions to required residence time. An assumed residence-time factor, as related to a particular required residence time for the injected water, may then be used to plan the spacing and location of production and injection wells.

The phenomenon of hydrodynamic dispersion is related mainly to the nature of the pore system of the aquifer and to the flow of the fluid (Bear, 1972, p. 580-581). The Hueco bolson consists of unconsolidated deposits of interbedded clay, silt, sand, and gravel (Meyer, 1976). Therefore, the pore system could be implied to have a high degree of heterogeneity, and the results of this study may not reflect the actual flow conditions. For preliminary planning, large residence-time factors could be used; for long-range plans, a solute-transport model including the simplified aspects of hydrodynamic dispersion would be very useful.

Long-Term Simulations

Long-term projections of potentiometric head were made to assess the effects of artificial recharge on water-level declines. Simulations were made for an area of about 16 square miles near the proposed sewage-treatment plant. The potentiometric surface in the Hueco bolson in January 1978 (fig. 1) and the 1977 pumpage were used as the initial conditions for the long-term simulations. The projected altitudes of the potentiometric surface in the Hueco bolson in this area after 10 and 20 years, respectively, of injection through wells at four sites, nodes 16-19, 16-23, 20-19, and 20-23 are shown on figures 2 and 3. The annual injection rate was 8,950 acre-feet, or about 2,240 acre-feet per node, for the first 10 years (fig. 3), and 11,770 acre-feet, or about 2,940 acre-feet per node, for the second 10 years (fig. 3). The annual well-field pumping rate that was used in the simulations was nearly 33,000 acre-feet for the first 10 years and nearly 43,000 acre-feet for the second 10 years. The pumpage of the well field was 28,550 acre-feet in 1977.

Rises in water levels (potentiometric head) of a few feet are projected at sites 16-23 and 20-23 (fig. 2) after the first 10 years; the projected declines range from a few feet near the injection sites to as much as 20 feet in the northwest part of the area. The declines projected for the next 10 years range from about 4 feet at injection site 16-23 to about 35 feet in the southwest part of the area (fig. 3).

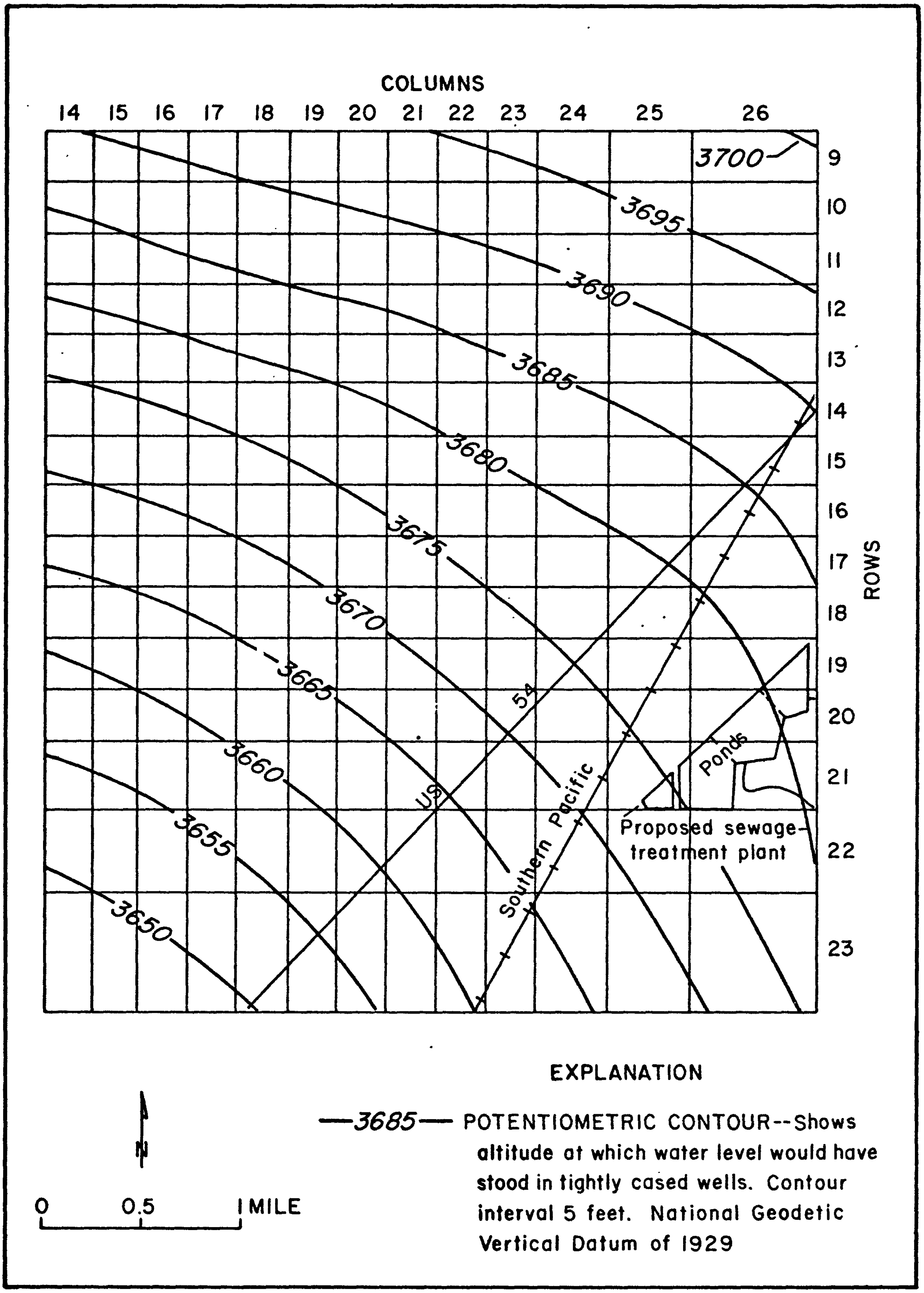

FIGURE 1.-Altitude of the potentiometric surface in the Hueco bolson in the vicinity of the proposed sewage-treatment plant, January 1978

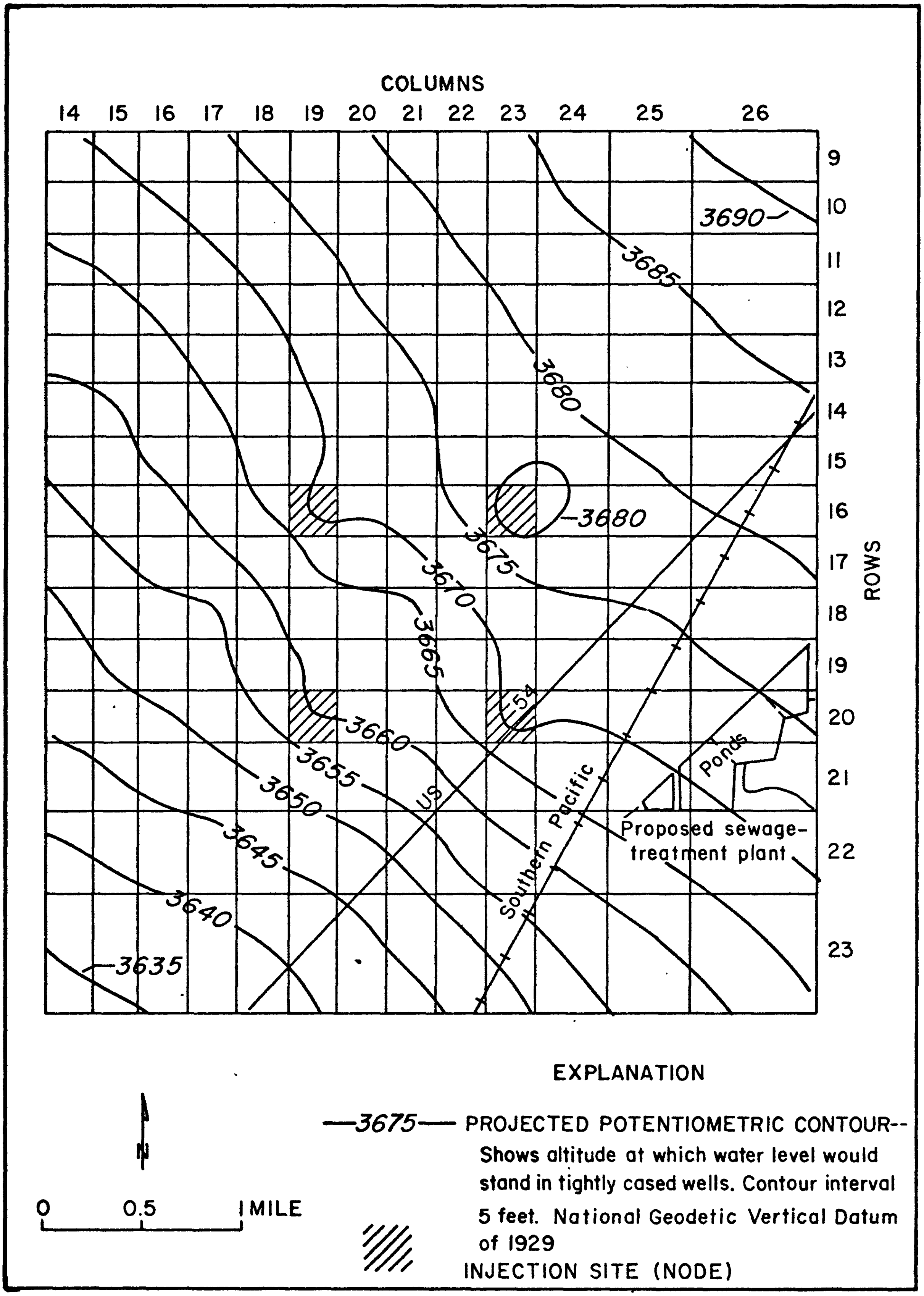

FIGURE 2.-Altitude of the projected potentiometric surface in the Hueco bolson after 10 years of well injection at four sites in the northeast El Paso area

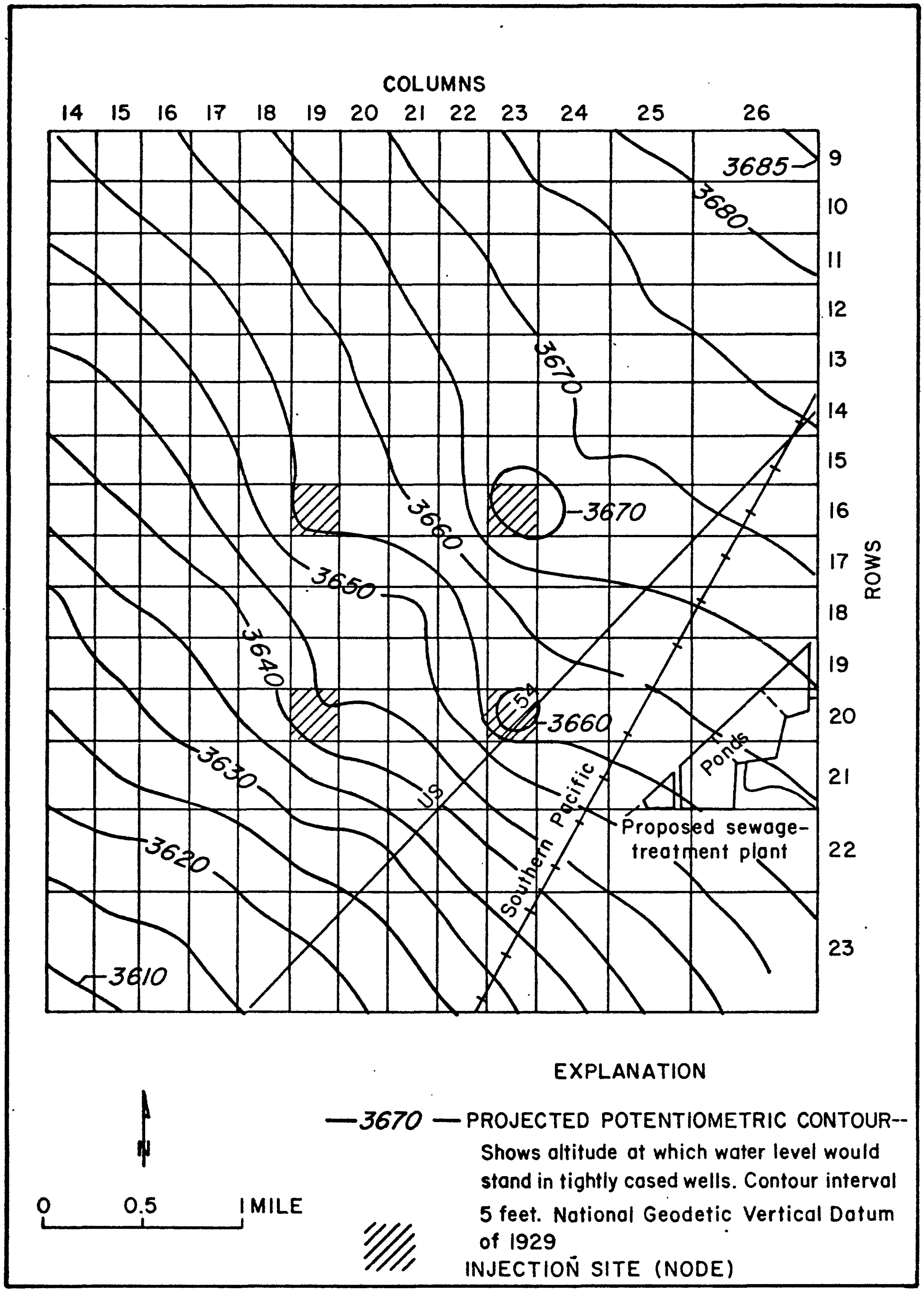

FIGURE 3.-Altitude of the projected potentiometric surface in the Hueco bolson after 20 years of well injection at four sites in the northeast El Paso area

The time periods and the injection and pumping rates for the simulations shown on figures 4 and 5 are identical to those on figures 2 and 3. The difference is that injection was divided between two nodes (16-23 and 20-23) instead of four. The projections again were limited to the 16-square-mile area about the injection sites.

After simulation of the first 10 years of injection and pumping, rises of more than 10 feet would occur at the injection sites, and declines would range from a few feet near the injection sites to more than 20 feet in the northwest part of the area (fig. 4). After the next 10 years, rises at injection sites 16-23 and 20-23 would be 10 and 2 feet, respectively; declines would range from several feet near the injection sites to more than 35 feet in the southwest part of the area (fig. 5).

The main purpose of these long-term simulations is to show only the range of water-level declines that may be expected in a relatively small area under assumed stresses of pumping and injection. The need for more precise projections will require a better definition of these stresses and the development of a larger model than the one used in this study. Information on actual injection tests and additional observation-well data will be helpful.

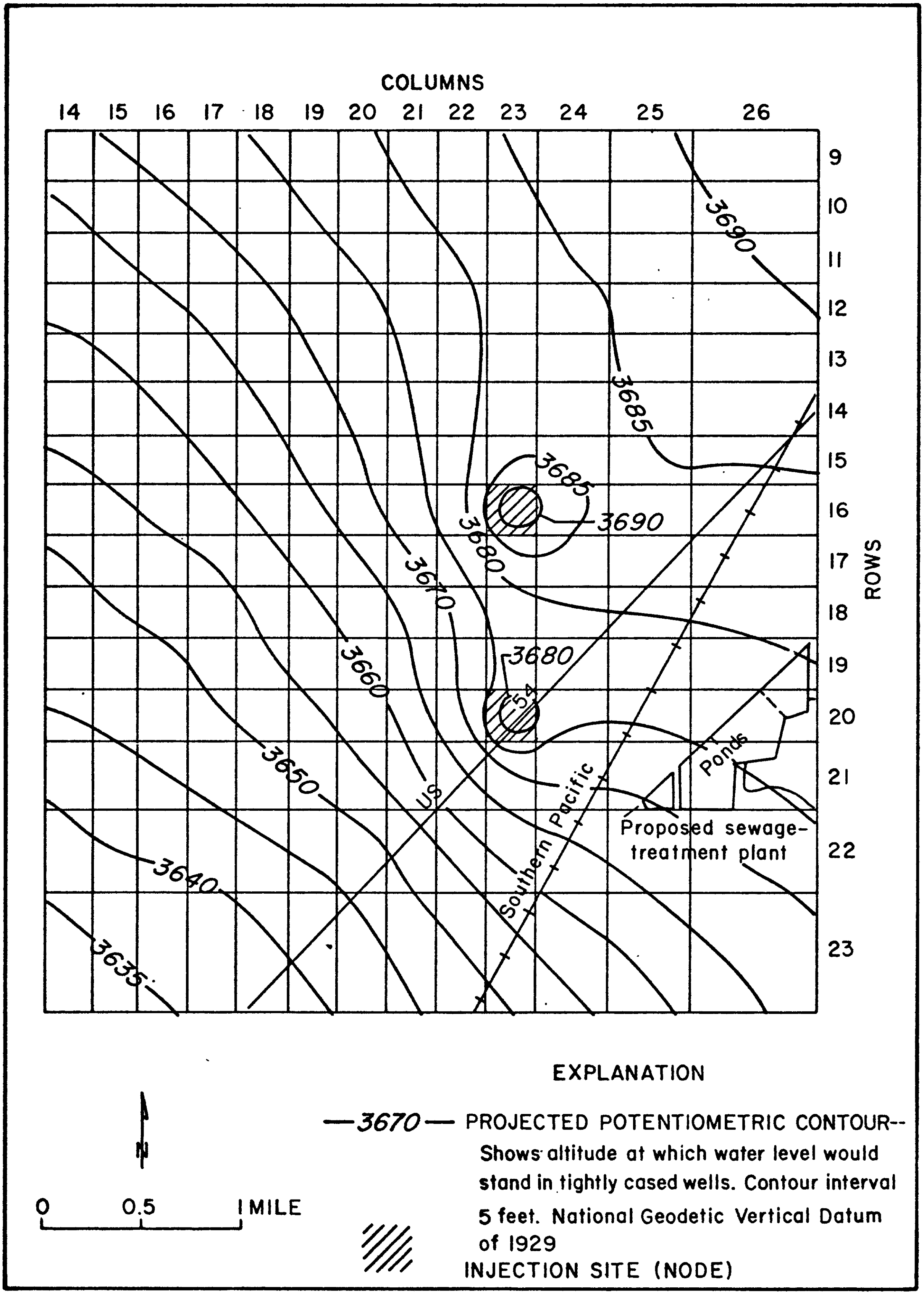

FIGURE 4.-Altitude of the projected potentiometric surface in the Hueco bolson after 10 years of well injection at two sites in the northeast El Paso area

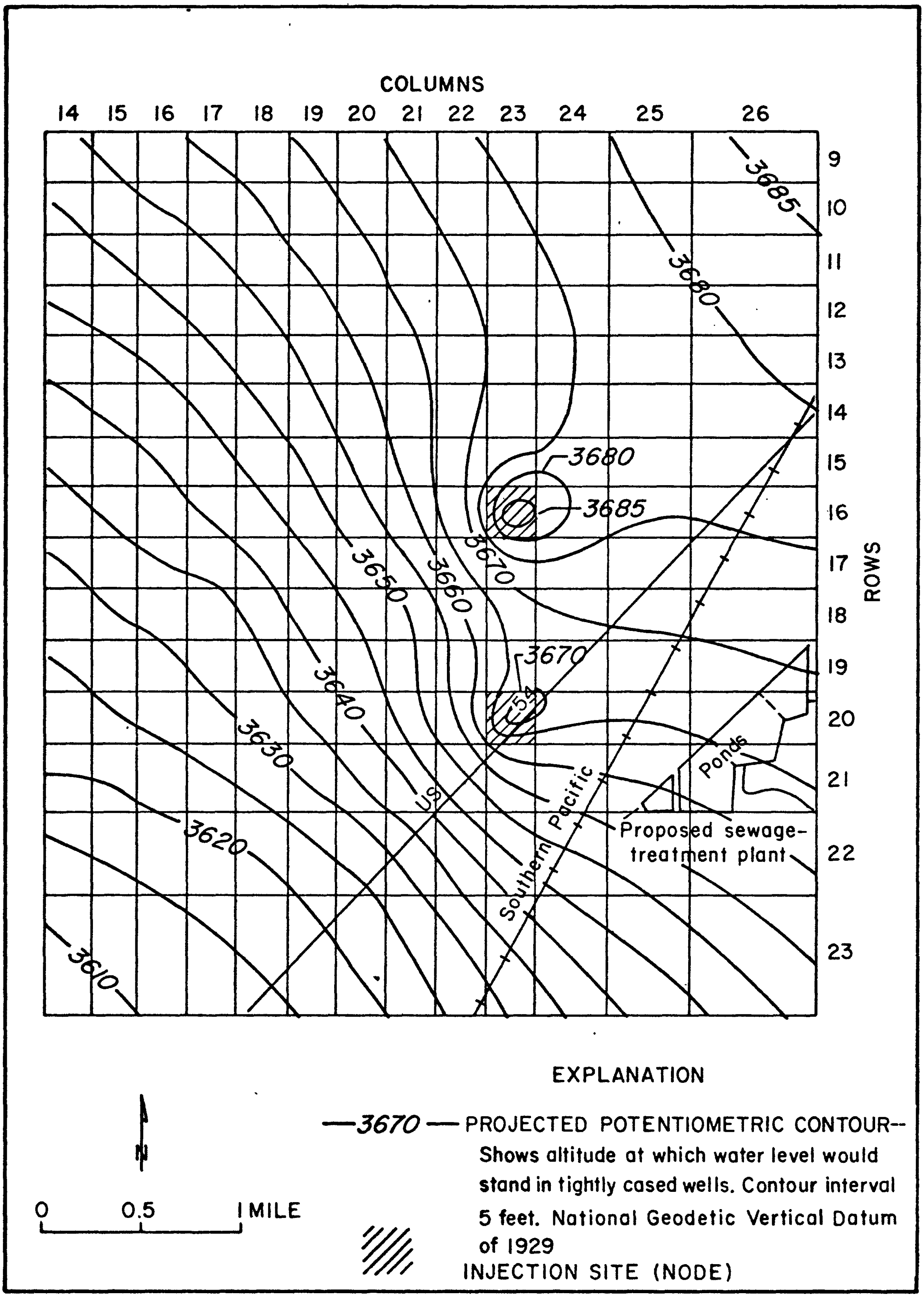

FIGURE 5.-Altitude of the projected potentiometric surface in the Hueco bolson after 20 years of well injection at two sites in the northeast El Paso area

The injection sites used in the simulations were located in proximity to the proposed sewage-treatment plant, in consideration of the obvious economic advantages. The few existing pumping wells in the area will allow flexibility in the location of injection sites and other production wells relative to the potential for recovering a large part of the injection water. No additional criteria have been developed to define what constitutes favorable conditions to recover all or most of the injected water. Many areas within the northeast El Paso area appear adequate for this purpose; however, additional studies may be needed to confirm this observation.

POTENTIAL FOR CLOGGING OF THE INJECTION WELLS AND AQUIFER

Physical Effects

Most problems associated with artificial-recharge operations arise from physical clogging of the well screen and the aquifer around the well bore. Suspended solids in the injected water, even in very small concentrations, tend to clog the aquifer. Problems of this nature have been experienced during injection of treated sewage effluent into wells tapping the Magothy aquifer of Long Island, New York (Vecchioli, 1972; Vecchioli and others, 1975). The total suspended sediment in some of these experiments ranged from 0.3 to 1.85 mg/L (milligrams per liter) as silica (SiO_2). Although the sands of the Magothy aquifer are finer grained than the deposits of the Hueco bolson, some clogging probably will occur in the northeast El Paso area during injection of effluent containing suspended sediment within the same range of concentration. The effects of such clogging may be minimized by periodically pumping the injection well to clean and redevelop it.

The injection pipe needs to extend below the deepest anticipated water level to avoid cascading water and consequent air entrainment. In addition, positive pressure needs to be maintained everywhere within the injection string to avoid air leaks that might provide a source of entrained air in the injected water. Computation of pipe-friction losses for anticipated injection rates will aid in estimating the proper size of the injection pipe to maintain a positive pressure (Reeder, 1975). A spring-loaded foot valve, which is operable over the range of anticipated injection rates, could also be installed to maintain positive pressure in the injection pipe (Brown, Signor, and Wood, 1978).

The injection capacity will vary with the transmissivity of the aquifer, the efficiency of the injection well, and the quality of the injected water, particularly with regard to suspended solids. Moreover, the efficiency of the injection wells will tend to decrease with time, and probably will need to be redeveloped by pumping. In the case of severe clogging, more drastic redevelopment methods, such as surging, swabbing, or acidizing may be needed.

Bacterial Clogging

Bacterial action can severely clog the injection-well bore if not controlled. However, tests by Ehrlich, Ehlke, and Vecchioli (1972, 1973) indicate that such clogging can be controlled by chlorination. In controlled-injection experiments, such treatment was successful in preventing well-bore and aquifer clogging, despite the fact that some bacteria survived in the aquifer a few feet from the injection well. Moreover, recharge of chlorinated water from Lake Kinnereth in Israel resulted in considerable bacterial action after recharge was halted, although clogging was by suspended organic matter in the recharge water (Rebhun and Schwarz, 1968). In addition, R. C. Prill (U.S. Geological Survey, written commun., 1978) has found that clogging of the surface of a spreading basin being recharged by tertiary-treated effluent occurred in episodes that were closely correlated with intermittent failures of the chlorination system. All of the above evidence indicates that clogging by bacterial action can be avoided or minimized by continuous chlorination of the recharged water.

Chemical-Reaction Effects

The potential exists in artificial-recharge operations for clogging of the well screen or the aquifer by chemical reactions within the injected water, between the injected water and the native ground water, or between the injected water and the aquifer materials. The reactions involving aqueous solutions include mineral precipitation by thermodynamic supersaturation of the solution with respect to a particular mineral.

Chemical analyses of samples of the native ground water in the Hueco bolson and of samples of the proposed injection water from treated sewage effluent are given in table 2. To determine the potential for clogging by precipitation, these analyses were evaluated by use of a mineral solution-equilibrium model (Kharaka and Barnes, 1973). The results indicated that the sewage effluent is undersaturated with respect to calcite ($CaCO_3$). If calcite is present, it would be dissolved from the skeletal framework of the aquifer rather than be precipitated during injection. Analyses for silica were not available for the proposed sewage effluent; therefore, the potential for silicate reactions could not be determined. Iron is present in such small concentrations in the proposed sewage effluent that it should not pose a clogging problem.

The redox potential for the proposed sewage effluent was not determined, but it would be desirable to make this determination and to determine additional chemical parameters, including silica, before a recharge facility is constructed. Although redox reactions are unlikely to cause clogging, the oxidation of pyrite, if present in the aquifer, could result in a lowered pH and mobilization of trace metals, which may adversely affect the quality of the recovered water.

Reactions involving the mixing of the injected water with the native ground water were not considered in this preliminary study. However, computer programs are available to simulate such reactions. These simulations need to be made before final plans for artificial recharge are made, and need to include data on silica and on the redox potential for both waters.

Table 2.--Chemical analyses of the native ground water in the Hueco bolson and the proposed injection water from treated sewage effluent[1]

	Native ground water from the Hueco bolson	Treated sewage effluent
silica	38 mg/L	38 mg/L
calcium	45 mg/L	35 mg/L
magnesium	11 mg/L	0.5 mg/L
sodium	96 mg/L	165 mg/L
alkalinity (as $CaCO_3$)	129 mg/L	100 mg/L
chloride	65 mg/L	90 mg/L
sulfate	54 mg/L	100 mg/L
nitrogen	<2.1 mg/L	1.5 mg/L
iron	<0.1 mg/L	0.05 mg/L
manganese	0.01 mg/L	0.005 mg/L
hardness (as $CaCO_3$)	158 mg/L	89 mg/L
pH	8.1	7.5-8.0
sodium adsorption ratio	3.3	7.2
specific conductance	510 µmhos/cm	840 µmhos/cm
dissolved solids	391 mg/L	650 mg/L

[1] Reported by Parkhill, Smith and Cooper, Inc. (1978).

Samples of the aquifer materials were obtained from the drill bit in an area several miles south of the area of the proposed recharge facility. Analyses of these samples indicate that the clay minerals are predominantly montmorillonite and mixed-layer clays. These minerals possess a layered-lattice structure that permits hydration and cation exchange on the internal as well as the external surfaces of the clay particles. These clays are commonly termed "swelling clays" because the process of hydration and cation exchange results in expansion of the lattice structure. The internal expansion (or contraction) of the lattice varies with the type of clay, and with the dissolved-solids concentration and the ratio of certain cations in the pore water. Therefore, these clay minerals may expand or contract in the presence of water that is different in composition from the native water, and these changes in the volume of the clays will alter the hydraulic conductivity of the aquifer.

Sodium ions are most commonly involved in the reactions that alter the hydraulic conductivity of an aquifer containing clay minerals, but these reactions tend to be counteracted by an increase in the dissolved-solids concentration of the injected water. Therefore, the injection of water that contains sodium, but which has a relatively small concentration of dissolved solids, will commonly reduce the hydraulic conductivity; the injection of water containing a relatively large concentration of dissolved solids will not reduce the hydraulic conductivity.

The relationship between the sodium concentration in water, expressed as the sodium adsorption ratio (SAR) , dissolved-solids concentration, and the reduction in hydraulic conductivity has been extensively studied. McNeal and Coleman (1966) constructed a graph to show the SAR and dissolved-solids concentration at which various soils have a 25-percent reduction in hydraulic conductivity (fig. 6). A plot of the water quality of the effluent that is proposed for injection is also shown on figure 6. This water has a dissolved-solids concentration of 8.8 milliequivalents per liter and an SAR of 7.6, which plots to the right of and above all of the samples tested by McNeal and Coleman (1966) except the Gila clay of New Mexico. Therefore, of the soils tested by McNeal and Coleman, only the Gila clay would have shown a measurable decrease in hydraulic conductivity by exposure to the effluent.

The clay-fraction mineralogy of the various soil samples, as presented by McNeal and Coleman (1966, table 1), is given in table 3. The sample of the Gila clay has a montmorillonite content (product of clay percentage and clay-mineral fraction) of 29 percent, as compared to Waukena clay, which has the next highest value at 12 percent. The values for the montmorillonite content of the samples from the Hueco bolson (table 3) range from 10 to 38 percent.

The sodium adsorption ratio (SAR) is determined by the equation:

$$SAR = \frac{[Na^{+}]}{[([Ca^{++}]+[Mg^{++}])/2]^{\frac{1}{2}}}$$

where the bracketted terms represent the concentration of the ion in milliequivalents per liter.

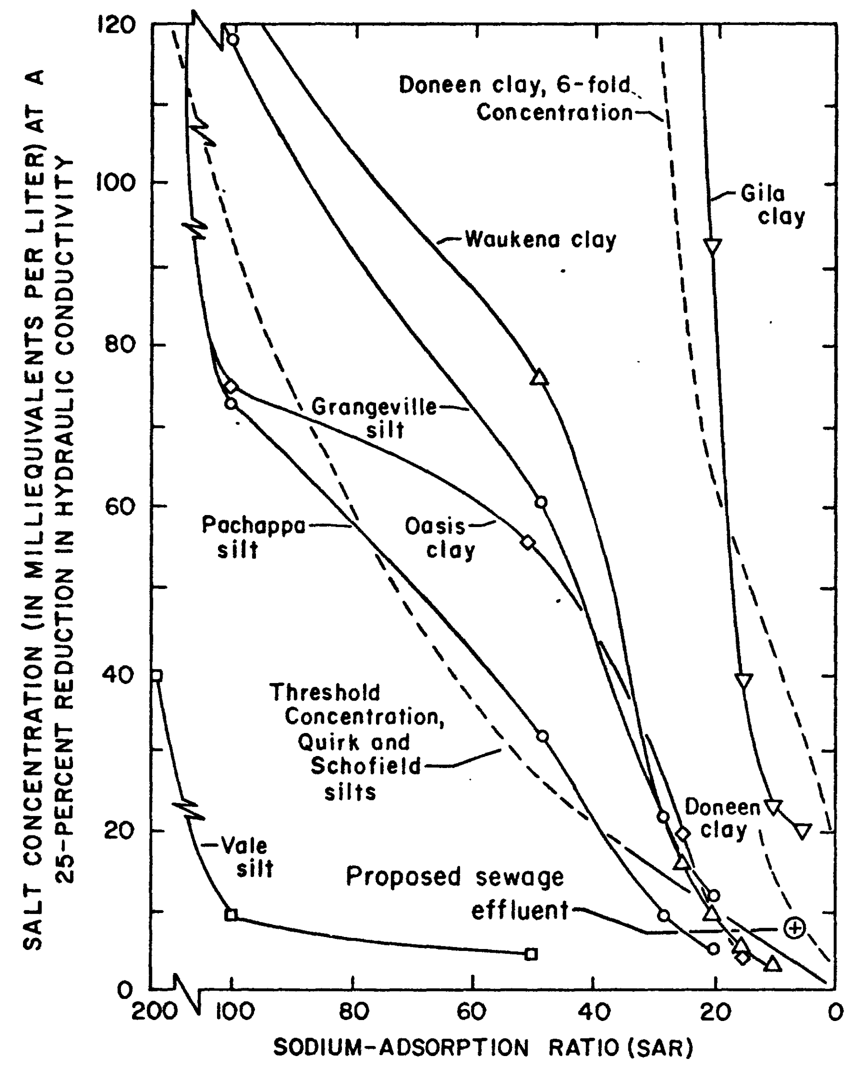

FIGURE 6.-Salt concentrations and sodium-adsorption ratios at which a 25-percent reduction in hydraulic conductivity ocurred for selected soils

Table 3.--Clay-fraction mineralogy of soil samples from various locations in the United States (from McNeal and Coleman, 1966)

USSL No.	Soil type and location	Depth	pH*	CEC*	Surface area	Clay	Clay-fraction mineralogy†						HC*
							Mica	Q+F*	Kaol*	Mont*	Verm*	Chlor*	
		cm			m^2/g	%	%	%	%	%	%	%	
62	Oasis cl, Utah	5-15	7.7	14.8	91	22.5	34	12	3	25	6	19	0.079
68	Vale sil, Oregon	5-15	10.0	40.6	174	11.3	20	6	0	29	13	8	0.200
84	Gila c, New Mexico	5-20	8.0	41.2	272	60.4	25	8	7	48	7	5	0.053
3280	Pachappa sl, Calif.	0-15	7.6	10.3	50	12.6	25	12	9	32	9	8	1.22
3556	Waukena cl, Calif.	12-50	8.7	24.8	145	30.1	25	9	7	40	13	7	0.170
3563	Aiken cl, Calif.	5-30	5.7	16.2	115	45.5	4	2	60	1	4	14	1.18
3585	Grangeville sl, Calif.	30-60	7.7	16.8	89	14 2	21	3	10	31	29	6	6.53

*Abbreviations: pH = pH of saturated soil plaste; CEC = cation-exchange capacity, meq/100 g; Q+F = quartz plus feldspar; Kaol = kaolinite; Mont - montmorillonite; Verm = vermiculite; Chlor - chlorite; HC = average initial hydraulic conductivity to 0.8N salt solution, cm/hour.

†Soils 68 and 3280 also contained 24% and 7% clay-size amphous minerals, respectively, and soil 3563 contained 15% gibbsite.

The mixed-layer clays, which were identified in the material from the Hueco bolson but were not included in the soils analyzed by McNeal and Coleman (1966), may be almost as important in the process of clogging as montmorillonite. Therefore, the total percentage of montmorillonite and mixed-layer clays need to be used for comparison with the data presented by McNeal and Coleman. This combined clay percentage ranges from 28 to 55, or from slightly less to substantially more than that of the Gila clay. On the basis of the combined percentage, clogging of the clay layers would probably occur because of the relatively large sodium concentration in the sewage effluent.

Detailed mineralogical data are not available concerning the content or mineralogy of clay-size materials in the sand beds. However, an estimate of their clay content was made using a gamma-ray log of a test hole drilled about a mile west of the proposed injection-well sites. For the estimates, clay mineral content for the sand beds was computed from the formula:

$$S_c = \frac{C\gamma - S\gamma}{C\gamma - SC\gamma} C_c \qquad (2)$$

where S_c = clay content of sand bed, in percent;

$C\gamma$ = gamma counts for clay bed;

$S\gamma$ = gamma counts for sand bed;

$SC\gamma$ = gamma counts for clean sand; and

C_c = clay content of clay bed, in percent.

A selenite bed occurring at a depth of 4,110 feet in the test hole had the least gamma activity of any bed logged in the test hole, and was assumed to have a gamma activity equal to that of clean sand. Based on this assumption, the ratios of the gamma counts for the sand and clay beds indicate that the clay mineral content of the sand beds is about one-third that of the clay beds. From table 4, that content is about 50 percent, so that the sand beds may contain 15-20 percent clay minerals. On this basis, the sand-bed materials might be expected to react, relative to clogging by clay-mineral expansion, similarly to Oasis clay, Pachappa silt, or Grangeville silt, which have similar clay-mineral contents (table 3). Based on this analysis, the hydraulic conductivity of the sand layers themselves could not be reduced by more than 25 percent (fig, 6), unless the SAR of the sewage effluent were 20 or more, which is much greater than that of the proposed recharge water.

In conclusion, comparison of the clay mineralogy of the clay beds and of inferred clay contents of the sand layers for the Hueco bolson aquifer materials to those for the soil samples tested by McNeal and Coleman (1966) indicate that a significant reduction in hydraulic conductivity might occur within the clay layers due to clay-recharge water interactions; however, the reductions in hydraulic conductivity in the sand layers should not be large. Because the hydraulic conductivity of the clay layers is already relatively small, overall effects of water quality on the transmissivity of the aquifer should be small. Prior to construction of the injection facility, cores of the sand layers would need to be obtained and tested to determine the effects of effluent water quality on changes in hydraulic conductivity because the soils tested by McNeal and Coleman might not be fully comparable to these materials.

Table 4.--Clay-mineral analyses of samples of aquifer materials from the Hueco bolson

Sample number	Well number[1]	Depth (feet)	Weight (percent of total sample)				
			Kaolinite	Illite	Montmo-rillonite	Mixed clay	Total clay minerals
1	JL-49-22-215	442	3	6	36	10	55
2	do.	559	4	3	26	21	54
3	JL-49-13-833	236	7	17	20	16	60
4	do.	1,212	2	2	38	8	50
5	JL-49-13-834	866	8	6	25	21	60
6	JL-49-13-726	288	7	5	16	22	50
7	do.	434	4	4	25	7	40
8	do.	475	6	7	10	18	41
9	do.	856	6	6	16	13	41
10	do.	969	5	5	38	17	65

[1] City of El Paso wells located 7 to 10 miles south of the area of this report.

The importance of strict water-quality controls for the injection water cannot be overemphasized. These controls may involve chlorination and the removal of clogging agents. No attempt has been made in this preliminary study to consider all of the possible chemical reactions that could be detrimental to a successful recharge program. Experimental injections need to be performed as part of additional planning of the artificial-recharge project to evaluate the system under field conditions.

CONCLUSIONS

The preliminary study of the feasibility of recharging the Hueco bolson with treated sewage effluent resulted in the following conclusions:

1. The model simulation analyses indicate that the spacing and location of the injection and production wells can be arranged within the present well-field layout to allow a predetermined residence time for the injected water and to still assure a good recovery potential.

2. Maximum 20-year water-level declines of about 35 feet, under the anticipated injection and pumping rates, are projected for the area near the proposed injection site several miles west of the proposed treatment plant.

3. Because initial clogging of the injection wells and the aquifer at the well bore may be caused by suspended solids in the injected water, more data on the suspended-solids concentration of the proposed effluent are needed.

4. The injection wells need to be constructed and developed similarly to production wells to facilitate redevelopment by pumping. Problems related to air entrainment in the injection water may be resolved through measures designed to maintain positive pressures throughout the injection system.

5. Chemical reactions involving mineral precipitation or dissolution by the proposed injection water probably will cause little clogging of the aquifer system; however, additional data on the silica content and redox potential are needed for both the recharge and the native ground water in order to verify this observation.

6. Although the relatively large sodium concentration of the injection water may reduce the hydraulic conductivity of the clay layers in the aquifer, available evidence indicates that the permeable sands should not be seriously affected.

7. The proposed injection water will require strict water-quality controls, which may involve chlorination and the removal of suspended solids.

8. Experimental injection with the proposed injection water need to be performed to evaluate the system under field conditions.

9. The existing observation-well network (water quality and water levels) need to be expanded to include areas near the oxidation ponds in the vicinity of the proposed treatment plant. This monitoring program is needed to obtain information about the ground-water system prior to any contemplated injection.

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