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SITE SUITABILITY DATA ON POTENTIAL LOCATION OF A DISPOSAL FACILITY: COLLAPSE POTENTIAL AND PERMEABILITY

Weldon Spring Site Remedial Action Project
Weldon Spring, Missouri

SEPTEMBER 1991 **REV. 2**

U.S. Department of Energy
Oak Ridge Operations Office
Weldon Spring Site Remedial Action Project

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Weldon Spring Site Remedial Action Project

Site Suitability Data on Potential Location of a Disposal Facility: Collapse Potential and Permeability

Revision 2

September 1991

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U.S. DEPARTMENT OF ENERGY
Oak Ridge Operations Office
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NOTE

Revision 1 of this document was entitled *Suitability of the Weldon Spring Site for Potential Location of a Disposal Facility*. In response to comments, the title has been changed in this revision to reflect more accurately the content and purpose of the report.

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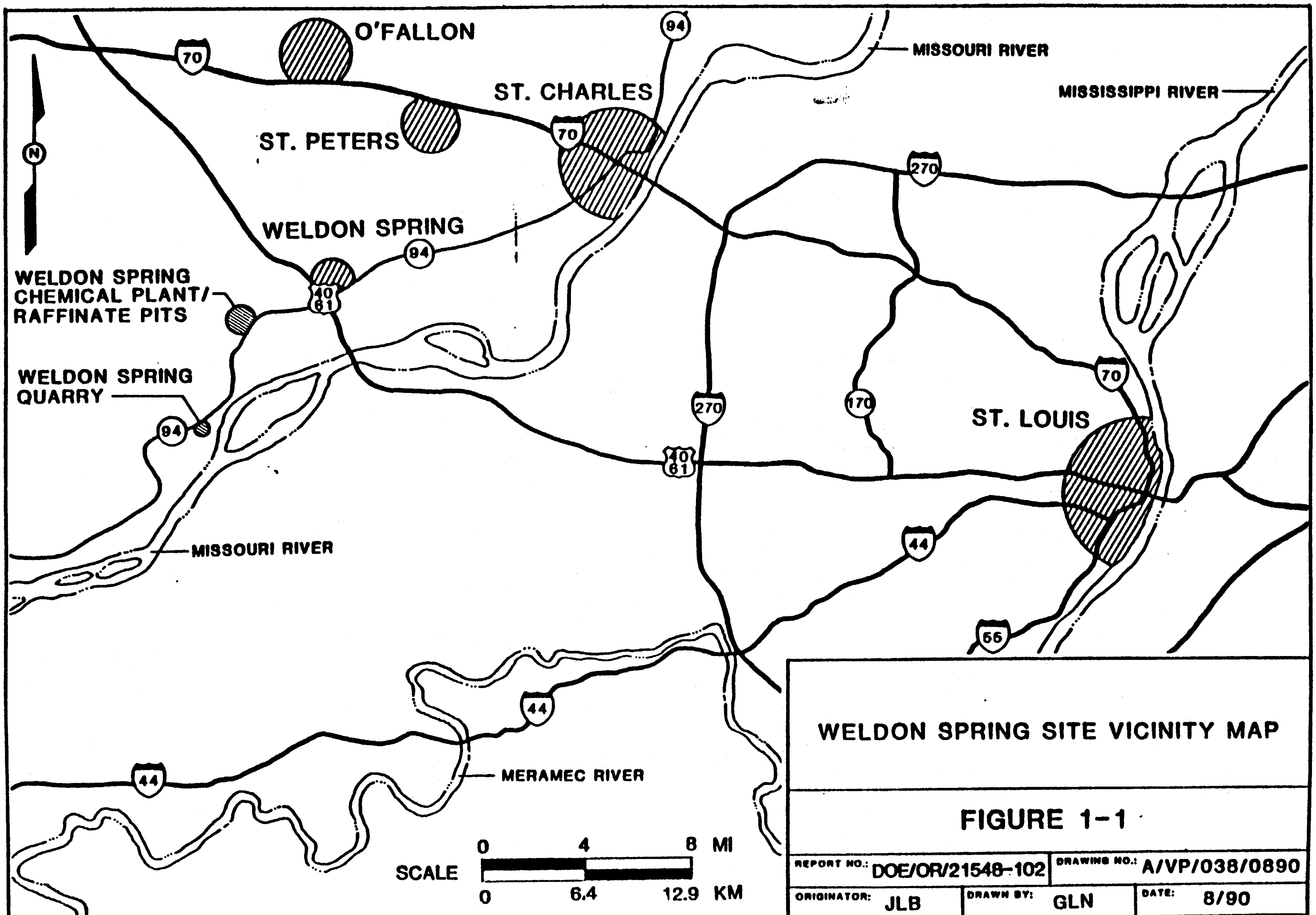
1 INTRODUCTION

This report summarizes the geological, geotechnical, and hydrogeological data describing the U.S. Department of Energy's (DOE) Weldon Spring Site Remedial Action Project (WSSRAP). Specific data are presented to facilitate evaluation of the suitability of the Weldon Spring Site as a location for a mixed low-level radioactive and hazardous waste disposal facility. Information regarding two aspects of site suitability is presented: (1) suitability of the soil mantle (overburden) at the WSSRAP site as a foundation material for the proposed disposal cell and (2) suitability of the bedrock underlying the proposed cell.

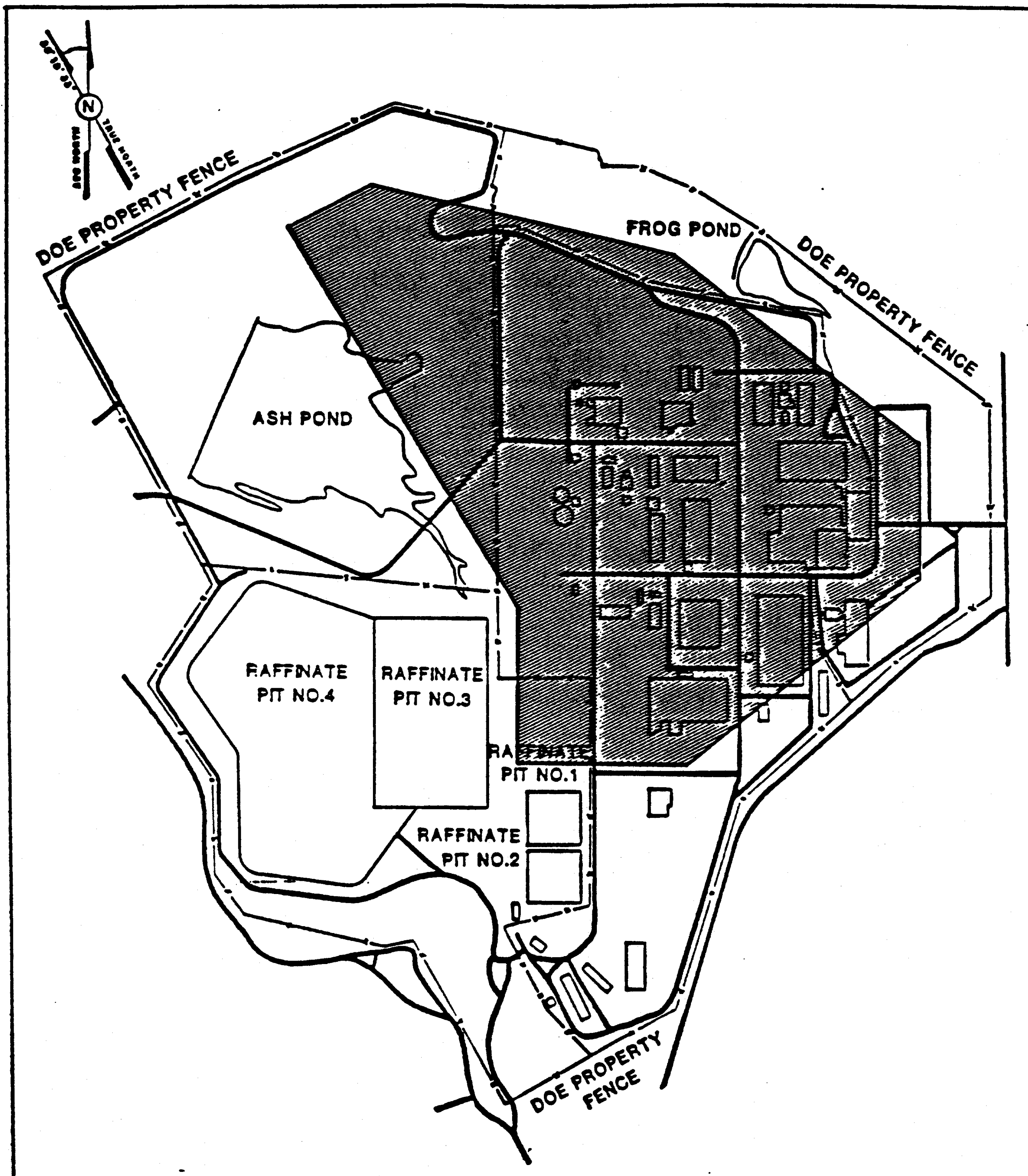
The WSSRAP is located in St. Charles County, Missouri, approximately 30 miles west of St. Louis. The site consists of two noncontiguous areas: a 220 acre tract of land approximately two miles southwest of the town of Weldon Spring (the Weldon Spring site) and an 8.6 acre quarry approximately six miles southwest of Weldon Spring (Figure 1-1).

Figure 1-2 shows an area designated for scrutiny within the Weldon Spring site; the disposal cell study area. A detailed historical account of activities impacting the Weldon Spring Site and quarry may be found in the Weldon Spring Site Remedial Action Project Chemical Soil Investigation Sampling Plan (MKF and JEG 1988a).



WELDON SPRING SITE VICINITY MAP	
FIGURE 1-1	
REPORT NO.: DOE/OR/21548-102	DRAWING NO.: A/VP/038/0890

ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90



SCALE 0 500 1000 FT
0 152.4 304.8 M

DISPOSAL FACILITY STUDY AREA

FIGURE 1-2

REPORT NO.: DOE/OR/21548-102		DRAWING NO.: A/CP/129/1290	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 12/90	

2 SUMMARY

The following properties of the overburden at the Weldon Spring site are appropriate to consider in assessing the suitability of these units as a foundation for a potential disposal facility.

1. Triaxial shear tests and one-dimensional consolidation tests indicate the soil units would provide adequate bearing and a sound foundation for a potential disposal cell.

2. Available data indicate the Ferrelview Formation and clay till have coefficients of permeability less than 1×10^{-7} cm/sec.

3. The basal till and residuum are more heterogeneous, consisting of zones of low hydraulic conductivity gravelly clays ($K < 1 \times 10^{-7}$ cm/sec) and higher permeability, noncohesive gravels. To be conservative, the residuum is assumed to have a coefficient of permeability equal to 1×10^{-3} cm/sec. Triaxial permeability tests are performed on saturated samples, providing additional conservativism when calculating the unsaturated coefficient of permeability of the overburden system in totality.

4. Soil batch tests have indicated that the Ferrelview Formation and clay till retard migration of uranium, vanadium, chromium, and lead.

5. It is anticipated that shallow portions of the topsoil/fill and loess units may be removed during building demolition and soil remediation. The resulting excavation would be filled with compacted clay. Based on available data, the effective coefficient of permeability of this layered overburden system will be less than an equivalent 30 foot thick layer with a coefficient of permeability of 1×10^{-7} cm/sec.

The following properties of the bedrock beneath the Weldon Spring site are appropriate to consider when assessing the site for catastrophic collapse potential. Specifically, attention is given to solution features which would threaten the effectiveness of potential disposal facility.

1. Slug test data indicate that a few high conductivity features are randomly distributed in the saturated bedrock.

2. Pumping test data indicate lateral anisotropy, but no significant conduits exist within the zones of influence of these tests.

3. Water level measurements on and around the site reveal a well-developed groundwater divide, suggesting that the groundwater flow system is characterized by diffuse flow with only minor components of discrete flow.

4. Zones of drilling fluid loss occurred in roughly half the borings on site; there is no pattern in the distribution that indicates these zones are laterally continuous.

5. Zones of dissolution within the bedrock are generally limited to the upper 20 to 30 feet of the bedrock, laterally discontinuous, and unsaturated.

6. No closed depressions on the top surface of the bedrock or overburden, which would indicate existing sinkholes, have been encountered in drilling, mapping, air survey, or visual reconnaissance techniques.

7. In the Weldon Spring area, conduits are recharged where the overburden, which ranges in thickness from approximately 15 to 55 feet on the site, have been removed by erosion. Because the overburden has low permeability, it is believed that no significant dissolution of the carbonate bedrock beneath the site has occurred since deposition of the overburden.

8. The low permeability overburden covering the bedrock at the disposal facility study area has rendered any existing solution features within the bedrock inactive.

9. No voids have been detected in the overburden, and no voids larger than 3.8 ft (in GT-47) in vertical extent have been detected in bedrock in the disposal facility study area.

10. No active groundwater conduits have been identified in the bedrock beneath the disposal facility study area.

3 OVERBURDEN CHARACTERISTICS

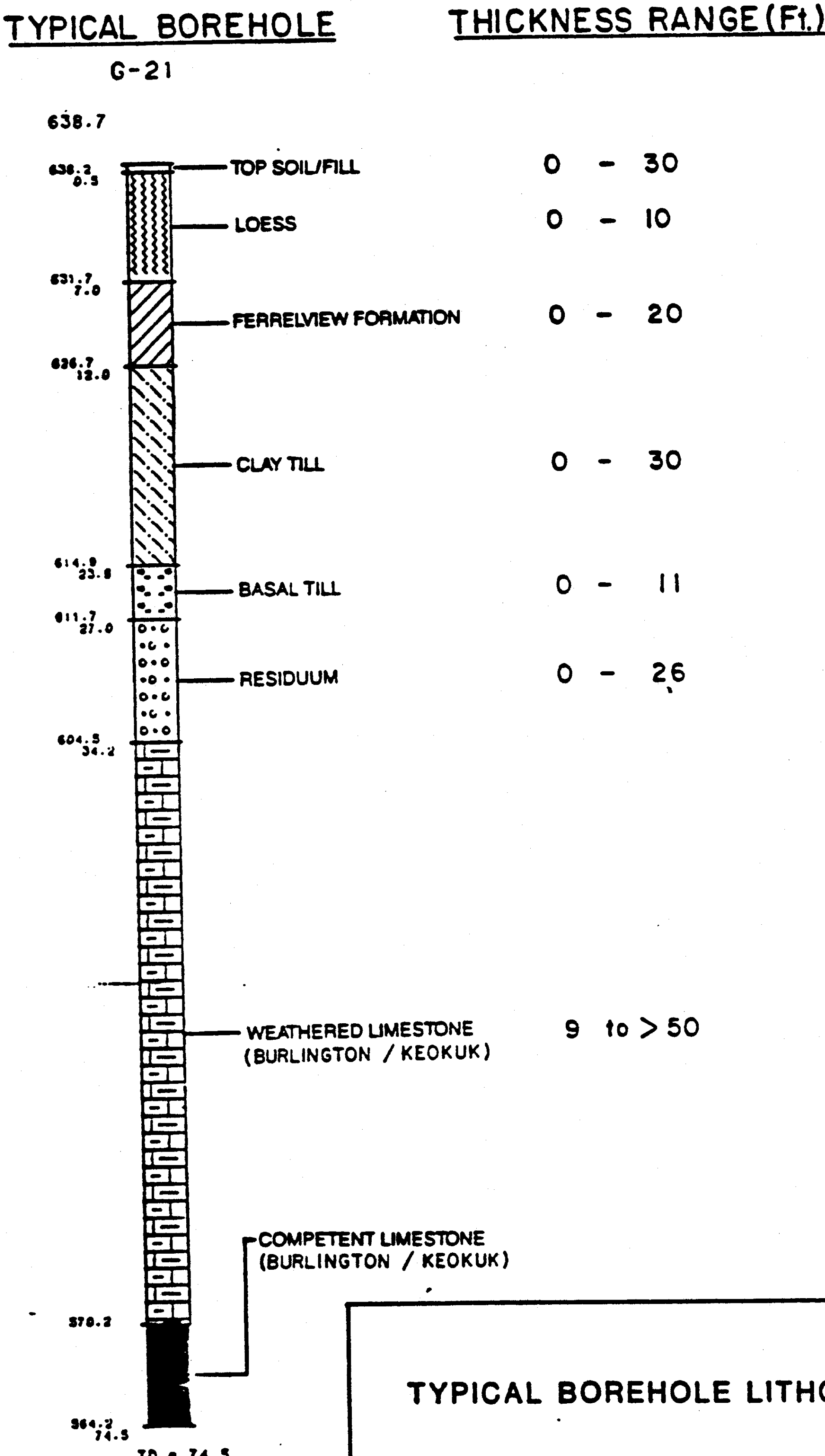
3.1 Stratigraphy

Six mappable overburden strata were identified during geotechnical drilling in the Weldon Spring site (WSS) (Figure 3-1). From oldest to youngest, these units consist of residual material from weathering of the limestone bedrock (residuum), two units of glacial origin (basal till, clay till), the Ferrelview Formation (an interglacial deposit; Howe and Heim, 1968), a wind-deposited unit (loess), and topsoil/fill. Figures 3-2 through 3-6 are isopachs of each unit (loess not included) and represent the thickness and lateral distribution of each overburden unit. Figures 3-7 and 3-8 show cross section views of the overburden units across the disposal facility study area in two directions. Figure 3-9 shows the locations of those cross sections.

The residuum is a highly heterogenous unit generally consisting of gravelly clay to clayey gravel ranging in thickness from 0 to 26 feet. The gravel fraction consists of angular chert and minor weathered limestone fragments. Interstitial clay is typically red, moderately plastic, and at the moisture contents encountered during sampling forms a tight matrix within this fraction. Of the five samples successfully recovered from the residuum, three consisted of noncohesive gravels. The residuum is the product of in situ weathering of the underlying silty, argillaceous, very cherty, coarse-grained, crystalline limestone during, and probably prior to, the Pleistocene. Low areas of the bedrock topography tend to have thicker sections of residuum than the higher areas.

The basal till consists of loosely bound sandy, silty clay with abundant angular chert gravel and cobbles. As with the residuum, sampling of the basal till proved difficult. Of the four samples successfully recovered, one consisted of noncohesive chert gravel. Deposition of the basal till appears to have been controlled by bedrock topography. This unit ranges in thickness from 0 to 11 feet and is present mainly in the western and north central areas of the site.

The clay till consists of very stiff, sandy, silty clay with low- to high-plasticity, subrounded pebbles of chert, igneous and metamorphic rock, and iron oxide nodules. In addition, fractures filled with pyrolusite abound in this unit. The clay till ranges in thickness from 0 to 30 feet and is recognized in all but two boreholes on the site.

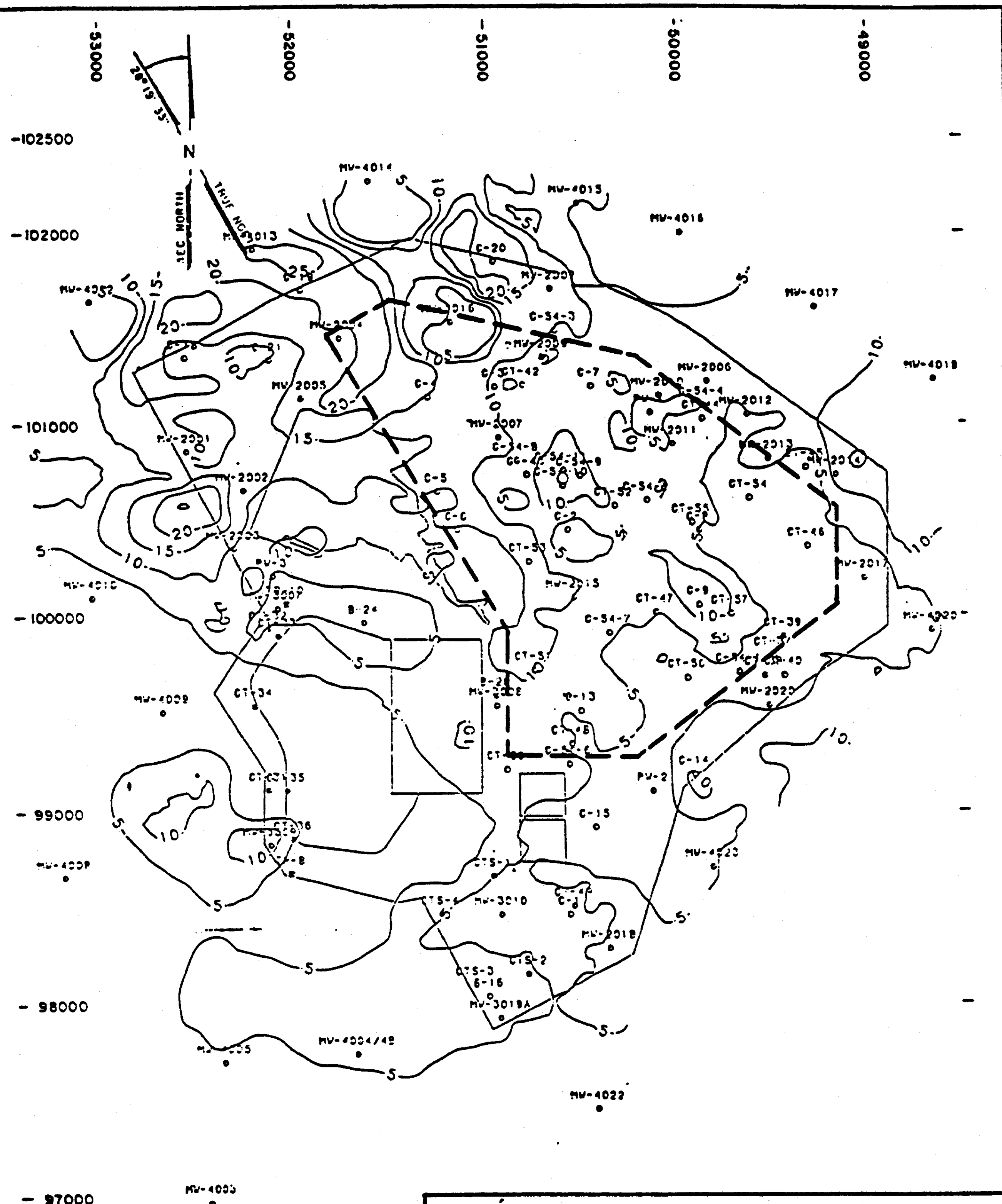


TYPICAL BOREHOLE LITHOLOGY

FIGURE 3-1

REPORT NO.: DOE/OR/21548-102	DRAWING NO.: A/PI/061/0890

ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90



LEGEND

—10— THICKNESS CONTOUR of RESIDUUM

CONTOUR INTERVAL 5.0 FT.

SCALE IN METERS

120 60 0 120 240 360

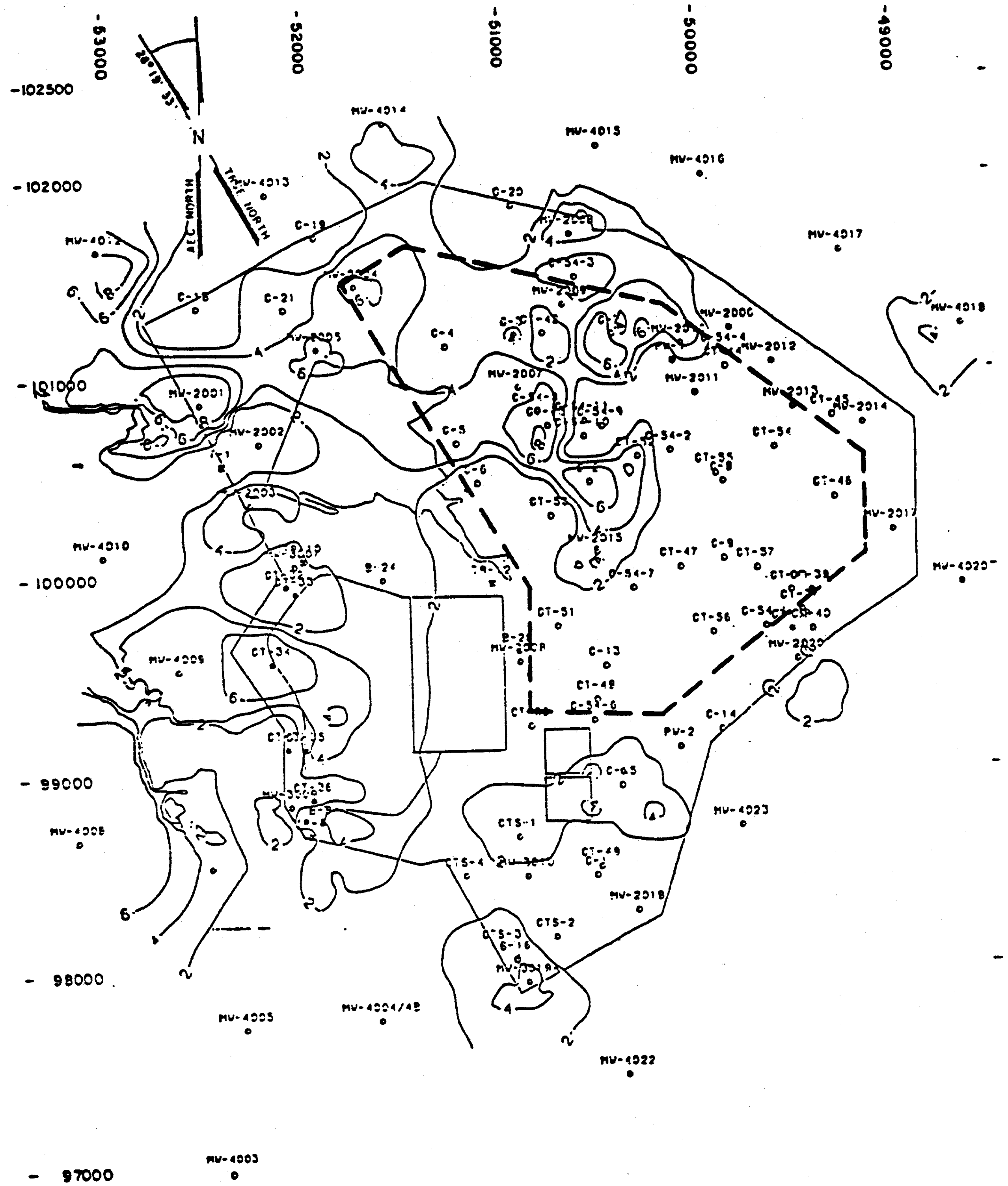
SCALE IN FEET

500 250 0 500 1000

ISOPACH MAP OF RESIDUUM

FIGURE 3-2

REPORT NO.:	DOE/OR/21548-102		EXHIBIT NO.:	A/CP/130/1290	
ORIGINATOR:	JLB	DRAWN BY:	GLN	DATE:	12/90



LEGEND

—— 6 —— THICKNESS CONTOUR of BASAL TILL

CONTOUR INTERVAL 2.0 FT.

SCALE IN METERS

120 60 0 120 240 360

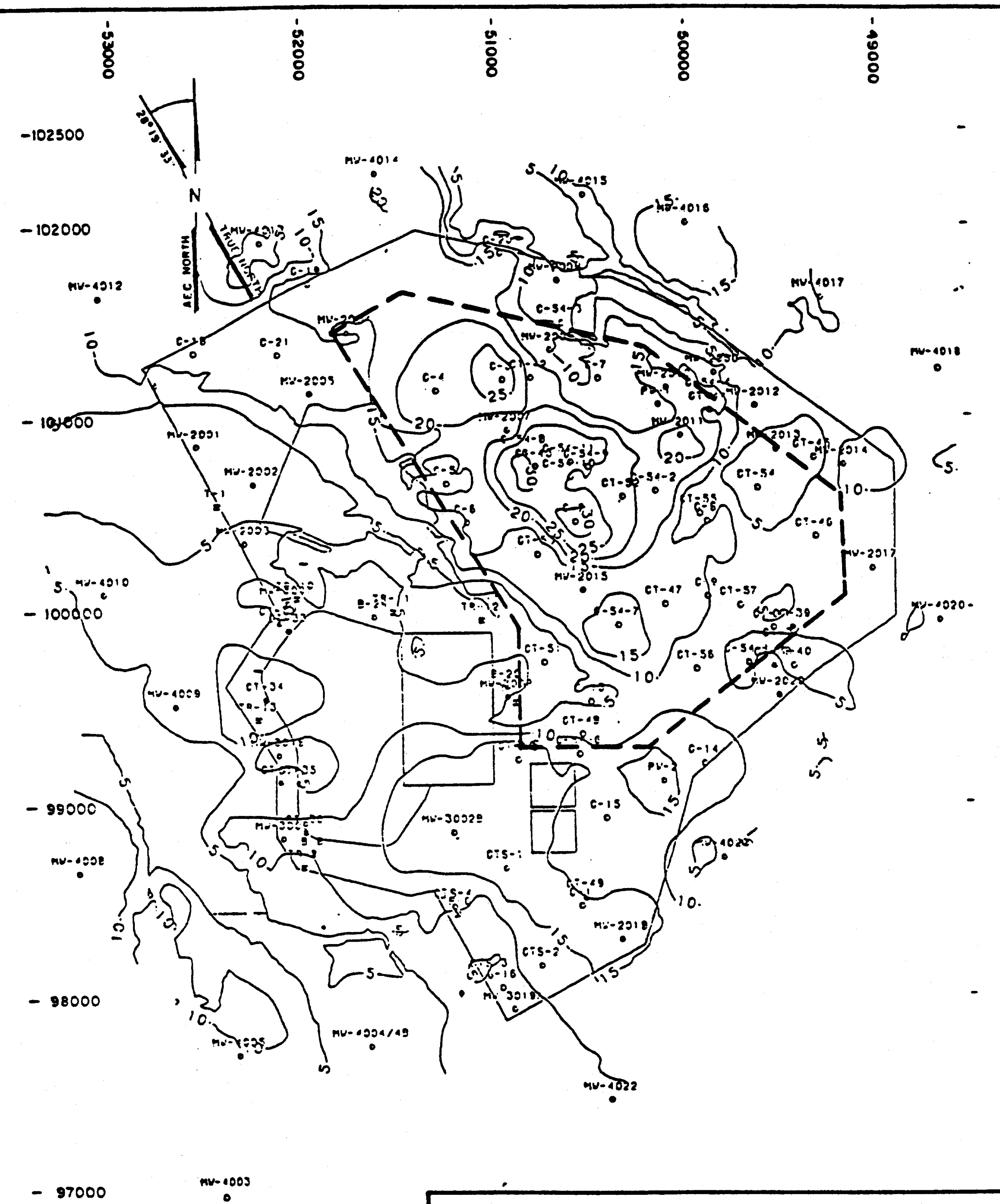
SCALE IN FEET

500 250 0 500 1000

ISOPACH MAP OF BASAL TILL

FIGURE 3-3

REPORT NO.: DOE/OR/21548-102		EXHIBIT NO.: A/CP/131/1290
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 12/90



LEGEND

——10—— THICKNESS CONTOUR of CLAY TILL

CONTOUR INTERVAL 5.0 FT.

SCALE IN METERS

120 60 0 120 240 360

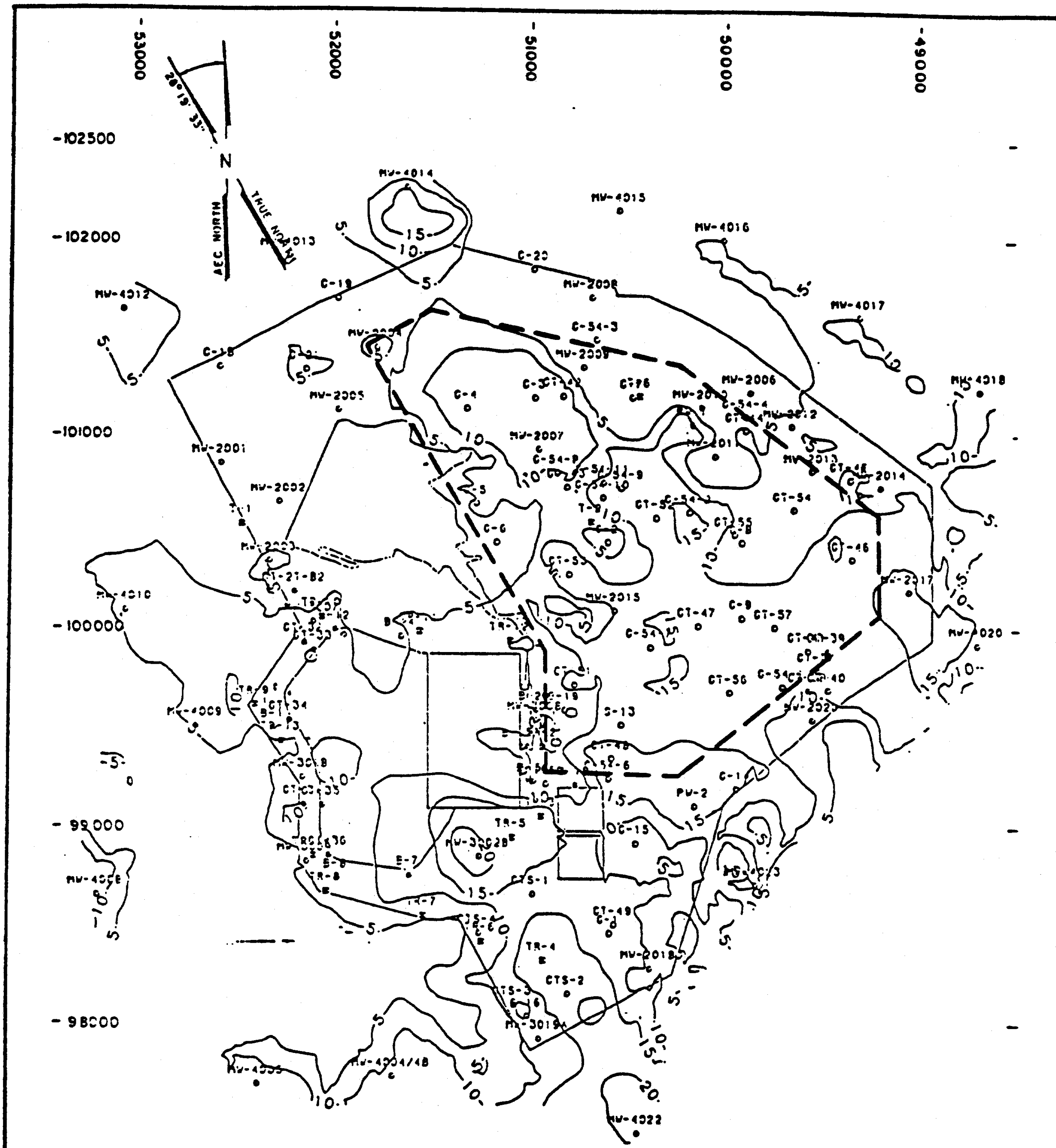
SCALE IN FEET

500 250 0 500 1000

ISOPACH MAP OF CLAY TILL

FIGURE 3-4

REPORT NO.: DOE/OR/21548-102		EXHIBIT NO.: A/CP/132/1290	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 12/90	



LEGEND

——10—— THICKNESS CONTOUR of FERRELVIEW FORMATION

CONTOUR INTERVAL 5.0 FT.

SCALE IN METERS

120 60 0 120 240 360

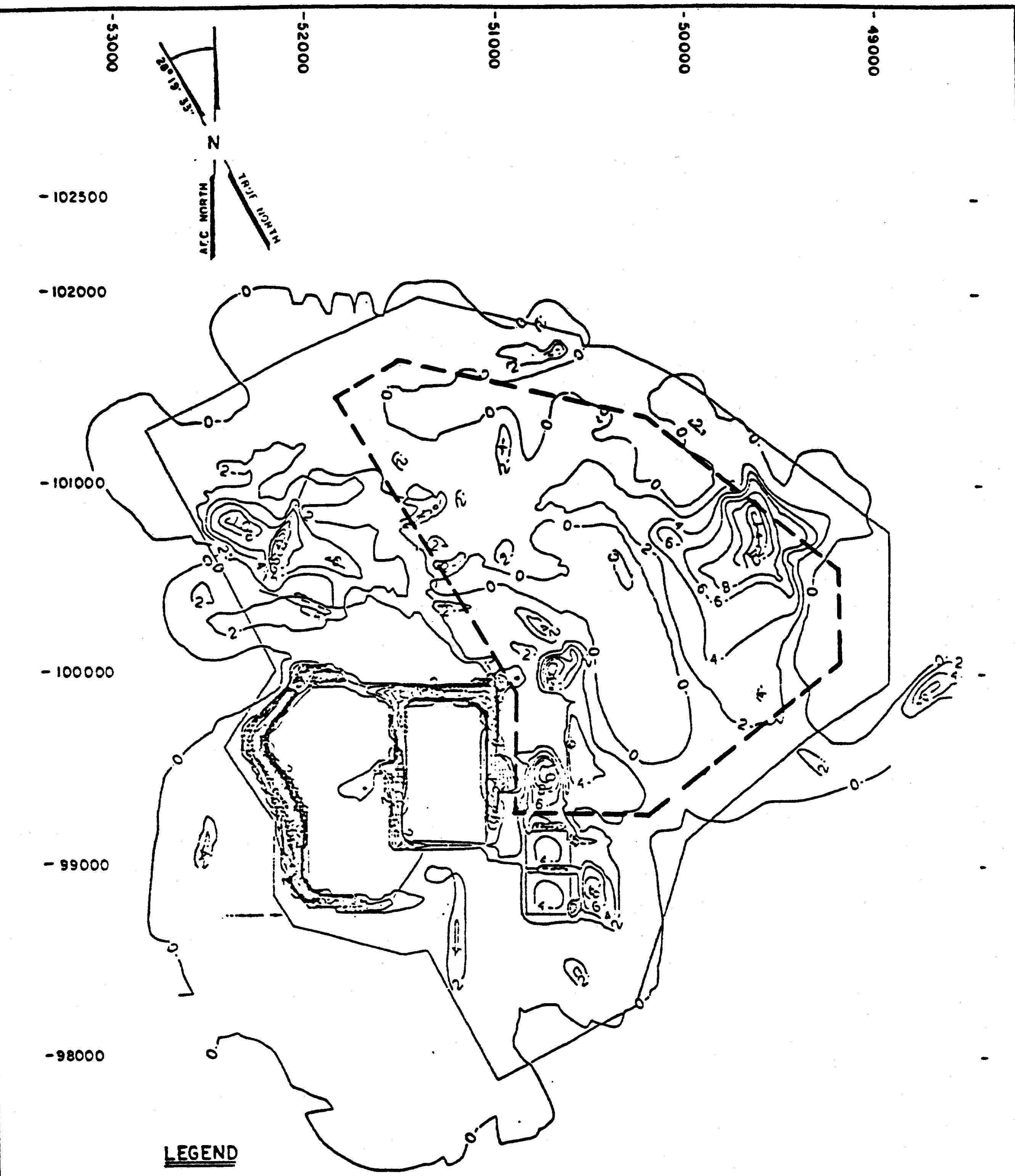
SCALE IN FEET

500 250 0 500 1000

ISOPACH MAP OF FERRELVIEW FORMATION

FIGURE 3-5

REPORT NO.: DOE/OR/21548-102		EXHIBIT NO.: A/CP/133/1290	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 12/90	



LEGEND

THICKNESS CONTOUR of TOPSOIL / FILL

CONTOUR INTERVAL 2.0 FT.

SCALE IN METERS

120 60 0 120 240 360

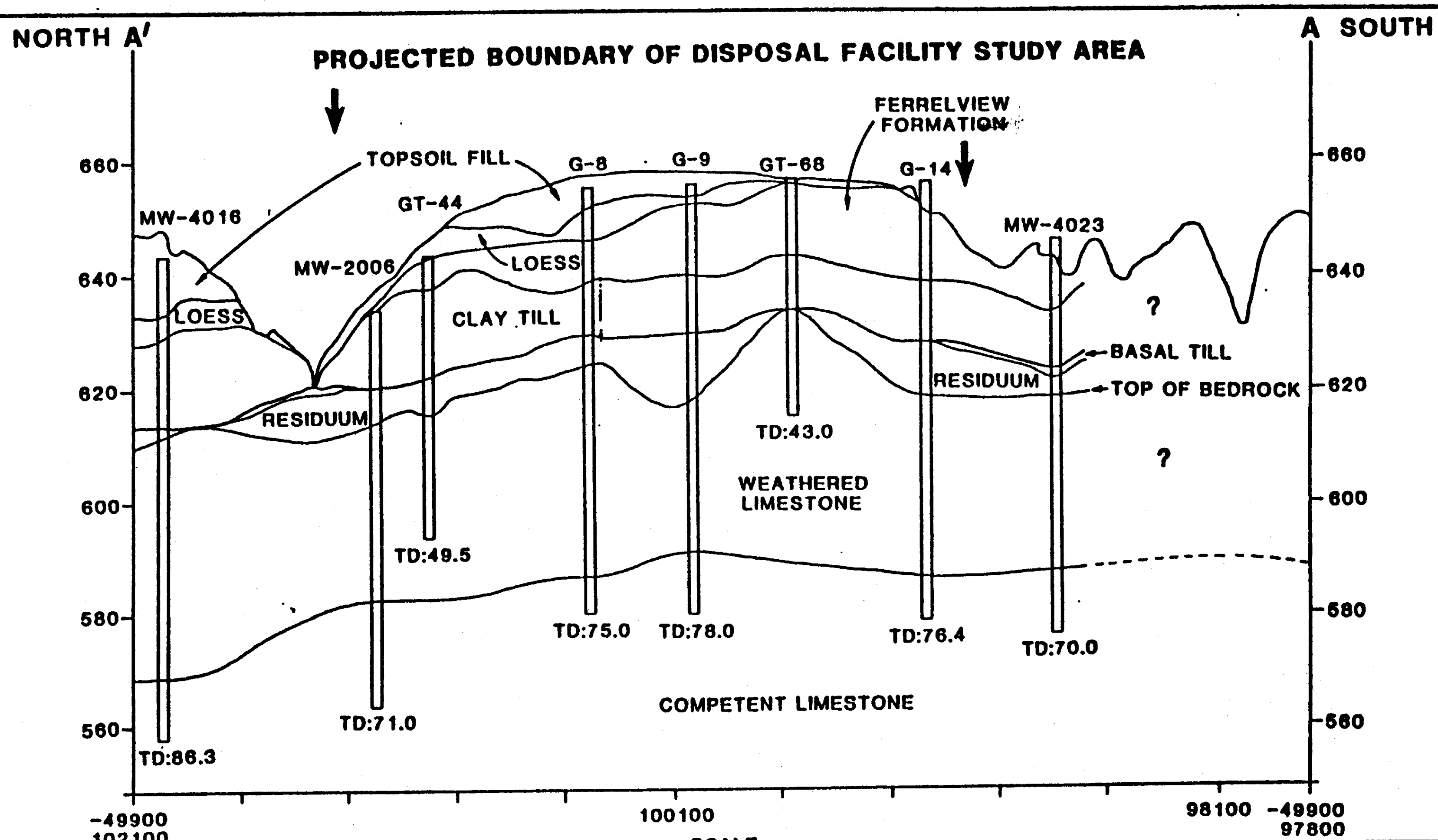
SCALE IN FEET

500 250 0 500 1000

ISOPACH MAP OF TOPSOIL/FILL UNIT

FIGURE 3-6

REPORT NO.: DOE/OR/21548-102		EXHIBIT NO.: A/CP/134/1290	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 12/90	



SCALE

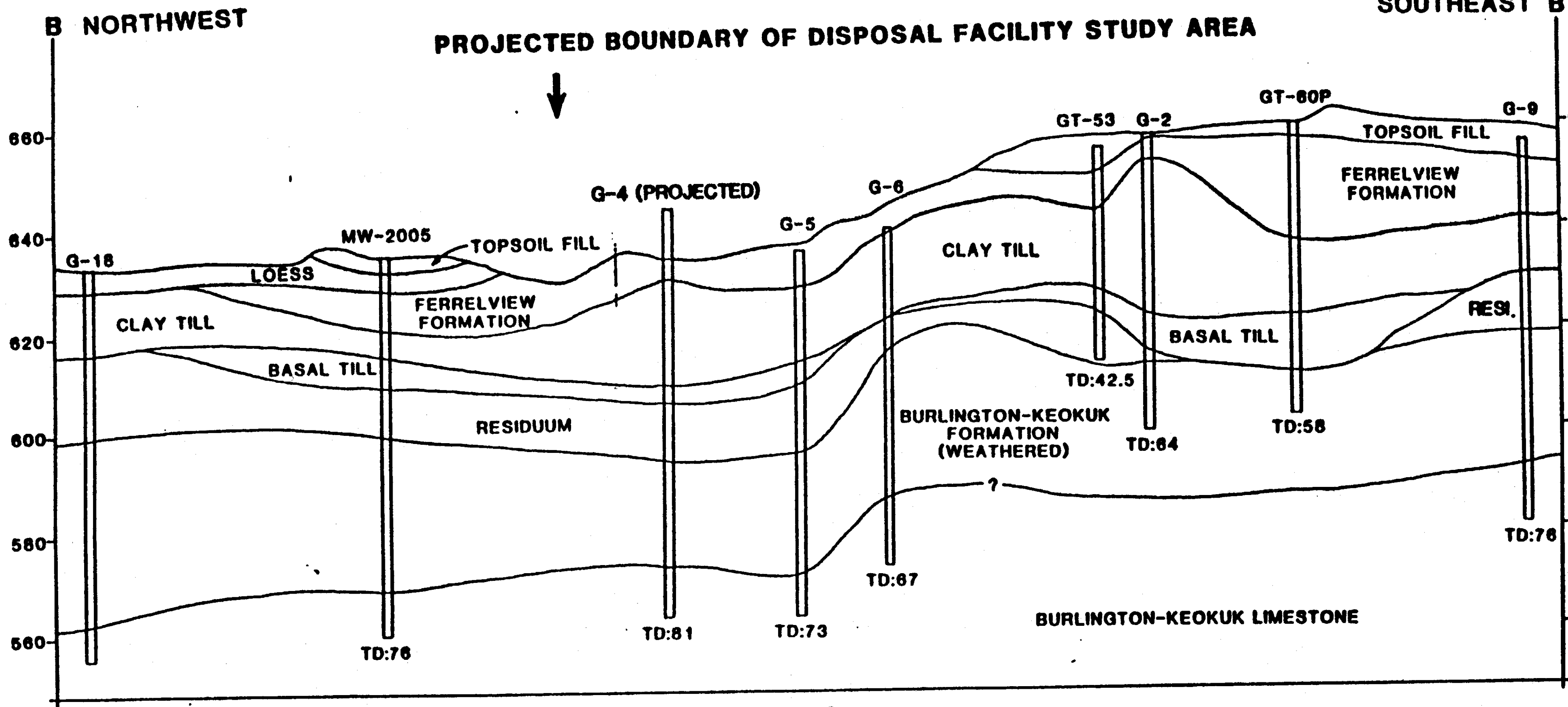
HORZ. SCALE 1 UNIT — 400 FEET (122.0 M)

VERT. SCALE 1 UNIT — 20 FEET (6.1 M)

GEOLOGIC CROSS-SECTION A-A'

FIGURE 3-7

REPORT NO.: DOE/OR/21548-102		DRAWING NO.: A/CP/058/0890	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90	

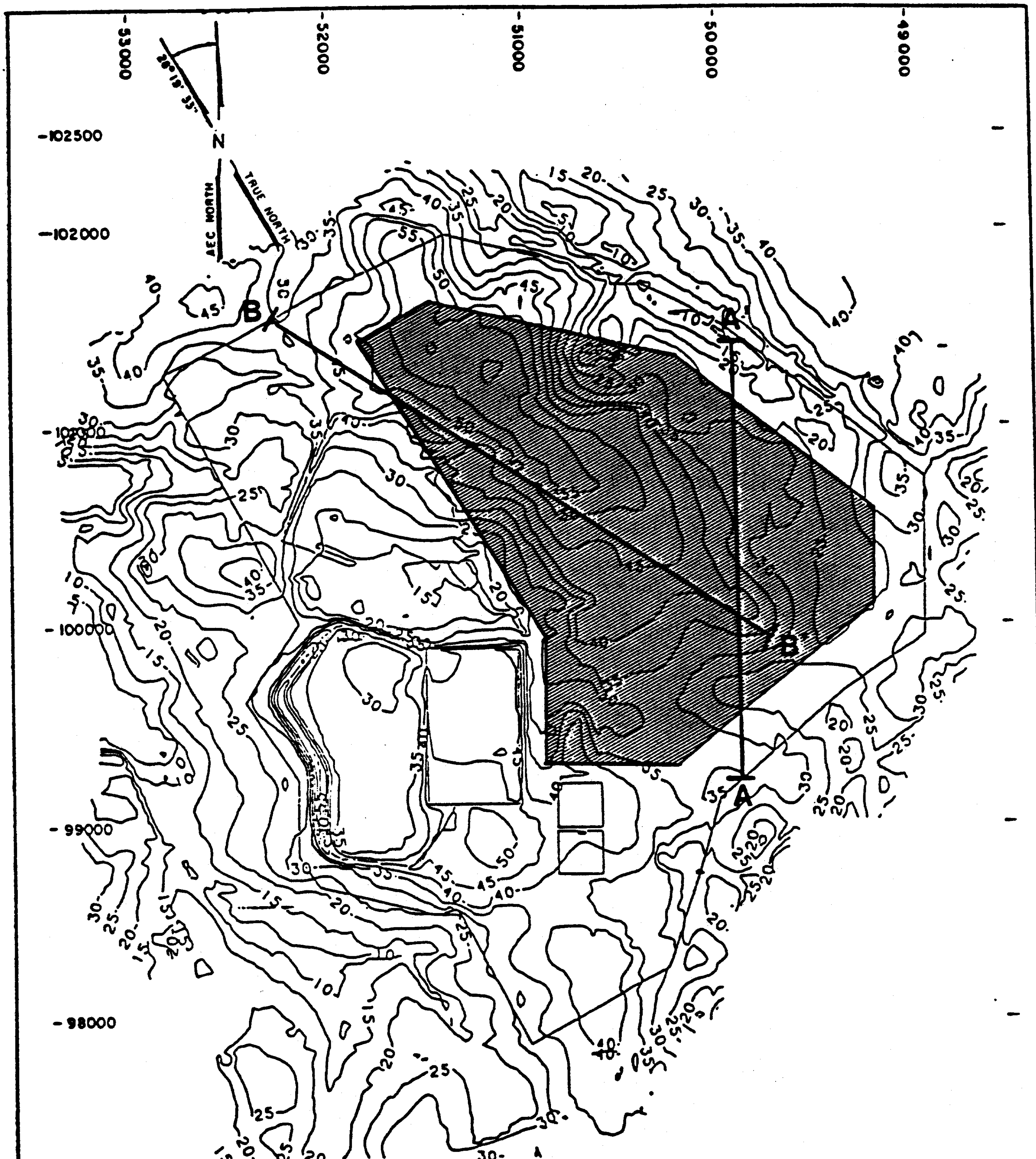


SCALE
HORZ. SCALE 1 UNIT = 200 FEET (61.0 M)
VERT. SCALE 1 UNIT = 20 FEET (6.1 M)

GEOLOGIC CROSS-SECTION B-B'

FIGURE 3-8

REPORT NO.: DOE/OR/21548-102	DRAWING NO.: A/CP/059/0890
ORIGINATOR: JLB / DRAWN BY: GLN	DATE: 8/90



LEGEND

—10— THICKNESS CONTOUR

SCALE IN METERS

120 60 0 120 240 360

SCALE IN FEET

500 250 0 500 1000

OVERBURDEN ISOPACH WITH DISPOSAL FACILITY STUDY AREA (ALSO SHOWING CROSS-SECTIONS LOCATION)

FIGURE 3-9

REPORT NO. DOE/OR/21548-102		DRAWING NO.: A/CP/135/1290
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 12/90

The Ferrelview Formation consists of very stiff, low to high plasticity clay and silty clay. Iron oxide nodules and fractures filled with pyrolusite are common in this unit. The Ferrelview Formation ranges in thickness from 0 to 20 feet and is present over most of the site.

The loess unit was deposited by wind and consists of low plasticity clayey silt and silty clay with traces of fine sand. This unit, which is sporadically distributed on the site, ranges in thickness from 0 to 11 feet.

The topsoil/fill unit consists of clayey silt and silty clay with organic matter. The fill portion is thought to have been excavated on or near the site, transported to the current locations, and recompacted. This unit varies greatly in thickness because of its use as construction material for raffinate pit dikes and as fill for leveling the surface topography prior to construction of the Weldon Spring uranium feed materials plant (WSUFMP) buildings during the 1950s. The topsoil/fill unit ranges in thickness from 0 to 30 feet, but is not an important unit within the boundary of the disposal facility study area.

3.2 Engineering Properties

3.2.1 Physical and Index Properties

Geotechnical investigations have been used to determine the engineering properties of the overburden units within the chemical plant area. This section summarizes the physical and index properties of different soil units.

The uppermost soil unit of the site is the topsoil/fill unit. This unit, ranging in thickness from 0 to 16 feet at the disposal facility study area may be removed before the cell is constructed.

The loess unit was randomly deposited by wind across the site. This material exhibits low to medium plasticity with a plasticity index (Pi) ranging from 10 to 30. It does not collapse when wet. The moisture content ranges from 15% to 30% and the dry unit weight from 90 to 105 pcf. Fine content usually ranges from 95% to 99%.

The Ferrelview Formation, underlying the loess exhibits a moderate to high plasticity (Pi from 20 to 50). Most of the material is silt and clay, the percent of fines ranging from 85% to 98%. The moisture content ranges from 15% to 30% and the dry unit weight from 90 to 115 pcf.

The clay till unit is the most extensive overburden unit at the WSS. It contains minor amounts of sand and gravel. The Pi ranges from 25 to 45. The percent of fines is between 70% and 95%. The moisture content and dry unit weight range from 12% to 35% and from 72 to 120 pcf respectively.

The basal till unit is the most gravelly soil unit within the site overburden. The Pi is between 12 and 28, the percent of fines from 28% to 84%, the moisture content about 18% and the dry unit weight from 102 to 120 pcf.

The interstitial clay portion (matrix) of the residuum exhibits a Pi from 28 to 50. Fines ranges from 35 to 80%. The moisture content and the dry unit weight range from 10% to 25% and 100 to 117 pcf respectively.

Based on test results from Phase I (October 1988 to May 1989) geotechnical investigations, average values for each overburden unit were calculated for each test type and are shown in Table 3-1 (MKF and JEG 1990b).

3.2.2 Consolidation and Strength Parameters

One dimensional consolidation tests have been performed to determine consolidation characteristics of the overburden units. Tests performed during Phase I Geotechnical Investigation (October 1988 to May 1989) have been interpreted.

One dimensional consolidation tests indicate that with the exception of the basal till, on which testing was impossible due to a lack of undisturbed samples, all overburden units are over-consolidated. For analytical purposes, the basal till is conservatively assumed to be normally consolidated. The average virgin compression ratio (the compression index divided by the sum of the void ratio plus 1) for all overburden units ranges from 0.14 to 0.17. The average recompression ratio (the recompression index divided by the sum of the void ratio plus 1) ranges from 0.02 to 0.05.

TABLE 3-1 Average Values of Laboratory Test Results of Overburden Soil Samples (Based on test results from October 1988 to May 1989)

Overburden Unit	% of Grain Size				Atterberg Limit		Unified Soil Classif.	Specific Gravity	Unit Weight (pcf)		Moisture Content (%)
	Gravel	Sand	Silt	Clay	Liquid Limit (%)	Plasticity Index (%)			Dry	Wet	
Loess	0	2	68	30	41	22	CL	2.71	100	113	22.5
Ferrelview	0	5	60	35	48	31	CL-CH	2.68	101	124	23.0
Clay Till	1	19	40	40	52	36	CL-CH	2.71	108	128	19.8
Basal Till/ Clay Till	0*	26	39	35	37	20	CL	2.61	106	125	18.3
Residuum	28	24		48	72	50	GC	2.79	88	118	22.9
Raffinate Pit Dike Fill	0	12	48	40	49	31	CL	2.63	102	125	20.8

NOTES:
1. Values in table are average values based on available laboratory test results as of May 1989. (–) denotes result not available yet or no test was performed. Average values from additional testing subsequent to May 1989 will be published in addendum or separate report.
2. Average values were calculated using arithmetic mean method unless otherwise noted.
3. All tests are performed on disturbed or undisturbed samples.

* Gravel portion of the basal till usually not obtainable from conventional sampling methods used. Therefore, gradation values are for the non-gravel size particles.

TABLE 3-1 Summary of Laboratory Testing Soil Samples (Based on test results from October 1988 to May 1989) (Continued)

Overburden Unit	Hydraulic Conductivity (Permeability) (cm/sec)	Consolidation	Coeff. of Consolidation (cm^2/sec)	Shear Strength: Total (from UU test)	Shear Strength: Eff. (from CU test)
Loess	6.2×10^{-6}	$C_c = 0.144$[a] $C_r = 0.022$[b]	4.1×10^{-4}	c = 1160 psf $\phi = 0$	c' = 240 psf $\phi' = 35°$
Ferrelview Formation	8.9×10^{-8}	$C_c = 0.173$ $C_r = 0.033$	6.0×10^{-4}	c = 1380 psf $\phi = 0$	c' = 250 psf $\phi' = 19°$
Clay Till	2.6×10^{-8}	$C_c = 0.153$ $C_r = 0.042$	1.4×10^{-4}	c = 1140 psf $\phi = 0$	c' = 110 psf $\phi' = 26°$
Basal Till/Clay Till	3.8×10^{-8}	– –	–	c = 1060 psf $\phi = 0$	– –
Residuum	5.0×10^{-8}	$C_c = 0.142$ $C_r = 0.052$	1.0×10^{-4}	–	c' = 260 psf $\phi' = 15°$
Raffinate Pit Dike Fill	–	– –	–	–	c' = 310 psf $\phi' = 17°$

NOTE: See also notes shown on Page 1 of Table

C_c = virgin compression ratio
C_r = recompression ratio
Values averaged using geometric mean method.

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Consolidated undrained triaxial compression (CU or R) tests and unconsolidated, undrained tests (UU or Q) were performed on undisturbed samples of the overburden. Shear strength parameters for each soil type were developed on the basis of tests results from Phase I Geotechnical Investigation (October 1988 - May 1989). Average calculated values for the undrained shear strength, and for effective and total cohesion and friction angles are presented in Table 3-1.

None of the overburden units tested proved weak or unfavorable for foundation purposes. The condition of the in situ overburden units would provide adequate bearing and a sound foundation for a disposal cell.

3.3 Hydraulic Properties

Hydraulic conductivity testing discussed in this section has employed water as the testing fluid. State of Missouri regulation 10 CSR 25-7 (2)(N)1.A (III)(a), says that a demonstration shall be made to the MDNR which shows that a hypothetical leachate must move slower than or equal to the rate at which water moves through the overburden column. This report does not attempt to make that demonstration, however that demonstration will be covered in a supplement to this report.

3.3.1 Laboratory Testing

The permeability, or hydraulic conductivity of various overburden strata at the WSS were determined through constant head triaxial permeability tests on undisturbed samples. Tests on disturbed samples from loess and Ferrelview Formation units were also performed. All tests were performed according to Army Corp of Engineers Procedure EM 1906.

The constant head triaxial permeability test measures the hydraulic conductivity of a saturated sample subjected to a constant head and hydraulic gradient. The tests were performed at different confining pressures, ranging from 1000 to 7000 psf, to simulate in situ loading conditions. The lowest measurable permeability of a soil sample subjected to this test is 1.0E-09 cm/sec. Hydraulic conductivities lower than this value are assumed to be 1.0E-09 cm/sec in the calculations.

Three undisturbed samples from the loess unit were tested. The average calculated permeability is 1.96E-06 cm/sec. Additional tests on disturbed loess samples were performed in the material staging area (MSA) footprint. Together they show an average permeability of 2.66E-07 cm/sec. For conservative purposes the first value would be used in calculations.

The permeability of the Ferrelview Formation unit was calculated by averaging the results from eight tests on undisturbed samples. Seven other tests were performed on disturbed samples from the MSA. The average permeability including MSA samples is 1.08E-08 cm/sec and neglecting MSA samples is 2.36E–08 cm/sec. Calculations will use 1.08E-08 cm/sec.

Eight undisturbed samples from the clay till unit have been tested. The average calculated permeability is 2.24E-08 cm/sec.

The average permeability of the basal till, calculated from three test results is 7.7E-08 cm/sec. These data will not be used in calculating the hydraulic conductivity of the overburden because the unit is heterogeneous and the data may not reflect actual hydraulic conductivity.

Although the three tests on samples from the residuum unit show a relatively low permeability of about 4.0E-08 cm/sec, a value of 1.0E-03 cm/sec was assumed in calculations due to the extreme heterogeneity of this unit.

Test results and calculated average values for the permeability of different overburden units are shown in Table 3-2.

A disposal facility built in the study area would increase the effective stress and thus the confining pressure at which the overburden units are subjected. Since permeability is inversely proportional to confining pressure, the use of listed average permeability values in calculations is conservative.

Another conservative assumption is the saturated condition associated with the permeability tests. Since permeability decreases with decreasing moisture content, and

TABLE 3-2 Laboratory Permeability Measurements of Overburden Units

BOREHOLE	SAMPLE ID	UNIT	COEFFICIENT OF PERMEABILITY (cm/sec)	GEOMETRIC MEAN
GT 50	ST 02	Loess	2.0E-05	
GT 55	ST 06	Loess	1.9E-06	
GT 58P	ST 01	Loess	2.0E-07	1.96E-06
TPMS 2	BU-01	Loess	2.0E-08	
TPMS 3	BU-01	Loess	3.0E-07	
TPMS 4	BU-01	Loess	9.0E-09	
TPMS 5	BU-01	Loess	2.0E-06	
TPMS 6	BU-01	Loess	3.0E-07	
TPMS 7	BU-01	Loess	1.0E-07	
TPMS 8	BU-01	Loess	6.0E-08	
TPMS 9	BU-01	Loess	3.0E-07	1.64E-07
GT 43	ST 04	Ferrelview	7.0E-08	
GT 43	ST 03	Ferrelview	3.2E-06	
GT 48	ST 05	Ferrelview	1.0E-08	
GT 56	ST 04	Ferrelview	2.9E-08	
GT 58P	ST 03	Ferrelview	<1.04-09	
GT 59	ST 02	Ferrelview	2.0E-07	
GT 62	ST 07	Ferrelview	<1.E-09	
GT 63P	ST 01	Ferrelview	7.0E-09	2.34E-08
TPMS 2	BU-02	Ferrelview	<1.0E-09	
TPMS 4	BU-02	Ferrelview	<1.0E-09	
TPMS 5	BU-02	Ferrelview	9.0E-09	
TPMS 6	BU-02	Ferrelview	<1.0E-09	
TPMS 7	BU-02	Ferrelview	1.0E-07	
TPMS 8	BU-02	Ferrelview	<1.0E-09	
TPMS 9	BU-02	Ferrelview	4.0E-08	1.08E-08

TABLE 3-2 Laboratory Permeability Measurements of Overburden Units (Continued)

BOREHOLE	SAMPLE ID	UNIT	COEFFICIENT OF PERMEABILITY (cm/sec)	GEOMETRIC MEAN
GT 45	ST 07	Clay Till	1.7E-08	
GT 50	SB 08	Clay Till	6.5E-08	
GT 51	ST 07	Clay Till	1.7E-08	
GT 58	ST 09	Clay Till	<1.04-09	
GT 59	ST 06	Clay Till	2.0E-07	
GT 60P	ST 10	Clay Till	1.04-09	
GT 60P	SB 15	Clay Till	2.0E-07	
GT 67P	ST 08	Clay Till	1.0E-07	2.29E-08
GT 43	SB 17	Basal Till	3.8E-08	
GT 60P	SB 17	Basal Till	2.0E-07	
GT 62	SB 13	Basal Till	6.0E-08	7.7E-08

Residuum - Assumed value 1.0E-03 (cm/sec)

since no perched water zones have been identified in the studied area, in situ permeability is expected to be lower than the laboratory results indicate.

The mean permeability values, see Table 3-2, and thicknesses for each overburden unit are used to express the effective coefficient of permeability for a layered heterogeneous system as given by Todd 1980.

$$K_{ef} = \frac{z_1 + z_2 + ... + z_n}{z_1/K_1 + z_2/K_2 + ... + z_n/K_n} \qquad (3\text{-}1)$$

where:

K_{ef} = effective coefficient of permeability
z_n = thickness of unit n
K_n = coefficient of permeability of unit n

The most conservative scenarios for calculating the overall permeability of the layered overburden system assumes the minimum thickness for the clay till layer, this unit having the lowest hydraulic conductivity.

For purposes of this discussion, building demolition and soil remediation are assumed to result in a level cut 10 feet beneath the present grade in the process buildings area. This cut is then filled with 10 feet of recompacted clay. Beneath this cut, an average of 10.0 feet of Ferrelview Formation, 5.0 feet of clay till, 0 (zero) feet of basal till, and 5.0 feet of residuum are assumed, based on the thickness represented in Figures 3-2 to 3-6. Only the natural soil layers will be considered in the calculations, this assumption being more conservative.

Given the thicknesses listed above, the average coefficients of permeability for the Ferrelview Formation and clay till of 2.34×10^{-8} and 2.29×10^{-8} cm/sec, respectively (Table 3-2), and assuming a value of 1×10^{-3} cm/sec for the residuum, the effective coefficient of permeability for this layered system would be 3.09×10^{-8} cm/sec.

For an equivalent 30 feet layer, this hydraulic conductivity (K_{30}) corresponds to

$$K_{30}, = 3.09E\text{-}08 * \frac{30}{20} = 4.64E\text{-}08 \text{ cm/sec}$$

Another approach can be made by calculating the minimum required thickness of a natural soil layer with a hydraulic conductivity of 2.36E-08 cm/sec (the mean hydraulic conductivity value for the Ferrelview Formation from Table 3-2), in order to be equivalent with a 30 feet layer with K=1.0E-07 cm/sec.

$$D = \frac{2.36E\text{-}08 * 30}{1.0E\text{-}07} = 7.02 \text{ feet}$$

Consequently, according to test results, the permeability of the natural layered system is much lower than a required condition of a 30 feet layer with a permeability of 1.0E-07 cm/sec.

The DOE recognizes that permeability values presented in this report are determined using water as the fluid in the laboratory test. As a part of a series of special studies, the DOE will compare these values with values derived using a synthetic leachate as the test fluid. The fluid will be selected by identifying the worst case composition of probable leachates (by natural or synthetic formulation). These leachates will result from in situ water draining from wastes emplaced in the disposal cell and water entering the disposal cell and filtering through the wastes.

Analytical data from characterization studies (total, toxic contaminant leaching process [TCLP], etc.) will be evaluated to determine which contaminates are of concern for each waste that may be placed into the disposal cell. A list of characterization studies that will be evaluated during the data review process will be provided to the architect/engineer (A/E). The wastes to be evaluated include (but are not limited to):

1) Stabilized raffinate pit sludge.

2) Stabilized raffinate pit sludge in intimate contact with surface contaminated rubble and debris.

3) Weldon Spring Site (WSS) soils and any associated interstitial water that are radiologically contaminated (primarily with uranium but does contain some thorium and radium).

4) Soils and interstitial water contaminated with nitroaromatics from the contaminated areas of the quarry.

5) WSS soils contaminated with heavy metals.

6) Water treatment plant residuals that will be generated from normal operations.

Specific parameters that will be evaluated for each waste listed above may include (but are not limited to) heavy metals, nitroaromatic compounds, radiological compounds (primarily uranium, radium, thorium), anions (nitrate, sulfate, fluoride, and chloride), and physical characteristics (pH, Eh, ORP, etc.)

In most cases leachate from a treated waste will be less hazardous than leachate from untreated waste. But in some cases, geochemical interactions between waste forms could cause a treated waste to produce higher concentrations of a contaminant than the untreated waste. This concern has not been thoroughly investigated. During data review, this issue will be evaluated to determine the appropriate waste condition that will produce a worst case leachate.

3.3.2 Field Testing (Constant Head)

Constant head permeability testing was performed in two boreholes in the disposal facility study area (GT 59 and GT 61). Testing and calculations followed the procedures outlined in the U.S. Bureau of Reclamation Earth Manual, Appendix E-18. All tests were performed within the unsaturated zone above the water table. The tests were made by pushing the rods into the undisturbed soil; then the rods were filled with water and a full level was maintained by adding water as the water level dropped. The volume of water added was recorded for the testing period of ten minutes. Additional tests were performed in five boreholes within the temporary storage area (TSA) footprint. Table 3-3 summarizes field test soil hydraulic conductivity values.

Two additional tasks have been proposed to investigate the in situ permeability of the Ferrelview Formation, clay till unit, and basal till unit. These tasks focus on determination of in situ permeability testing with particular attention paid to the influence of macropore features on hydraulic conductivity.

Task 1

Task 1 is preparation of a sampling plan and engineering specifications and performance to obtain and test soil samples for hydraulic parameters including moisture retention characteristics, saturated hydraulic conductivity, volumetric water content, bulk density, and porosity. The major objectives of this task are to compare the results of permeability testing on large diameter and conventional sized samples of fractured glacially derived soil and to obtain the necessary input parameters for saturated/unsaturated flow modeling from an engineered disposal cell to the potentiometric surface. Major elements of this task are:

- Selection of sampling locations.
- Selection of sampling methods for large diameter (6-12 inches) and conventional sized samples.
- Specification of packaging and ship requirements.
- Specification of test methods and analysis of constant head triaxial permeability tests and other parameters listed above.
- Supervision of field sampling and coordination of laboratory testing.
- Observation of geologic and engineering aspects of soil fabric properties upon exposure during excavation.
- Evaluation of results and observations and preparation of an interpretive report.

Task 2

Task 2 is preparation of a sampling plan and specifications and performance of permeability testing on conventional sized samples using a synthesized leachate as a permeant. Soil samples for this task will be collected as part of Task 1.

Major elements of this task include:

- Preparing laboratory specifications for preparing constant head triaxial permeability tests on conventional sized samples using synthesized leachate.

- Evaluation of results and preparation of an interpretive report.

An interpretive final report summarizing the results of Task 1 and Task 2 and all laboratory testing will be written. This report will provide a comparison of small and large diameter permeability testing, permeability testing with leachate, and calculation of unsaturated hydraulic conductivity from moisture retention characteristics. The DBM should include a preliminary outline of the final report.

3.4 Geochemical Properties

The U.S. Geological Survey (USGS) Water Resources Division and the University of Missouri-Rolla conducted laboratory sorption experiments to determine how effectively the Ferrelview Formation and clay till unit might retard the migration of nitrate, uranium, vanadium, aluminum, chromium, and lead (Skelton 1990). Batch tests of Ferrelview Formation and clay till samples were run at pHs of 4.5, 7.0, and 9.0. Leachate analyses of the Ferrelview Formation samples were conducted at 24, 48, 120, 240, and 480 hours. Leachate analyses of the clay till samples were conducted at 24, 120, and 480 hours. The leachate used was drawn from Raffinate Pit 3 and spiked with aluminum, chromium, lead, nickel, and uranium. Initial contaminant concentrations are listed in Table 3-4. Results of batch testing as reported by USGS are summarized below.

- Nitrate was not attenuated in these batch tests.

- Uranium was strongly attenuated in acidic to neutral batch tests of the Ferrelview Formation, with apparent distribution coefficients (Kd) of approximately 200 at pH 4.5 and 7.0. At pH 9.0, Kd was approximately 40. In the clay till batch tests, uranium apparent Kd values were approximately 400, 11, and 120 at pH 4.5, 7.0, and 9.0, respectively.

TABLE 3-3 Summary of In Situ Permeability Test Results

BOREHOLE NUMBER	TEST INTERVAL OR DEPTH (Feet)	STRATIGRAPHIC UNIT	CALCULATED HYDRAULIC CONDUCTIVITY (cm/sec)[1]
GTS-1	36.5	Residuum (CL)	ND
GTS-2	10.0	Ferrelview (CL)	ND
	25.0	Clay Till (CL)	ND
GTS-3	7.5	Ferrelview (CL)	ND
	17.5	Clay Till (CL)	ND
	22.5	Resdiuum (CL)	ND
GTS-4	5.0	Ferrelview (CL)	ND
	24.0	Basal Till (CL)	ND
GTS-5	15.0	Ferrelview (CH)	1.25×10^{-7}*
GT-59	22.5	Clay Till (CH)	4.95×10^{-7}*
GT-61	51.5	Basal Till (ML)	8.56×10^{-5}

1 Values marked by asterisk are results of single tests.
2 ND = results below detection limit (10^{-8} cm/sec).

- Like uranium, vanadium was strongly attenuated in acidic to neutral batch tests of the Ferrelview Formation, with apparent distribution coefficients of approximately 1,500 and 1,300 at pHs 4.5 and 7.0, respectively and approximately 60 at pH 9.0. In the clay till sample runs, vanadium apparent Kd values were approximately 220, 95, and 88 at pH 4.5, 7.0, and 9.0, respectively.

TABLE 3-4 Initial Contaminant Concentrations for Soil Batch Tests (ppb)

F	7.0-7.2	Mo	4000-4400
NO3	1300-1400	Ni	43-59
SO4	610-660	Se	260
Al	70-330	Sr	2000-2300
Cr	52-60	V	480-520
Pb	96-115	U	3100-3400
Li	3900-4100		

Although these concentrations may not be representative of leachate from the proposed disposal facility, the ability of the soils to retard migrations of these contaminants should be approximately constant.

- Aluminum concentrations increased at pH 4.5, but were attenuated at pH 7.0 and 9.0.

- Chromium was slightly attenuated at all pHs.

- Lead was strongly attenuated at all pHs.

Soil batch tests on samples from the Ferrelview Formation and clay till indicate that these soils retard migration of uranium, vanadium, chromium, and lead. Aluminum is attenuated in neutral to alkaline water. Nitrate is not attenuated.

Nitroaromatic compounds are not attenuated in the Ferrelview Formation or the Clay Till (USGS 1990 correspondence).

Water quality data from monitoring wells at the Weldon Spring site illustrate the effectiveness of contaminant retardation processes occurring within the overburden. Uranium concentrations decrease by several orders of magnitude between water samples from the raffinate pits and groundwater from monitoring wells adjacent to the pits. Trace metals generally decrease to below background concentrations within short distances from known sources. Nitrate and sulfate are not attenuated and have well-defined plume geometries in the vicinity of the raffinate pits and other sources (MKF and JEG 1989).

3.5 Effects of Proposed Building Dismantlement Activity

Several of the main process and support buildings of the former uranium feed materials plant are within the disposal cell study area. Preliminary review of the as-built drawings of the foundations of these buildings indicates that the process buildings were constructed on spreader footings which extend less than 5 feet into the subjacent soils. Several pilings (less than 20) are present in the disposal facility study area but all are less than 14' deep with the majority being less than 6' deep. Each building also contains a sump or series of sumps which extend approximately 6 feet into the subjacent soils. In addition, certain heavy machinery required special foundations including deep shafts and pilings. Excavation of the building foundations, pilings, and contaminated soils would result in removal of large volumes of the in situ soils.

This excavation would be filled with borrowed soil. In the process of regrading the excavation, the fill would be compacted to yield a low permeability foundation material.

Permeability tests performed on remolded samples from loess and Ferrelview Formation units (which may be used as borrow sources) within the MSA footprint yielded very low permeabilities (see Table 3-2). Nearby off site borrow sources have also been located, and samples tested exhibited relatively low permeability, ranging from 3.0E-07 to less than 1.0E-09 cm/sec, with an average value of 3.28E-08 cm/sec.

4 HYDROGEOLOGIC CHARACTERISTICS

4.1 Bedrock Stratigraphy

Bedrock units beneath the Weldon Spring site range in age from Cambrian to Mississippian. The uppermost regional aquifer begins in the Burlington-Keokuk Limestone which lies approximately 15 to 55 feet below ground surface. The water table ranges from slightly above to approximately 30 feet below the top of bedrock. In general, the uppermost portion of the bedrock is unsaturated (MKF and JEG 1989). Descriptions of the sedimentary rocks underlying the Burlington-Keokuk Limestone in the vicinity of the Weldon Spring site are available in reports by Bechtel (BNI 1987), Kleeschulte and Emmett (1986 and 1987), and the DOE (MKF and JEG 1988b, 1989).

The Burlington-Keokuk Limestone is thinly to thickly bedded and contains up to 60% chert as nodules and interbeds. It is silty and argillaceous near the top. Approximately 140 feet of Burlington-Keokuk Limestone was encountered in a boring drilled to the Ordovician St. Peter Sandstone in a section adjacent to the southern boundary of the Weldon Spring Site.

Core drilling on site has allowed definition of two units in the Burlington-Keokuk Limestone based on lithology and the degree of fracturing and weathering exhibited in the rock (Figure 3-1). The thickness of the weathered and fractured upper horizon ranges from 9 feet to more than 50 feet. This upper unit, designated as the weathered limestone, is typically a grayish orange to yellowish gray, thinly bedded, silty, argillaceous limestone commonly containing up to 60% chert as nodules and interbeds with minor interbeds of pure, finely to coarsely crystalline limestone. The silty, argillaceous limestone is micritic to finely crystalline, fossiliferous, closely fractured (0.1 to 1 foot spacing between fractures), and slightly to severely weathered with abundant iron and manganese oxide staining in the matrix and along fractures. Solution features in the weathered limestone are discussed in Section 4.3.2.

Beneath the weathered limestone is the competent limestone. The lithology and degree of weathering change gradually at the interface of the two units. The competent limestone is thinly to massively bedded, gray to light gray, finely to coarsely crystalline, stylolitic, fossiliferous, slightly weathered to fresh, with 20% to 40% chert. The competent limestone also contains minor interbeds of silty, argillaceous limestone, but lacks significant fracturing relative to the weathered portion, has very little iron-oxide staining, and exhibits fresh pyrite on some fracture surfaces.

In both the weathered and competent units, the chert is diagenetic. Silicified crinoids and brachiopod fossils are common. Inclusions of large, single-crystal calcite grains in chert indicate incomplete replacement. Silicification in the silty, argillaceous limestone is much more irregular than in the competent limestone. Also, chert nodules in the silty, argillaceous limestone tend to be more finely divided and irregularly-shaped.

Whitfield et al. (1989) describe the upper 15 to 25 feet of the Keokuk Limestone as a tan, cherty argillaceous limestone which weathers to "tripolitic" chert and "burr stone" chert. This description probably corresponds to the weathered limestone.

4.2 Hydrogeology

Several hydrogeologic studies have been performed at the Weldon Spring site and in its vicinity. The USGS has divided the stratigraphic sequence into three aquifers and one confining layer (Kleeschulte and Emmett 1987). These units are the alluvial aquifers, a shallow bedrock aquifer, a leaky confining layer, and a deep bedrock aquifer. As defined by the U.S. Geological Survey (USGS), no alluvial aquifers are present at the Weldon Spring site. The shallow bedrock aquifer is approximately 240 feet thick and lies directly beneath the overburden. The deep bedrock aquifer lies approximately 620 feet beneath the surface.

Bechtel performed a site-specific hydrogeologic study in which the Burlington-Keokuk Limestone was divided into two units based on core characteristics, hydraulic conductivity, and seismic velocities. The upper unit (the uppermost aquifer), has greater hydraulic conductivity than the lower unit (the unweathered bedrock aquifer) (BNI 1987). Studies by the WSSRAP geologists refer to these subdivisions of the shallow bedrock aquifer as the weathered and competent zones of the Burlington-Keokuk Limestone, respectively.

Because in its studies the USGS focused on the region while the Project Management Contractor (PMC) focused on the Weldon Spring site itself, in this report, the aquifer nomenclature defined by the USGS is used to refer to regional aquifer characteristics whereas that defined by the WSSRAP geologists is used to refer to site-specific aquifer characteristics.

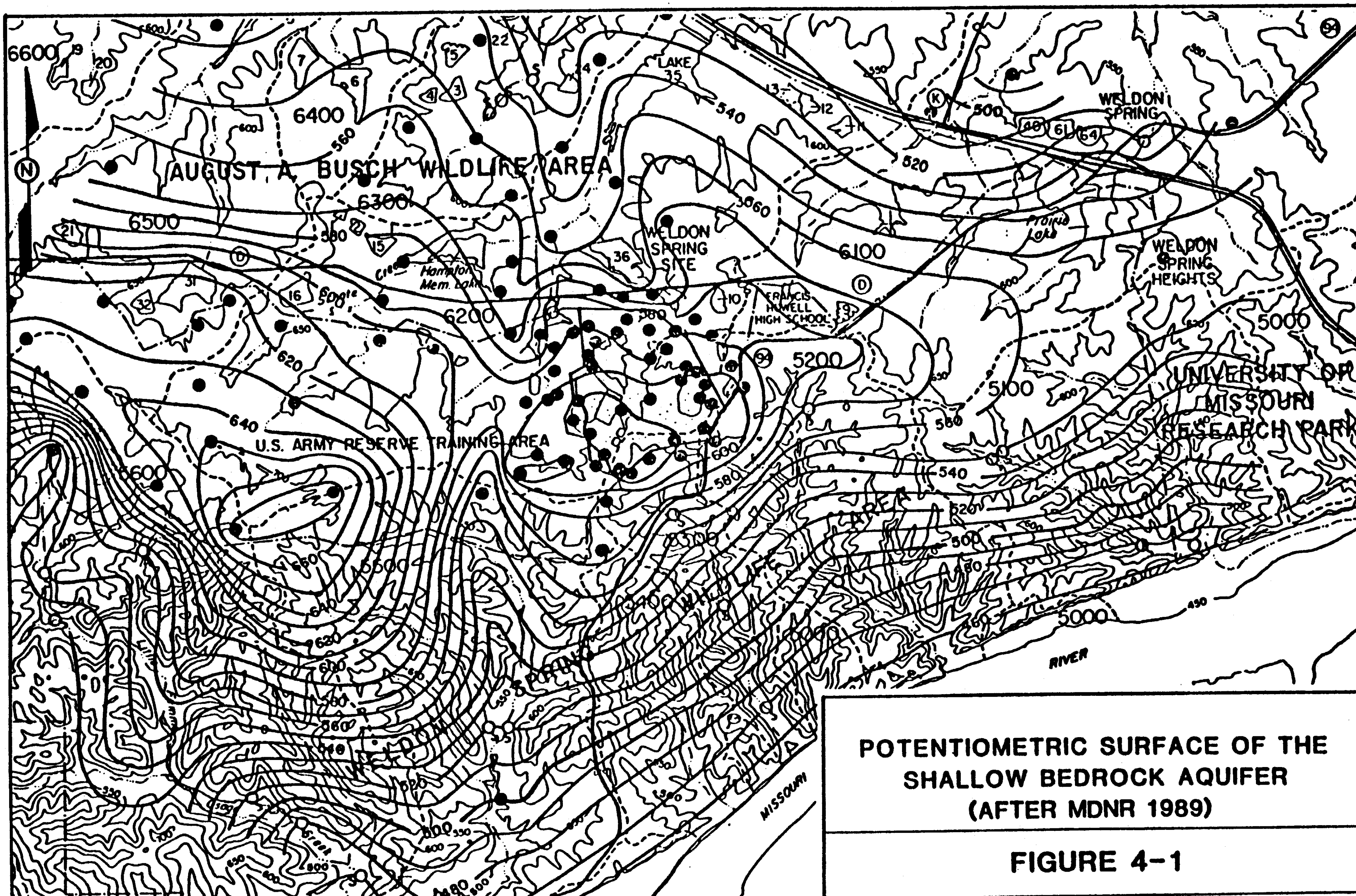
In the Weldon Spring area, the shallow bedrock aquifer is of immediate concern because this hydrostratigraphic unit lies directly beneath the site and discharges to springs and streams in both the Mississippi and Missouri River drainages. The following subsection discusses the hydrogeology of the shallow bedrock aquifer in the vicinity of the Weldon Spring site.

4.2.1 Shallow Bedrock Hydrogeology in the Weldon Spring Area

Groundwater flow in unconfined carbonate aquifers varies between diffuse-flow and conduit-flow end members (Atkinson 1977; Fetter 1980; Gunn 1985; Quinlan and Ewers 1985; Smart and Hobbs 1986; White 1988). Synonyms for conduit-flow used in the literature include free-flow and discrete-flow. The shallow bedrock aquifer in the Weldon Spring area exhibits characteristics of both a diffuse-flow and conduit-flow carbonate aquifer. The following discussion is based on the references listed above.

4.2.1.1 Diffuse-Flow Aquifers. In diffuse-flow end member carbonate aquifers, water flows along joints and bedding planes that have not been significantly enlarged by dissolution. Flow is laminar and can be evaluated using Darcy's Law. Discharge is generally through numerous small springs and seeps. The water table in diffuse-flow aquifers is well defined and can rise to a substantial elevation above regional base level.

The potentiometric surface of the shallow bedrock aquifer in the Weldon Spring area has a groundwater divide roughly coincident with the surface drainage divide (Figure 4-1 after MDNR 1989) (Kleeschulte and Emmett 1987). The groundwater divide rises to approximately 160 feet above the Missouri River, the nearest point of which is approximately 1.5 miles to the southeast, and to an elevation approximately 100 feet higher than Dardenne Creek, which is located approximately 1.5 miles to the north.



LEGEND

Spring ● Well

—560— Potentiometric contour in feet. Contour interval = 10 feet.

SCALE 0 1/2 1 MI

0 .8 1.6 KM

POTENTIOMETRIC SURFACE OF THE SHALLOW BEDROCK AQUIFER (AFTER MDNR 1989)

FIGURE 4-1

REPORT NO.: DOE/OR/21548-102		DRAWING NO.: A/VP/037/0890
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90

In general, the potentiometric contours on Figure 4-1 trend parallel to the groundwater divide. This suggests that any given portion of the shallow bedrock aquifer near the groundwater divide is recharged primarily by local infiltration of precipitation rather than by large-scale flow from outcrop areas to the west and southwest. Another major portion of the water budget for this aquifer comes from losing streams.

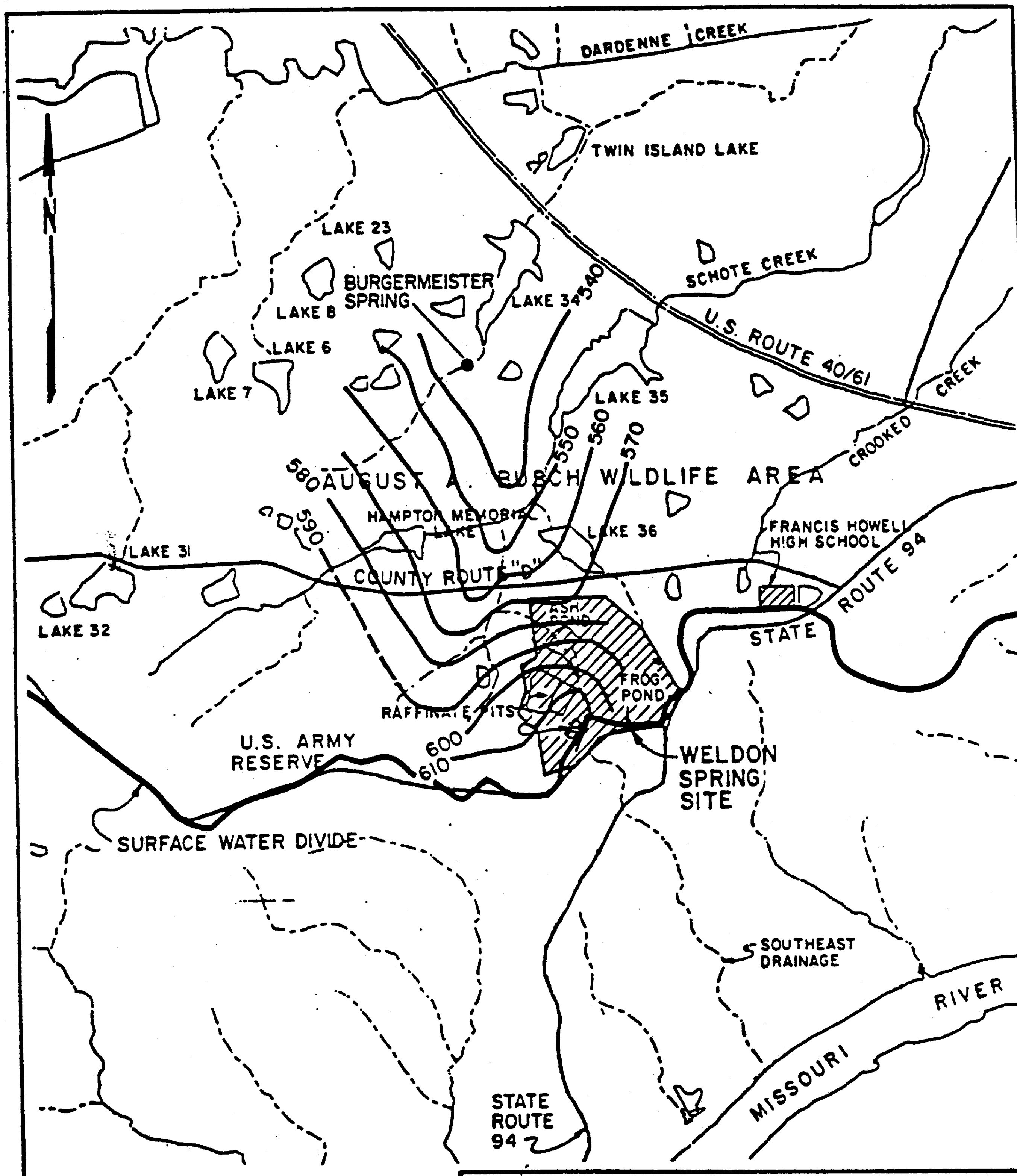
On the basis of the lack of evidence of laterally extensive conduits beneath the Weldon Spring site, groundwater flow in the shallow bedrock aquifer beneath the site is conceptually characterized as diffuse. It is believed that the groundwater flows mostly along nearly horizontal fractures and partings in bedding planes in the bedrock while a lesser component flows downward through nearly vertical fractures (DOE 1989a).

4.2.1.1 Conduit-Flow Aquifers. Conduit-flow end member carbonate aquifers have extensive solution-enlarged passages. The vast majority of flow occurs in conduits. Flow may be turbulent and cannot be adequately evaluated using Darcy's Law. Regional discharge may occur through a few large springs which are highly responsive to precipitation events. Because of the capacity of the conduits, the water table is nearly flat and only slightly elevated above the regional base level.

Of the numerous springs in the Weldon Spring area, the majority are classified as either perennial springs with small maximum discharge or wet weather springs (MDNR, 1989, Plate 7).

A significant discharge point for the shallow bedrock aquifer in the vicinity of the Weldon Spring site is Burgermeister Spring. Figure 4-2 indicates the large influence this spring has on the potentiometric surface of the shallow bedrock aquifer. The Missouri Department of Natural Resources (MDNR) has conducted a dye injection study of the spring by injecting dye in the losing stream reaches of the unnamed tributaries of Schote Creek. These tributaries originate in the raffinate pits and Ash Pond areas.

Dye injected downstream from the chemical plant process sewer outfall was detected at two springs in the southeast drainage easement (Dean 1984). A water tracing study in the same drainage revealed four losing stream reaches with associated springs (Hoffman 1987). The southeast drainage is in communication with the shallow aquifer in that the lower two springs in the southeast drainage are perennial springs which receive some



LEGEND:

—580— POTENTIOMETRIC CONTOUR (FT-MSL)

0 3200 6400 FT

0 975.4 1950.7 M

SCALE

SOURCE: KLEESCHULTE & EMMETT, 1987

POTENTIOMETRIC SURFACE, BURGERMEISTER SPRING VICINITY (AFTER USGS)

FIGURE 4-2

REPORT NO.:	DOE/OR/21548-102	EXHIBIT NO.:	A/VP/068/1290		
ORIGINATOR:	JAB	DRAWN BY:	GLN	DATE:	12/90

contribution from discharge of the groundwater to the conduits feeding those springs. This has been established but not proved by visual observations by both DOE/PMC and MDNR/DGLS personnel. Detailed data are presented in the Spring and Seep Report (MKF and JEG 1989).

Gaining streams, springs, and seeps in the region are also important in the discharge of the shallow bedrock aquifer. For the WSS groundwater flow model being done by Argonne National Laboratory, Dardenne Creek is considered a constant head hydrogeological boundary to this shallow aquifer system.

4.2.2 Site Hydrogeology

4.2.2.1 Surface Hydrology and the Vadose Zone. No natural drainages presently traverse the site. Six major surface impoundments (Ash Pond, Frog Pond, and Raffinate Pits 1 through 4) act as recharge sources. Ash Pond may dehydrate during periods of low precipitation because in 1988, an isolation dike and diversion ditch were constructed around Ash Pond to prevent runoff from adjacent portions of the site from filling this impoundment, subsequently causing contaminants to be transported off-site in overflow from the pond. Frog Pond and the raffinate pits contain water perennially. Leaky process, storm, and abandoned sanitary sewers may provide additional recharge. Backfill material surrounding these sewers may become partially saturated with water during storms. If so, this water gradually infiltrates into the subjacent soil.

A water balance study was conducted by Shell Engineering Associates from 1983 through 1985 at the Weldon Spring raffinate pits. The results from the annual seven-month study periods show volumetric loss of fluid from the pits due to seepage ranging from 50 m^3/d for Pit 3 to 6.2 m^3/d for Pit 2 (see Bechtel National Inc., 1986. Report on Water Balance Studies from 1983 to 1985, Weldon Spring Raffinate Pits. DOE/OR/20722-94, March).

These roughly constant recharge sources are thought to have caused perched water tables within the overburden and groundwater mounding in the weathered zone of the Burlington-Keokuk Limestone directly beneath the site (BNI 1987; MKF and JEG 1989).

Overflow from Frog Pond (and Ash Pond before the diversion ditch was constructed) occurs only after significant precipitation events. The raffinate pits were designed to overflow into the southeast drainage; however, overflow from these impoundments has not been observed since the plant was closed in 1966. Surface runoff from the northwest portion of the site and overflow from Frog Pond (with a combined surface area of approximately 150 acres, excluding Ash Pond) flows into three unnamed, ephemeral tributaries of Schote Creek. As discussed above, two of these streams lose to the subsurface, and this discharge has been traced to springs in the Busch Wildlife Area.

Surface runoff from the southeast portion of the site (surface area approximately 22 acres) and runoff collected by the process and storm sewers in the chemical plant area is discharged from the site into the southeast drainage easement.

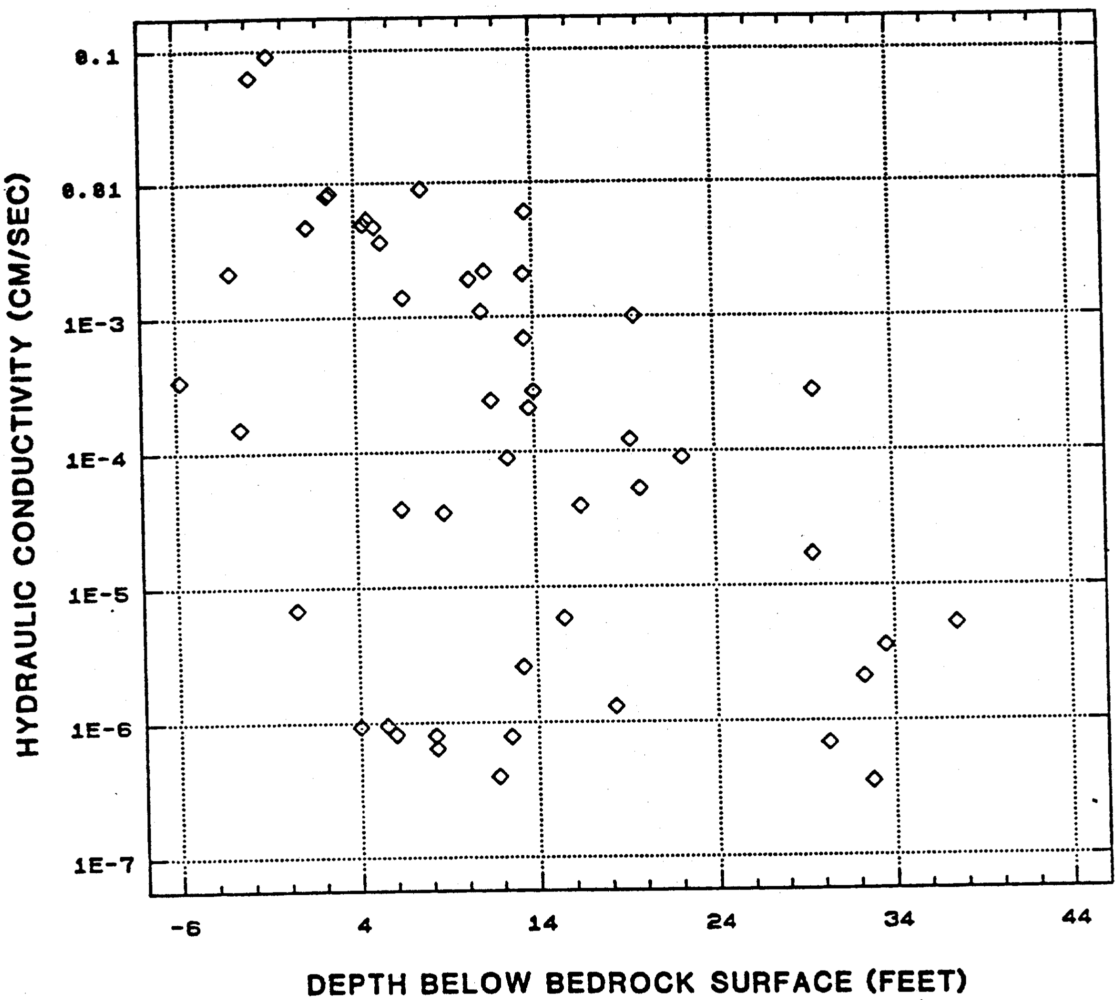
Water flows through the overburden in an unsaturated state, except where perched water tables may have developed. These perched zones are near the raffinate pits and the leaking water lines and sewers. No perched water zones have been detected beneath the disposal facility study area (MFK and JEG 1988b).

4.2.2.2 Subsurface Hydrogeology in the Burlington Keokuk Formation

4.2.2.2.1 Hydraulic Conductivity. Borehole packer testing results performed by Bechtel are displayed in Figure 4-3. The data support a concept of decreasing hydraulic conductivity with increasing depth. As the figure shows, ranges of hydraulic conductivity as determined by packer testing have lesser average values as the depths at which the tests were performed increases. Packer tests performed by the PMC in two angled holes shown in Figure 4-4 indicate confirmation of these results.

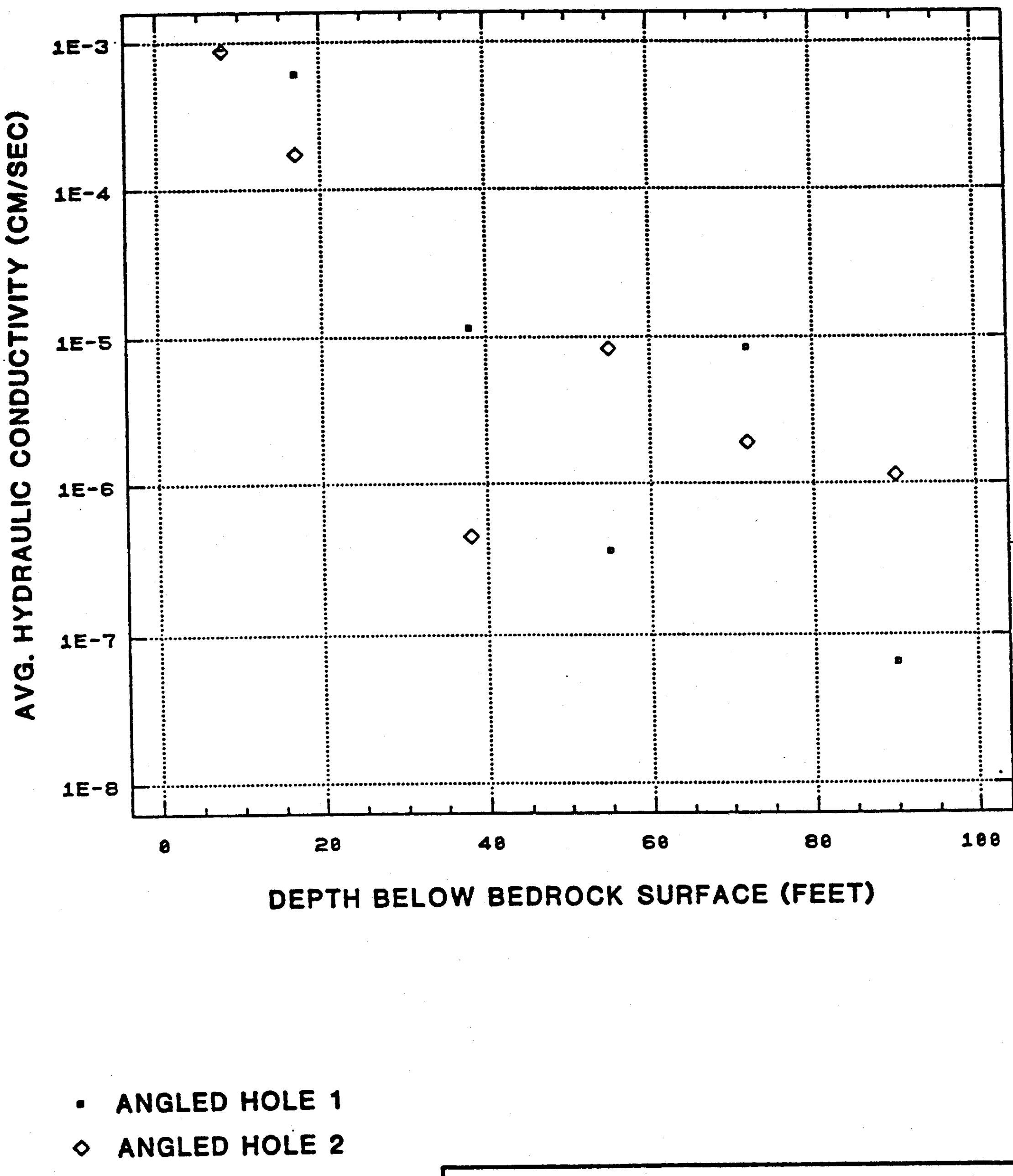
The concept that hydraulic conductivity decreases with depth is supported by physical observation of core, outcrop observation, diminishing zone of drilling water loss with depth, diminishing zones of vugs and voids with depth, and the tendency of the Burlington-Keokuk to become massive with depth.

FIGURE 4-3 REPRESENTS RESULTS OF PACKER TESTS PERFORMED BY BNI IN 1985(?). THE DEPTH LOCATIONS ARE REPRESENTED BY THE MIDPOINT OF THE TEST INTERVAL.



RESULTS OF PACKER TESTING PERFORMED BY BECHTEL VS. DEPTH BELOW BEDROCK SURFACE			
FIGURE 4-3			
REPORT NO. DOE/OR/21548-102		EXHIBIT NO.: A/PI/169/0891	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/91	

FIGURE 4-4 REPRESENTS RESULTS OF PACKER TESTS PERFORMED BY PMC IN 1989(?). THE DEPTH LOCATIONS ARE REPRESENTED BY THE MIDPOINT OF THE TEST INTERVAL.



RESULTS OF PACKER TESTS IN AH-1 AND AH-2 VS. DEPTH BELOW BEDROCK SURFACE

FIGURE 4-4

REPORT NO DOE/OR/21548-102		EXHIBIT NO.: A/PI/170/0891	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/91	

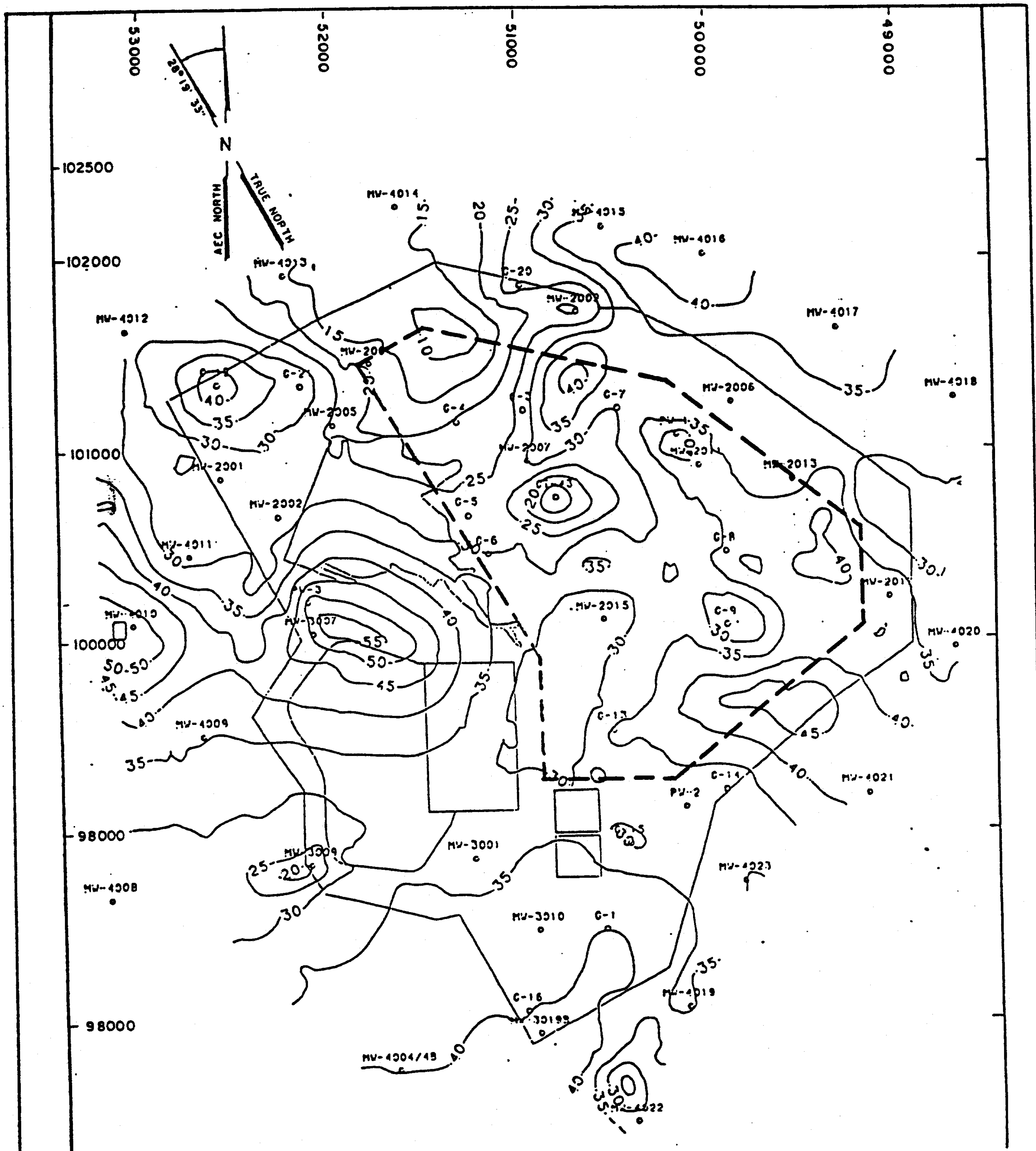
The weathered limestone ranges in thickness from 9 feet to more than 50 feet (Figure 4-5). Within this unit, the decreasing frequency of horizontal fractures and decreasing apertures of both horizontal and vertical fractures with increasing depth, and the concentration of high porosity lenses of unconsolidated gravelly material near the top of the bedrock probably cause a decreased hydraulic conductivity with depth.

In situ single well hydraulic conductivity tests (slug tests) were performed on 44 monitoring wells and 25 observation wells from October 1988 to September 1989. Solid PVC slugs were utilized which induced a vertical head displacement of 2 to 5 feet. The Bouwer and Rice method was used in data reduction and yielded hydraulic conductivities ranging from $2x10^{-4}$ to $9.5x10^{-8}$ cm/sec (MKF and JEG 1990a).

In March 1987, slug tests were performed on three overburden monitoring wells (MW-3011, MW-3004, and OW-3503). The results of these tests indicate an average saturated hydraulic conductivity in the clay till of 1.2E-10 cm/sec (MKF and JEG 1987).

The mean hydraulic conductivity based on seepage rates from the Shell Engineering Associates water balance study was 1.6E-06 cm/sec. This mean value corresponds with the upper end of values for hydraulic conductivity for the Ferrelview Formation and clay till unit as determined by triaxial tests.

4.2.2.2.2 Transmissivity and Storativity. In the spring of 1989, three pumping tests were performed in the Burlington-Keokuk Limestone at the Weldon Spring Site. In general, the pumping wells and the observation wells are about 90 ft deep and screened for 40 ft below the phreatic surface. The pumping wells draw from the weathered zone and upper competent zone of the Burlington-Keokuk Limestone. Each pumping well is surrounded by nine observation wells arranged on rays bearing N 60° E, N 60° W, and due south (Figure 4-6). PW-1 and PW-3 were pumped at rates of 0.3 gpm for 16 and 7 days, respectively. PW-2 was pumped at 0.4 gpm for 6 days. Results of these tests are in Table 4-1 (MKF and JEG 1990a).



LEGEND

—10— THICKNESS CONTOUR of WEATHERED LIMESTONE

CONTOUR INTERVAL 5.0 FT.

SCALE IN METERS

120 60 0 120 240 360

SCALE IN FEET

500 250 0 500 1000

ISOPACH MAP OF WEATHERED LIMESTONE

FIGURE 4-5

REPORT NO.:	DOE/OR/21548-102		DRAWING NO.:	A/CP/064/0890	
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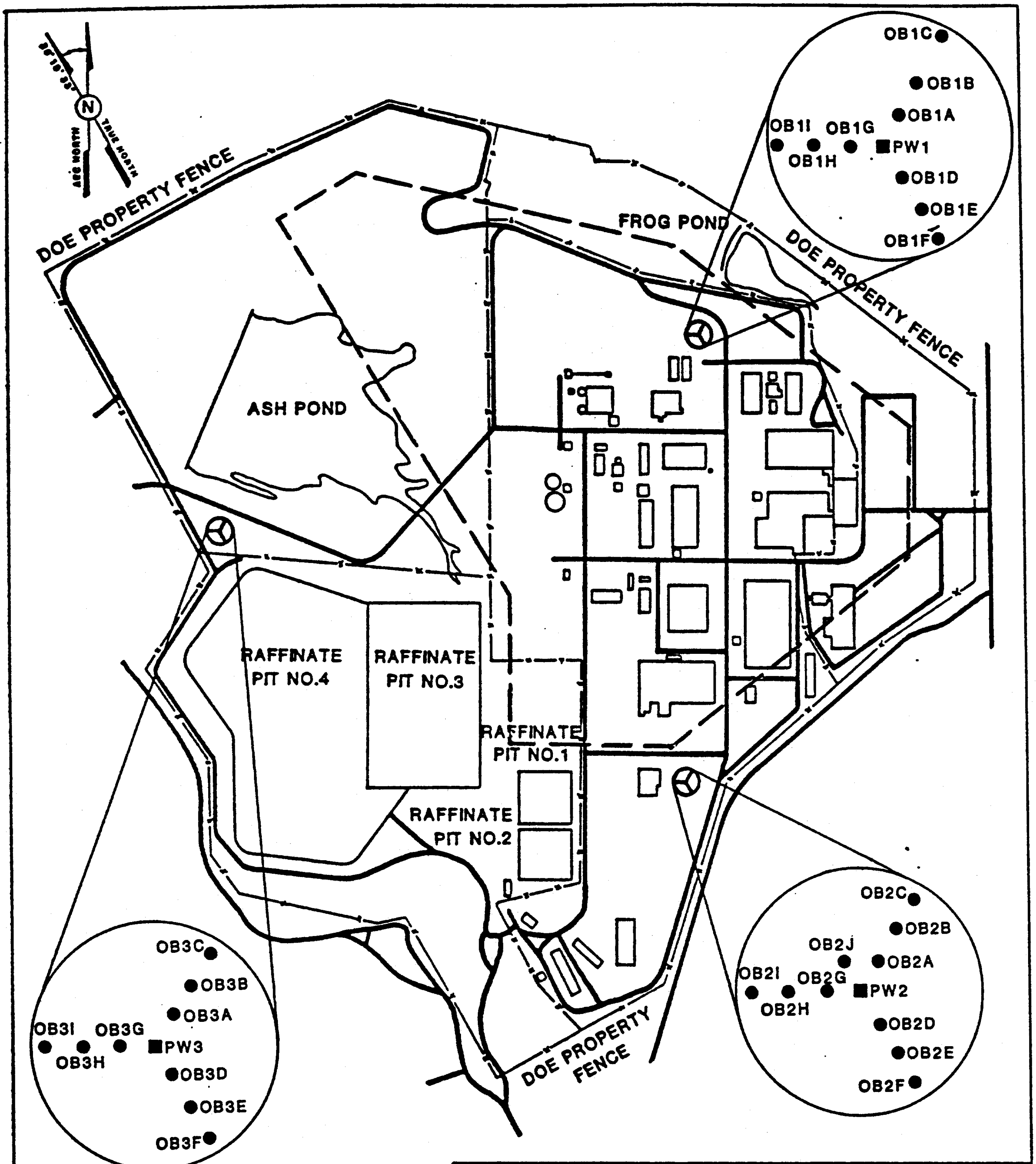


SCALE 0 500 1000 FT / 0 152.4 304.8 M

PUMPING AND OBSERVATION WELL LOCATIONS

FIGURE 4-6

REPORT NO.: DOE/OR/21548-102	DRAWING NO.: A/CP/060/0890	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90

TABLE 4-1 Summary of Pumping Test Results, Hantush Areal Anisotropy Analyses

Pumping Well	Tx (gpd/ft)	Ty (gpd/ft)	Theta	S
PW-1	28.4	14.4	N 72° W	2.3×10^{-4}
PW-2	72.4	20.5	N 10° W	1.1×10^{-3}
PW-3	24.3	14.4	N 12° E	3.8×10^{-4}

Notes:
- Tx: Transmissivity along major axis
- Ty: Transmissivity along minor axis
- Theta: Orientation of major axis
- S: Storativity

The measured transmissivities varied with direction. This caused the cones of depression to become elongated parallel to the direction of greatest transmissivity. The orientation of maximum transmissivity is generally parallel to measured trends of vertical joints within the aquifer. PW-2 has an additional observation well which is screened in the competent portion of the limestone from 45 to 50 feet below the bottom of the screen in PW-2. The static water level in this deep observation well is approximately 16 feet lower than that of PW-2 and did not draw down during pumping of PW-2 (Beaver 1989).

The approaches used in reduction of the pumping test data include the Cooper-Jacob method (Cooper and Jacob 1946) for determining transmissivity and storage coefficient and the Hantush leaky-aquifer method (Hantush and Thomas 1966) for determining anisotropy, transmissivity, and storativity. To evaluate a fractured formation using these methods, an equivalent porous medium approach must be applied. Using this approach, a representative continuum of spatially defined values of hydraulic conductivity, porosity, and compressibility are assumed. These assumptions are valid as long as the fractures within the rock are sufficiently dense to cause its hydraulic behavior to resemble that of a granular porous medium (Freeze and Cherry 1979). The results of aquifer testing performed at the site were used by Argonne National Laboratory to assist in the development of a porous media based numerical model of the groundwater at the site.

4.2.2.2.3 Heterogeneity and Anisotropy. Two series of wells have been installed to monitor the static water level and water quality of the upper zones of the shallow bedrock aquifer beneath the site. One series monitors the weathered zone of the Burlington-Keokuk Limestone and the other monitors the deeper, competent zone. There is a hydraulic gradient between these zones in which the deeper, competent portion has lower static water levels. A third series of wells has recently been installed to monitor the phreatic surface.

Geochemical studies indicate that although this hydraulic gradient exists between the weathered and competent zones of the Burlington-Keokuk Limestone, communication between these zones may be very limited. Contaminants detected in wells monitoring the weathered zone of the Burlington-Keokuk Limestone were not unilaterally detected or were present only at significantly lower concentrations in associated deeper wells (MKF and JEG 1989).

In general, contaminant distributions in the weathered zone of the Burlington-Keokuk Limestone reflect discrete sources (DOE 1989a). For example, the principal source of nitrate contamination in groundwater is seepage from the raffinate pits. Concentrations measured in wells systematically decrease as distance increases from this source.

In conduit flow systems, observation wells drilled to monitor contaminants are likely to be ineffective unless each well taps into a conduit (Quinlan and Ewers 1985). The areal distribution of contaminants observed in monitoring wells is quite erratic because contaminants are observed only in wells that tap conduits, so the observation of systematic patterns of some contaminants at the WSS supports the hypothesis that transport beneath the site occurs predominantly through diffuse flow.

The lack of drawdown in the deep well associated with PW-2, the hydraulic gradient between the weathered and competent zones, and the lack of chemical evidence for large-scale communication between the two zones all suggest the aquifer is semi-confined at depth.

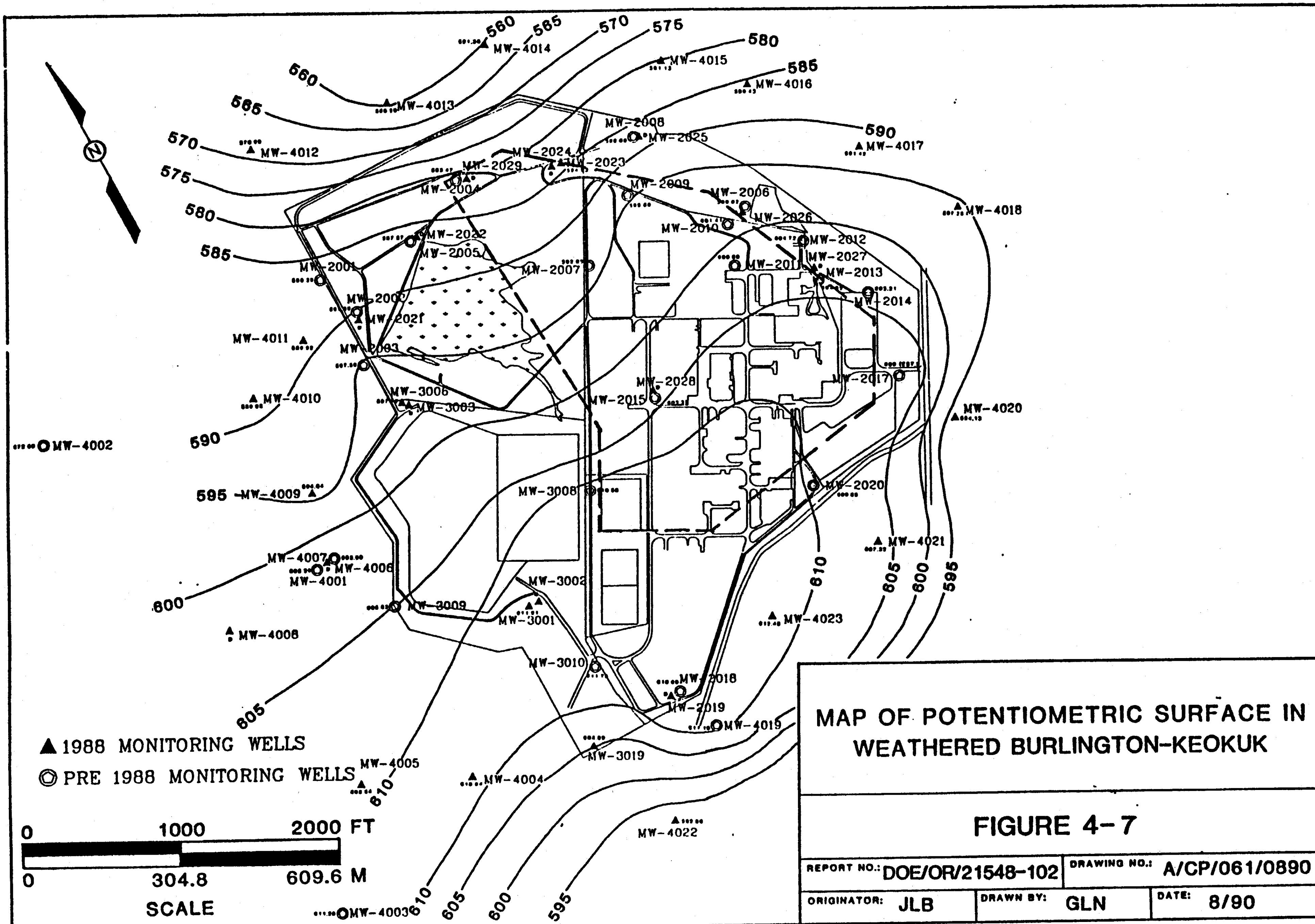
In the Weldon Spring area, the effects of a high transmissivity solution feature (e.g., discharge at a spring or through a groundwater conduit) in the shallow bedrock aquifer are well illustrated on potentiometric contour maps because the specific yield of the shallow bedrock aquifer is low. For example, Figure 4-2 shows a linear trough in the potentiometric surface associated with Burgermeister Spring. The potentiometric contours strongly reflect this discharge point. Therefore, a sinkhole or groundwater conduit with comparable discharge located beneath or peripheral to the site would clearly influence the potentiometric surface of the weathered zone of the Burlington-Keokuk Limestone beneath the site (Quinlan and Ewers 1985). However, no such features are evident on the site potentiometric surface map (Figure 4-7). For this reason, no active groundwater conduits with significant discharge are believed to exist within the saturated zone beneath the site or close enough to the site periphery to affect the potentiometric surface of the weathered zone.

Losses of drilling fluid and observation by down-hole camera in the weathered limestone prompted the MDNR to perform six borehole dye injections in wells around the periphery of the Weldon Spring site (MW-2020, MW-3007, MW-4014, MW-4016, MW-4018, and MW-4023). No dye was recovered at any of the monitoring locations for these tests. At the time dye was injected into MW-3007, Burgermeister Spring, which is a discharge point for the conduit projecting back toward this well, was not monitored (MDNR 1989). As discussed in the following section, the zones of high porosity which cause drilling water loss, and into which dye tracers were injected, are generally in unsaturated bedrock.

4.3 Solution Effects on Bedrock

4.3.1 Solution Effects in the Weldon Spring Area

Evidence of dissolution of bedrock in the general Weldon Spring area includes losing streams, swallow holes, springs, and seeps. Several losing stream segments and one swallow hole have been linked by dye tracer studies to springs (MDNR 1989). Fishel and Williams (1944) and Roberts and Theis (1951) report sink holes north of the drainage divide (but not on the Weldon Spring site (WSS). As discussed in Section 4.2, bedrock conduits have been dye traced to the north of the WSS, and the southeast drainage contains losing stream segments connected to springs downstream.



MAP OF POTENTIOMETRIC SURFACE IN WEATHERED BURLINGTON-KEOKUK

FIGURE 4-7

REPORT NO.: DOE/OR/21548-102		DRAWING NO.: A/CP/061/0890
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90

4.3.2 Solution Effects on Bedrock Beneath the Site

Solution effects on the bedrock at the Weldon Spring site have been studied through drilling and coring of 92 vertical boreholes and two inclined boreholes. These cores have been logged for lithologic and geotechnical data and packer tests. Borehole dye injections were performed in certain borings. Effects of dissolution of the bedrock include vugs lined with secondary minerals, lower percentage of core recovery in the upper 20 to 30 feet of the bedrock versus competent deeper sections in many borings, loss of circulation of drilling fluids during the drilling of roughly half the borings, lower rock quality designation (RQD) values for the upper 10 to 50 feet of bedrock cores, and greater porosity in the upper portion of the bedrock compared to deeper competent portions of the bedrock.

4.3.2.1 Vugs. Small isolated solution features (vugs) are quite common in cores from the weathered limestone unit and less common in cores from the deeper competent limestone. These vugs are generally lined with euhedral calcite and drusy to euhedral quartz.

4.3.2.2 Core Loss. Table 4-2 identifies cores taken from bedrock beneath the Weldon Spring site. An asterisk (*) identifies these borings within the disposal facility study area. Intervals with identifiable core loss or unconsolidated fill material are listed in column three. For cores drilled by Bechtel, only the reported voids and unconsolidated void fills are noted.

For cores drilled by the PMC, core recovery of less than 85% is considered excessive core loss. If the exact position of core loss could not be determined, the loss is expressed as the length recovered divided by the length of core run.

There are a number of reasons for core loss. For example, unconsolidated, residual material formed by dissolution within the bedrock may wash out ahead of the core barrel or fall out of the inner barrel as the drill string coring tool is retracted to the surface. Also, the core can be destroyed if the equipment malfunctions or if abrasive rock fragments become stuck in the core barrel. Core loss zones may also indicate voids in the bedrock.

In general, core loss is concentrated in the top 20 to 30 feet of bedrock, and less than 5 feet of loss occurred per boring. Exceptions include MW-4009, MW-4010, and PW-3, where the bases of the lowest losses were at 56.2, 44.0, and 61.4 feet, respectively, below the top of bedrock. Total core losses of 24.9 and 24.3 feet occurred in MW-4009 and MW-4010, respectively. None of these borings are located near the disposal facility study area.

4.3.2.3 Loss of Drilling Fluid. Complete loss of drilling fluid indicates a zone with high porosity, but is not considered a certain indicator of voids. Loss of drilling water generally occurred in zones of core loss, except in borings GT-42, GT-46, and MW-2006 which is outside the disposal facility study area. Drilling water was lost in the overburden in four cases (G-54-6, MW-2004, MW-2005, MW-4012), probably in gravelly zones which are in hydraulic communication with the vadose bedrock. Only MW-2004 is within the boundary of the disposal facility study area, and it is located on the extreme northwest boundary. Also, fractured, vuggy chert layers and unconsolidated chert gravels left by dissolution of incompletely silicified limestone would have high hydraulic conductivity, which could lead to both lost drilling water and core loss.

Figure 4-8 depicts the structure on top of the weathered Burlington-Keokuk Limestone and has locations of wells and borings whose borings did and did not experience complete loss and circulation of drilling water. Although the distribution pattern of complete drilling water loss is somewhat random, it appears that in the south section of the disposal facility study area, a majority of borings suffered a complete loss of drilling water, while other areas within the disposal facility study area seem to have no pattern to the equal distribution of complete and partial loss.

Boreholes (4) within the disposal facility study area did lose drilling water below the static water level. However, the overwhelming majority of borings and wells show lost circulation zones, if any, occur in high porosity weathered bedrock above the phreatic surface.

TABLE 4-2 Core Loss/Void Fill Descriptions

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
G-1 (B)	N				
*G-2 (B)	N				
G-2A (B)	N				
*G-3 (B)	N				
*G-5 (B)	N	0.4	46.6-47.0	Clay-filled void	40.0
*G-6 (B)	N	2.7 7.7 0.6 0.2	Not determine 31-40 40-40.6 66.7-66.5	Void Clay & chert gravel fill Void Void	
*G-7 (B)	N	5.0	21.0-26.0	Clay & angular chert gravel	18.5
*G-8 (B)	N	3.8 2.0	30.5-34.3 42.0-44.0	Clay & chert gravel, semi-competent chert layersClay filled void	30.0
*G-9 (B)	N	0.4 2.0	41.5-41.9 45.2-47.2	Clay & chert gravel fill Clay & chert gravel fill	37.5
*G-13 (B)	31.0	1.2 0.5 3.0	29.8-31.0 40.8-41.3 44.0-47.0	Clay & chert gravel fill Sand & chert gravel fill Clay & chert gravel fill	28.5

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
(B) Boring drilled and logged by Bechtel National, Inc. Only cavities and fill material on logs reported in this table.
(CE) Boring drilled and logged by the Army Corps of Engineers. Only cavities and fill material on logs reported in this table.
All other borings drilled and logged by the PMC.
* = indicates well or boring is in the Disposal Facility Study Area or within 50 feet of the DFSA boundary

TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
G-14 (B)	37.9	0.5	38.3-38.8	Clay filled void	37.5
G-15 (B)	N				
G-16 (B)	44.5	10.0	46.5-56.5	Clay and chert gravel fill	34.0
G-18 (B)	29.0				30.0
G-19 (B)	N	0.5	39.5-40.0	Void (in residuum?)	41.5
G-20 (B)	32.5				32.5
G-21 (B)	N	19.8	34.2-54-0	Clay and chert/limestone gravel fill	34.2*
*G-53-1 (CE)	24.6	0.7	24.5-25.2	Void	18.0
*G-54-2 (CE)	45.0				43.0
*G-54-3 (CE)	19.2	0.8 0.7 0.4	20.3-21.0 21.8-22.5 23.3-23.7	Void Void Void	19.2
*G54-4 (CE)	23.5	1.1 2.0	23.1-24.2 24.6-26.6	Void Void	23.5
*G-54-5 (CE)	N				
*G-54-6 (CE)	38.2	1.0 2.2	41.2-42.2 42.5-44.7	Void Void	40.2

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
*G-54-7 (CE)	43.3	2.0 1.2	45.8-47.8 48.1-49.3	Clay filled void Void-clay filled?	43.8
*G-54-8 (CE)		N			
*G-54-9 (CE)		0.3 0.6 0.45	62.8-63.1 63.6-64.2 64.7-65.15	Void Void Void	56.2
*GT-42	37.0	2.2 0.9	Run 1 7.8/10.0 51.0-51.9	Washout weathered chert Washout weathered chert	35.0
*GT-43	59.0	0.9	Run 1 3.6/4.5	Washout	57.5
*GT-44	30.0	0.5 2.0	30.0-0.5 41.7-43.7	Washout Washout	29.0
*GT-45	25.0	1.1 1.9 1.8 2.8 2.0	22.1-23.2 26.1-28.0 29-32 (1.8 loss) 32.0-34.8 Run 4 1.5/3.5	Washout (chert rubble at base) Washout Washout Void (?) bit drop Washout	21.0
*GT-46	21.0				20.5
*GT-47	39.0	5.5 3.4	38.3-43.8 Run 2 1.3/4.7	Washout & possible voids 40.0-43.8 Washout & possible voids 45.0-46.0	35.5

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
*GT-48	N	5.6	Run 1 2.8/8.4	Washout	33.6
*GT-50	N	4.3	Run 1 3.7/8.0	Washout	35.5
*GT-51	46.0	1.3 7.5 5.8	Run 1 3.1/4.4 Run 2 0.5/8.0 Run 3 0.2/6.0	Mechanical? Mechanical? Circulation loss, cause unknown	31.0
*GT-52	N				49.5
*GT-54	N	1.3	41.8-43.1	Washout	30.0
*GT-55	37.3	1.5 3.8	Run 1 4.25/7.75 Run 2 5.5/9.25	Washout Washout	33.0
*GT-56	26.5	4.1 6.5	Run 1 5.9/10.0 Run 2 3.0/9.5	Void? 28.6-29.6 Unknown	23.5
MW-2001 (B)	N				
MW-2002/2A (B)	N				
MW-2003 (B)	N	2.9	45.6-48.5	Weathered fractured limestone with clay partings	38.8
*MW-2004 (B)	41.0	2.0	55.0-57.0	"Decomposed" chert/ limestone with clay partings	51.0

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
(B) Boring drilled and logged by Bechtel National, Inc. Only cavities and fill material on logs reported in this table.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
MW-2005 (B)	42.0				244.8
MW-2006 (B)	25.0	1.5	37.2-38.7	Chert and limestone gravel in clay	22.6
*MW-2007 (B)	N				
MW-2008 (B)	N				
*MW-2009 (B)	N	0.6 0.8	22.2-22.8 24.3-25.1	Clay with chert gravel Clay with chert gravel poor recovery to 54 (TD) washout?	20.5
*MW-2010 (B)	N				
*MW-2011 (B)	N	3.6	39.0-42.6	Chert filled voids	32.0
MW-2012 (B)	N	0.5 1.0	33.0-33.5 34.0-35.0	Void Void	25.5
*MW-2013 (B)	N				
MW-2014 (B)	N	2.0	36.0-38.0	Clay filled void	
*MW-2015 (B)	46.0				45.5
*MW-2016 (B)	N				
MW-2017 (B)	N	2.0 2.6	28.5-30.5 52.3-54.9	Clay filled void Chert filled void	23.5

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
(B) Boring drilled and logged by Bechtel National, Inc. Only cavities and fill material on logs reported in this table.
(CE) Boring drilled and logged by the Army Corps of Engineers. Only cavities and fill material on logs reported in this table.
All other borings drilled and logged by the PMC.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
MW-2018 (B)	N	2.3	35.0-37.3	Clay and limestone and chert gravel	32.5
MW-2020 (B)	27.6				23.7
MW-3001	N	0.8 3.4 2.5 2.0	54.0-54.8 58.5-61.9 63.2-65.7 73.0-75.0	Washout of clay and chert gravel Washout of chert gravel Washout of chert gravel Washout of rubblized limestone	53.5
MW-3002B (B)	N	(?) Earlier well in same area abandoned			
MW-3007 (B)	40				29.0
MW-3019A	N	Core loss due to broken core barrel			
MW-3019B	N	4.7 4.0	Run 1 3.8/8.5 Run 2 2.4/8.0	Washout Washout	35.0
MW-4001 (B)	N				14.0
MW-4003 (B)	40 (air)	2.0 0.7 6.0	33.0-35.0 39.3-40.0 41.0-47.0	Clay-filled void Void Partially clay-filled void	23.0

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
MW-4004	Cased	5.0 0.9 2.0	Run 2 2.1/7.1 Run 3 2.0/2.9 Run 4 2.0/4.0	Washout Washout Washout	23.5
MW-4005	N	8.0 5.4 2.7	Run 1 0.8/8.8 Run 1.8/7.2 Run 3 5.0/7.2 Run 6 6.7	Washout Washout Washout Mechanical destruction no core recovered	30.0
MW-4009	N	5.6 6.8 3.8 8.7	Run 1 2.9/8.5 Run 2 3.2/10.0 58.7-62.5 66.5-75.2	Washout Washout Void Void (mechanical?)	19.0
MW-4010	N	1.0 9.0 14.3	22.7-23.7 45.7-54.7 55.4-69.7	Washout Washout? silty sand cuttings retrieved void? Washout and void - silty sand retrieved from mud tank	15.7
MW-4011	N	0.8	30.4-31.2	Washout	
MW-4012	30.0	5.0	Run 1 2.0/7.5	Washout	33.0
MW-4013	52.0	1.3 1.6 0.7 0.9	37.0-38.3 Run 2 6.4/8.0 49.5-50.2 50.8-51.7	Clay-filled void Washout Washout?(rubble at base) Void? (water loss)	35.1

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
MW-4014	43.0	3.0 1.8 2.5	42.5-45.5 46.0-47.8 48.3-50.8	Void (bit drop) Void? (water loss) Washout	42.0
MW-4015	22.0	2.3 2.0	13-15.3 20.5-22.5	Void (1 ft bit drop) & washout Void? (water loss)	13.0
MW-4016	33.0	6.8 4.5	31.0-37.8 45.1-49.6	Several small voids and washout Voids?	30.0
MW-4017	N	1.9 1.0 1.5 1.4	40.8-42-7 44.2-45.2 45.5-47.0 49.4-50.8	Washout Void Washout Washout	40.0
MW-4018	47.0	1.5	46.5-48.0	Void (1 bit drop, lost circulation)	44.0
MW-4019 (B)	N				20.2
MW-4020	38.6	0.9 3.0	37.3-38.2 43.3-46.3	Void Void? and washout?	
MW-4021	N	2.3 5.0	Run 1 4.2/6.5 Run 2 5.0/10.0 Run 4	Washout Washout & numerous small voids Mechanical destruction of core	26.5

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
(B) Boring drilled and logged by Bechtel National, Inc. Only cavities and fill material on logs reported in this table.
(CE) Boring drilled and logged by the Army Corps of Engineers. Only cavities and fill material on logs reported in this table.
All other borings drilled and logged by the PMC.
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TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
MW-4022	N	4.6 2.0	Run 1 3.1/7.7 55.7-57.7 Run 5	Washout Washout Mechanical destruction of core	35.0
MW-4023	N	1.4	45.6-47.0	Washout	28.9
*PW-1	32.0	1.9 1.2	30.9-32.8 45.4-46.6	Washout? Void? Washout	27.7
PW-2	37.0	0.5 0.5 5.0 2.3 1.6 1.2	37.7-38.2 39.5-40.0 Run 2 5.0/10.0 Run 3 0.9/3.2 Run 4 3.7/5.3 Run 5 3.8/5.0	Washout Void - partial fill? Washout Mechanical destruction of core Washout Washout	36.5
PW-3	36.0	1.4 0.8 2.6 4.9 0.6 2.2	17.8-19.2 21.0-21.8 22.8-25.4 Run 3 2.5/7.6 35.3-35.9 75.2-77.4	Void? Washout Washout Washout Split spoon clayey, silty sand Void	16.0

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
(B) Boring drilled and logged by Bechtel National, Inc. Only cavities and fill material on logs reported in this table.
(CE) Boring drilled and logged by the Army Corps of Engineers. Only cavities and fill material on logs reported in this table.
All other borings drilled and logged by the PMC.
* = Indicates well or boring is in the Disposal Facility Study Area or within 50 feet of the DFSA boundary

TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
*AH-1	37.7	2.2 3.2 2.7 1.6	42.4-44.6 45.0-48.2 52.0-54.7 Run 8 3.4/5.0	Washout Washout Washout Washout	35.5
*AH-2	51	1.7 2.0	51.0-52.7 53.4-55.4	Washout Void or washout	51
*GT-58P	31.8	2.0 0.4 1.7 0.5 1.5	30.0-32.0 32.8-33.2 34.0-35.7 53.0-53.5 55.1-56.6	Void? (lost circulation) Void? Void Washout-drilled 22 min/ft	29.5
GT-60P	N				
GT-63P	N			Circulation lost in overburden	22.0
GT-64P	23.6	1.1 8.6 1.3 0.7	23.7-24.8 28.7-37.4 38.7-40.0 40.5-41.2	Washout? (lost circulation) Washout & voids (drilled extremely fast) Void Void	22.0
*GT-65P	51.0	0.9 3.0	48.5-49.4 50.0-53.0	Washout Void & washout (lost circulation, drilled slower toward bottom)	48.5

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
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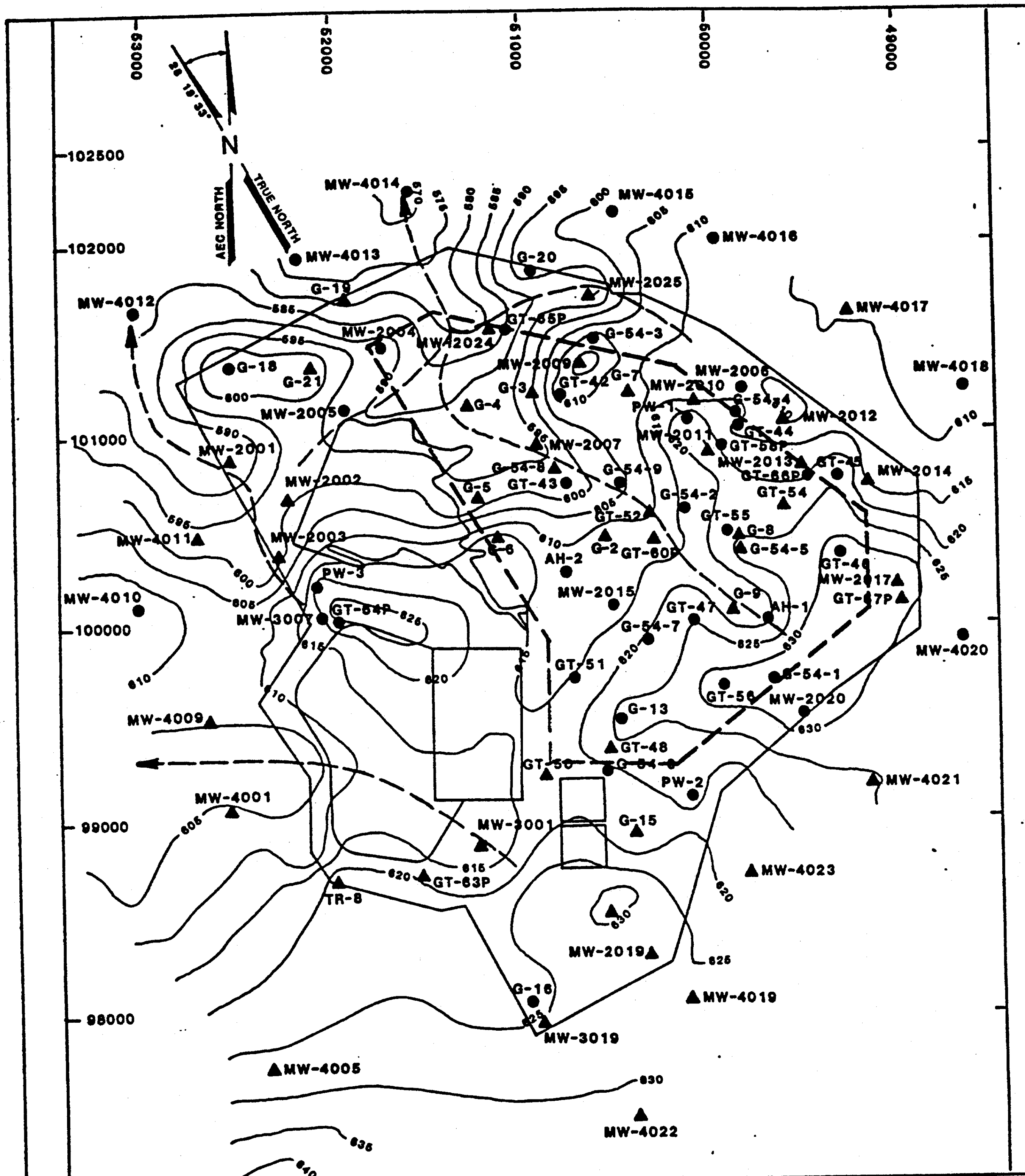
All other borings drilled and logged by the PMC.
* = indicates well or boring is in the Disposal Facility Study Area or within 50 feet of the DFSA boundary

TABLE 4-2 Core Loss/Void Fill Descriptions (Continued)

BOREHOLE	COMPLETE LOSS OF CIRCULATION	LENGTH OF CORE LOSS (ft)	CORE LOSS/VOID FILL INTERVAL (ft)	INFERRED CAUSE OF CORE LOSS/TYPE OF VOID FILLED	DEPTH OF TOP OF BEDROCK (ft)
*GT-66P	24.5	0.6 1.0 0.4 0.9	23.2-238 27.0-28.0 29.6-30.0 34.4-35.3	Washout Void Washout Void	23.2
GT-67P	N	1.3	34.5-35.8	Washout	34.5

Circulation loss: N-circulation not completely lost, numbers in this column indicate depth of complete loss of circulation.
(B) Boring drilled and logged by Bechtel National, Inc. Only cavities and fill material on logs reported in this table.
(CE) Boring drilled and logged by the Army Corps of Engineers. Only cavities and fill material on logs reported in this table.
All other borings drilled and logged by the PMC.
* = indicates well or boring is in the Disposal Facility Study Area or within 50 feet of the DFSA boundary



LEGEND

▲ NO COMPLETE LOSS

● COMPLETE LOSS

—630— CONTOUR OF TOP OF WEATHERED LIMESTONE

— — —► TREND OF LINEAR DEPRESSION

CONTOUR INTERVAL 5.0 FT.

SCALE IN METERS

120 60 0 120 240 360

SCALE IN FEET

500 250 0 500 1000

WELLS AND BORINGS WHICH EXHIBITED CIRCULATION LOSS DURING DRILLING (TOP OF WEATHERED BURLINGTON-KEOKUK LIMESTONE)

FIGURE 4-8

REPORT NO.: DOE/OR/21548-102		DRAWING NO.: A/CP/062/0890
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90

This discussion has been presented to provide detail on the degree of karst development which may indicate the degree of potential for catastrophic collapse.

High porosity zones (which may be identified as a result of drilling water loss), in unsaturated carbonate bedrock are well documented in the scientific literature. Gunn (1985) and Smart and Friederich (1986) refer to this as the subcutaneous zone. At low recharge rates, flow through the subcutaneous zone is predominantly vertical along many low capacity routes. Hypothetically, as recharge rates increase, for example due to water loss during drilling, lateral flow is favored because of the decrease in hydraulic conductivity with depth. Conceptually, the drilling fluid flows away from the borehole in all directions until a vertical conduit of higher capacity is reached (Smart and Friederich, 1986) or until the hydraulic gradient induced by drilling water is dissipated.

4.3.2.4 Rock Quality Designation. Discontinuity of the rock cores was quantified by calculating the rock quality designation (RQD) for each length of core recovered (core run). The RQD of a core run equals the cumulative length of core pieces 4 inches long or more, divided by the total length of the run, and expressed as a percent. On this basis, 73% of the RQD values for the weathered limestone unit are very poor (0%-25%) or poor (26%-50%) (Table 4-3). Conversely, the competent limestone has 79% fair to excellent RQD values. Lower RQD ratings for the weathered limestone unit result from a higher degree of core loss which may be attributed to dissolution and fracturing near the surface of the bedrock.

4.3.2.5 Dissolution Along Vertical Fractures. Two angled borings were cored by the PMC at 60 degrees from horizontal along bearings of N 42° E and N 39° W in order to intersect the northwesterly and northeasterly regional bedrock joint sets, respectively (Roberts and Theis 1951). In samples recovered from these borings, vertical fractures near the bedrock surface were obscured by poor quality core and/or core loss probably caused by the weathered nature of portions of the rock. Below the bedrock surface, spacing between vertical fractures is sporadic, ranging from 5 to 18 feet and averaging approximately 10 feet. Vertical fractures near the bedrock surface may have been enlarged by dissolution but subsequently have been filled with clay. The apertures of these fractures appear to decrease in width in short vertical distances. In boring AH-2, five out of six fractures encountered at depths greater than 12 feet below the top of bedrock have apertures of 1 mm or less. The ratio of horizontal partings to vertical fractures in these angled holes is approximately 20:1 or greater. Horizontal partings typically occur along shaley interbeds and bedding plans that exhibit mineralization and/or clay deposition.

TABLE 4-3 Summary of Rock Quality Designation (RQD) Values

Stratigraphic Unit	Percentage of Core Runs in Given Range Very Poor	Poor	Fair	Good	Excellent*
Weathered Limestone	41	32	21	5	1
Competent Limestone	9	12	44	25	10

Note: * RQD designations are defined as follows:

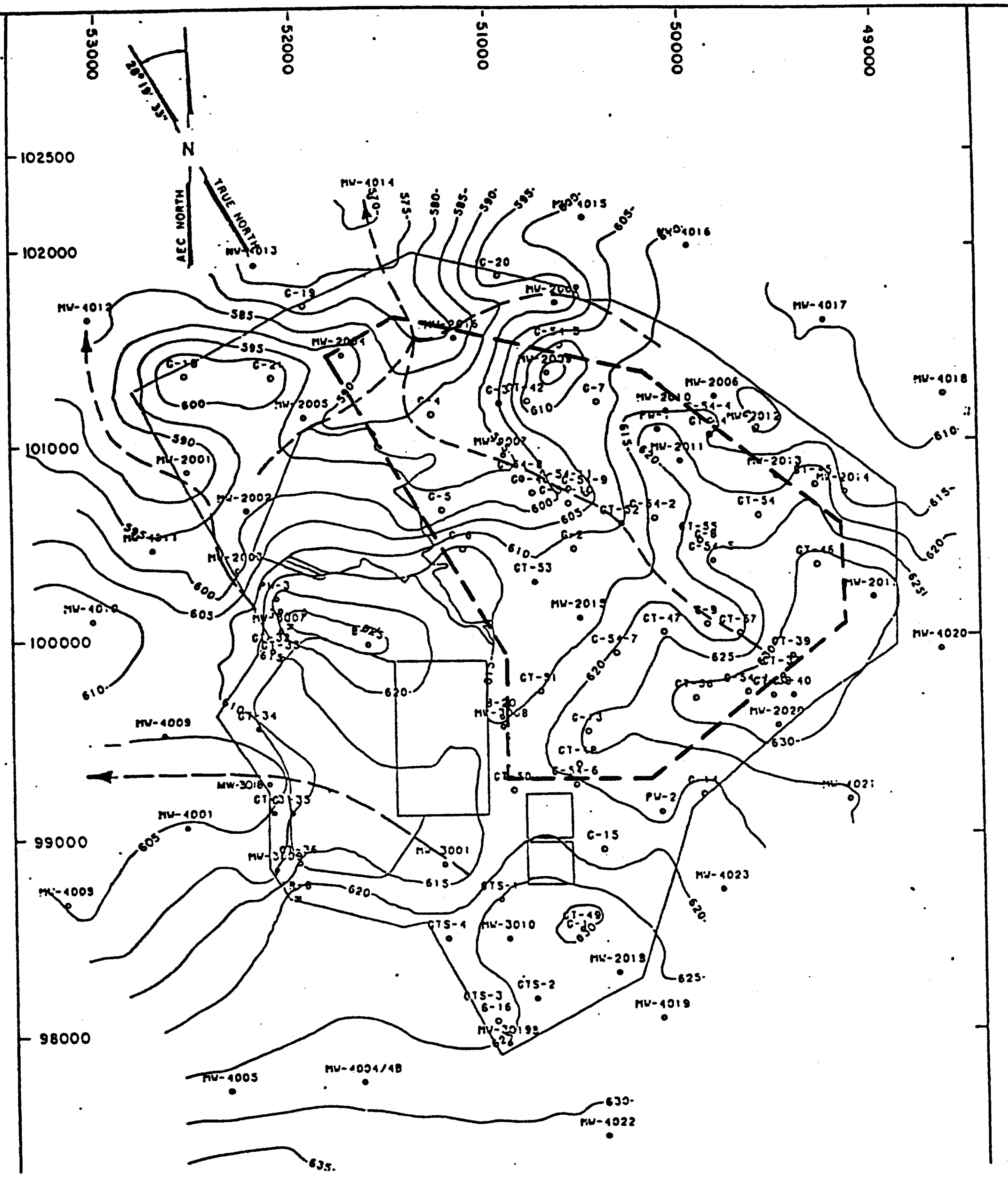
Very Poor	0-25%
Poor	26-50%
Fair	51-75%
Good	76-90%
Excellent	91-100%

4.3.2.6 Bedrock Topography. Previous investigations at the Weldon Spring Site have reported irregularities on the top surface of the Burlington-Keokuk Limestone. Bechtel's interpretation inferred sharp pinnacles on the weathered limestone surface (BNI 1984). Additional in fill drilling and more detail mapping has shown this to be incorrect. Up to 60 feet of relief on the bedrock surface has been documented on the site, but large variations in elevation over short distances have not been observed (Figure 4-9).

No closed depressions or sink features have been identified. Several linear depressions are inferred to represent pre-glacial drainages. Development of these drainages may have been determined by northeasterly and northwesterly regional joint sets (MKF and JEG 1989).

4.3.3 History of Dissolution

The Weldon Spring site is situated very near the southern extent of the Pleistocene continental glaciation. The basal till, clay till, and Ferrelview Formation were deposited during and immediately following the Kansan Glacial Age. The loess may be Wisconsinan in age (BNI 1987). Assuming similar precipitation patterns prior to deposition of the glacial till, the entire bare bedrock surface would be subject to more rapid recharge and dissolution. After deposition of the low permeability Quaternary overburden strata, the rate of



LEGEND

CONTOUR INTERVAL 5.0 FT.

—630— CONTOUR OF TOP OF WEATHERED LIMESTONE

— — —→ TREND OF LINEAR DEPRESSION

SCALE IN METERS

120 60 0 120 240 360

SCALE IN FEET

500 250 0 500 1000

CONTOUR MAP ON TOP OF WEATHERED LIMESTONE

FIGURE 4-9

REPORT NO.: DOE/OR/21548-102		DRAWING NO.: A/CP/065/0890	
ORIGINATOR: JLB	DRAWN BY: GLN	DATE: 8/90	

dissolution of bedrock beneath this cover was reduced. Where the overburden has been thinned by erosion, solution features in the bedrock may have been reactivated.

Large-scale dissolution in carbonate rocks is accomplished by relatively low temperature meteoric waters in saturated rock (Thrailkill 1968). Recharge by runoff of meteoric waters can be focused to discontinuities in low permeability beds, leading to accelerated dissolution at the recharge point (Mylroie 1987). One mechanism by which runoff is focused is in a losing stream. In the watershed of the stream, most water is lost due to runoff while a minor portion of precipitation infiltrates directly into the soils, and another part is lost through evapotranspiration. If water sinks through a losing segment of the stream bed and directly recharges the carbonate bedrock beneath the stream, dissolution of the bedrock beneath the losing segment may be relatively accelerated.

Conduits detected by dye studies of the losing streams northwest of the site and Burgermeister Spring probably formed prior to deposition of the overburden. However, these conduits have probably also been enlarged since deposition of the Quaternary soils by focusing of recharge where the soils have been thinned or removed by erosion. Horizontal continuity of the soil cover within the Weldon Spring site, and more specifically, thicker overburden at the disposal facility study area, has prevented similar focused recharge there.

4.4 Considerations For Determining Suitability of Bedrock

Dissolution of finely divided chert and silty, argillaceous limestone has resulted in zones of unconsolidated, insoluble residue up to 10 feet thick and possible voids up to approximately 3.8 vertical feet within the bedrock beneath the disposal facility study area. These zones of dissolution are generally limited to the upper 20 to 30 feet of the bedrock, laterally discontinuous, and unsaturated. Although poor core recovery and loss of drilling fluid occurred in the weathered limestone, cumulative core losses in most borings were less than 5 feet.

Features that develop in soluble bedrock and which would threaten the effectiveness of a disposal cell include groundwater conduits and sinkholes. A groundwater conduit located beneath a disposal facility could rapidly transport contaminants escaping the collection system and migrating through the vadose zone. A sinkhole formed by subsidence or collapse into voids in the overburden or bedrock could cause fracturing of the cell foundation and compromise the cell liner.

4.4.1 Conduit Potential

As discussed in Section 4.2, groundwater flow within the shallow bedrock aquifer in the Weldon Spring area is characterized by minor components of conduit flow superimposed on diffuse flow. One conduit-flow element near the site boundary was traced from losing stream segments northwest of the site. This conduit is recharged where the overburden units, which on the site range in thickness from approximately 15 to 55 feet, have been removed by erosion.

Although the Southeast Drainage contains losing stream segments, no water movement from this drainage to adjacent drainages or subjacent bedrock has been detected (MDNR 1989). Additional studies by the PMC of this drainage are now under way.

The shallow bedrock aquifer beneath the Weldon Spring site is recharged primarily by infiltration through the overburden. Overburden units buffer the capacity of the water to dissolve calcite in the bedrock. Also, groundwater in the saturated zone is at or near equilibrium with calcite. Therefore, it is believed that significant dissolution of the carbonate bedrock has not occurred since deposition of the glacial overburden units.

MDNR borehole dye injections done in 1988 in six wells on the site perimeter failed to locate any groundwater conduits leading off site (MDNR 1989). Slug tests of 63 wells on site indicate that the saturated bedrock beneath the site is heterogeneous and has some high porosity features, but no laterally extensive conduits. The results of three pumping tests conducted at the site indicate lateral anisotropy which in one case (PW-1) was coincident with the trend of a major fracture set (bearing N72W). Additional evidence of fracture influences which are analogous to delayed yield effects encountered in fractured aquifers have been inferred from late-time drawdown data. However, the low sustained yields from all three pumping wells (0.3-0.4 gal/min) suggest that none of them directly intercepted a major conduit-type water bearing fracture (Beaver 1991).

A well-developed groundwater divide, indicative of diffuse-flow conditions, traverses the site. No active groundwater conduits traversing the disposal cell study area have been detected.

4.4.2 Sinkhole Potential

Sinkholes are formed by dissolving limestone bedrock which may result in limestone (roof) collapse, (3) cover collapse, and (4) cover subsidence (Beck and Sinclair 1986).

A limestone solution sinkhole is formed as limestone is removed in solution, leading to a closed depression on the limestone surface. Such features generally form in exposed or thinly covered limestones (Beck and Sinclair 1986). At the Weldon Spring Site, no such closed depressions on the top surface of the bedrock are present.

Limestone collapse sinkholes form when the roof of a void in the bedrock fails. Such a void must be sufficiently extensive vertically to permit pressure from the material above it to overcome the bearing strength of the material in its roof. These features are rare. No vertically extensive voids have been encountered in drilling in the disposal facility study area or detected by seismic investigations at the Weldon Spring site (GSI 1988).

Cover collapse sinkholes form in mantled carbonate settings where cohesive soil overlies the bedrock. Soil is washed into conduits or enlarged fractures, creating a void in the overlying material. Eventually the bearing strength of the soil bridging the void is exceeded and the cover collapses (Beck and Sinclair 1986; Beck 1987). No voids have been detected in the overburden at the Weldon Spring Site. The apparent lack of active groundwater conduits has probably prevented the formation of cover collapse sinkholes.

A common mechanism triggering cover collapse sinkholes is the construction of surface impoundments such as the raffinate pits. Such impoundments increase the load on subjacent soils and provide a source of water which can percolate downward, eroding cover material into solution cavities or conduits (Beck and Sinclair 1986). The fact that no sinkholes have been triggered beneath the Raffinate Pits and the fact that no sinkholes have been reported in the uplands of the Weldon Spring area, where the unconsolidated soils are thickest, suggests this area is not prone to sinkhole formation.

5 GLOSSARY

anisotropic — Having physical properties that vary in different directions.

aquifer — A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

argillaceous — Applied to all rocks or substances composed of clay minerals, or having a notable proportion of clay in their composition, as shale, slate, etc.

chert — A compact siliceous rock of varying color composed of microorganisms or precipitated silica grains. Occurs as nodules, lenses, or layers in limestone and shales.

cobble — A rock fragment between 64 mm and 256 mm in diameter, thus larger than a pebble and smaller than a boulder.

coefficient of permeability — See hydraulic conductivity.

conduit — A water-filled underground passage that is always under hydrostatic pressure.

conduit-flow aquifer — An aquifer in which the groundwater flows primarily through conduits.

confining bed — A unit that has a significantly lower ability to transmit water than the aquifers that it separates.

Darcy's Law	An empirical formula describing laminar flow of fluids through porous media:

$$Q = -K \frac{dh}{dl} A$$

Where: Q = discharge rate
K = hydraulic conductivity of porous medium

$\frac{dh}{dl}$ = hydraulic gradient

A = cross-sectional area

diffuse-flow aquifer	An aquifer in which conduit systems are either absent or so poorly integrated that they have little influence on the groundwater circulation.
discrete-flow aquifer	See conduit-flow aquifer.
drusy	Clusters or aggregates of euhedral or subhedral crystals incrusting the walls of a cavity.
end member	One of two or more distinctive forms between which more or less gradual and continuous variation occurs.
euhedral	A crystal completely bounded by its own regularly developed crystal faces.
evapotranspiration	A term embracing that portion of meteoric precipitation returned to the air through direct evaporation or by transpiration of vegetation.
free-flow aquifer	See conduit-flow aquifer.

heterogeneous	A characteristic of a medium that varies with position within it.
hydraulic conductivity	The volume of water at existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
lysimeter	A structure containing a mass of soil and so designed as to permit measurement of water draining through the soil.
macropores	Fractures or other openings in unconsolidated sediment which enhance the capability for groundwater flow.
micrite	A limestone with very fine subcrystalline texture.
neutron log	A method of logging gamma radiation in boreholes. Gamma radiation is related to the hydrogen content of rock.
overburden	This general term is used by the Weldon Spring Remedial Action Project (WSSRAP) to refer specifically to the unconsolidated sediment units overlying the Burlington-Keokuk Limestone at the Weldon Spring site. From bottom to top, these units are residuum, basal till, clay till, Ferrelview Formation, loess, and topsoil/fill.
phreatic surface	The surface in an unconfined aquifer at which the water pressure is atmospheric. Also referred to as the water table.
Pleistocene	The earlier of the two epochs comprising the Quaternary Period.
pyrolusite	A mineral, MnO^2, Tetragonal. The principal ore of manganese.
residuum	See overburden.

silicification	Either the introduction of silica into pores, or replacement by silica of existing minerals.
storage coefficient	The volume of water that an aquifer releases from storage per unit surface area of aquifer per unit decline in the component of hydraulic head normal to that surface.
subcutaneous	Unsaturated portion of carbonate bedrock. Generally contains many solution features.
subrounded	A roundness grade in which considerable wear is shown.
tensiometry	The measure of pressure head in soils.
terrane	A general area of rock outcrops.
transmissivity	The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient.
vadose	A term used to designate subsurface water above the zone of saturation in the zone of aeration.
vug	A cavity, often with a mineral lining of different composition from that of the surrounding rock.
water table	See phreatic surface.
weathering	The processes by which air, rain water, plants, bacteria, and changes of temperature, cause rock to change in character, decay, and finally crumble into soil.

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