ATTACHMENT I

Hydrogeologic Assessment
of
Proposed Waste Disposal Site

Sequoyah Fuels Corporation
Gore Facility

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SUMMARY

An area approximately 2000 feet north of the Sequoyah Fuels Corporation Gore Facility has been proposed as a disposal site for contaminated solid waste for facility generated material only. The area occupies approximately 25 acres with a working volume of roughly 950,000 yd^3. A preliminary hydrogeologic investigation of the area for disposal suitability consisted of evaluating data from one core hole and four monitor wells constructed in January 1984 to determine lithologic and hydrogeologic characteristics. The study included a period of water level observations, followed by field tests conducted on two of the wells to determine permeability properties of the rock and calculation of groundwater velocity. The area is located on top of a wooded knoll and all drainage is away from the dedicated disposal area.

The site study revealed that the area is underlain by repetitive sequences of thick gray shales with thin, dense, tight layers of well cemented siltstones and sandstones. The hydrologic field tests indicate a rock permeability of 1.5 to 3.1 gallons per day per square foot with groundwater velocity of 117 to 235 feet per year. Depth to groundwater is approximately 40 to 50 feet below ground surface.

This preliminary investigation indicates that the site is suitable for the proposed disposal of plant wastes. Burial of material could be placed as deep as 30 feet, leaving approximately 10 feet of an underlying unsaturated zone. A low permeability clay cap and crowned vegetated surface would insure that rainfall seepage would be minimal. Additional monitor wells would provide for on-going quality assurance of stabilization.

INTRODUCTION

Sequoyah Fuels Corporation has selected an area approximately 2,000 feet due north of its process building near Gore, Oklahoma as a potential location for disposal of plant contaminated solid wastes. The land is owned by Sequoyah Fuels. Four monitor wells and one core hole were drilled in January 1984 to determine lithologic and hydrogeologic characteristics of the area. The wells were initially constructed for lithologic data and to monitor site water levels. Slug tests were performed in November 1984 to characterize the underlying aquifer permeability. The results of the drilling operations and field tests are reported in this report.

FIELD INVESTIGATION

Four monitor wells (#2334-#2337) and one core hole (PC-1) were drilled at the subject study area during the week of January 11-17, 1984. The area of investigation is shown in figure 1 along with the four well sites and the core hole location.

Drilling Procedure

Because of the importance of accurately determining the depth to the underlying groundwater horizon, no drilling fluid was used while drilling or coring. The cuttings, consisting mostly of pulverized rock dust, were evacuated from the well bore by compressed air. A 4-7/8-inch Crisdrill core bit was used at PC-1 to obtain a 3-inch core from the 11 foot to 55 foot interval. The core was logged by P. A. Chenoweth, Consulting Geologist and is described on Table 1. The hole has since been cemented back to the surface. The four monitor wells were drilled with a 7-inch tricone rock bit. Lithologies and water levels for the wells are shown

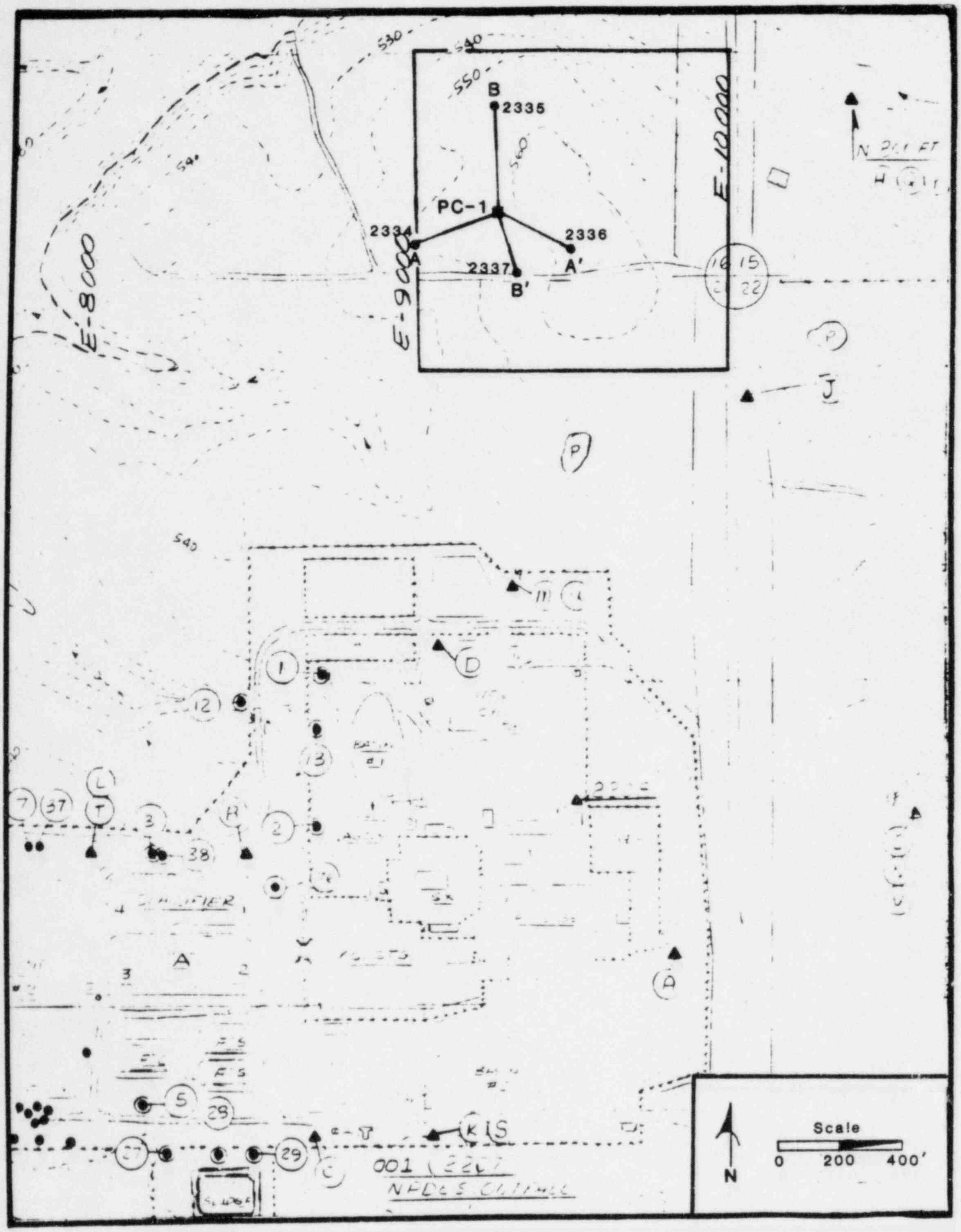


FIGURE 1 LOCATION MAP - SEQUOYAH FACILITY

TABLE I: LITHOLOGIC CORE LOG

PC-1 CORE HOLE

SEQUOYAH FACILITY

Depth (feet)	Elevation (feet above msl)	Lithologic Description	Remarks
0 - 11.0	557.2 - 546.2	Soil and forest loam on deeply weathered yellowish-gray clay shale	Drilled
11.0 - 12.4	546.2 - 544.8	Lost core	Core #1: 11.0' - 16.0'; recovered 3.6' of core from 12.4' -16.0'
12.4 - 14.0	544.8 - 543.2	Yellowish and ocherous weathered shale	
14.0 - 14.8	543.2 - 542.4	Gray, silty shale	
14.8 - 15.4	542.4 - 541.8	Siltstone, yellow, weathered. Dip 5-10°	
15.4 - 16.0	541.8 - 541.2	Shale, gray, soft, weathered to yellow	
16.0 - 17.2	541.2 - 540.0	Yellow weathered gray clay shale as above. Broken into small fragments and chips	Core #2: 16.0' - 26'; recovered 9.6' from 16.0' - 25.6'
17.2 - 18.5	540.0 - 538.7	Single bed of yellowish-white hard siltstone	
18.5 - 23.8	538.7 - 533.4	Siltstone, mottled, white and dark gray. Blebs and flecks of carbonaceous matter, slightly calcareous, tight	19.4' - 19.6' Vertical dark streaks (plant frag's?). 20.1' - 21.0' yellowish white bed with a 2" rusty colored band near middle. Toward base siltstone becomes laminated, light and dark gray. Still slightly calcareous
23.8 - 25.6	533.4 - 531.6	Shale, very dark gray, crumbly, soft, with streaks of black siltstone	
25.6 - 26.0	531.6 - 531.2	Lost core	
26.0 - 27.5	531.6 - 529.7	As above, light/dark gray tight calcareous siltstone with dark gray carbonaceous streaks and blotches	Core #3: 26.0' - 36.0' recovered 8.0' from 26.0' - 34.0. Core loss interval not shown

TABLE I: LITHOLOGIC CORE LOG

PC-1 CORE LOG

SEQUOYAH FACILITY

(Continued)

Depth (feet)	Elevation (feet above msl)	Lithologic Description	Remarks
27.5 - 28.0	529.7 - 529.2	Tight, non-calcareous light gray siltstone	
28.0 - 29.0	529.2 - 528.2	Shale, silty, light gray	
29.0 - 34.0	528.2 - 523.2	Shale, light gray at top becoming darker with depth. Lighter gray shale is silty, becoming less so with depth	32.0' - 34.0' very dark gray, uniform soft clay shale. Traces of pyrite. Some vertical joints
34.0 - 36.0	532.2 - 531.2	Lost core	
36.0 - 44.6	531.2 - 512.6	Dark gray to very dark grayish blue, soft	Core #4: 36.0' - 46.0' recovered 8.6' from 36.0' to 44.6.' Abundant pyrite from 36.8 - 37.0'. Core jammed in interval from 40.0' - 42.0' Recovery is all small angular pieces. No apparent natural jointing
44.6 - 46.0	512.6 - 511.2	Lost core	
46.0 - 47.0	511.2 - 510.2	Lost core	Core #5: 46.0' - 55.0' recovered 8.0' from 47.0' to 55.0'.
47.0 - 49.5	510.2 - 507.7	Dark gray shale as above	Basal 2" of shale is gradational into siltstone below
49.5 - TD	507.7 - 502.2	Siltstone, very hard, dense, as above - mottled light and dark gray. Slightly calcareous	53.0 - 53.6 quite calcareous

in Figures A-1 through A-4 in Appendix A.

Typical of the area around the Sequoyah Facility, air drilling often results in water levels taking weeks or months to reach static levels. This is because the majority of groundwater movement is through secondary porosity features, such as fractures or joints, and very little water moves interstitially. If no fractures are encountered to produce enough water to wash the sides of the wellbores during drilling, some of the dust-size cuttings adhere to the sides of the well and form an impermeable seal. Eventually, the formation fluid pressure may become great enough to break through the mud (dust) caked wall, and the well begins to exhibit normal static water levels.

Well #2334 has been the quickest of the four site wells to reach a constant static water level. During the drilling of this well evidence of a significant amount of groundwater was observed at a depth of about 50 feet at which point the powdery cuttings which had been lifted out of the well by air decreased. Also, the larger cuttings from the well were very damp. When the total depth of 60 feet was reached, the injection of air was stopped for about ten minutes. When the flow of air resumed, several gallons of water sprayed out of the well. This procedure was repeated two more times, each time resulting in a successively cleaner spray of water as the cuttings were purged. Apparently enough water was entering the wellbore from the formation to wash any mud from the walls.

For the remaining three wells there was no evidence of any groundwater during drilling. After reaching total depth in each well, the flow of

air was stopped for ten minutes, but no water came out of the hole when the air flow resumed. When the drill string was removed from wells #2335 and #2337, a trace of water was found on one or two feet of the bottom joint of drill rod. However, no water was found on the drill string removed from well #2336.

Completion Procedures

The monitor wells were drilled in numerical order starting with #2334. With the exception of well #2335, each was cased to the total drilled depth. Well #2335 was drilled to a depth of eighty feet. It was plugged back to a 55-foot depth using twenty-three feet of cuttings and two feet of hydrated bentonite pellets. The well was drilled to eighty feet to ascertain whether or not the fractures encountered during previous drilling about one mile east of the facility in the bottom shale zone were present at the report site; they were not.

Each well was completed using 4-inch ID Schedule 40 PVC casing with flush joint connections. The bottom ten feet of the casing was slotted using a hacksaw, and a rubber bottom plug was screwed into the bottom of the screen. A PVC removable cap was placed on the top of the casing to exclude foreign matter. A sand pack of 8-12 mm frac sand was then placed in the annulus to a height approximately ten feet above the top of the screened interval. A 2-foot layer of bentonite pellets was added to the top of the sand pack. Approximately twenty gallons of fresh water were poured down the annulus to hydrate the bentonite pellets and form a seal between the lower portion of the well and any overlying zones. A 2-foot frac sand pad was placed over the hydrated bentonite, and cement was placed from the top of the pad up to the surface using a tremie line.

A 6-foot protective steel casing with a locking cap was placed around each well casing.

Site Geology/Hydrology

The Sequoyah Facility encompasses approximately 2,000 acres of rolling pastureland and heavily-wooded hills in western Sequoyah County, Oklahoma. The entire area is located on the southwest flank of the large physiographic feature known as the Ozark Uplift. A thin Pleistocene terrace material covers much of the Pennsylvanian-age Atoka formation which dips gently to the northwest at less than 4 degrees. Deposited in shallow water, deltaic, and paludal environments near the north margin of the Arkoma Basin, the Atoka is composed of complexly bedded shale, silt, and very fine sandstone (figures 2 and 3). This formation serves as the uppermost bedrock throughout the facility area, including the survey area covered in this report. Site lithologic information is shown on the well completion diagrams in Appendix A.

Hydrology

The lithology encountered at the site is not conducive to formation of an aquifer capable of yielding much water. The tight, dense shale acts more as an aquitard than as a transporter of groundwater. The siltstone and very fine grained sandstone exhibit very little porosity or permeability, therefore storage and movement of groundwater is minimal. Secondary porosity features such as fractures serve as the primary pathways for any groundwater flow in the area. These conditions are consistent with findings throughout the Sequoyah Facility acreage. In this regard, the site is ideal as there are no drinking water wells in the immediate vicinity, the water is poor quality and availability

FIGURE 2: SEQUOYAH FUELS CORPORATION
SEQUOYAH FACILITY
PROPOSED PIT AREA
NORTH OF PLANT
EAST-WEST CROSS SECTION

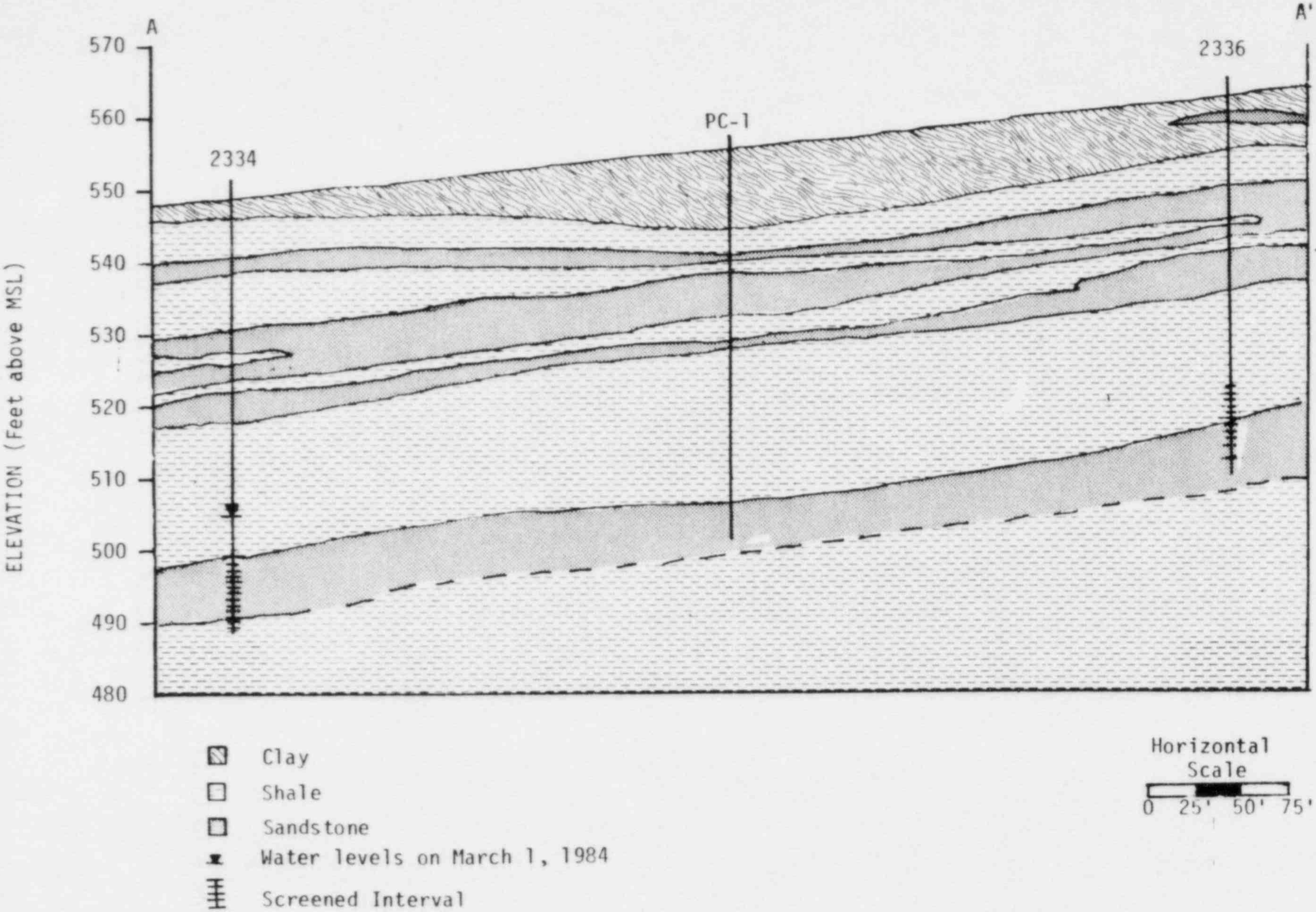
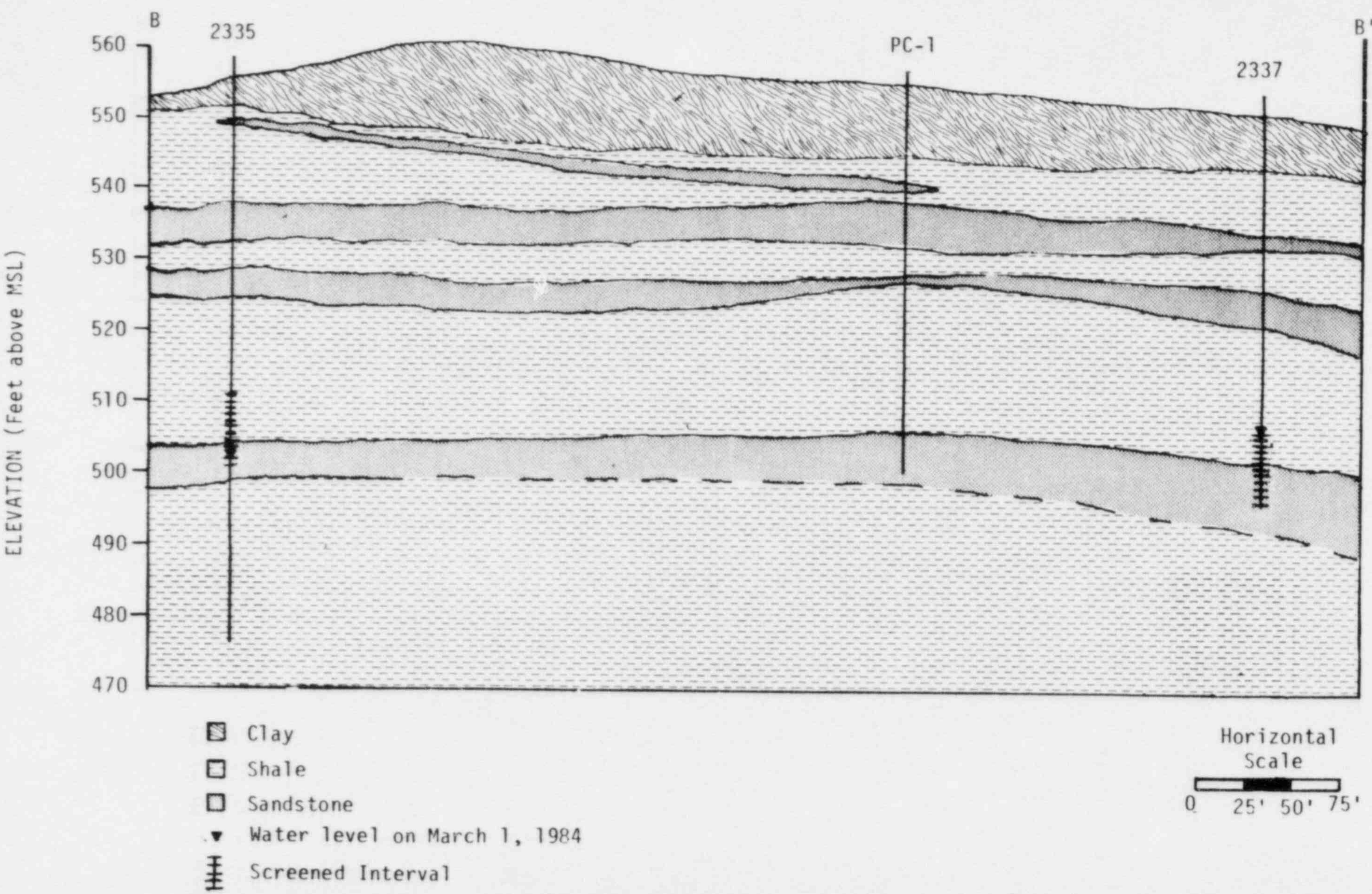


FIGURE 3: SEQUOYAH FUELS CORPORATION
SEQUOYAH FACILITY
PROPOSED PIT AREA
NORTH OF PLANT
NORTH-SOUTH CROSS SECTION



from the tight formation is negligible. The possibility of future use is essentially non-existent.

FIELD TESTING

Well #2336 has remained dry to date since completion. Well #2335 characteristically has less than 1 foot of water in it, whereas well #2337 typically has less than 10 feet and well #2334 less than 16 feet of water. Generally, water was encountered while drilling at a depth of about 50 feet below grade.

Slug tests were performed in November 1984 in the two wells having the greatest amount of water to determine aquifer permeability. Data collected from the test were evaluated following a procedure described by Bouwer and Rice (1976). This evaluation is described in the following section.

Slug Test Procedure and Assumptions

The slug tests were conducted by rapidly evacuating 2.3 liters of water (one bailer volume) from each of wells #2334 and #2337. A transducer placed in each test well was activated upon removing the sample volume and recovery levels were recorded with time. The data (residual drawdown vs. time) was then plotted (figures 4 and 5) and evaluated.

In conducting this type of test, some assumptions are made. First, the essentially instantaneous removal of water from the well is assumed to create an immediate head differential between the water level in the well and the aquifer. Second, the well screen is assumed open and not restrictive to the flow of groundwater into the well. Third, the sand

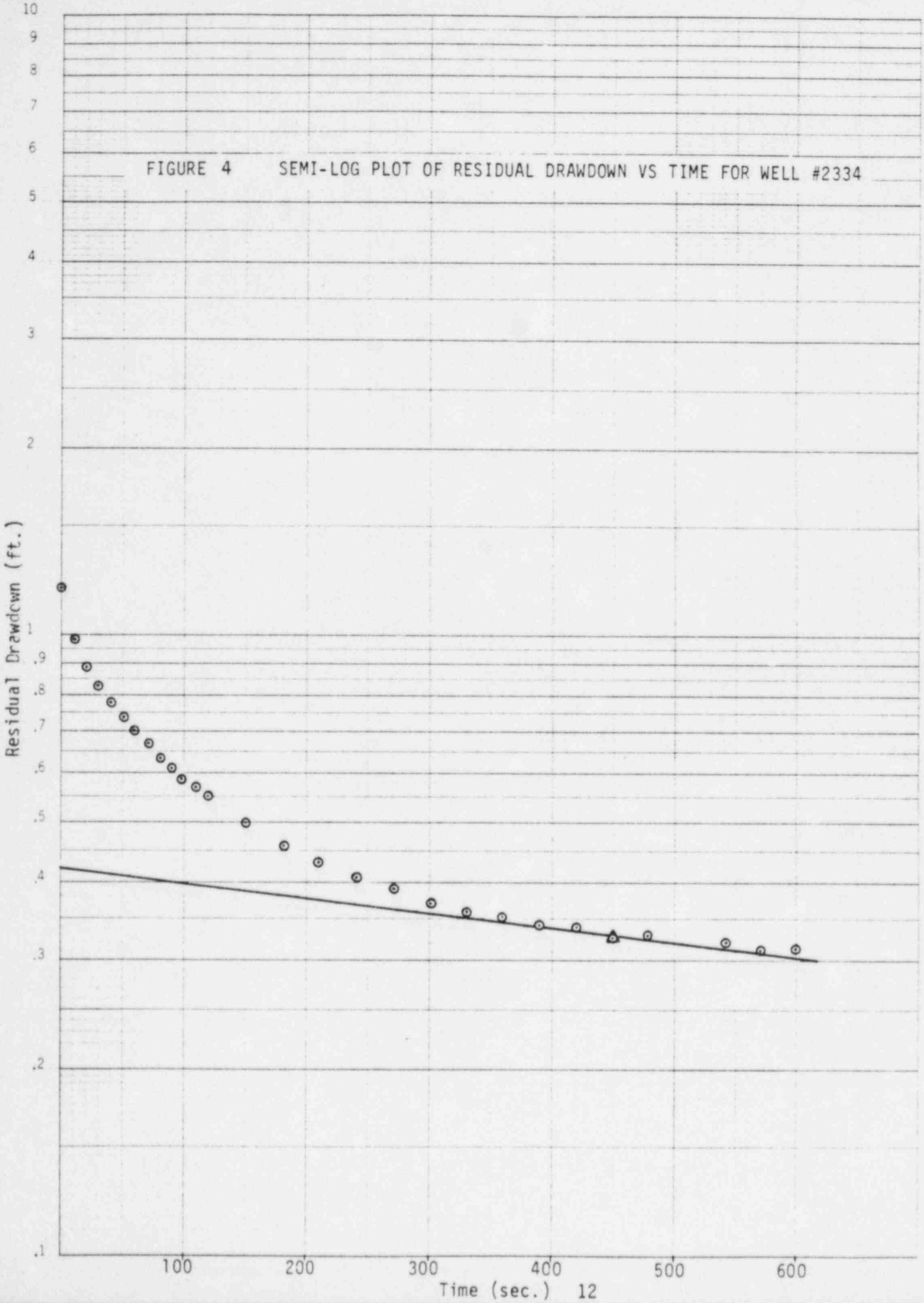
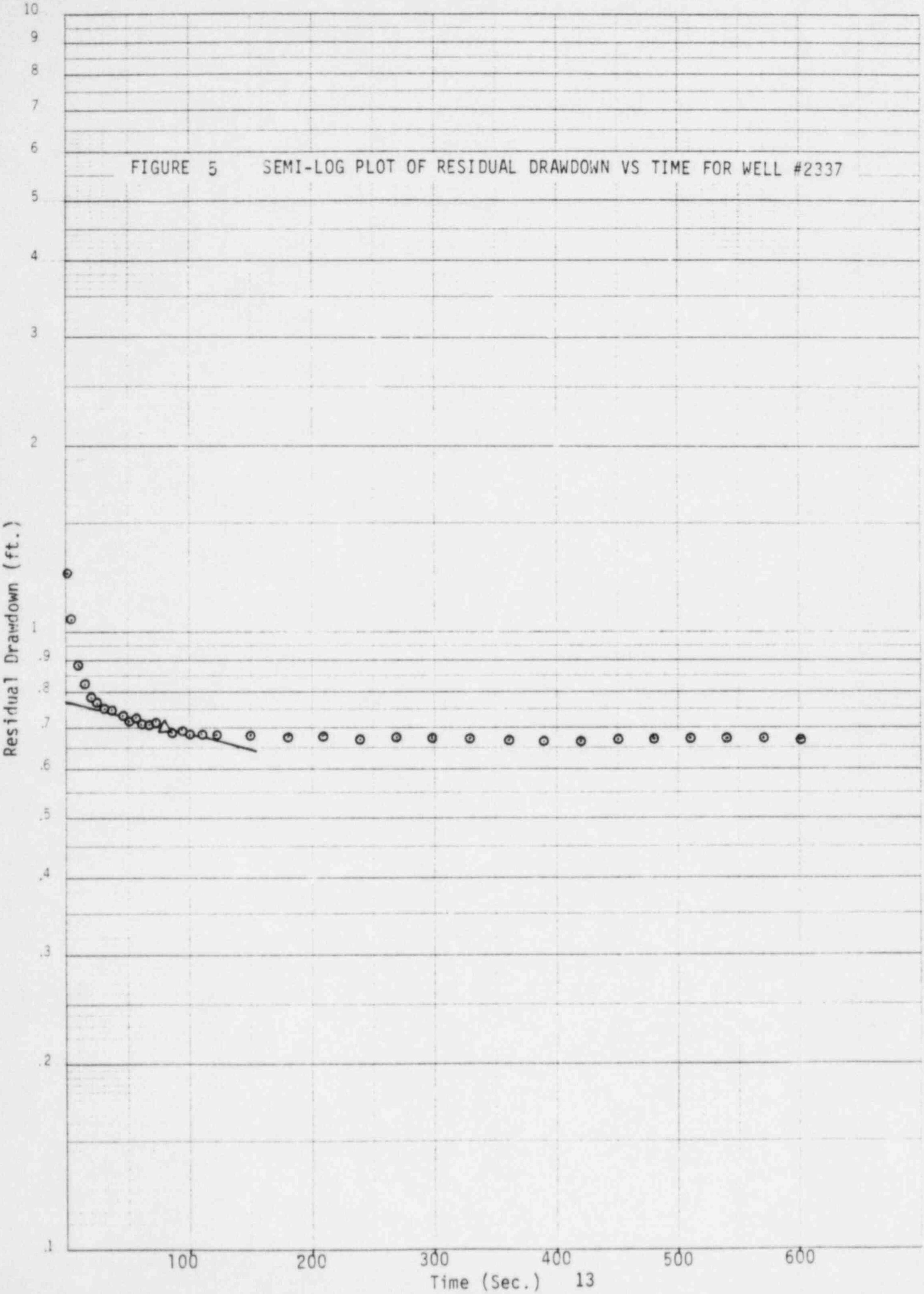


FIGURE 4 SEMI-LOG PLOT OF RESIDUAL DRAWDOWN VS TIME FOR WELL #2334
Residual Drawdown (ft.)
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
100
200
300
400
500
600
Time (sec.)

FIGURE 5 SEMI-LOG PLOT OF RESIDUAL DRAWDOWN VS TIME FOR WELL #2337



pack between the borehole and casing exhibits infinite permeability, and instantaneous drainage.

Wells #2334 and #2337 are both completed with hand slotted PVC casing across the aquifer. There may be a slight restriction of flow into the well because of an insufficient amount of open area in the hand slotted section. Also, the sand pack between the borehole and casing realistically does not exhibit infinite permeability and requires some finite drainage time. Lastly, the equations used in the calculations assume the well to fully penetrate the aquifer. Well #2334 meets this condition, however, well #2337 only partially penetrates the aquifer.

The method of Bouwer and Rice (1976) was used to approximate aquifer permeability for these slug tests. The method permits the calculation of permeability of an unconfined aquifer open to a completely or partially penetrating well. The calculation of aquifer permeability is based on the Theim equation (Davis and DeWiest, 1966, p. 203) of steady-state flow to a well.

Aquifer permeability is calculated from residual drawdown data using the following equation:

$$P = \frac{64.3 \times 10^4 \, r_c^2 \ln (R_e/r_w)}{2L} \, \frac{1}{t} \ln \frac{y_o}{y_t}$$

where P = permeability (gpd/ft^2)

R_e = effective radius of well (ft)

r_c = inside radius of the casing (ft)

r_w = radius of the borehole (ft)

L = length of perforated interval below the

potentiometric surface (ft)

t = time into recovery (seconds)

y_o = residual drawdown at $t = o$ (ft)

y_t = residual drawdown at selected time t (ft)

The term $\frac{1}{t} \ln \frac{y_o}{y_t}$ is obtained from the best fitting straight line in a plot of log y (residual drawdown) versus t (time into recovery).

The term $\ln R_e/r_w$ for a fully penetrating well is obtained from the relation:

$$\ln R_e/r_w = \left[\frac{1.1}{\ln H/r_w} + \frac{C}{L/r_w}\right]^{-1}$$

and for a partially penetrating well from the relation:

$$\ln R_e/r_w = \left[\frac{1.1}{\ln H/r_w} + \frac{A + B \ln (D-H)/r_w}{L/r_w}\right]^{-1}$$

where:

A, B and C = dimensionless coefficients that are functions of L/r_w and determined from type curves presented in Bouwer and Rice (1976)

D = distance from the potentiometric surface to the bottom of the aquifer (ft)

H = distance from the potentiometric surface to the bottom of the well (ft)

Groundwater flow velocities were calculated using the following equation:

$$v = \frac{(P)(dh/dl)}{(7.48)(\Theta)}$$

where:

v = average velocity of groundwater, ft/day

dh/dl = gradient

Θ = effective porosity, assumed to be 1% for fractured rock

P = permeability, gpd/ft^2

Slug Test Results

Permeability calculations for wells #2334 and #2337 are provided in Appendix B. A permeability value of 1.54 gpd/ft^2 was calculated from the slug test data on well #2334 and 3.10 gpd/ft^2 for data from well #2337. Assuming a 1% porosity (reasonable assumption from core samples), a groundwater velocity for the saturated zone in well #2334 and #2337 is calculated to be 117 ft/yr and 235 ft/yr, respectively. Saturated zone travel time to the Illinois River, the discharge for the aquifer, was estimated to be between 6-12 years. However, the disposal cell constructed at this site would be excavated to leave a minimum 10 feet of undisturbed material above the water table and the cell would be covered with a low permeability clay cap. These factors greatly minimize the possibility of leachate formation and migration to the water table.

Groundwater velocity calculations made for the area south of Pond 2 ("Environmental Assessment Update of Raffinate Pond #2," 1984) were reported to be approximately 122 ft/yr. This result is in close agreement to that which was determined for the similar lithology at the proposed disposal site.

Water level elevations taken on November 29, 1984 were used to construct the generalized potentiometric map (figure 6). Generally, groundwater flow follows the topography in a northwesterly direction, toward the Illinois River. One anomalously low water level is indicated, however,

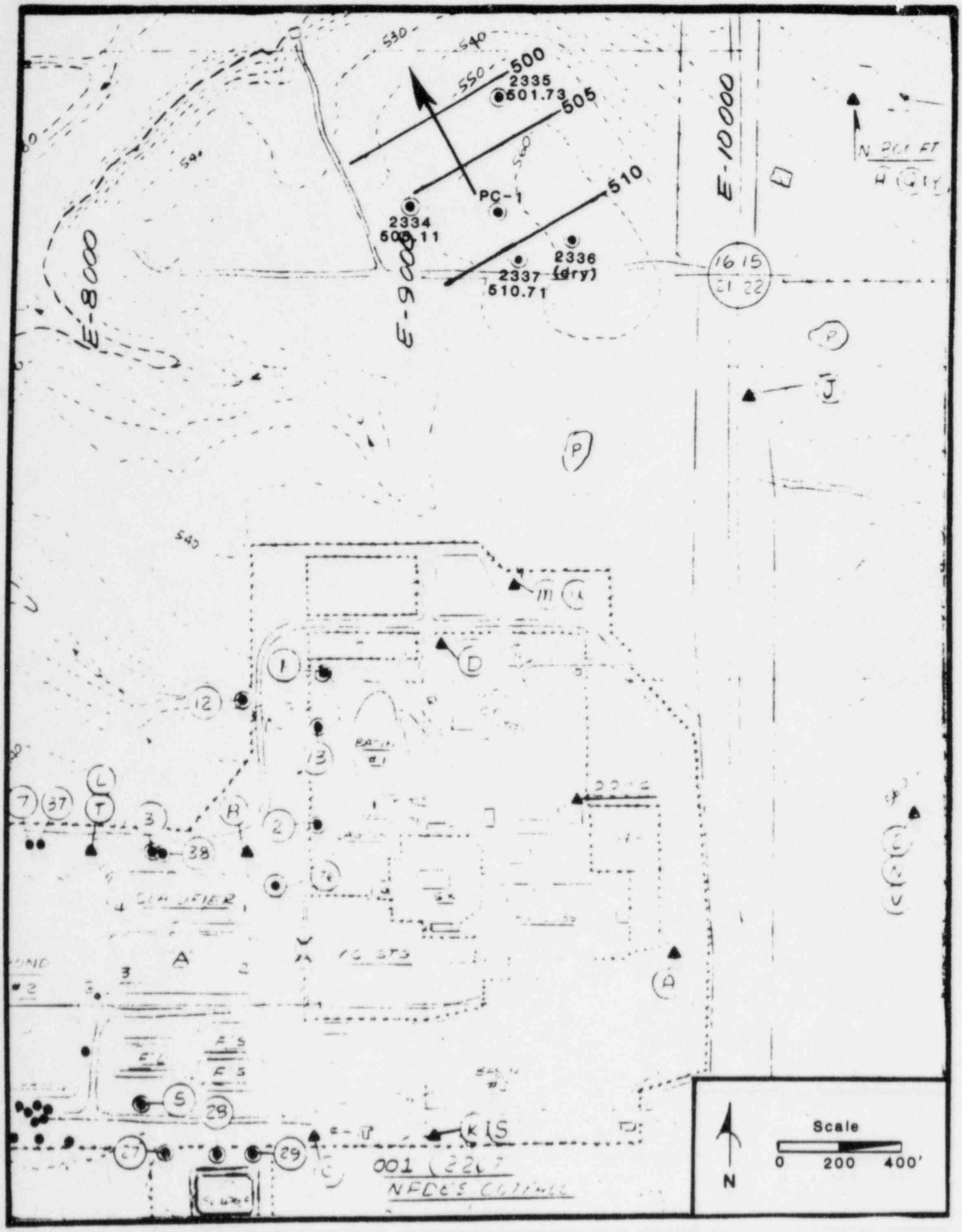


FIGURE 6 CONTOUR MAP WITH WATER LEVEL ELEVATIONS SHOWING GROUNDWATER FLOW DIRECTION IN STUDY AREA

in the area of monitor well #2336 which is dry to a depth of 50 feet.

CONCLUSIONS

The results of this investigation show that the subject site is hydrologically suitable for the construction of a solid waste disposal cell. Cell excavation could be made down to a depth of approximately 30 feet if needed, as the water table occurs at a depth from 40 to 50 feet. The proposed cell area is underlain by a considerable thickness of unsaturated layers of predominately shale with thin, dense siltstone/sandstone stringers. Permeability values of 1.54 gpd/ft^2 and 3.10 gpd/ft^2 were calculated for the study area. The site location is on a topographically high area with excellent drainage away from the area in all directions. This type location lends itself to optimum control of infiltration.

References

Bouwer, H. and R. C. Rice, June 1977, A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells: Water Resources Research, Volume 12, No. 3.

Davis, Stanley N. and Roger J. M. DiWiest, 1966, Hydrogeology, John Wiley and Sons, New York, 463 p.

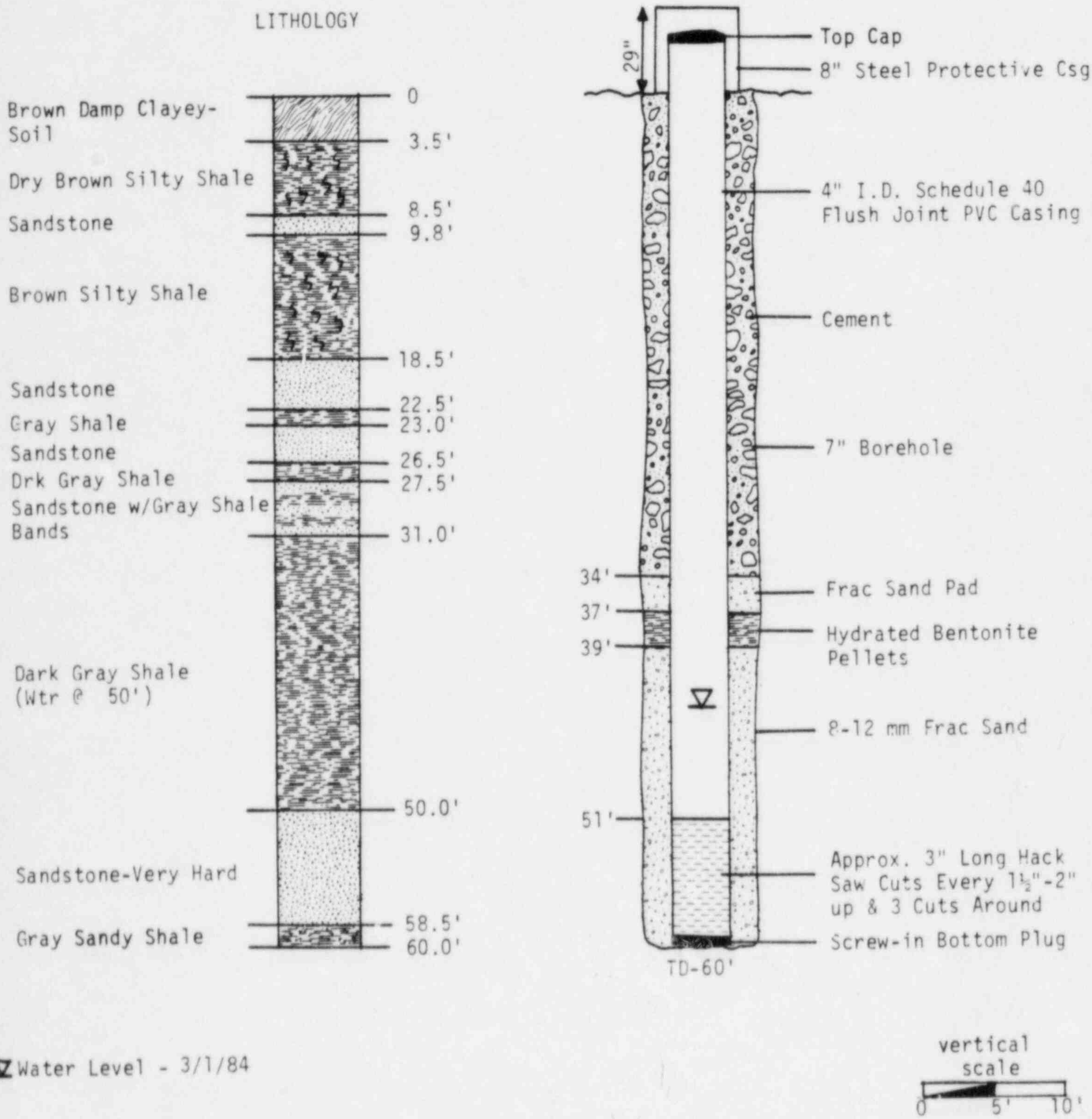
"Environmental Assessment Update of Raffinate Pond #2," June 1984, Sequoyah Fuels Corporation. Submitted to W. T. Crow, Nuclear Regulatory Commission.

Kerr-McGee Corporation, May 7, 1984, internal memo by C. K. Eisenberg.

Appendix A

Well Completion Diagrams and Core Hole
Information from Study Site
Sequoyah Fuels Facility

FIGURE A-1: WELL CONSTRUCTION DIAGRAM
MONITOR WELL #2334
SEQUOYAH FACILITY



▽ Water Level - 3/1/84

FIGURE A-2: WELL CONSTRUCTION DIAGRAM

MONITOR WELL #2335

SEQUOYAH FACILITY

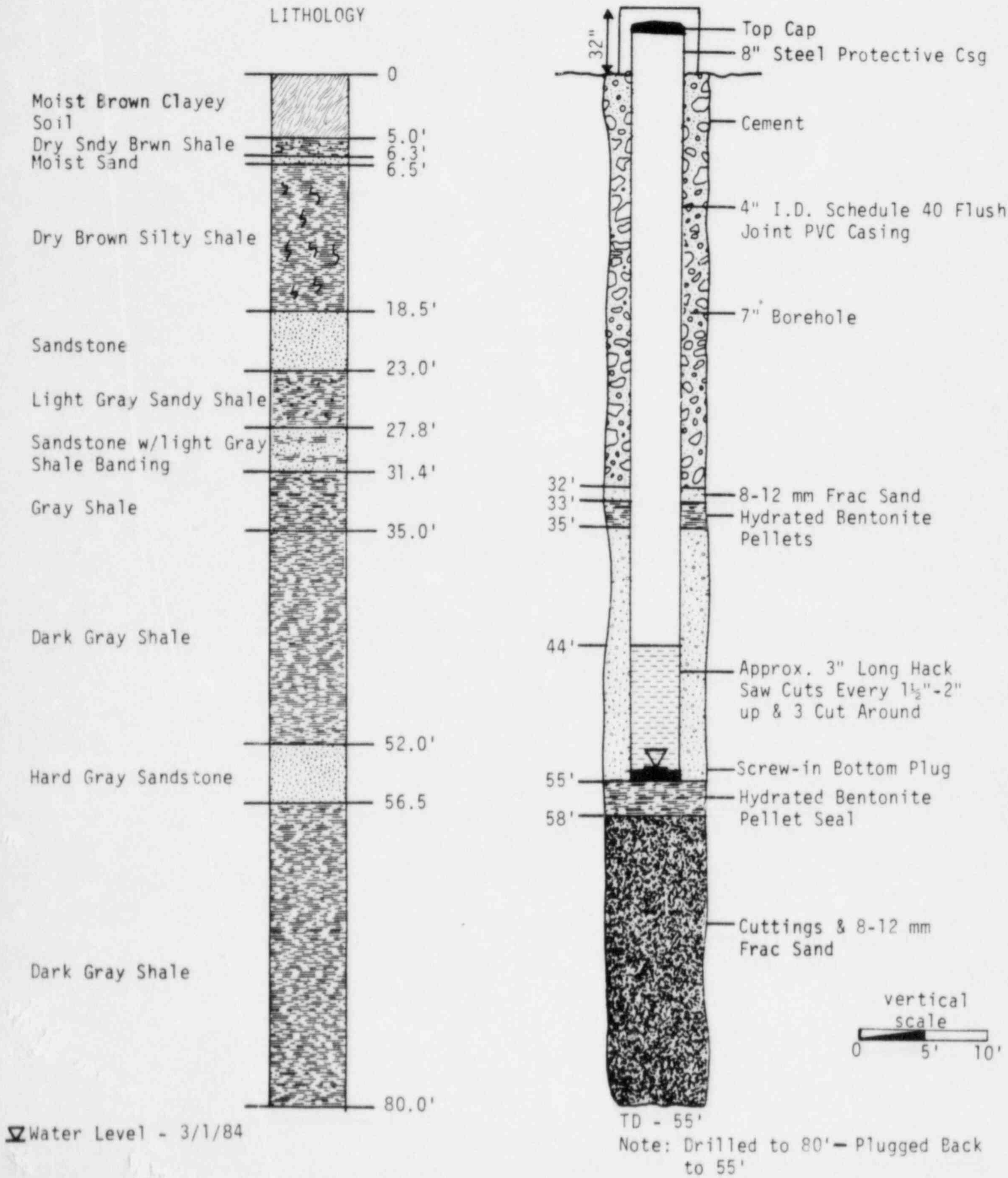
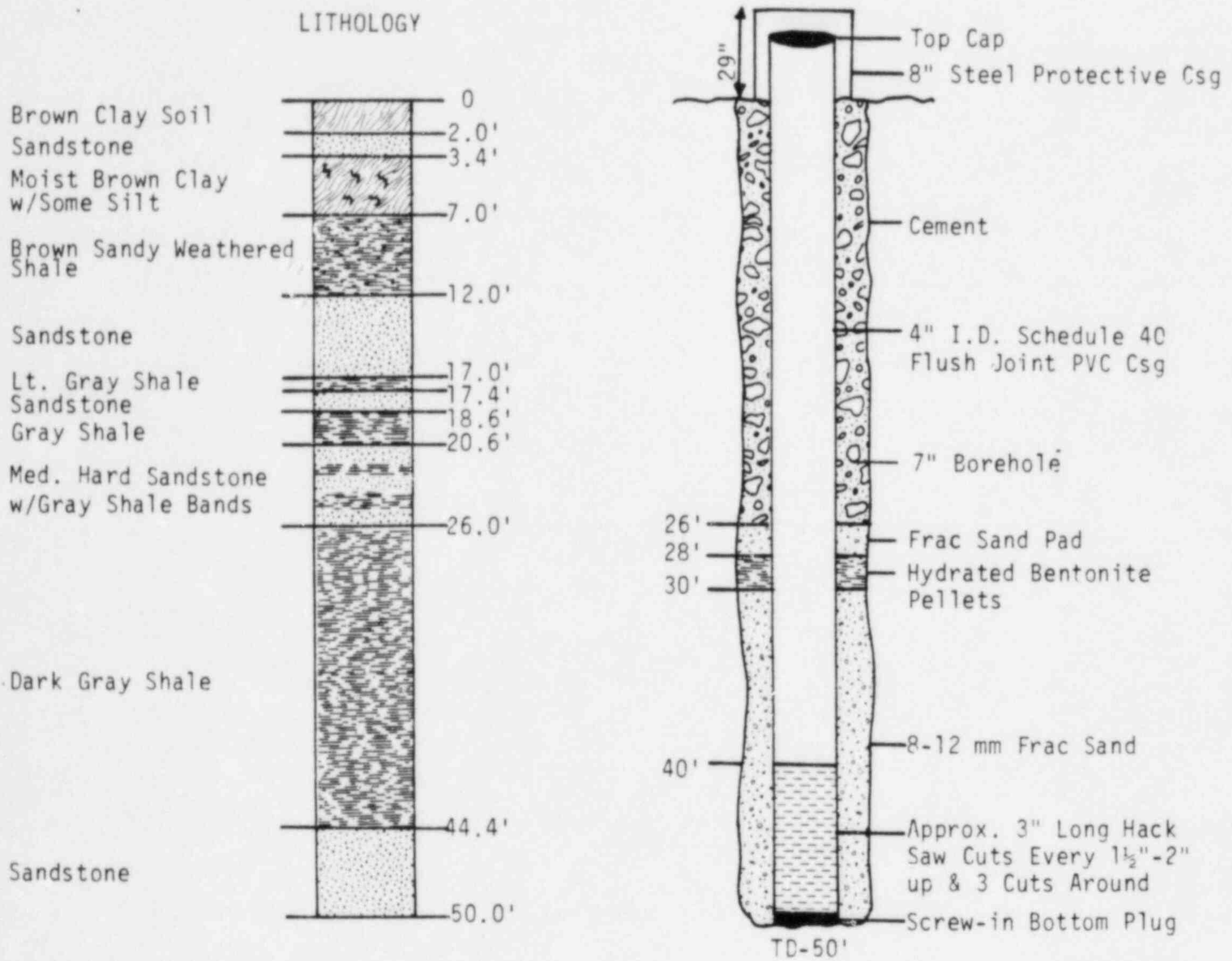


FIGURE A-3: WELL CONSTRUCTION DIAGRAM
MONITOR WELL #2336
SEQUOYAH FACILITY



∇ Water Level - 3/1/84 (No Measurable Water in Well)

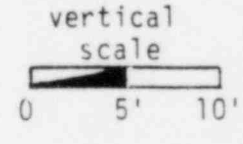
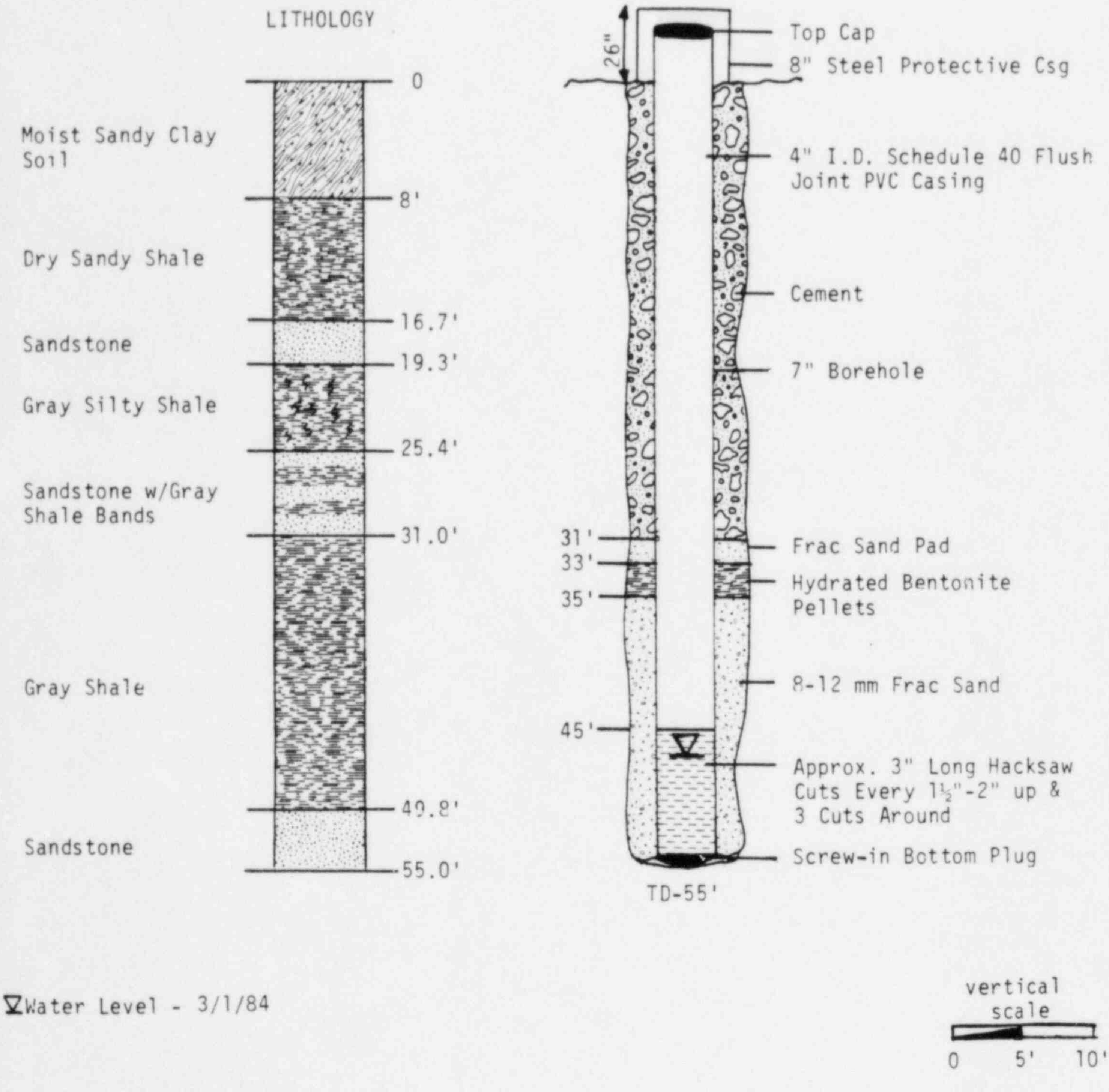
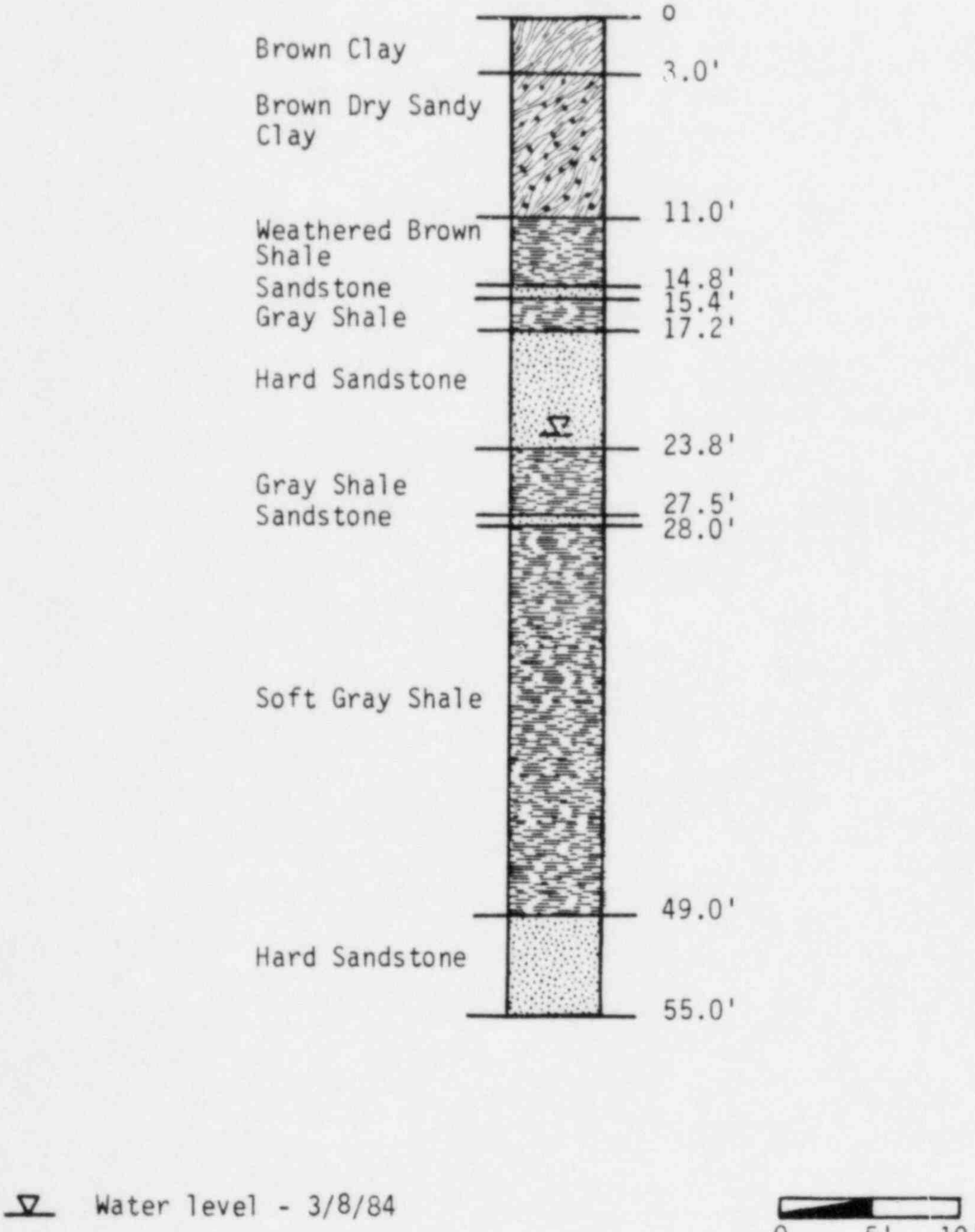


FIGURE A-4: WELL CONSTRUCTION DIAGRAM
MONITOR WELL #2337
SEQUOYAH FACILITY



∇Water Level - 3/1/84

FIGURE A-5: CORE HOLE LITHOLOGY
PC-1
SEQUOYAH FACILITY



Appendix B

Aquifer Permeability Calculations
Slug Test on Monitor Wells #2334 & #2337

Monitor Well 2334

Aquifer Hydrologic Coefficient Calculations

Bouwer and Rice Analysis (See Figure 4)

Well Constants

$H = 10$ ft $L = 9$ ft

$D = 10$ ft $y_o = .42$ ft

$r_c = .17$ ft $y_t = .33$ ft

$r_w = .29$ ft $t = 450$ sec.

$L/r_w = 18$, so $C = 1.6$

$$\left(\frac{1}{t}\right) \ln \left({}^{y_o}/y_t\right) = .00054 \text{ sec}^{-1}$$

Fully Penetrating Well Equation

$$\ln {}^{R_e}/r_w = \left[\frac{1.1}{\ln (10/.29)} + \frac{1.6}{(9/.29)}\right]^{-1}$$

$$\ln {}^{R_e}/r_w = 2.76$$

$$P = \left[\frac{(.17 \text{ ft})^2 (2.76)}{(2)(9 \text{ ft})} \frac{1}{450 \text{ sec}} \ln \frac{.42 \text{ ft}}{.33 \text{ ft}} (8.6 \ .10^4 \text{ sec/day}) (7.48 \text{ gal/ft}^3)\right]$$

$$P = 1.54 \text{ gal/day/ft}^2$$

Groundwater Velocity Calculations

$$\bar{v} = \frac{(1.54 \text{ gpd/ft}^2)\left(\frac{5.6}{360}\right)}{(7.48)(.01)} = .32 \text{ ft/day} = 117 \text{ ft/yr}$$

Monitor Well 2337

Aquifer Hydrologic Coefficient Calculations

Bouwer and Rice Analysis (See Figure 5)

Well Constants

$H = 5.2$ $L = 10$ ft

$D = 5.2$ $y_o = .76$ ft

$r_c = .20$ ft $y_t = .70$ ft

$r_w = .29$ ft $t = 80$ sec.

$L/r_w = 20$, so $C = 1.6$

$$r_c = \left[(.17)^2 + .20\,(.29^2 - .17^2)\right]^{\frac{1}{2}}$$

$$r_c = .20$$

$$\left(\frac{1}{t}\right) \ln \left(y_o/y_t\right) = .00103$$

Fully Penetrating Well Equation

$$\ln\ R_e/r_w = \left[\frac{1.1}{\text{Ln}\ (5.2/.29)} + \frac{1.6}{10/.29}\right]^{-1}$$

$$\ln\ R_e/r_w = 2.34$$

$$P = \left[\frac{(.20)^2}{(2)}\ \frac{2.34}{(10)}\ \frac{1}{80}\ \ln\ \frac{.76}{.70}\ (8.6\ .10^4\ \text{sec/day})\ (7.48\ \text{gal/ft}^3)\right]$$

$$P = 3.10\ \text{gal/day/ft}^2$$

Groundwater Velocity Calculation

$$\bar{v} = \frac{(3.10\ \text{gpd/ft}^2)}{(7.48)}\ \frac{\left(\frac{5.6}{360}\right)}{(.01)} = 64\ \text{ft/day} = 235\ \text{ft/yr}$$

ATTACHMENT II

Current Plant Geophysical Setting

May 25, 1985

ATTACHMENT II

CURRENT PLANT GEOPHYSICAL SETTING

This material is provided as general background information describing the facility and disposal area natural setting. The area has been extensively studied and therefore provides a sound basis for Sequoyah Fuels assessment that on-site disposal of radiological waste materials is appropriate.

Regional Description

Physiographic Setting

The Sequoyah Facility is located on the southwest flank of the Ozark Uplift, a broad asymmetric dome which occupies an area of 40,000 square miles in Missouri, Arkansas, and Oklahoma. The site is very near the southwest margin of the Ozark Uplift, near the junction of the Springfield Plateau and the Boston mountains subprovinces. West and southwest of the Arkansas River the region is divided into the Arkansas Valley and the Prairie Plains homocline physiographic provinces; the boundary between those two segments is also approximately a mile or two from the plant. Thus the Sequoyah Facility is near the common corners of the Boston Mountains and Springfield Plateau subprovinces of the Ozark Uplift province and the Arkansas Valley and Prairie Plains homocline

provinces. None of these boundaries is precisely located, either here or elsewhere, but in this immediate area it is appropriate to designate the Arkansas River as the dividing line between the Arkansas Valley province and the Ozark Uplift. The plant lies in the Ozark Uplift, though at the extreme southwest edge (Huffman, 1958, p. 10[1]; Purdue and Miser, 1916[2]). Prongs of the Ozark Uplift extend southwest into the Arkansas Valley and the Prairie Plains homocline provinces; the most prominent of these in this part of Oklahoma are Warner horst, northwest of the plant about the same distance. Between these two prongs the structurally low area is referred to as the Porum syncline; the Sequoyah plant is within this syncline (Arbenz, 1956).

Topography

The Sequoyah property, about 2,000 acres in Secs. 15, 16, 21, 22, 27 and 28, T.12N., R.21E., Sequoyah County, Oklahoma consists of rolling open pastureland, heavily wooded slopes and wooded stream channels. About one-third of the acreage is in pasture; a small field on the west side is cultivated in soybeans, the remainder is wooded. The lowest elevation, approximately 450 feet above see level is at the bank of the Arkansas River near the southwest corner of the property in Sec. 28. The highest point, about 700 feet above sea level, is the summit of a prominent

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1 Huffman, G. G., 1958, Geology of the Ozark Uplift - Okla. Geol. Survey Bull. 77, 281 p.

2 Purdue, A. H., and Miser, H. D., 1916, Eureka Springs - Harrison folio, Arkansas - Missouri - Geologic Atlas of the United States, folio 202: U. S. Geol Survey.

conical hill about a mile southeast of the plant buildings, at the southeast corner of Sec. 22. Maximum relief in the Sequoyah property is thus about 250 feet, although the general appearance is that the topography is subdued and gently rolling.

The plant buildings are situated on an east-west trending hill which rises to 580 feet above sea level, about 130 feet above the nearby Illinois River bank. Construction of the buildings and the north-south highway (Oklahoma Hwy. 10) which crosses the property has somewhat changed the natural topography of some of the hillsides and crest, but east of the main road the same east-west summit upon which the plant is built remains undisturbed.

North of the plant the hill slopes down to Salt Branch, a west-northwest flowing intermittent stream which drains into the Illinois River just northwest of Sequoyah's property. North of Salt Branch the land again rises rapidly on a rocky tree-covered escarpment to an elevation of more than 600 feet. Viewed in profile the plant is on an intermediate hill between higher ones to the north and soutn. The plant-site hill is separated from the bluffs to the north by a rather deep stream valley; southward the land rises gently for about a half mile, then abruptly to the top of the southern and highest hill.

The proposed disposal site for the calcium fluoride sludge, non-combustible trash and incinerator ash is located approximately 2,000 feet north of the facility buildings. This area is elevated above the

surrounding topography and is underlain by repetitive sequences of thick gray shales with thin, dense, tight layers of well cemented siltstones and sandstones.

Drainage

The land in the area of the plant is drained by several small intermittent streams which empty into the Illinois River. The largest stream in the area, other than the Arkansas and Illinois Rivers, is Salt Branch, a semi-permanent creek, which is dry only in the driest months.

Plant process water (the "combination stream") is directed down a small natural drainageway that flows south from the facility and then west to the Illinois River. Another fairly long intermittent stream flows northeast in the eastern part of the property, joining others to form Salt Branch near Carlisle school.

There are no other streams of note within the Sequoyah acreage. During rainy periods runoff is carried down a few shallow natural drains which flow north to Salt Branch and west or northwest to the Illinois River. Careful sprigging and seeding with Bermuda grass has prevented any erosion that might have resulted from the clearing of trees and excavation for construction of the plant and roadways.

There is one spring on the Sequoyah property. It is located about 30 feet north of the "Port" road approximately 100 yards east of the bridge over the plant combination stream. The spring falls in the category of

"surface seepage" or spring of 8th magnitude as defined by Meizner (1923)[3] for it seldom flows more than a thin trickle. An area approximately ten feet by ten feet is moist most of the year and supports a few cattails and water-seeking grasses. The water emerges from the top of a smooth dark blue clay shale stratum which appears to be about four feet thick, resting on a massive sandstone bed.

Geology

Regional Geologic Setting

The Sequoyah Facility is situated on a thin Pleistocene terrace which covers outcrops of the Atoka formation. The terrace is on the southwest flank of the Ozark Uplift in a shallow salient between two horst-like projections of the Ozarks. At this location the Atoka is thin, less than 400 feet, for it was deposited near the north margin of the Arkansas Valley (Arkoma) sedimentary basin and the upper portion has since been removed by erosion.

At the time of Atokan deposition (Middle Pennsylvanian), the Ozark region was a low lying land area drained to the south by streams which built deltas out into the gradually subsiding trough of the Arkoma basin. This

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[3] Meizner, O. E., 1923, Outline of groundwater hydrology with definitions: U. S. Geol. Survey Water Supply Paper 494, 71 p.

area was submerged in post Atokan time by Des Moinesian and perhaps by Mesozoic seas, but subsequent erosion has removed all local evidence of those events. During the pluvial episodes of the Quanternary period the Arkansas and Illinois Rivers and their tributaries were considerably higher and flowed more swiftly than at present. A deposit of coarse gravel, mainly chert, mixed with silt and clay, was left on the hill where the Sequoyah plant is now located. A line of similar terraces parallels each of the major rivers which cross Oklahoma.

The chert was most likely derived from exposures of Mississippian formations in the Ozarks, thence carried south to its present site. Its angularity and vitreous texture attest to a relatively short distance of transport.

Structure

The rocks underlying the Sequoyah property are, for the most part, nearly flat lying although there is some suggestion of a gentle southwestward plunging nose about half a mile wide. This structure is a very minor feature within the larger Porum syncline (Arbenz, 1956[4]). A dip of less than 4° to the northwest was observed on a sandstone bed in a clay borrow pit north of raffinate Pond No. 2. A like dip was observed on the same bed in the ditch of the Port road southwest of the same pond. In the woods south of the plant combination stream, there is a suggestion of dip to the south. Except for the near-vertical dips near a fault on

[4] Arbenz, Kaspar, 1956, Tectonic map of Oklahoma: Okla. Geol. Survey.

the east side, these are the only locations where sufficient dip is present to permit a clinometer reading. Even at those places the structural attitude must be taken with some degree of doubt for this could as well be initial dip rather than the result of post-depositional tilting.

The Carlisle School fault is the most prominent structural feature in the immediate area. The plane of the fault is nowhere exposed but its presence is revealed by vertical beds of sandstone which form low hummocky parallel ridges south of Carlisle school. The ridges stretch for a couple of hundred yards across a pasture. They are about 150 feet apart and are the surface expression of sandstone beds a foot or two thick. Deep weathering does not allow a more precise determination of the actual ridge-forming strata, but float in the area suggests the presence of at least two massive sandstone layers. Similar to other faults on the flank of the Arkoma basin, the Carlisle School fault is a nearly vertical normal fault, downthrown to the southeast. The Oklahoma State Geologic and Tectonic Maps show the fault as being a western extension of the very long and prominent Marble City fault (Arbenz, 1956; Miser, 1954)[4]. Detailed mapping by Kerr-McGee Corporation geologists and consultants suggests that the Marble City fault actually passes southeast of the Carlisle School fault and that the latter is a secondary and parallel feature.

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[4] Arbenz, Kaspar, 1956, Tectonic map of Oklahoma: Okla. Geol. Survey.

Jointing and fracturing are present but not prominent in most of the Atoka rocks in the area. The silty shales and shaly siltstones are much less conspicuously jointed than the purer clay shale, and the joints that are observable are wavy, irregular and short. Most of the sandstone beds likewise lack prominent jointing; where they can be seen, they are short and irregular. A single exception is found in the upper layer of the highest sandstone sequences. This bed, about 4 to 6 inches thick, is a smooth-bedded brown dense very fine grained sandstone. It is broken by a rectangular joint system which creates a mosiac-like pavement wherever an expanse of the layer crops out. The joints are perpendicular to the bedding plane and occur in two directions, the north-south set being far more prominent than the complimentary set. West of the plant site (at the two locations north and southwest of raffinate pond #2) the principal joint set trends N27°W; in a road exposure of the same bed about a half mile east of the Oklahoma Highway 10, the orientation is N3°W. In both cases the joints are vertical and weathering has widened them to as much as 1/4 inch.

Stratigraphy - Atoka Formation

The thickness of the Atoka formation is about 390 feet beneath the Sequoyah plant area. A single deep well, drilled to Precambrian basement for disposal purposes, was carefully logged from 170 feet to total depth of 3,122 feet. The base of the Atoka formation, at 390 feet, rests on the unconformity at the top of the Wapanucka limestone. The Wapanucka

appears on the surface about ten miles northeast of the plant site and the top of the Atoka, marked by the Hartshorne sandstone, is about six miles southwest of the facility. Regional dip is therefore generally southwest; this is also the approximate direction of thickening of the Atoka. Those members of the Atoka exposed at the plant are about in the middle of the formation. The Atoka is characterized by very irregularly bedded discontinuous units of sandstone, siltstone and shale with subordinate thin limestones in the lower part. Those strata exposed on the hillsides below the Sequoyah Facility are no exception to this rule; in fact, it is difficult to trace any single member for more than a few hundred yards as they rapidly thin and disappear. Channeling of one unit into another is common.

In addition to the deep well mentioned above, a large number of core holes, test and monitor wells, and soil and foundation borings have been drilled in the area. The CH series of 21 core tests, drilled prior to the construction of the plant, were fairly deep and carefully logged. They form a valuable bank of data for interpretation of the shallow subsurface[5].

There are two locations suitable for surface measurement of the strata. One location is west of the plant along the ditches of the Port road and in the banks and bed of the combination stream, and in the road cuts along Highway 10 north of the plant. Elsewhere scattered outcrops can be assembled to provide a fairly coherent picture of the areal geology.

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5 Hemphill and Shelby Drilling Company (Oct-Nov 1967)

The Atoka formation in the subsurface below the plant (interpreted from the deep well, core holes and surface sections) has several distinct features. There is a basal shale ten feet thick overlain by a 30 foot thick sandstone bed, the thickest and most persistent unit in the Atoka. This sandstone bed probably correlates with the lower part of the Spiro sandstone member, a subsurface unit identified in the gas fields to the south. Above the 30 foot sandstone is another ten foot shale overlain by a second 30 foot thick unit of sandstone. This upper sandstone member is less massive than the lower one, being separated by shale beds into three distinct layers seven or eight feet thick. These three beds, together with the lower 30 foot sandstone, correspond to the whole Spiro member. The lithology was described from well cuttings as very fine-grained gray, finely glauconitic sandstone with traces of porous buff fine-crystalline limestone.

From the top of the Spiro sandstone at a depth of 300 feet in the disposal well (279 feet above sea level) upwards to 205 feet (374 feet above sea level), the Atoka is hard dark gray siltstone, tight and probably impermeable. At 205 feet there is a five foot thick bed of black carbonaceous shale. From 200 to 164 feet the rocks are similar to those below the black shale, i. e., black to dark gray hard siltstone. Samples examined during drilling show the strata to be hard black carbonaceous shale upwards to the 104 foot level of the disposal well. The stratum next above is approximately 30 feet of very fine-grained medium gray sandstone and hard siltstone and silty sandstone. This bed

directly beneath the main plant buildings. This is the only drill hole which found more than 12 feet of terrace material. From this hole the terrace thins unevenly in all directions to a feather edge around the lip of the hill.

In common with many other such features in Oklahoma, this terrace is probably Pleistocene in age, a remnant of much more extensive deposits laid down during high water stages of the Illinois and Arkansas Rivers. Downcutting by these streams has left this scrap of terrace high above the present valley. Similar but much larger terraces to the west of the plant area have yielded fossil mammoth bones and other evidence of a Pleistocene age.

The surface soil on the hill top and elsewhere on the terrace is seldom more than three or four inches of dark reddish brown organic material. The soil and material on which it is developed are geologically young and the top of the hill is generally free of forest. The soil probably corresponds to the Storden or Clarion types common in areas of glacial till (Thornbury, 1954, fig. 47)[6]. Indeed, the terrace itself much resembles a till deposit, although it had a different origin.

Three types of unconsolidated sediment make up the terrace: gravel, silt and clay. The three varieties commonly are intermixed. Pebbles of chert which comprise the gravel facies are scattered through silt or clay beds, and a silt and clay mixture is common. At a few places there are pockets of nearly pure clay, pure silt and sand or pure gravel. Both the gravel

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[6] Thornbury, W. D., 1954, Principles of geomorphology: New York, John Wiley

layers and the clay have been exploited for construction materials. The gravel makes very good road material; individual pebbles and cobbles, seldom more than three or four inches in diameter are rounded, smooth and very hard. Most of the dirt roads around the area are covered with a layer of this material. The clay, where it occurs nearly pure, has been excavated and used to form the foundation dikes and linings of the raffinate retention ponds at the facility as well as for other small farm ponds in the vicinity.

The gravel is almost 100% chert, vitreous and smooth. It occurs in brown, white, cream and buff pebbles up to four inches in diameter; most are subrounded and show evidence of a relatively short distance of stream transport. It is estimated that gravel composes less than one-third of the terrace material. The silt and silty sand fraction is brownish-red and buff in color, uniformly fine to very fine grained and unconsolidated. Locally, it has been leached to grayish-white color. Quartz is the dominant mineral, coatings of limonite lend a rusty color to some patches.

The clay is varicolored, mainly shades of brownish-red, tawny, and yellowish-buff. Some leaching has produced nearly vertical dike-like gray-white streaks up to one inch in width in the reddish matrix. Illite is the principal clay mineral. The clay occurs in layers and lenses of varying purity generally with an admixture of extremely fine quartz. One large area has been mapped as consisting of silt and silty clay; this is really a terrain of interbedded silt and clay layers and lenses

consisting of mixtures of the two fractions in a wide range of proporations.

Nearly pure clay has been found in three or four locations in the terrace. Concentrations of the very fine material in such pockets or lenses is likely the result of vagaries of fluvial and perhaps eolian currents during formation of the terrace. The clay from a pit north of raffinate Pond No. 2 is mainly a red to brown and gray soft plastic clay, with minor amounts of silt and scattered fine sand grains. Two rectangular pits excavated in an area southeast of the plant revealed a layer of brown and light tan to buff dry plastic clay, up to eight feet thick and lying beneath a two foot layer of brown silt and soil.

The clay minerals present in these deposits belong to the illite group, or the micaceous clays. These types are characterized by a very finely micaceous texture and varying degrees of fissility. Twenhofel[7] (1932,) presents an average chemical analysis of 236 fluvial clays from the Mississippi and Nile rivers. The illite in the Sequoyah property is very similar to that average.

Hydrogeology

Water-bearing properties of rocks and soils

<u>Atoka formation</u>: The bedrock just beneath the surface in the area of the Sequoyah Facility is interbedded siltstones, very fine sandstones and

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[7] Twenhofel, W. H., 1932, Treatise on sedimentation, 2nd Edition: Baltimore, Williams and Wilkins, 96 5p.

shales as described above. Most of the shale strata are silty, a few can be described as pure clay shales. None of the grains of sandstone observed are coarser than the fine grade (1/8 to 1/4 mm) of the Wentworth scale (Wentworth, 1922)[8]; most fall within the very fine and sand grade (1/16 to 1/8 mm). Many layers of sandstone are tightly cemented with a siliceous cement; clay and silt are important accessory materials in the sandstones. For reasons outlined previously, it is believed that the portion of the Atoka formation in the plant area is believed to have been deposited in a swampy deltaic environment by slow moving streams debouching into shallow marine waters. The site of deposition was far removed from any highland area, probably also protected from strong marine currents, and perhaps in part non-marine (Blythe, 1959)[9]. Owing to the manner in which the formation was laid down, the outstanding lithologic character of the Atoka is diversity. The small portion of the section present and the small area involved in the Sequoyah property and the immediately surrounding region can be generalized as two sandstone units, neither greater than sixteen feet in thickness, separated by 35 feet of shale. The two sandstones appear to merge north of the property, but tongues of sand extend south into the intervening shale sequence. Those tongues, less than four or five feet thick at the plant site, generally thin and disappear within a quarter mile south of the plant.

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[8] Wentworth, C. K., 1922, A scale of grade and class terms for elastic sediments: Jour. Geol., Vol. 30, p. 377-392.

[9] Blythe, I. G., 1969, Atoka formation on the north side of the McAlester basin: Okla. Geol Survey Circ. 47, 74 p.

None of the Atoka rocks are notably porous or permeable. In fact. the opposite is true; these rocks are tight and impermeable, forming an aquiclude rather than an aquifer. Based on microscopic study of surface samples, the porosity is less than 1%. There is some indication of fracturing and jointing in the uppermost evenly bedded sandstone layers and in the clay shales; these constitute the only potential avenues along which groundwater may travel. In the logs of the deep well, the shallowest stratum which can be considered to be an aquifer is in the Spiro member 318 to 322 feet below the surface. That unit bears saltwater (probably connate water) upwards of 100,000 ppm NaCl equivalent (Schlumberger Well Survey Co. Personal communication).

Terrace material: The crest of the hill upon which the Sequoyah Facility is located is covered by a mantle of silt, silty clay, and gravel. These materials are arranged in a haphazard distribution resulting from the manner of their formation in a stream swollen by glacial meltwater and subject to rapid fluctuations in velocity and capacity. During occasional dry periods along the ancient riverbed, the silt and clay fractions were blown about, redeposited, and probably concentrated in protected areas; comparable sorting by aqueous currents possibly took place during fluvial periods. The terrace is characterized by a disorderly array and mixture of the three sediment types. The gravel, which probably is the least of the three in the terms of gross bulk, but is by far the most conspicuous member, is also the most porous. Rainfall on the gravel beds slips away into the subsurface as soon as it falls. The gravel layers rest on silty clay or clay of the terrace, and locally,

on beds of shale or sandstone in the Atoka. Water which has passed through the gravel moves laterally at the top of the underlying stratum. Most of it emerges very shortly afterward at a lower elevation along the sides of the hill.

During and shortly after a rain the pasture land and soil are soggy; they dry very quickly. The soil above the terrace is quite thin and cannot retain water for long. Soil in the forested part of the land, developed mostly on Atokan bedrock, has a deeper layer of humus and a better defined soil profile. It retains moisture for a greater length of time.

The patches of clay and silty clay are nearly impervious and water which falls in areas underlain by these types of sediment rapidly runs off. Soil in the areas of clay and silty substrata are thin, less than six inches of brownish organic matter. Grass is the dominant natural vegetation cover.

In summary, all the rock and soil types in this area, with the sole exception of the gravel, are low in porosity and permeability. Vertical downward movement will be almost wholly confined to the first few subsurface inches, for beneath the weathered zone there are no passageways that might permit fluid movements. Having reached a bedding plane in the Atoka along which it may travel, water will move downdip.

The little fluid that eventually finds its way to the water table will move at right angles to the water table contours, along imaginary flow

lines. Because the elevation and shape of the water table contour map is based to a large extent on the topography, the direction of subsurface flow will be downhill - south, west and northwest.

Perched water: There is no evidence to suggest the presence of a perched water table in this area. Following a period of heavy rainfall the terrace material may be saturated for a brief period, thus producing a temporary and transitory body of water. This water drains out rapidly, however, and leaves the soil dry throughout most of the year.

Confined ground-water: Confined water, at least at shallow depth, has not been found in the area of the Sequoyah Facility. Lacking any other evidence the assumption is the shallowest confined water is that in the upper member of the Spiro sandstone as shown on the electrical logs of the deep well. The injection well is located directly west of the main plan building, halfway between the building and raffinate ponds. Elevation of the kelly bushing was 579 feet, ground level at the time of drilling was 563 feet. The top of the water (it occurs in the middle of three sandstone beds which comprise the upper half of the Spiro) is at an elevation 245 feet above sea level. This is approximately 200 feet lower than the bed of the Arkansas river.

The strata or their equivalents contain salt water and crop out on the Ozark uplift north of the plant precluding measuring or mapping the probable piezometric surface probably slopes southwest in this area. In that area of recharge, meteoric waters are entering the subsurface, resulting (theoretically) in a downdip freshening of the water and a

pressure gradient in that same direction. A geologic feature of this region is that the Spiro sandstone in the Arkoma basin (south of the downdip from the area under discussion) bears neither, salt or fresh, water yet it is porous and permeable.

Groundwater quality

The area is unlikely to attract large users of groundwater, since that source is meager and intermittent. Moreover, there are ample and dependable sources of surface water in the two large rivers and in Tenkiller reservoir, about seven miles to the north. The Sequoyah plant obtains its water from Tenkiller and any new industry or new community in the area doubtlessly also will depend on that source or on the Illinois and Arkansas Rivers.

Any fluids leaking into the subsurface will travel first along the shallow joint system and structural dip toward the northwest, eventually reaching the Illinois River. Fluids moving vertically down to the water table from the disposal area can be expected to move southwest, west or northwest and eventually to reach the Illinois. In neither case would the fluid entering this system reach an area from which groundwater is now being withdrawn.

Climatology

The area receives ample rainfall in the spring and fall and is prone to have dry weather and high temperatures during the summer months. Vegetation grows quickly in the spring, tends to be dormant in the hot summer and may brown off in the late summer. Some growth takes place

during the cooler, wet fall months although the vegetation does not completely regain its color until the spring. The normal annual rainfall is about 40 inches and the mean temperature is 62°F. During a 62-year period for which records were kept, the extreme high temperature was 115° and the low was minus 15°F.

Winds in the area are somewhat variable and tend to be lighter than those to the west in Oklahoma.

Sequoyah County lies in a zone having an approximate probability of 1.66 x 10^{-3} of having a tornado in any given year (once every 600 years).

DOCKET NO. 40-8027

CONTROL NO. 25367

DATE OF DOC. 05/24/85

DATE RCVD. 05/29/85

FCUF ✓ PDR ✓

FCAF LPDR ✓

WM I&E REF. ✓

WMUR SAFEGUARDS

FCTC OTHER

DESCRIPTION:

approval: Comprehensive solid waste disposal and storage plan

06/13/85 INITIAL CEC