GEOHYDROLOGY AND SURFACE WATER HYDROLOGY PROGRAMS OF THE EQUITY/DOE BX IN SITU OIL SHALE PROJECT RIO BLANCO COUNTY, COLORADO

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ABSTRACT

The geohydrology and surface water hydrology programs are portions of the Environmental Research Plan (ERP) of the Equity/DOE BX In Situ Oil Shale Project, Rio Blanco County, Colorado. The ERP program includes a surface and ground water monitoring program and a geohydrologic testing program.

The objective of the surface and ground water monitoring program for the Equity/DOE Project is to determine the surface and subsurface effects of project operations in order to estimate the hydrologic impacts which could result from commercial oil shale development. At the present time, the preoperational monitoring program has been completed, and an operational monitoring program is in effect. A post-operational monitoring program will begin at the conclusion of the project. The monitoring program is designed specifically to determine: 1) changes in downstream water quality of Black Sulphur Creek; 2) potential leakage from the process water holding pond; and 3) changes in water quality of the alluvial, upper and lower aquifers.

The objectives of the Equity/DOE geohydrologic tests were to characterize the in situ geohydrologic properties of the upper aquifer, Mahogany zone, and leached zone of the Uinta and Green River formations. This paper presents: 1) single well geohydrologic testing and analysis of the isotropic properties of the upper aquifer; and 2) in situ geohydrologic testing and analysis to determine the 3-dimensional anisotropic properties of the leached zone.

INTRODUCTION

The BX In Situ Oil Shale Project is located in the central portion of the Piceance Creek Basin of northern Colorado (see Figure 1). Within this basin, a section of oil shale bearing rocks in the Parachute Creek member of the Green River Formation, commonly referred to as the "leached" zone, contains very large reserves of oil in place as oil shale. This section of leached zone has enough permeability and porosity to permit in situ retorting of the oil shale without resorting to mining and/or other fracturing techniques. The purpose of this project is to demonstrate the technical feasibility of using superheated steam at 1,000°F and 1500 psig as a heat-carrying medium to retort the oil shale in situ and to provide a mechanism for the recovery of this oil with minimum impact on the environment. More specifically, the oil shale will be retorted by injecting superheated steam into the leached zone through an array of injection wells and recovering the steam/water/oil and gas produced from the leached zone through an array of production wells.

The environmental research plan is designed to determine the surface and subsurface effects of project operations in order to allow estimates of the environmental impacts of commercial oil shale development.

Stream and Aquifer Descriptions

The BX project site is located adjacent to Black Sulphur Creek, which is a tributary to Piceance Creek. There are no diversions from the creek upstream of the project site. Runoff from snowmelt is the primary cause of peak flows, which occur from May through July. Base flow from ground water contributions occurs predominantly from October through April.

The principal aquifers within the project area are the Uinta and Green River formations. The upper aquifer is about 600 feet in thickness and consists of the Uinta formation and upper Parachute Creek member. It is separated from the lower aquifer by the Mahogany zone, an interval of about 100 feet in thickness which acts as a confining horizon. The lower aquifer consists of the leached zone of the Parachute Creek member and is about 540 thick at the project site.

An alluvial aquifer exists adjacent to the project area along Black Sulphur Creek. Alluvial monitor wells in the project area indicate that this alluvium is more than 20 feet thick.

Surface and Ground Water Monitoring Program

The objectives of the surface and ground

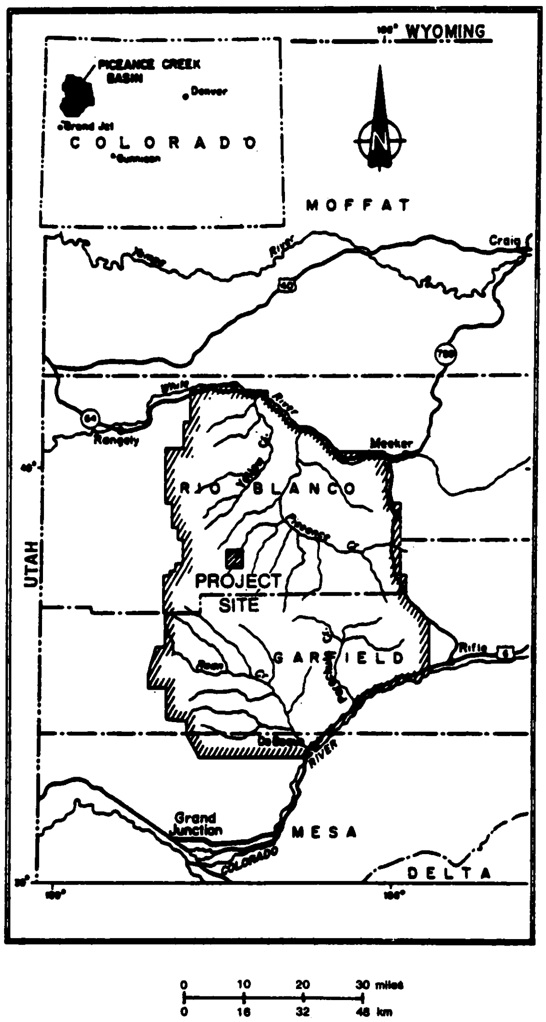

Figure 1. Location Map of Equity/DOE BX In Situ Oil Shale Project.

water monitoring program are to determine the surface and subsurface effects of the research project operations. The program will occur in three phases: pre-operational, operational, and post-operational.

The pre-operational program was designed to determine:

1) Existing stream flow characteristics of Black Sulphur Creek at points located immediately upstream and downstream of the project site;
2) Existing water quality of Black Sulphur Creek at locations immediately upstream and downstream of the project site, and
3) Existing quality of the alluvial, upper and lower aquifers.

The operational program is designed to determine:

1) Changes in downstream water quality of Black Sulphur Creek;
2) Potential leakage from the process water holding pond, and
3) Changes in water quality of the upper, lower and alluvial aquifers.

The data collected are used to assess the degree of potential impacts, to determine any previously unidentified problem areas, and to assess the applicability of on-going monitoring for future work.

The post-operational program is designed to assess the magnitude of hydrologic impacts from the residuals of the research operation. The environmental consequences of a commercial-scale operation will be extrapolated from this information.

Several monitoring stations were established in order to accomplish the objectives of the environmental research plan (See Figure 2).

Flow in Black Sulphur Creek was measured at stations above and below the project site with 18" Parshall flumes. Field measurements of flow, temperature, specific conductance, pH, dissolved oxygen, and turbidity were made at these stations. Also, water quality samples were collected from these stations for laboratory analysis.

Five shallow wells were used to monitor water levels and water quality in the alluvial aquifer. The wells are situated to enable detection of leakage from the water storage pond at the site.

In addition, water quality is monitored in wells completed in the upper aquifer and the leached zone.

Surface and ground water monitoring and sampling at the project site are being conducted by the project operators who are familiar with the objectives of the monitoring program and the proper procedures established for sampling and field measurements. In addition, VTN's environmental specialists make regular visits to the project site to provide quality assurance and control.

<u>Geohydrologic Testing and Analysis Program</u>

The objectives of the geohydrologic testing and analysis program were to establish:

1) Isotropic properties of the upper aquifer;
2) Anisotropic properties of the leached zone, or lower aquifer, and
3) Rate of ground water movement through the upper aquifer, leached zone, and Mahogany zone.

<u>BX Well Field Design</u>

The BX well field (see Figure 3) is designed for injection of superheated steam into eight injection wells. The steam will mobilize oil which will flow both horizontally and vertically to five production wells. This process requires two types of well completion (see Figure 4). The steam injection wells are perforated near the top and bottom of the leached zone at depths of approximately 239 to 258 and 384 to 408 meters. These perforated intervals are referred to as the upper and lower injection horizons. Production wells are completed to the middle portion of the leached zone at depths of approximately 300 to 390 meters. Several wells are completed in the upper aquifer for monitoring water quality and the geohydrologic properties of this aquifer. Throughout the discussion of geohydrologic testing and analysis, all wells are referred to as observation wells.

<u>Geohydrologic Test and Analysis of the Upper Aquifer</u>

On September 7, 1979, a constant discharge test was performed on the upper aquifer by pumping one well at a constant rate of 1.25 gpm. The test was terminated after three hours when the water level dropped below the intake of the pump. The results of the single-well pump test were used to measure the isotropic properties of the upper aquifer. Results indicate a very low transmissivity of 0.05 m^2/day and a horizontal permeability of 1.89 x 10^{-6} cm/sec (see Table 1). These results were about one to three magnitudes lower than regional data compiled by Weeks, et.al. (1974) and were probably affected by poor well completion and inadequate perforation of the well casing. Therefore, this

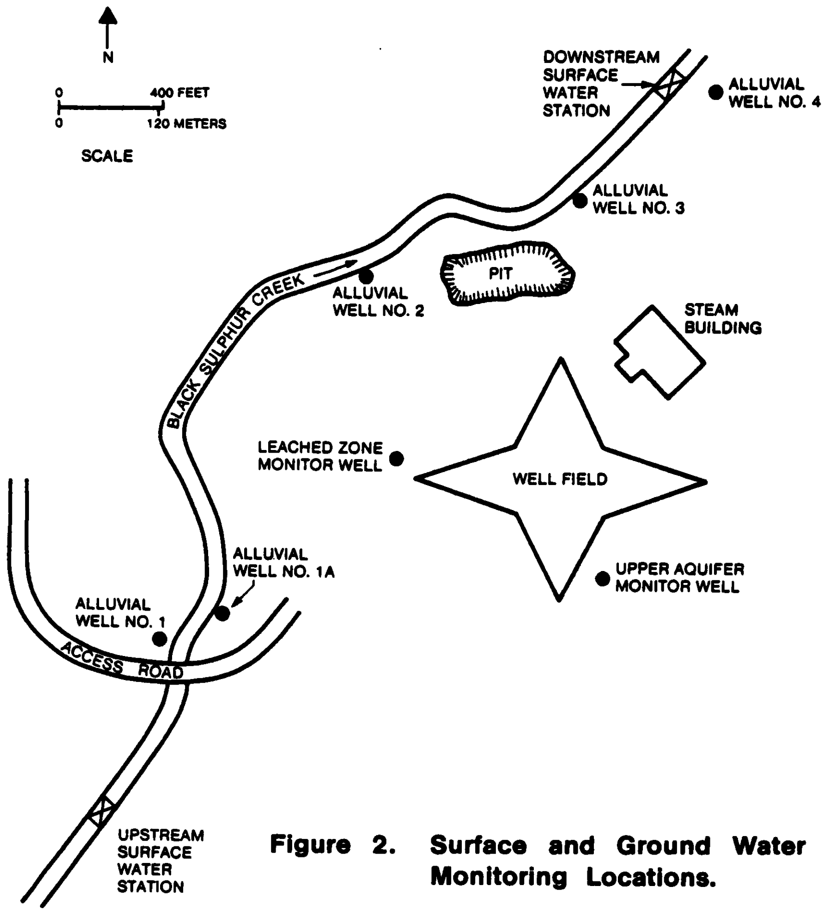

Figure 2. Surface and Ground Water Monitoring Locations.

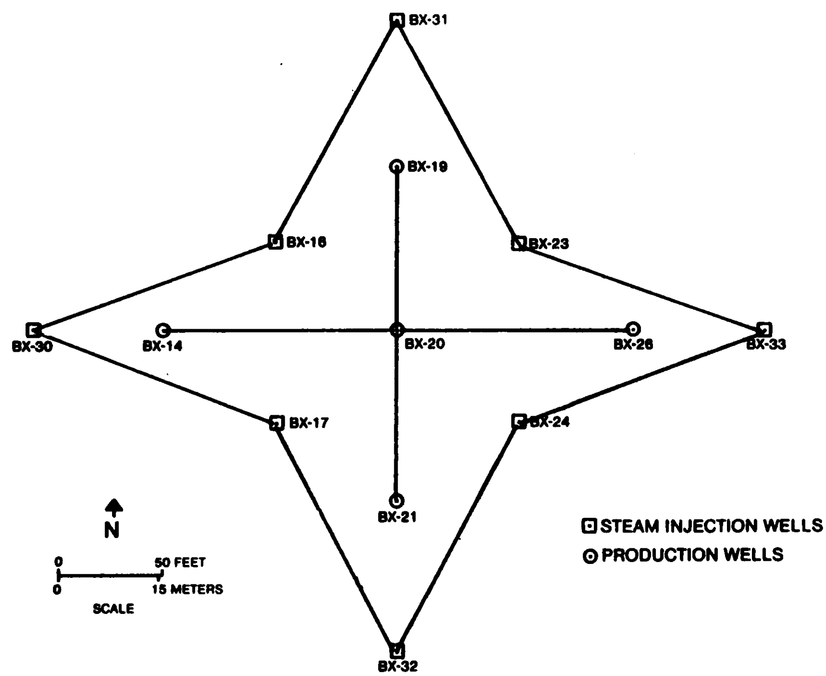

Figure 3. Ground Surface Location of Wells Used in Geohydrologic Testing.

TABLE 1

SUMMARY OF GEOHYDROLOGIC ANALYSIS

	Average Values of Parameters Tested									
	Pumping or Injection Rate	Thickness of Interval Tested		Horizontal Transmissivity		Horizontal Permeability		Vertical Permeability		Storage Coefficient
	gpm	Meters	Feet	m^2/day	gpd/ft	cm/sec	gpd/ft^2	cm/sec	gpd/ft^2	
Interval Tested										
Upper Aquifer	1.25	28	91	0.05	4.0	1.89×10^{-6}	0.04	N.A.	N.A.	1.0×10^{-4}
Leached Zone										
Production Horizon	13	90	295	4.66	375	6.00×10^{-5}	1.27	N.A.	N.A.	2.32×10^{-3}
Upper and Lower Injection Horizons	50	50	164	11.43	920	2.64×10^{-4}	5.61	N.A.	N.A.	7.50×10^{-4}
Upper Leached Zone	22	88	287	12.26	987	1.62×10^{-4}	3.44	1.32×10^{-5}	0.28	1.54×10^{-3}
Lower Leached Zone	28	82	268	11.45	922	1.62×10^{-4}	3.44	9.91×10^{-4}	0.21	1.54×10^{-3}

See Figure 4 for schematic cross-section of intervals of leached zone tested.

N.A. Not analyzed for this parameter.

test may not represent the specific aquifer properties, although a general indication of the aquifer properties was determined.

Geohydrologic Test and Analysis of the Leached Zone

Geohydrologic testing of the leached zone was performed by both constant discharge and constant injectivity tests. The initial constant discharge test indicated relatively low values of transmissivity. During this test the only three observation wells which showed a positive response were those which were perforated to the same interval as the pumped well (the production horizon). This test indicated that the aquifer could deliver water to the pumped well only at a very low rate (13 gpm). Further aquifer testing was performed by an injectivity test because it could quickly provide data. Figure 4 illustrates the general flow test scheme and geohydrologic nomenclatures of the leached zone.

Geohydrologic Test and Analysis of the Production Horizon

A 24-hour drawdown test and 24-hour recovery test were performed on the production horizon of the leached zone from May 12-14, 1979. The drawdown test was run at a constant rate of about 13 gpm.

BX-26 was used as the pumping well; observation wells include those shown in Figure 3. The results of this test were used to measure the isotropic properties of the production horizon and were analyzed by the Jacob straight line method (Ground Water and Wells, 1966). Results indicate a transmissivity of 4.66 m^2/day and a horizontal permeability of 6 x 10^{-5} cm/sec (see Table 1).

Injectivity Geohydrologic Test and Analysis

A 43-hour injection test and 31-hour recovery test were performed on the leached zone during June 4-7, 1979. The injection test was run by injecting water into well BX-16 at a constant rate of 50 gpm with approximately 400 psi at the well head. The following analyses of this test are divided into horizons of perforation and zones of expected flow during the in situ process. The divisions of perforated intervals are: 1) wells perforated in the upper and lower injection horizons which were used in analysis for horizontal transmissivity, horizontal and vertical permeability, and directional transmissivity; and 2) wells perforated in the production horizons, used to analyze horizontal transmissivity and horizontal and vertical permeability of the upper and lower

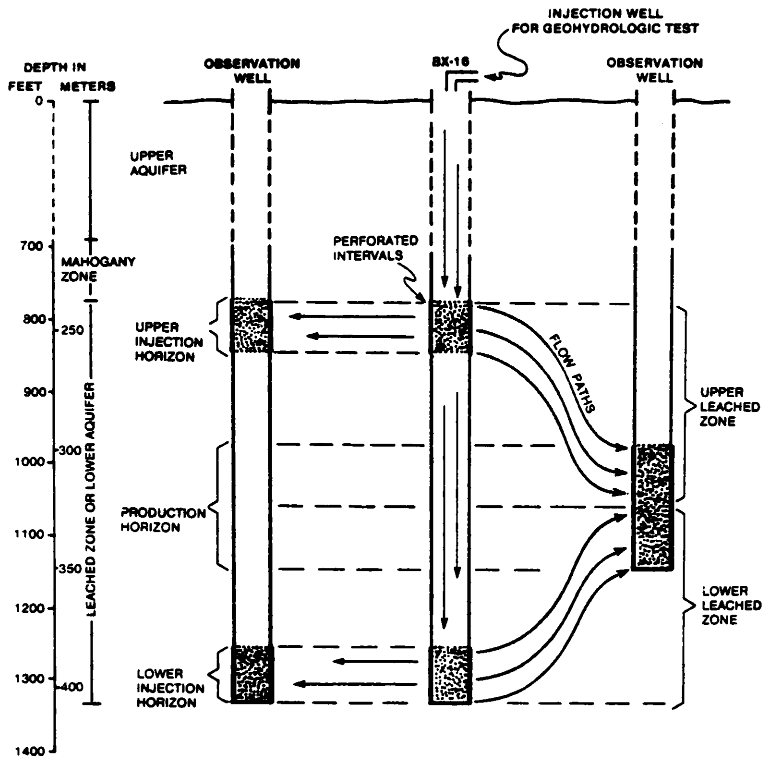

Figure 4. **Schematic Cross-Section of Geohydrologic Nomenclatures and Flow Path Directions Within the Leached Zone During Geohydrologic Test.**

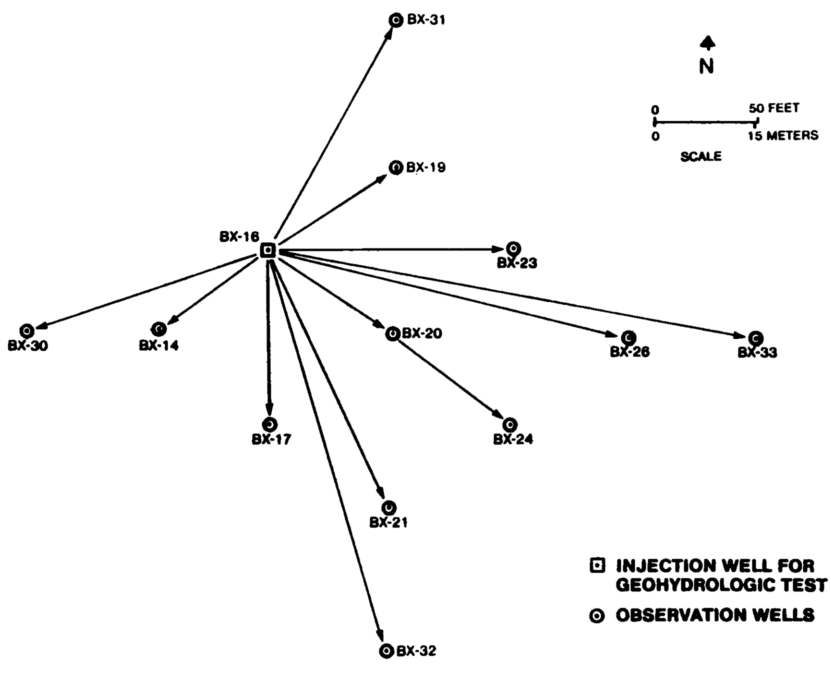

Figure 5. **General Flow Path Directions During Geohydrologic Test.**

leached zones. Figure 5 illustrates that the general horizontal flow path of water injected into BX-16 was toward the observation wells.

The upper and lower perforated intervals of injection well BX-16 represent 44% and 56% of the total perforated interval. Therefore, it is assumed that the same percentage of injected water will flow in the upper and lower leached zones. This is approximately 22 gpm and 28 gpm, respectively. The basic assumption for both vertical permeability analysis and correction for partial penetration effects of the horizontal flow component is that flow paths from an injection well (BX-16) to the five observation wells perforated to other intervals (production horizon) can be analyzed for horizontal and vertical permeability and horizontal transmissivity by assuming that the flow is confined to upper and lower leached zones.

Geohydrologic Analysis for Upper and Lower Injection Horizons

Seven wells (BX-17, BX-23, BX-24, BX-30, BX-31, BX-32 and BX-33) are perforated in the upper and lower injection horizons which are the same intervals as BX-16. The analysis of data from these wells indicates the aquifer characteristics of the upper and lower injection horizons. These are approximately the intervals in depth of 239 to 258 and 384 to 408 meters of the leached zone. These observation wells were not affected by partial penetration and were analyzed by the Jacob straight line method (Ground Water and Wells, 1966). These horizons have an average horizontal permeability of about 2.64 x 10^{-4} cm/sec, horizontal transmissivity of 11.43 m^2/day, and a storage coefficient of 7.5 x 10^{-4}.

Geohydrologic Analysis of the Upper and Lower Leached Zone

The analysis of the upper and lower leached zones assumes that the horizontal permeability and storage coefficient of these zones are equal for each zone for all observation wells. This value is equal to the average of the values for the wells perforated to the production horizon from the first test, and the values from wells perforated to the upper and lower injection horizons. The results of this analysis indicated an average permeability of 1.62 x 10^{-4} cm/sec and an average storage coefficient of 1.54 x 10^{-3}.

The upper leached zone is approximately located in the interval between 239 and 328 meters and has an average transmissivity of 12.26 m^2/day.

The lower leached zone is approximately located in the interval between 328 and 408 meters and has an average transmissivity of 11.45 m^2/day.

Geohydrologic Analysis of Vertical Permeability of the Leached Zone

The Weeks (1969) method was used to determine vertical permeability between the injection well (BX-16) and five of the observation wells (BX-14, BX-19, BX-20, BX-21, BX-26), which are perforated at intervals different from the injection well (Weeks, 1969). Therefore, changes in water levels in these observation wells indicate the properties of both horizontal and vertical permeability of the leached zone. The analysis included correction of water level measurements for partial penetration effects. Analysis of these data are summarized in Table 1. Analysis of the upper leached zone indicates an average horizontal to vertical permeability ratio of about 12 to 1, with an average vertical permeability of 1.32 x 10^{-5} cm/sec.

Analysis of the lower leached zone indicates an average horizontal to vertical ratio of about 16 to 1, with an average vertical permeability of 9.91 x 10^{-4} cm/sec.

The average value for the full extent of the leached zone for horizontal to vertical permeability is a ratio of about 14 to 1, with an average vertical permeability of 1.16 x 10^{-5} cm/sec.

Two-Dimensional Horizontal Anisotropic Analysis of the Leached Zone

An analysis of the horizontal dimension of anisotropy was performed on the upper and lower leached zones. The Papadopulos (1965) method was used in the analysis. This analysis was based on flow from BX-16 to the production wells to simulate the flow directions during well field operations. The effects of partial penetration on water level measurements in the production wells were corrected using the Weeks (1969) method and analyzed for horizontal anisotropy by the Papadopulos (1965) method. The same assumptions were used as in the vertical permeability analysis. The results of this analysis (Table 2) indicate major and minor horizontal transmissivities of 43 m^2/day and 38 m^2/day in the upper leached zone. The direction of major transmissivity was N 78° E.

In the lower leached zone, the major and minor transmissivities were 39 m^2/day and 36 m^2/day, with the direction of major transmissivity of N 73° W. For the full thickness of the leached zone, the average horizontal transmissivity is 78 m^2/day,

TABLE 2

RESULTS OF RESERVOIR ANISOTROPIC ANALYSIS OF THE UPPER AND LOWER LEACHED ZONES

Parameter Tested	Units	Interval Tested: Upper Leached Zone	Lower Leached Zone	Total Thickness of Upper and Lower Leached Zone
Major Horizontal Transmissivity	gpd/ft	1048	960	2008
	m^2/day	43	39	82
Minor Horizontal Transmissivity	gpd/ft	931	885	1816
	m^2/day	38	36	74
Mean Horizontal Transmissivity	gpd/ft	987	922	1909
	m^2/day	40	38	78
Direction of Major Horizontal Transmissivity Axis		N 78° E	N 73° W	E - W*

* Approximate Direction

the ratio of major to minor horizontal transmissivity is approximately 1.1:1, and the major direction is generally east to west. The contrast in major and minor transmissivity is very small, which indicates fairly isotropic conditions in the horizontal dimension of the leached zone.

CONCLUSION

The pre-operational phase of the surface and ground water monitoring program has been completed. The existing characteristics of the hydrologic systems prior to the beginning of steam injection have been described in reports to Equity Oil Company and DOE. The monitoring program is presently in the operational phase. The monitoring results to date have not identified any changes in the water quality of Black Sulphur Creek or of the alluvial, upper and lower aquifers that may have been caused by project operations. It is expected that the designs of the operational and post-operational phases of the program remain as described unless future monitoring results indicate a need for revision.

The geohydrologic testing and analysis program established the following information on aquifer properties at the BX well fields:

1) The upper aquifer has relatively low values of permeability and transmissivity, resulting in a low rate of ground water movement (0.1 m/yr).
2) The leached zone, or lower aquifer, is anisotropic.
   a. Horizontal anisotropy is relatively small, as indicated by the ratio of major to minor horizontal transmissivity (1.1:1).
   b. Vertical anisotropy is great, as indicated by the ratio of horizontal to vertical permeability (14:1).

   The mining process could be inhibited by the relatively low vertical permeability and the current well perforation design.
3) The rate of dispersion of residuals (mobilized mineral constituents of the formation due to the steam leaching process) will be relatively slow within the leached zone because of a relatively slow rate of ground water movement (7.1 m/yr).
4) The rate of ground water movement (leakage) through the Mahogany Zone could not be determined, due to improper completion of upper aquifer observation wells.
5) Recommendations:
   A) Prior to commercial scale development, determine the leakage/confinement properties of the Mahogany Zone and the dispersion rates of residuals.
   B) Determine optimum perforation intervals for injection and production wells to

increase vertical sweep and improve the efficiency of the mining operations.

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