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Evaluating Cover Systems for Solid and Hazardous Waste

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ATTCH. C (CONT.)

is erosion objectionable in itself but erosion can degrade the seriously reduce its effectiveness.

..uate Erosion Potential — Step 19

The USDA universal soil loss equation (USLE) is a convenient tool for use in evaluating erosion potential. The USLE predicts average annual soil loss as the product of six quantifiable factors. The equation is:

$$A = R\ K\ L\ S\ C\ P$$

where A = average annual soil loss, in tons/acre
R = rainfall and runoff erosivity index
K = soil erodibility factor, tons/acre
L = slope-length factor
S = slope-steepness factor
C = cover-management factor
P = practice factor

The data necessary as input to this equation are available to the evaluator in a figure and tables included below. Note that the evaluations in Step 8 on soil composition and Steps 25-32 on vegetation all impact on the evaluation of erosion also.

Factor R in the USLE can be calculated empirically from climatological data. For average annual soil loss determinations, however, R can be obtained directly from Figure 20. Factor K, the average soil loss for a given

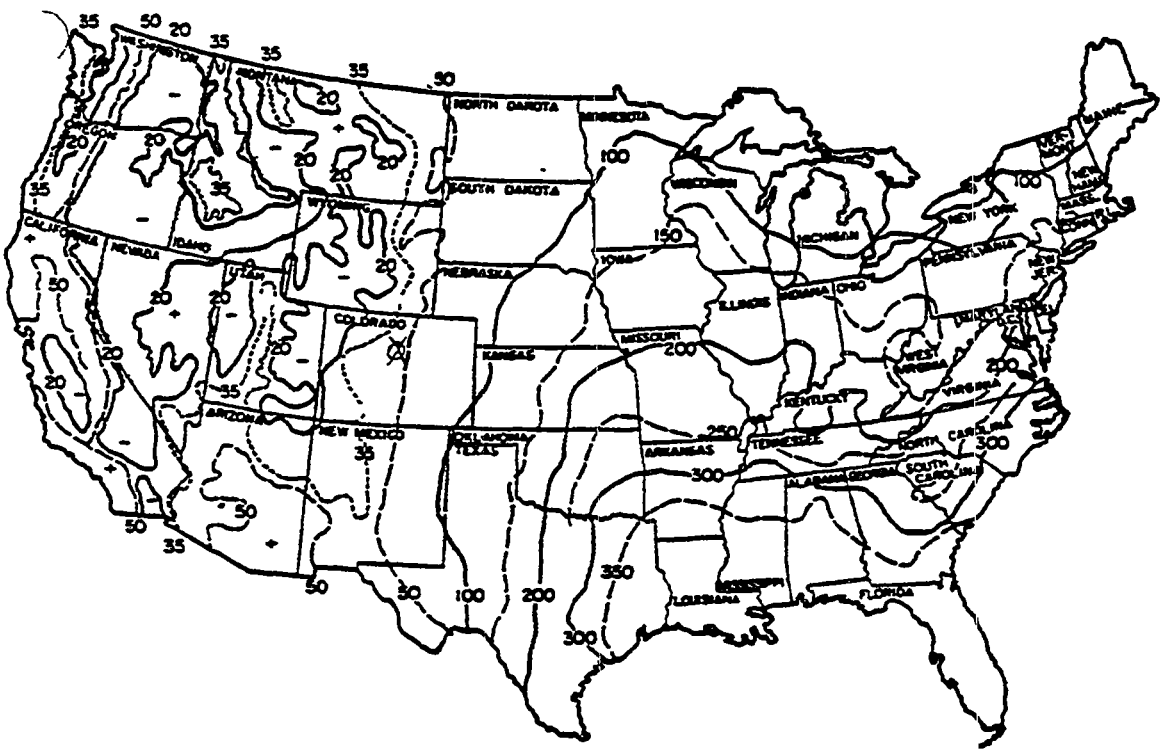

Figure 20. Average annual values of rainfall-erosivity factor R.[11]

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soil in a unit plot, pinpoints differences in erosion according to differences in soil type. Long-term plot studies under natural rainfall have produced K values generalized in Table 5 for the USDA soil types.

TABLE 5. APPROXIMATE VALUES OF FACTOR K FOR USDA TEXTURAL CLASSES[11]

Texture class	Organic matter content		
	<0.5%	2%	4%
	K	K	K
Sand	0.05	0.03	0.02
Fine sand	.16	.14	.10
Very fine sand	.42	.36	.28
Loamy sand	.12	.10	.08
Loamy fine sand	.24	.20	.16
Loamy very fine sand	.44	.38	.30
Sandy loam	.27	.24	.19
Fine sandy loam	.35	.30	.24
Very fine sandy loam	.47	.41	.33
Loam	.38	.34	.29
Silt loam	.48	.42	.33
Silt	.60	.52	.42
Sandy clay loam	.27	.25	.21
Clay loam	.28	.25	.21
Silty clay loam	.37	.32	.26
Sandy clay	.14	.13	.12
Silty clay	.25	.23	.19
Clay		0.13-0.29	

CONSERVATIVE

The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.

The evaluator must next consider the shape of the slope in terms of length and inclination. The appropriate LS factor is obtained from Table 6. A nonlinear slope may have to be evaluated as a series of segments, each with uniform gradient. Two or three segments should be sufficient for most engineered landfills, provided the segments are selected so that they are also of equal length (Table 6 can be used, with certain adjustments). Enter Table 6 with the total slope length and read LS values corresponding to the percent slope of each segment. For three segments, multiply the chart LS values for the upper, middle, and lower segments by 0.58, 1.06, and 1.37, respectively. The average of the three products is a good estimate of the

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are listed in Table 8. These values are based on rather limited field data, but P has a narrower range of possible values than the other five factors.

TABLE 8. VALUES OF FACTOR P[11]

Practice	Land slope (percent)				
	1.1-2	2.1-7	7.1-12	12.1-18	18.1-24
	(Factor P)				
Contouring (P_c)	0.60	0.50	0.60	0.80	0.90
Contour strip cropping (P_{sc})					
R-R-M-M[1]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting (P_{cl})	0.30	0.25	0.30	0.40	0.45
Contour terracing (P_t)[2]	[3] $0.6/\sqrt{n}$	$0.5/\sqrt{n}$	$0.6/\sqrt{n}$	$0.8/\sqrt{n}$	$0.9/\sqrt{n}$
No support practice	1.0	1.0	1.0	1.0	1.0

[1] R = rowcrop, W = fall-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that rowcrop strips are always separated by a meadow or winter-grain strip.

[2] These P_t values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, the P_t values are multiplied by 0.2.

[3] n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

Example: An owner/operator proposes to close one section of his small landfill with a sandy clay subsoil cover having the surface configuration shown in Figure 21. The factor R has been established as 200 for this locality. The evaluator questions anticipated erosion along the steep side and assigns the following values to the other factors in the USLE after inspecting Tables 5 through 8:

$$K = 0.14 \quad LS = 8.3 \quad C = 1.00 \quad P = 0.90$$

The rate of erosion for the steep slope of the landfill is calculated as follows:

$$A = 200\ (0.14\ \text{tons/acre})\ (8.3)\ (1.00)\ (0.90) = 209\ \text{tons/acre}$$

This erosion not only exceeds a limit recommended by the permitting authority but also indicates a potential

Attachment A3

AQUIFER TESTING PROGRAM RESULTS

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1.0 INTRODUCTION

This attachment presents the data, analysis, and results of the aquifer testing program conducted by Harding Lawson Associates (HLA) in the western portion of Section 25 at Rocky Mountain Arsenal (RMA) The aquifer testing program was performed in support of Task 93-03 Feasibility Study Soils Support Program as described in the Draft Final Work Plan for the Hydrogeologic and Geotechnical Program (HLA, 1995a) The purpose of the aquifer testing program was to evaluate the hydraulic properties such as hydraulic conductivity and transmissivity of the hydrostatic units in the western portion of Section 25

The western portion of Section 25 has been selected as the proposed site of the hazardous waste landfill that is part of the overall conceptual remedy for the Onpost Operable Unit at RMA (Program Manager for Rocky Mountain Arsenal [PMRMA], 1995) As discussed in the Landfill Site Feasibility Report (HLA, 1995b), the hydrogeology of the proposed landfill site had not been studied in detail To facilitate the designation of the landfill site, as well as the design of future groundwater monitoring programs proposed for the area, further characterization of the hydrostratigraphic units at the proposed site was necessary

1.1 Geology and Hydrogeology of Section 25

A detailed discussion of the geologic setting of the proposed site was presented in the Landfill Site Feasibility Report (HLA, 1995b) and is not included here for brevity In general, the site is immediately underlain by the Quaternary surficial deposits commonly called the Quaternary alluvium The alluvium is composed of primarily clay, silt, and fine- to medium-grained sand with some coarse-grained sand and gravel Underlying the alluvium is the Cretaceous-Tertiary Age Denver Formation (Fm) The Denver Fm is composed primarily of claystone with interbedded siltstone, sandstone, and lignite

Groundwater in the western portion of Section 25 occurs under both unconfined and confined conditions The Quaternary alluvium and the uppermost weathered portion of the Denver Fm form a generally continuous unconfined groundwater system This flow system is referred to as the unconfined flow system (UFS) Confining strata inhibit groundwater interaction between the UFS and the deeper, more permeable zones, such as sandstones, siltstones, and lignites in the Denver Fm, causing confining conditions to exist The confined groundwater underlying the UFS is referred to as the confined flow system (CFS)

1.2 Test Methods and Data Analysis

For the aquifer testing program in Section 25, aquifer tests were conducted in both the UFS and CFS flow systems In western portion of Section 25, the UFS occurs within the weathered Denver Fm and the alluvium in the area is predominantly unsaturated The aquifer testing program, therefore, was designed to evaluate the hydraulic properties of the two Denver Fm flow systems (UFS and CFS) Because the hydraulic properties of each flow system are different, different approaches for the test methods and data analysis were selected and implemented

Unconfined Flow System Aquifer Tests

The Denver Fm UFS tests consisted of single-well hydraulic tests (rising head slug tests) at five well locations (25022, 25027, 25028, 25065, and 25066) The tests were conducted between November 20 and 22, 1995, and the well locations are illustrated in Figure A3 1

A slug test provides water-level response data following the rapid removal of a small volume of water The water-level response data can be used to estimate the hydraulic conductivity of the aquifer Due to the small volume of water removed, a slug test has a much smaller area of influence than an aquifer pumping test, and therefore provides an estimate of hydraulic conductivity near the well bore Slug tests from a number of wells in an area provide an indication of the hydraulic conductivity variability across an area as the lithology of the aquifer changes This is especially useful in Section 25 where the UFS occurs in a variety of lithology including Denver Fm claystone,

sandstone, and siltstone HLA chose to perform slug tests in a number of wells in the UFS rather than an aquifer pumping test for the following reasons

- Well development data in the proposed testing area indicated a relatively low hydraulic conductivity and a thin saturated interval Both of these conditions would indicate that a pumping test of the aquifer would be unsatisfactory because the well would likely dewater before significant response could be measured in nearby wells
- Estimates of hydraulic conductivity at several well locations within the weathered Denver Fm were considered more useful than a single pumping test result because of the variability in the hydraulic conductivity of the UFS throughout the area

The Denver Fm UFS slug tests were analyzed using the Hvorslev method and Bouwer and Rice method Both of these methods represent standard procedures for slug test data analysis and are described in further detail in this attachment

Confined Flow System Aquifer Test

The Denver CFS test consisted of one 72-hour aquifer pumping test conducted at Well 25064 between November 13 and 20, 1995 The aquifer pumping test location, including observations wells monitored during the aquifer pumping test, is shown in Figure A3 1 An aquifer pumping test is a standard method used to estimate the hydraulic properties of an aquifer such as hydraulic conductivity and transmissivity

The Denver Fm CFS aquifer test data were analyzed using three methods

- Theis type-curve method
- Cooper and Jacob semilogarithmic method
- Theis recovery method

These three methods represent standard procedures for aquifer test analysis and are described in further detail in the following sections

2.0 SINGLE-WELL HYDRAULIC TESTING

Single-well hydraulic tests (rising head slug tests) were performed at five monitoring wells located in Section 25 at RMA (Figure A3 1) between November 20 and 22, 1995 The objective of the slug testing was to provide site-specific hydraulic conductivity data from monitoring wells located near the proposed landfill site The five monitoring wells identified for testing (25022, 25027, 25028, 25065, and 25066) are screened across the Denver Fm UFS Well 25022 is screened across the contact of weathered sandstone and weathered claystone of the Denver Fm Well 25027 is screened in the weathered sandstone of the Denver Fm Wells 25028, 25065, and 25066 are screened in the weathered claystone of the Denver Fm

2.1 Equipment and Procedures

The equipment used during the slug testing varied due to well diameter (4-inch-diameter or 2-inch-diameter) and casing thickness (Schedule 40 or Schedule 80) During the test, a slug of water was removed from the well using a bailer Two different sizes of bailers were used for the tests a 1 65-inch-diameter stainless steel bailer, and a 1 80-inch-diameter stainless steel bailer For two of the wells (25022 and 25066), a 4-foot-long bailer length was used and for three wells (25027, 25028, and 25065), shorter bailer lengths (2 feet, 1 foot, and 3 feet, respectively) were used due to restrictive bends in the well casings Water levels were measured during pretest monitoring and during the test using a Solinst electronic water-level indicator

The field procedures used during slug testing were as follows

- Bailers and measuring devices were decontaminated before each test
- Upon arrival at the well to be tested, the static water level was measured and recorded
- The bailer was lowered to just below the top of the water column in the well for Wells 25066, 25027, 25028, and 25065 The water level within the well was then allowed to reequilibrate until it recovered to static water level
- For Well 25022 and a second test for Well 25065, the bailer was submerged and withdrawn "instantaneously" and no equilibration time was necessary

- To begin the test, the bailer was "instantaneously" removed and the volume of water removed was recorded
- The time that the slug was pulled above the water column was recorded as the initial time Times and water-level measurements were then recorded with the Solinst water-level indicator at sufficient frequency to accurately monitor the recovery Measurements were taken until the well had reequilibrated to static conditions or until a minimum of 60 minutes had passed since the slug was removed
- After completion of the test, the data was entered into spreadsheets for subsequent data reduction
- Water removed from the well and decontamination water was containerized and transported to the North Boundary Treatment System (NBTS) for treatment

2.2 Data Analysis and Evaluation

The first step of slug test data analysis consisted of plotting the time and water-level data obtained during slug testing in the form of a water-level hydrograph for each test The purpose of the hydrograph is to evaluate the consistency of the data and to confirm that static water-level conditions existed prior to testing Hydrographs for each slug test (including the first and second tests of Well 25065) are presented in Figures A3 2 through A3 7

Hvorslev Method

A semilogarithmic plot was prepared for the rising-head (withdrawal) portion of each hydrograph Values plotted are the log of drawdown (withdrawal) versus arithmetic elapsed time The semilogarithmic withdrawal plot was then analyzed using a semilogarithmic analysis that is consistent with the Bouwer (1989) "slope" method The slug test analysis was based on the following equation, which describes the transient change in hydraulic drawdown after the slug is initiated (Hvorslev, 1951)

$$T = \frac{2\ 303\ C\ A}{2\pi(t_2 - t_1)} \log(s_1/s_2)$$

where

T = aquifer transmissivity (feet^2/day)

C = dimensionless shape factor (related to the geometry of the well completion interval)

A = cross-sectional area of well at water surface (including sandpack porosity for alluvial wells that are sandpacked above the water table) (feet^2)

s = hydraulic drawdown (feet)

t = elapsed time (day)

In the previous equation, subscripts identify contemporaneous time-drawdown measurements (i e , s_1 is the drawdown occurring at time t_1) Hvorslev (1951) defines the shape factor as follows

$$C = \ell\eta \left[\frac{L}{D} + \sqrt{1 + \left(\frac{L}{D} \right)^2} \right]$$

where

L = length of test interval (feet)

D = borehole diameter (feet)

The equation for transmissivity predicts that a semilogarithmic plot of arithmetic time versus log drawdown should be a straight line If one considers a period of time over which the drawdown changes by a factor of 10, the following equation results

$$T = \frac{2\ 303\ C\ A}{2\pi\ \Delta t_{90}}$$

where

t_{90} = change in time over one log cycle of drawdown (minutes)

The change in time over one log cycle of drawdown is interpreted from a semilogarithmic plot as described by Bouwer (1989)

The semilogarithmic method is based on the assumption of quasi-steady-state flow near the borehole (i e , a succession of steady-state flow conditions) Fully transient solutions predict that quasi-steady-state conditions tend to be achieved at late recovery times Thus, in applying the semilogarithmic method to slug test data, preference is generally given to fitting the straight line to later-time data

The average hydraulic conductivity computation for the test interval is as follows

$$K = \frac{T}{B}$$

where

K = average hydraulic conductivity (feet/day)

B = test interval thickness (saturated thickness) (feet)

K (cm/s) = K (ft/day) x 3 53 x 10^{-4}

Bouwer and Rice Method

The Bouwer and Rice method uses the following equation

$$K = (r_c^2 (\ln(R_e/R))/2L_e)*(1/t)\ln(s/s_o)$$

where

K = hydraulic conductivity (feet/day)

r_c = the radius of the well casing

R = the radius of the gravel envelope

R_e = the effective radial distance over which head is dissipated (feet)

L_e = the length of screen or open section of the well through which water can enter

s_o = the drawdown at time t=0 (feet)

s_t = the drawdown at time t=t (feet)

t = the time since s_o=s

To calculate the ratio of the effective radial distance (Re) to the radius of the gravel envelope (R), Bouwer and Rice (1976) provide the following equation

$$\ln(R_e/R)=[(1\ 1/\ln(L_w/R))+(C/(L_e/R))]^{-1}$$

where

C = a shape factor obtained from Bouwer, 1989

L_w = the length from the water table to the bottom of the sandpack

The drawdown is plotted versus time on semilogarithmic paper and the slope of the line through that data is calculated The value of $(1/t)\ln(s_o/s_t)$ may be obtained from two points picked on that straight line At one point, $t=t_1$ and $s=s_1$, and at the second point, $t=t_2$, and $s=s_2$ (Fetter, 1988) Under these conditions $(1/t)\ln(s_o/s_t)=(1/(t_2-t_1)\ln(s_1/s_2)$ hydraulic conductivity can then be calculated using the equation listed above

2.3 Single-well Hydraulic Test Results

The results of the slug testing are summarized in Table A3 1, the results presented graphically in Figures A3 8 through A3 13, and the calculation sheets are included as Tables A3 2, A3 3, and A3 4 For each of the five wells (25022, 25027, 25028, 25065, and 25066), calculations of hydraulic conductivity were performed using the Hvorslev method and the Bouwer and Rice method The results of the two data sets were then compared to verify the accuracy of the analysis For each of the five wells, the two methods yield similar hydraulic conductivity values Based on the slug test results for the wells located in Section 25, the three wells in the weathered sandy claystone of the unconfined Denver Fm (Wells 25028, 25065, and 25066) yielded a hydraulic conductivity that ranged from 3 3 x 10^{-6} centimeters per second to 1 9 x 10^{-5} cm/s (9 4 x 10^{-3} feet per day (ft/day) to 5 4 x 10^{2} ft/day)

Based on the slug tests, the estimated transmissivity of the weathered claystone present at Wells 25028, 25065, and 25066 ranged from 0 11 ft^2/day to 0 68 ft^2/day with a geometric mean of 0 30 ft^2/day The estimated transmissivity of the Denver Fm sandstone at Well 25027 ranges between 24 to 29 ft^2/day with a geometric mean of 27 ft^2/day The estimated transmissivity of the Denver Fm sandstone at Well 25022 ranged from 7 2 ft^2/day to 8 8 ft^2/day with a geometric mean of 8 0 ft^2/day

For Well 25065, the two tests were run due to mechanical difficulty during the first test The two tests yielded similar results The value from the first test was not used in the final analysis of the geometric mean of the data set because the first few minutes of data were not properly recorded (Figure A3 11)

For Well 25027, which is in the Denver Fm weathered sandstone, the geometric mean hydraulic conductivity was calculated to be 1 71 x 10^{3} cm/s (4 9 ft/day) This value may reflect some contribution from the sandpack because a smaller volume of water was removed than originally desired due to the thin saturated zone For Well 25022, the hydraulic conductivity was calculated to be 4 0 x 10^{-4} cm/s (1 12 ft/day) This, too, may reflect some influence of the sandpack because a smaller diameter bailer was required to pass a blockage at ground surface in the well

3.0 AQUIFER PUMPING TEST

An aquifer pumping test of the Denver Fm CFS was conducted between November 13 and 20, 1995 The well array at the test site consisted of a pumping well (25064), two observation wells (25009 and 25063) completed in the same flow system, one well (25008) completed in the overlying UFS, and one well (25010) completed in the underlying Denver Fm CFS The locations of these wells are shown in Figure A3 1 Eight additional wells, four completed in the UFS and four completed in the Denver CFS, were monitored for background water-level trends as part of the test The locations of these background wells relative to the test site are also shown in Figure A3 1 Water levels were also measured (twice before and once after the pumping test) in the 13 previously mentioned wells (background well network and test site wells) and in 25 additional wells (secondary background well network) The secondary background well network is also shown in Figure A3 1 The sequence of aquifer testing activities is summarized in Table A3 5

3.1 Equipment and Methods

Pretest water-level monitoring was conducted using an electronic water-level indicator Water levels at the site and in the surrounding well network were measured and recorded from October 30, 1995, until the aquifer pumping test began on November 13, 1995 The wells at the site were also monitored with electronic transducers beginning on November 12, 1995

Pumping was accomplished using a 2-inch-diameter Bennett™ pump operating on a compressed air supply The pump supplied sufficient pressure at ground surface to allow the water to flow up into a 300-gallon tank used for temporary water storage A Little Giant™ submersible pump was used to transfer the water into a truck-mounted 1,800-gallon tank for transport to the onsite treatment facility at the North Boundary of RMA

Flow rates were measured during the pumping test using an in-line variable area flowmeter, and manually using a calibrated 5-gallon bucket and a stopwatch Flow rate was controlled using both a

needle valve connected to the discharge line and the air pressure regulators connected to the Bennett™ pump and compressed air bottles

Water levels were measured in the pumping and observation wells using electronic pressure transducers interfaced to a multiple-channel datalogger with internal memory for data acquisition and manually with an electronic water-level indicator The datalogger provided real-time digital readouts of water levels in the monitoring wells and the pumping well so that field personnel could monitor the operation and progress of the aquifer pumping test

3.2 Data Evaluation

To verify that the aquifer test measurements were recorded correctly and to make any necessary corrections for external influences such as barometric pressure and/or water-table elevation changes the following methods were used to evaluate the aquifer test data

- Hydrograph Evaluation
  - Compare manual measurements to electronic measurements to verify the electronic data
  - Review water-level hydrographs for test site wells and background monitoring wells for regional (background) water-level changes over time
  - Compare water-level data to barometric data to correct for barometric influences
- Flow Rate Evaluation
  - Compare manual measurements to electronic flow measurements recorded from the Bennett™ pump flowmeter to verify the flowmeter readings
  - Review the variability in flow rates recorded during the aquifer test period

Hydrograph Evaluation

Hydrographs (including both transducer measurements and hand measurements where appropriate) of the pumping well, observation piezometers, and background wells are presented in Figures A3 14 through A3 31 Where appropriate, hydrographs for both transducer reading and hand measurements were plotted Also, on each hydrograph, the measurements are illustrated as raw and corrected for

barometric pressure changes The procedure for correcting for barometric effects is described in the following section

Observation well hydrographs indicate that water levels at the site were relatively stable for one day before the pumping test Because hydrographs for the background wells show no regional trend, background trend corrections were not applied to drawdown data before analysis

Barometric Pressure Corrections

Barometric corrections were made on water-level data obtained from aquifer test monitoring wells Figure A3 32 illustrates the barometric pressure changes over the aquifer test time period The following equation was added to or subtracted from the raw pressure head to correct for barometric effects

$$COR = \left[\frac{Dm}{12\ Dw} (Bo - Ba) \right] \frac{BE}{100}$$

where

COR = barometric correction value (feet)

Dm = density of mercury (13 55 grams per cubic centimeter [g/cm^3])

Dw = density of water (1 0 g/cm^3)

Bo = standard barometric pressure used as a datum (inches of mercury)

Ba = barometric pressure at the time of measurement (inches of mercury)

BE = barometric efficiency (percent)

In the equation, the term in brackets is a standard correction for a nonvented transducer that provides a true gauge pressure reading Barometric efficiency (BE) is related to the formation response caused by barometric pressure variations (McWhorter and Sunada, 1977)

In general, values for BE were estimated through a calibration procedure The barometric efficiency was estimated at 80 percent through calibration and barometric induced water-level fluctuations were

dampened out The BE for two wells (25008 and 25010) was estimated at 20 percent because the hydrographs displayed very little effect from barometric influence

Flow Rate Corrections

Corrections associated with variations in flow rate were not applied to test data because, where feasible, test logistics were modified to reduce the significance of these effects For example, for this pumping test, a high priority was placed on holding the discharge flow rate as uniform as possible This was accomplished using an in-line flowmeter, corroborative flow rate measurements using the calibrated 5-gallon bucket and stopwatch method, and a control valve that could be used to adjust the flow rate as required Diligent flow rate monitoring and control eliminated the need for flow rate corrections and therefore, significantly reduced the uncertainty of subsequent test analyses Figure A3 33 illustrates the flow rate measurements throughout the test

3.3 Data Analysis Methods and Assumptions

The conceptual model used to analyze results at the pumping site assumes that the CFS can be conceptualized as an ideal confined aquifer with no leakage from underlying or overlying aquitards Water-level data obtained from the pumping and recovery periods were analyzed using the following three methods

- Theis type-curve method
- Cooper and Jacob semilogarithmic method
- Theis recovery method

These methods are described in the literature and represent standard procedures for aquifer test analysis All three methods were used to compute transmissivity and average hydraulic conductivity of the aquifer In addition, the first two methods provided a means for estimating the aquifer storage coefficient These methods of analysis were used to provide semi-independent estimates of aquifer characteristics at the test site The Theis type-curve method relies heavily on early-time pumping data, and the Jacob method gives preference to mid- to late-time pumping data The Theis recovery

method is based on analysis of well recovery after termination of pumping The analysis for each method is described below

The analytical solutions presented in this section are based on the pumping test response of an ideal aquifer, which is illustrated in Figure A3 34 These methods rely on a number of simplifying assumptions The degree to which computed aquifer parameters represent actual conditions depends on the extent to which the simplifying assumptions are met Assumptions that form the basis of the Theis type-curve method, Theis recovery method, and the Cooper and Jacob semilogarithmic method are as follows

1 The aquifer is uniform in hydraulic properties and the hydraulic conductivity is nondirectional (i e , aquifer properties are homogeneous-isotropic)

2 The formation is uniform in thickness and "seemingly" infinite in areal extent

3 The aquifer receives no recharge and contains no internal sources or sinks (with exception of the pumping well)

4 The pumping well penetrates and receives water from the full thickness of the water-bearing formation

5 The water removed from storage is discharged instantaneously when the head is lowered

6 All water removed from the well is derived from aquifer storage

These assumptions are rarely met in field tests due to the natural heterogeneities of a formation However, slight deviations from the above assumptions do not prohibit successful application of Theis and similar methods In some cases, it can be shown that certain violations of the governing assumptions still allow a portion of the test data to be analyzed using ideal aquifer solutions For example, the assumption of an aquifer of seemingly infinite areal extent is frequently violated because of the presence of impermeable and/or recharge boundaries However, in the presence of such boundaries, it is usually possible to analyze early-time data using an ideal aquifer solution

Theis Type-Curve Method

The Theis type-curve method analysis is performed by plotting field data (corrected drawdown versus time) on log-log paper having the same scale as the Theis type-curve This data plot is placed over the type-curve and, while keeping the coordinate axes of both plots parallel, the data plot is translated horizontally and vertically until a best fit with the type-curve is attained (see Figure A3 35) An arbitrary match point is selected, and W(u)* and (1/u)* are read from the type-curve and s* and t* are read from the data plot The transmissivity is then calculated using the following equation

$$T = \frac{Q}{4\pi} \frac{W(u)^*}{s^*}$$

where

T = aquifer transmissivity

Q = pumping flow rate

W(u)* = match point value on type-curve

s* = match point value for drawdown on data plot

The storage coefficient is calculated as follows

$$S = \frac{4T}{r^2} \frac{t^*}{(1/u^*)}$$

where

S = storage coefficient

t* = match point value for time on data plot

r = radial distance from pumping well to observation well

u* = match point value on type-curve

Aquifer parameters are assessed from data obtained at observation wells The Theis method cannot be used to analyze pumping well data

Cooper and Jacob (1946) Semilogarithmic Method

The Cooper and Jacob (1946) semilogarithmic method involves analyzing the pumping data from both the observation wells and the pumping well, although data obtained from the pumping well is usually subject to greater uncertainty In using the method, a plot of drawdown(s) versus the logarithm of time (t) is prepared as shown in Figure A3 36 A "best-fit" straight line is drawn through the data, and transmissivity is calculated as follows

$$T = \frac{2\ 303\ Q}{4\pi\ \Delta s}$$

where

T = aquifer transmissivity

Q = pumping flow rate

Δs = change in drawdown per log cycle of time (determined from the slope of the semi-logarithmic straight line)

From observation well data, the aquifer storage coefficient is computed by

$$S = \frac{2\ 24\ T\ t_o}{r^2}$$

where

S = storage coefficient

t_o = intercept of semilogarithmic straight line with time axis (s = 0)

r = radial distance from pumping well to observation well

The storage coefficient is estimated from data obtained at observation wells and cannot be reliably computed from pumping well data

Traditionally, the Cooper and Jacob analysis has been considered applicable for data where u is less than 0 01 in the following equation

$$u = \frac{Sr^2}{4Tt}$$

However, for practical considerations, it is only necessary for u to be less than 0 1

Theis Recovery Method

The Theis recovery method involves analysis of residual drawdown data obtained from both observation wells and the pumping well A semilogarithmic plot of residual drawdown (s′) versus the log of (t/t′) is prepared where

t = time since initiation of pumping

t′ = time since initiation of recovery

A "best-fit" straight line is drawn through the plotted points giving preference to intermediate- and later-time data (see Figure A3 37) Aquifer transmissivity is calculated using the following equation

$$T = \frac{2\ 303\ Q}{4\pi\ \Delta s'}$$

where

T = aquifer transmissivity

Q = flow rate during pumping

Δs′ = change in drawdown per log cycle of (t/t′), based on the slope of semilogarithmic straight line

The aquifer storage coefficient cannot be computed using the Theis recovery method

3.4 Results of the Aquifer Pumping Test

Field Results

A 72-hour pumping test of the Denver Fm CFS was conducted at the test site between November 13 and November 16, 1995 The average pumping rate during the pumping test was 1 8 gallons per

minute (gpm) and ranged from 1 6 to 2 0 gpm A graph of flow rate versus time is presented in Figure A3 33

At the end of the 72-hour pumping period, the pumping well (25064) exhibited 5 70 feet of drawdown (14 2 percent of the 40 feet of available drawdown) The closest observation well (25009), which was located a radial distance of 24 4 feet from the pumping well, exhibited 1 72 feet of drawdown Well 25063, located a radial distance of 29 0 feet from the pumping well, exhibited 1 51 feet of drawdown Wells 25008 (completed in the UFS) and 25010 (completed in the deeper CFS), located at radial distances of 10 8 and 19 68 feet, respectively, from the pumping well, exhibited no discernible response due to pumping

Following the pumping portion of the test, water-level recovery was monitored for 96 hours Post-test recovery monitoring with the transducers was concluded on November 20, 1995 At that time, the residual drawdown in the pumping well after correction for barometric pressure influence was 0 22 foot Residual drawdowns in nearby observation wells (25009 and 25063) after correction for barometric pressure influences were 0 26 foot and 0 19 foot, respectively

Theis Type-Curve Results

The Theis type-curve method is presented graphically by well in Figures A3 38 and A3 39 Transmissivity, hydraulic conductivity, and storage coefficient results obtained using this method are very consistent between wells The Theis curve plot for Well 25009 (Figure A3 38) shows a standard Theis curve with an inflection point at approximately t = 2,000 seconds (33 minutes) After this point, the drawdown continues to increase with time Both the early time portion of the curve can be fitted to the Theis type-curve and the later-time portion of the curve can be fitted to the Theis type-curve Although there are many possible causes for a response curve of this shape, HLA believes the likely cause may be a small overdeveloped zone immediately surrounding the pumping well or due to localized aquifer heterogeneity near the test site The same curve shape is shown in the Theis curve plot for Well 25063 During analysis, a greatest significance was placed on the later-

time data The values presented for the Theis analysis are based on a Theis curve fitted to the later-time data

Cooper-Jacob Results

Results from Cooper and Jacob's semilogarithmic method were consistent between wells and compared favorably with results of the two types of Theis analyses Graphs used for the Cooper and Jacob semilogarithmic analysis are presented in Figures A3 40 and A3 41 Results obtained from both observation Wells 25009 and 25063 met the $u \leq 0\ 1$ criterion for application of the Cooper and Jacob semilogarithmic analysis and are therefore considered valid

Theis Recovery Results

The Theis recovery method yielded consistent values of transmissivity and hydraulic conductivity between wells Graphs used for the Theis recovery analysis are presented in Figures A3 42 through A3 44

4.0 AQUIFER TESTING PROGRAM SUMMARY AND CONCLUSIONS

The results of the slug tests are presented in Table A3 1 The results of the slug tests indicate that the transmissivity and hydraulic conductivity of the Denver Fm claystone units are approximately two orders of magnitude lower than those measured in the Denver Fm sandstone units For example, the mean hydraulic conductivity for the claystone units is 6 8 x 10^{-6} cm/s whereas within the sandstone units the mean hydraulic conductivity is 9 1 x 10^{-4} cm/s

The results of the aquifer pumping test are presented in Table A3.6 The hydraulic conductivity of the confined Denver Fm sandstone is estimated at 7 61 x 10^{-4} cm/s The transmissivity and storativity were estimated at 75 5 square feet per day and 6 47 x 10^{3}, respectively It should be noted that throughout the pumping test, no measurable response was noted in the observation wells completed within the overlying and underlying aquifers (25008 and 25010) This indicates that the confining units separating the aquifers do inhibit groundwater flow between the aquifers

In conclusion, five slug tests in the UFS and one aquifer pumping test in the CFS were completed in the western portion of Section 25 The test results confirm that the Denver Fm weathered claystone units have significantly lower hydraulic conductivities than the Denver Fm weathered sandstone units The test results provide specific information on the hydraulic conductivity and transmissivity of the hydrostratigraphic units within the proposed landfill area that can be used in future hydrogeologic investigations including the proposed groundwater monitoring program for the proposed landfill area

5.0 REFERENCES

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Table A3.1: Summary of Results of Single Well Hydraulic Test Analyses

Well Number	Hvorslev Transmissivity (ft^2/day)	Hvorslev Hydraulic Conductivity (cm/s)	Bouwer and Rice Transmissivity (ft^2/day)	Bouwer and Rice Hydraulic Conductivity (cm/s)	Geometric Mean Transmissivity (ft^2/day)	Geometric Mean Hydraulic Conductivity (cm/s)	Test Interval Description
25022	8 8	$4\ 3 \times 10^{-4}$	7 2	$3\ 6 \times 10^{-4}$	8 0	$4\ 0 \times 10^{-4}$	Unconfined Flow System, Denver Fm, sandstone
25027	29	$1\ 9 \times 10^{-3}$	24	$1\ 6 \times 10^{-3}$	27	$1\ 7 \times 10^{-3}$	Unconfined Flow System, Denver Fm, sandstone
25028	0 27	$5\ 5 \times 10^{-6}$	0 21	$4\ 4 \times 10^{-6}$	0 24	$4\ 9 \times 10^{-6}$	Unconfined Flow System, Denver Fm, claystone
25065	0 79	$2\ 2 \times 10^{-5}$	0 59	$1\ 7 \times 10^{-5}$	0 68	$1\ 9 \times 10^{-5}$	Unconfined Flow System, Denver Fm, claystone
25066	0 13	$3\ 8 \times 10^{-6}$	0 10	$2\ 8 \times 10^{-6}$	0 11	$3\ 3 \times 10^{-6}$	Unconfined Flow System, Denver Fm, claystone

cm/s Centimeters per second
Fm Formation
ft Feet

Table A3.2

RISING HEAD SLUG TEST CALCULATION SHEET
HVORSLEV ANALYSIS

Drawdown calculations

Well Number	Log Drawdown Line	Time at t1 (minutes)	Time at t2 (minutes)	Drawdown s1 at t1 (feet)	Drawdown s2 at t2 (feet)	Log s1	Log s2	Calculated dt (minutes)
25022	A-A'	2 75	6 28	0 19	0 11	-0 721	-0 959	14 87
25027	A-A'	0 53	1 08	0 19	0 14	-0 721	-0 854	4 15
25028	A-A'	6 35	20 6	0 72	0 62	-0 143	-0 208	219 43
25028	B-B'	32 3	50	0 58	0 54	-0 237	-0 268	570 34
25065	A-A'	55	71 7	2 33	2 08	0 367	0 318	338 79
25066	A-A'	25	50	0 68	0 66	-0 167	-0 180	1928 27
25066	B-B'	123 9	219 5	0 62	0 58	-0 208	-0 237	3300 68
25065 (2)	A-A"	14 6	48 5	0 85	0 65	-0 071	-0 187	290 97

Well Number	Log Drawdown Line	dt (min)	Well Diameter (inches)	Borehole Diameter (inches)	Equivalent Free Water Area (ft2)	Depth to Ground Water (ft bgs)	Depth to bottom Sandpack (ft bgs)	Test Length Interval (ft)	Borehole Diameter (feet)	Shape factor C	Trans-missivity (ft^2/d)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/s)
25022	A-A'	14 87	2	6	0 0742	47 89	55	7 11	0 50	3 35	8 8	1 240	4 4E-04
25027	A-A'	4 15	2	6	0 0742	43 51	49	5 49	0 50	3 09	29	5 316	1 9E-03
25028	A-A'	219 43	2	5 625	0 0670	43 78	62	17 00	0 47	4 28	0 69	0 041	1 4E-05
25028	B-B'	570 34	2	5 625	0 0670	43 78	62	17 00	0 47	4 28	0 27	0 016	5 5E-06
25065	A-A'	338 79	2	8	0 1200	41 92	58 5	12 50	0 67	3 63	0 68	0 054	1 9E-05
25066	A-A'	1928 272	4	10 625	0 2458	42 1	58	12 00	0 89	3 30	0 22	0 019	6 5E-06
25066	B-B'	3300 68	4	10 625	0 2458	42 1	58	12 00	0 89	3 30	0 13	0 011	3 8E-06
25065 (2)	A-A'	290 97	2	8	0 1200	41 89	58 5	12 50	0 67	3 63	0 79	0 063	2 2E-05

Table A3.3

RISING HEAD SLUG TEST CALCULATION SHEET
BOUWER AND RICE ANALYSIS

Slope Calculations

Well Number	Log Drawdown Line	Hvorslev dt (min)	Slug Test Start Time t0 (min)	Time at t1 (min)	Time at t2 (min)	Elapsed Time t1-t0 (sec)	Elapsed Time t2-t0 (sec)	Draw-down s1 at t1 (feet)	Draw-down s2 at t2 (feet)	Log s1	Log s2	Slope m = s2-s1/t2-t1	Log of Initial Drawdown = log(s1)-mx1	Calculated s0 at t0
25022	A-A'	14 872	0	2 75	6 28	165	376 8	0 19	0 11	-0 72	-0 96	-0 07	-0 54	0 29
25027	A-A'	4 147	0	0 53	1 08	31 8	64 8	0 19	0 14	-0 72	-0 85	-0 24	-0 59	0 26
25028	A-A'	219 431	0	6 35	20 6	381	1236	0 72	0 62	-0 14	-0 21	0 00	-0 11	0 77
25028	B-B'	570 338	0	32 3	50	1938	3000	0 58	0 54	-0 24	-0 27	0 00	-0 18	0 66
25065	A-A'	338 793	0	55	71 1	3300	4266	2 33	2 08	0 37	0 32	0 00	0 54	3 43
25066	A-A'	1928 272	0	25	50	1500	3000	0 68	0 66	-0 17	-0 18	0 00	-0 15	0 70
25066	B-B'	3300 684	0	123 9	219 5	7434	13170	0 62	0 58	-0 21	-0 24	0 00	-0 17	0 68
25065 (2)	A-A'	290 973	0	14 6	48 5	876	2910	0 85	0 65	-0 07	-0 19	0 00	-0 02	0 95

Well Number	Log Draw-down Line	Hvorslev dt (min)	Test Interval Length (feet)	Diameter of Well Casing (inches)	Radius of Borehole (feet)	Le/Rw	C from B&R 1989, fig 2	Ln(Re/Rw) from Equation 5 B&R 1989	Calculated Drawdown at Time t0 (feet)	Elapsed Time t2-t0 (sec)	Drawd own at Time t2 (feet)	Equivalent Free Water Surface Radius Rc (feet)	Transmissivity (ft^2/day)	Hydraulic Conductivity (cm/sec)
25022	A-A'	0	7 11	2	0 250	28 440	1	2 749	0	0	0 11	0 153659	7 24	3 59E-04
25027	A-A'	0	5 49	2	0 250	21 960	0 7	2 578	0	0	0 14	0 153659	24 33	1 56E-03
25028	A-A'	0	17	2	0 234	72 533	2 8	3 386	0	0	0 62	0 146084	0 55	1 13E-05
25028	B-B'	0	17	2	0 234	72 533	2 8	3 386	0	0	0 54	0 146084	0 21	4 36E-06
25065	A-A'	0	12 5	2	0 333	37 500	2 4	2 721	0	0	2 08	0 195434	0 53	1 49E-05
25066	A-A'	0	12	4	0 443	27 106	2	2 456	0	0	0 66	0 279717	0 17	4 86E-06
25066	B-B'	0	12	4	0 443	27 106	2	2 456	0	0	0 58	0 279717	0 10	2 84E-06
25065 (2)	A-A'	0	12 5	2	0 333	37 500	2 4	2 721	0	0	0 65	0 195434	0 59	1 67E-05

Table A3.4

RISING HEAD SLUG TEST COMPARISON OF ANALYTICAL METHODS

Well Number	Log Drawdown Line	Bouwer & Rice T (ft^2/day)	Hvorslev T (ft^2/day)	Geometric Mean T (ft^2/day)	Bouwer & Rice K (ft/day)	Bouwer & Rice K (ft/day)	Hvorslev K (cm/s)	Hvorslev K (ft/day)	Geometric Mean K (cm/s)	Geometric Mean K (ft/day)	Comments
25022	A-A'	7 236	8 817	7 987	3 59E-04	1 018	4 38E-04	1 240	3 96E-04	1.12	unconfined flow system, Denver Fm sandstone
25027	A-A'	24.330	29 184	26 647	1 56E-03	4 432	1 88E-03	5 316	1.71E-03	4 86	unconfined flow system, Denver Fm sandstone
25028	A-A'	0 546	0 691	0 614	1 13E-05	0 032	1 43E-05	0 041	1 27E-05	0 04	unconfined flow system, Denver Fm claystone
25028	B-B'	0 210	0 266	0 236	4 36E-06	0 012	5 52E-06	0 016	4 90E-06	0 01	unconfined flow system, Denver Fm claystone
25065	A-A'	0 528	0 678	0 598	1 49E-05	0 042	1 91E-05	0 054	1 69E-05	0 05	unconfined flow system, Denver Fm claystone
25066	A-A'	0 165	0 222	0 192	4 86E-06	0.014	6 53E-06	0 019	5.63E-06	0 02	unconfined flow system, Denver Fm claystone
25066	B-B'	0 097	0.130	0.112	2.84E-06	0.008	3 82E-06	0 011	3 29E-06	0 01	unconfined flow system, Denver Fm claystone
25065 (2)	A-A'	0 592	0 789	0 684	1 67E-05	0 047	2 23E-05	0 063	1 93E-05	0 05	unconfined flow system, Denver Fm claystone

T = Transmissivity
K = Hydraulic conductivity
ft = feet
cm = centimeters
s = seconds

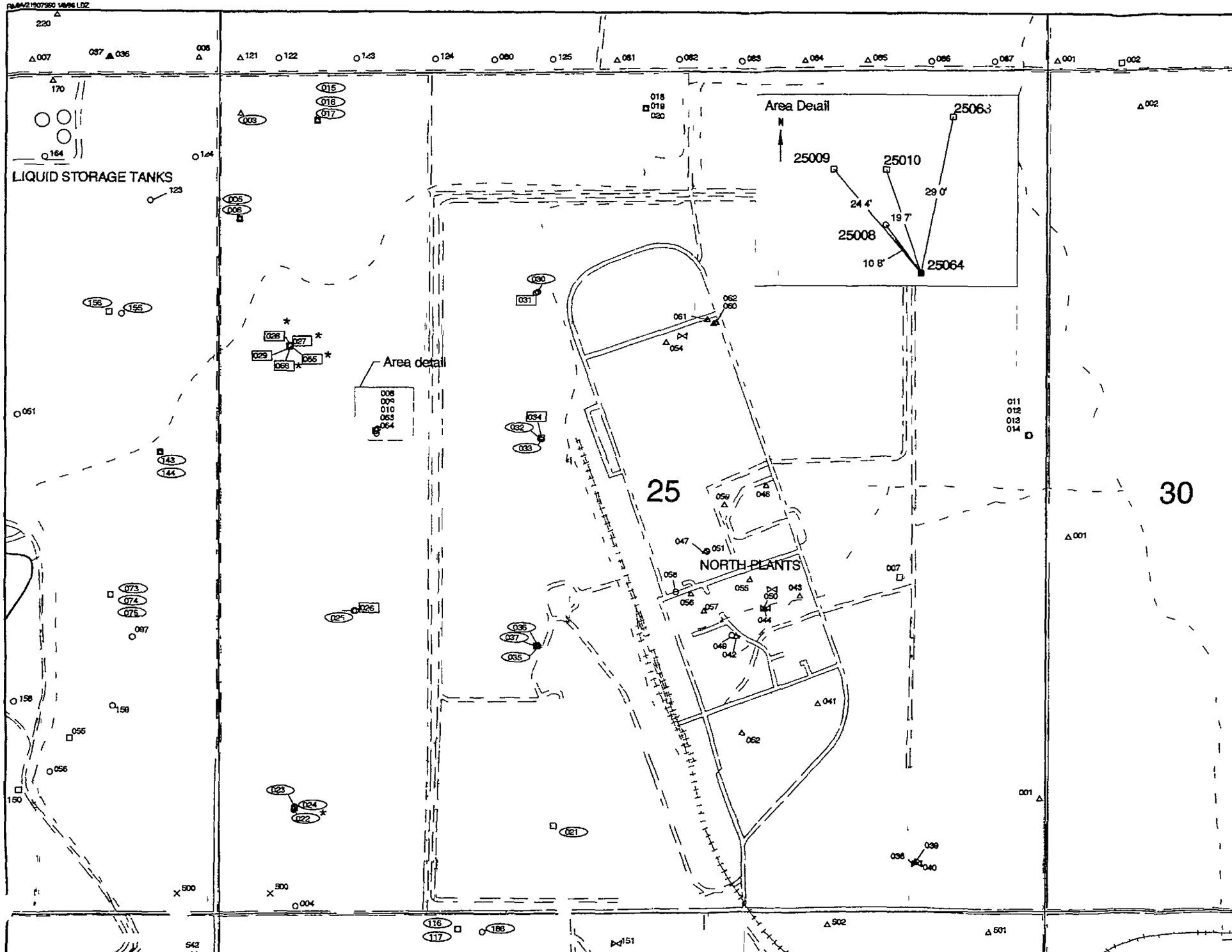
Table A3.5: Sequence of Aquifer Testing Activities

Date	Activities
10/30/95	Begin pretest monitoring, first round of water-level measurements
11/07/95	Second round of water-level measurements
11/12/95	Begin monitoring aquifer pumping and observation wells with transducers
11/13/95	Begin aquifer pumping test at 12 10 p m
11/16/95	End aquifer pumping test at 12 10 p m., begin recovery monitoring
11/20/95	End recovery monitoring of aquifer pumping test wells, begin slug tests
11/21/95	Continue slug tests
11/22/95	Complete slug tests, post-test round of water-level measurements

Table A3.6: Summary of Results of Aquifer Pumping Test Analyses

Well Number	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/s)	Storativity (unitless)
Summary of Theis Type-Curve Method Results				
25009	76 8	2 19	$7\ 74 \times 10^{-4}$	$6\ 27 \times 10^{3}$
25063	79.0	2 26	$7\ 96 \times 10^{-4}$	$6\ 52 \times 10^{3}$
Summary of Cooper-Jacob Semilogarithmic Method Results				
25009	73.3	2 09	$7\ 39 \times 10^{-4}$	$7\ 26 \times 10^{3}$
25063	79 2	2 26	$7\ 98 \times 10^{-4}$	$5\ 89 \times 10^{-3}$
Summary of Theis Recovery Method Results				
25009	81 6	2 33	$8\ 23 \times 10^{-4}$	NA
25063	66 3	1 89	$6\ 69 \times 10^{-4}$	NA
25064	70 7	2 02	$7\ 13 \times 10^{-4}$	NA
Geometric mean	75 5	2 16	$7\ 61 \times 10^{-4}$	$6\ 47 \times 10^{-3}$

cm/s Centimeters per second
ft Feet



Explanation

- 038 — Alluvial well with well number
- 192 — Unconfined Denver Formation well with well number
- 123 — Confined Denver Formation well with well number
- Unpaved roadway
- Surface drainage
- 25 — Section number
- 031 — Primary observation and background well network
- 030 — Secondary background well network
- * — Single well hydraulic test
- ■ — Pumping well

N

0 600

Scale in feet

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure A3 1

Aquifer Test Location Map
Section 25

Figure A3.2

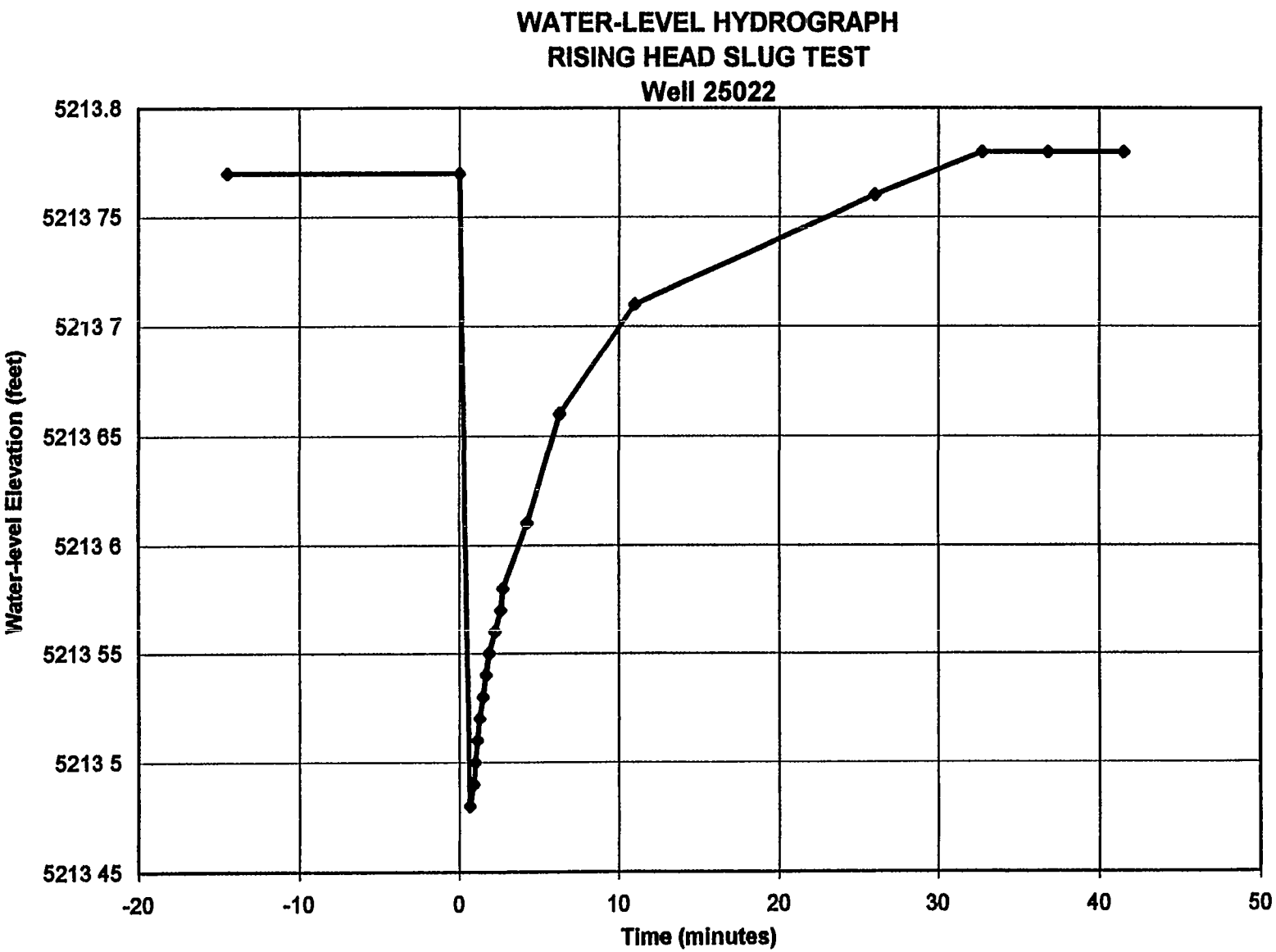

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25022
Water-level Elevation (feet)
5213.8
5213 75
5213 7
5213 65
5213 6
5213 55
5213 5
5213 45
-20
-10
0
10
20
30
40
50
Time (minutes)

Figure A3.3

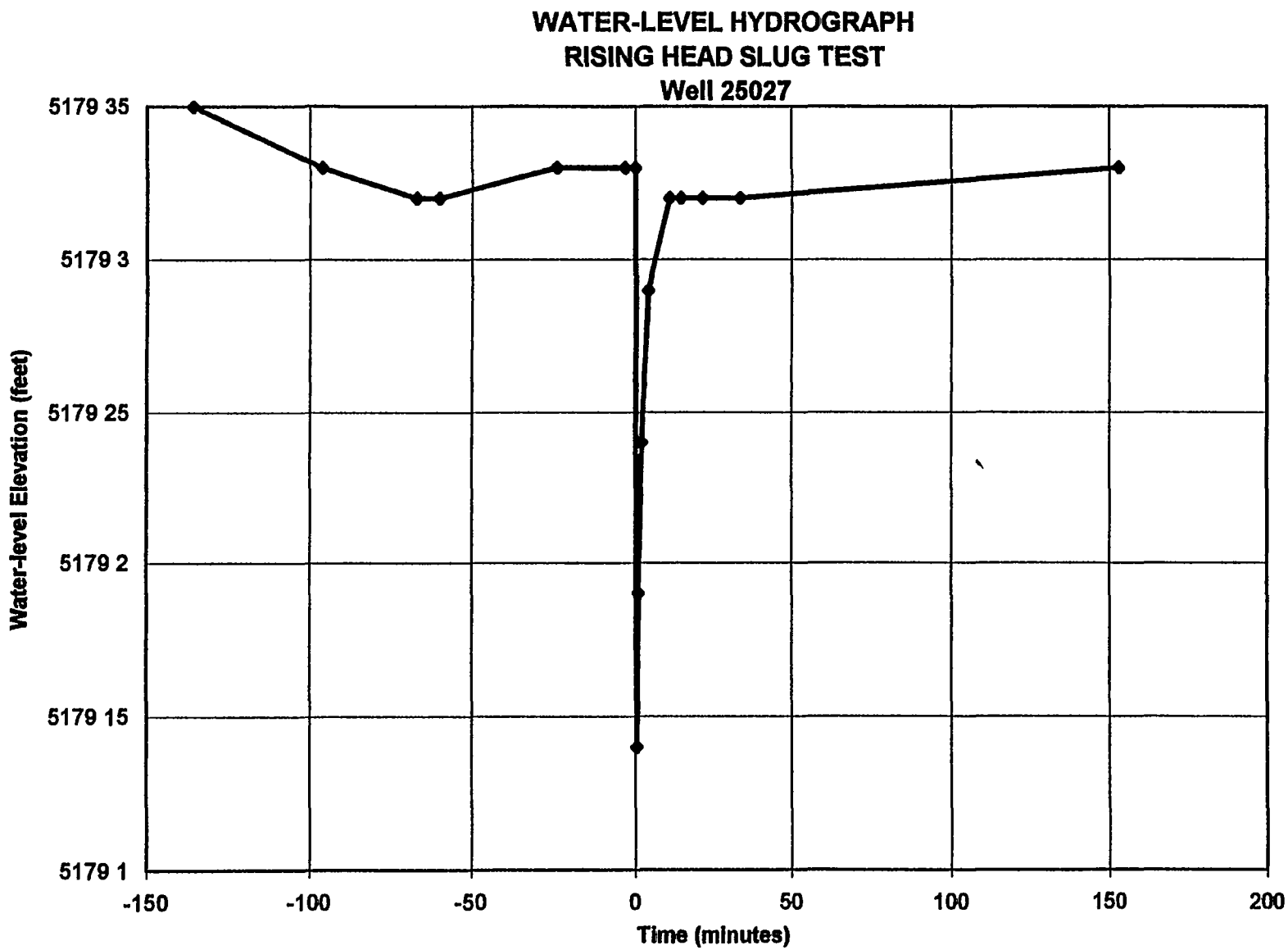

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25027
Water-level Elevation (feet)
5179 35
5179 3
5179 25
5179 2
5179 15
5179 1
-150
-100
-50
0
50
100
150
200
Time (minutes)

Figure A3.4

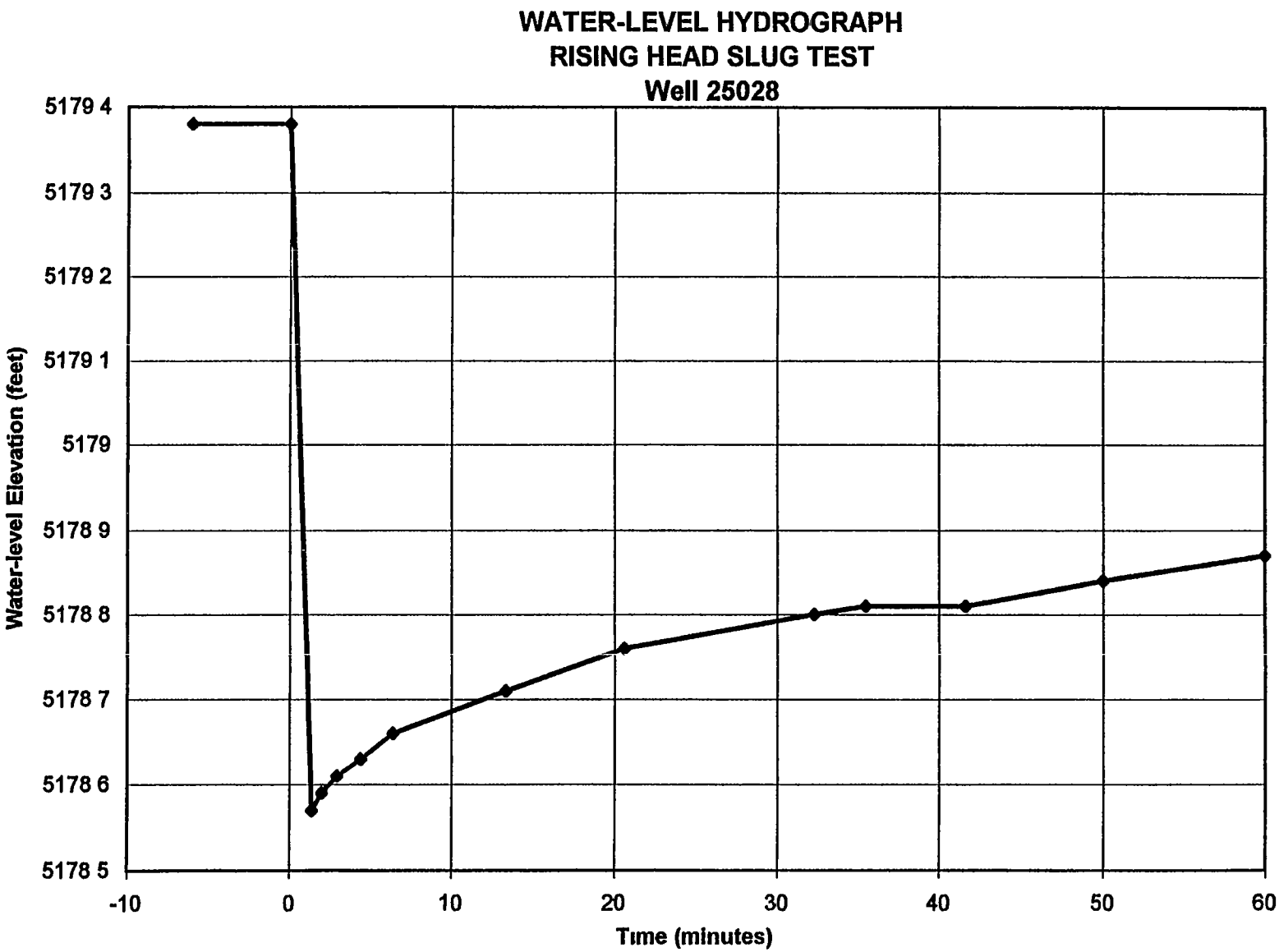

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25028
Water-level Elevation (feet)
5179 4
5179 3
5179 2
5179 1
5179
5178 9
5178 8
5178 7
5178 6
5178 5
-10
0
10
20
30
40
50
60
Time (minutes)

Figure A3.5

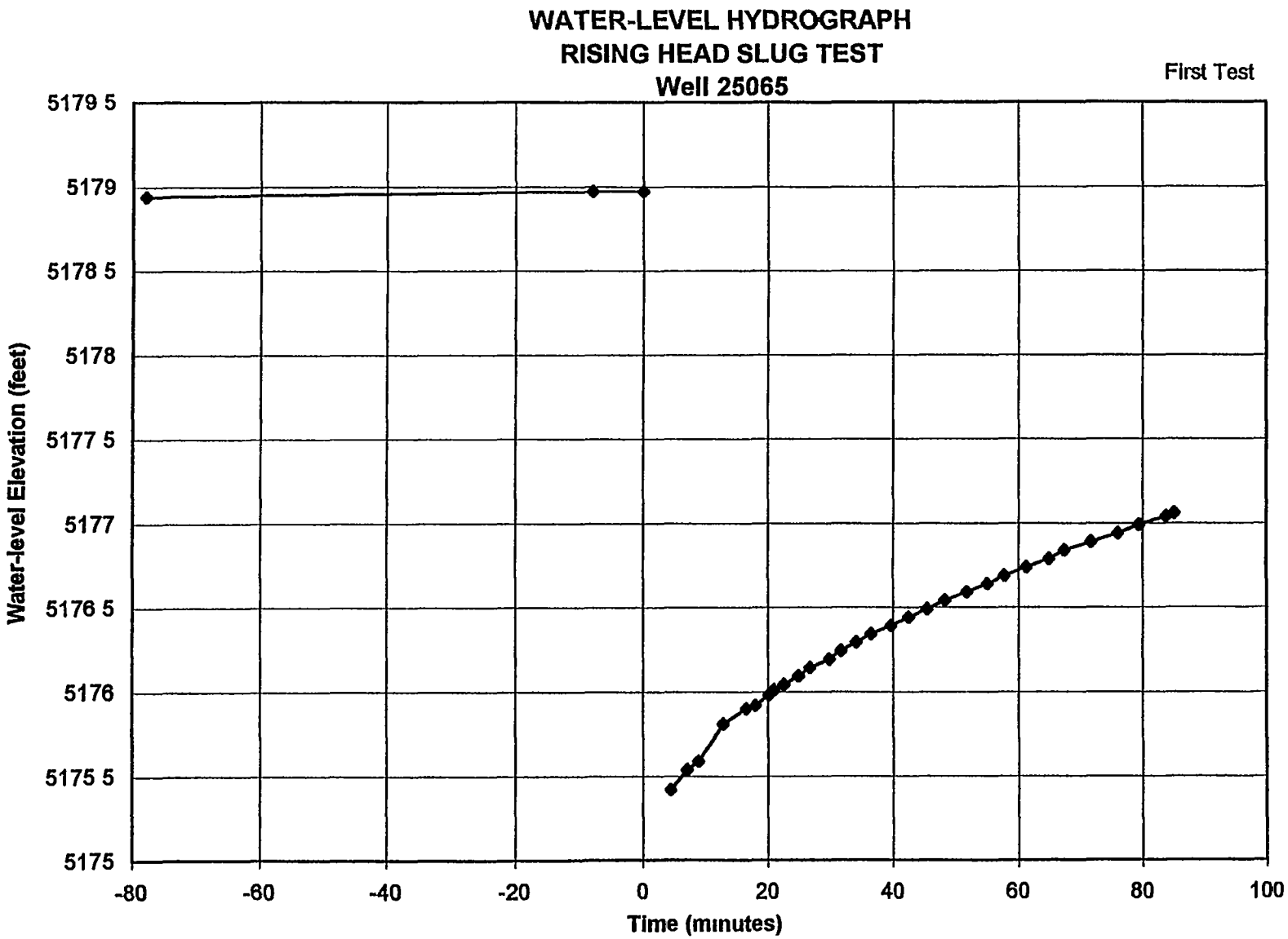

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25065
First Test
Water-level Elevation (feet)
5179 5
5179
5178 5
5178
5177 5
5177
5176 5
5176
5175 5
5175
-80
-60
-40
-20
0
20
40
60
80
100
Time (minutes)

Figure A3.6

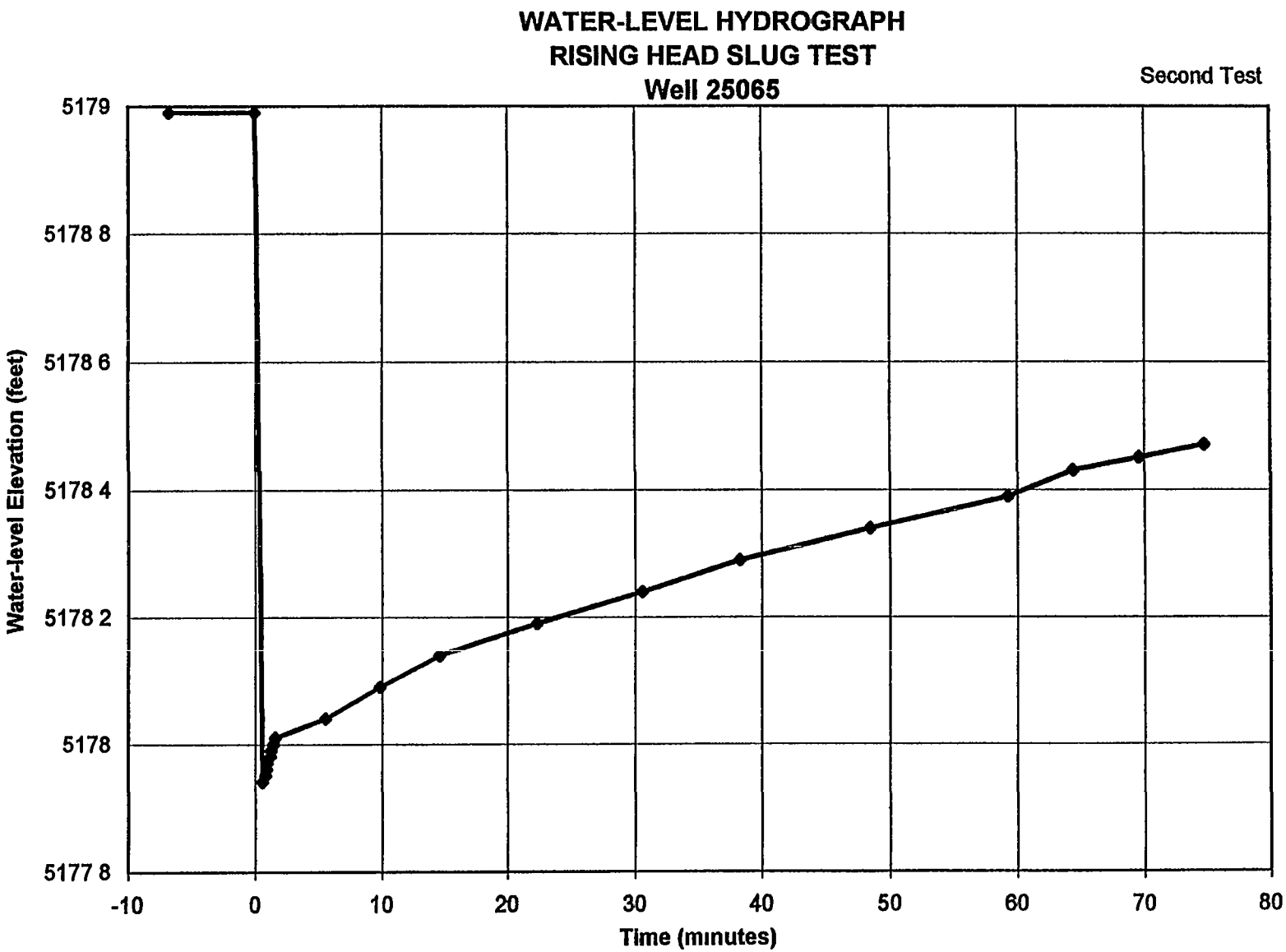

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25065
Second Test
Water-level Elevation (feet)
5179
5178 8
5178 6
5178 4
5178 2
5178
5177 8
-10
0
10
20
30
40
50
60
70
80
Time (minutes)

Figure A3.7

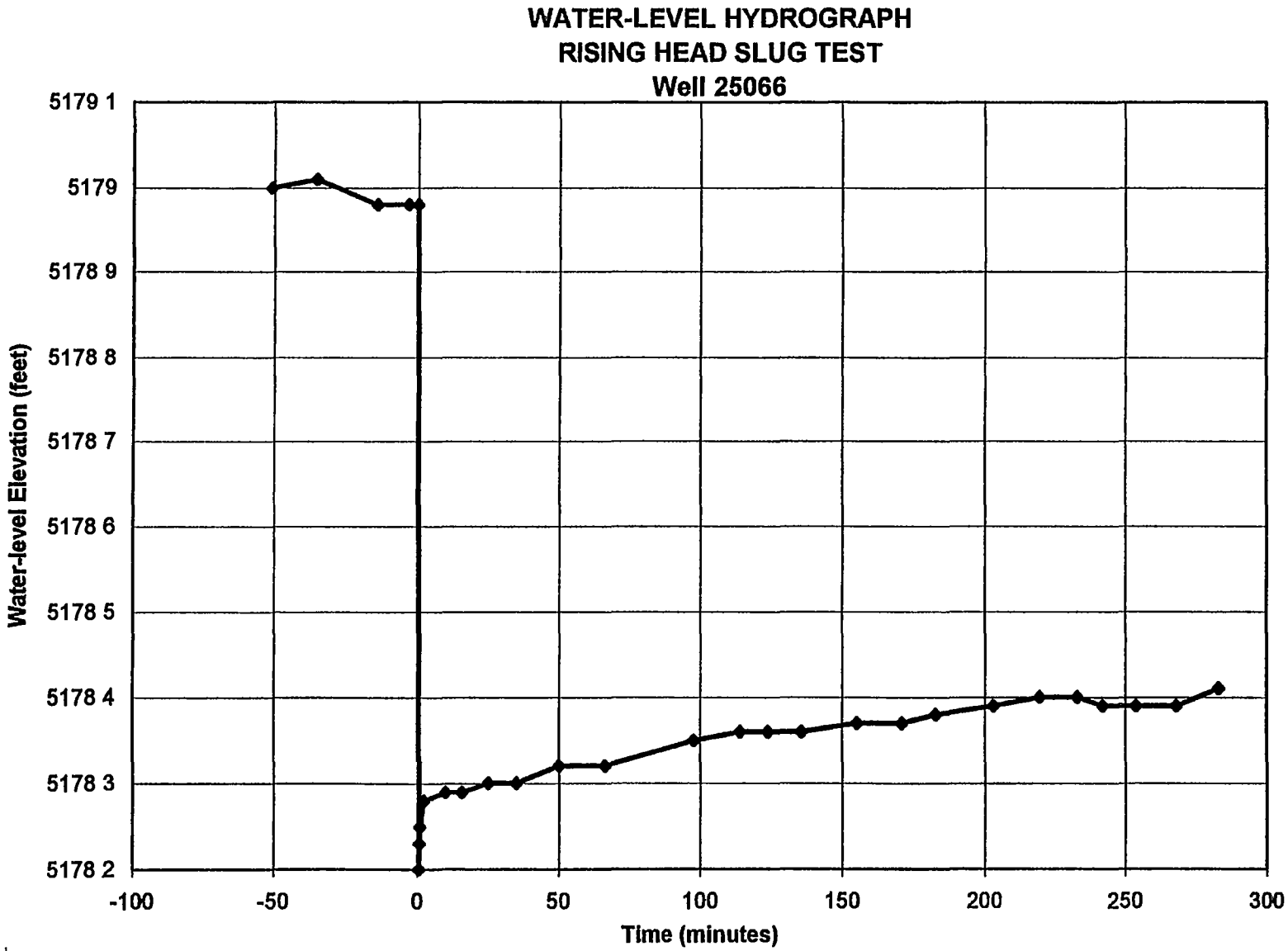
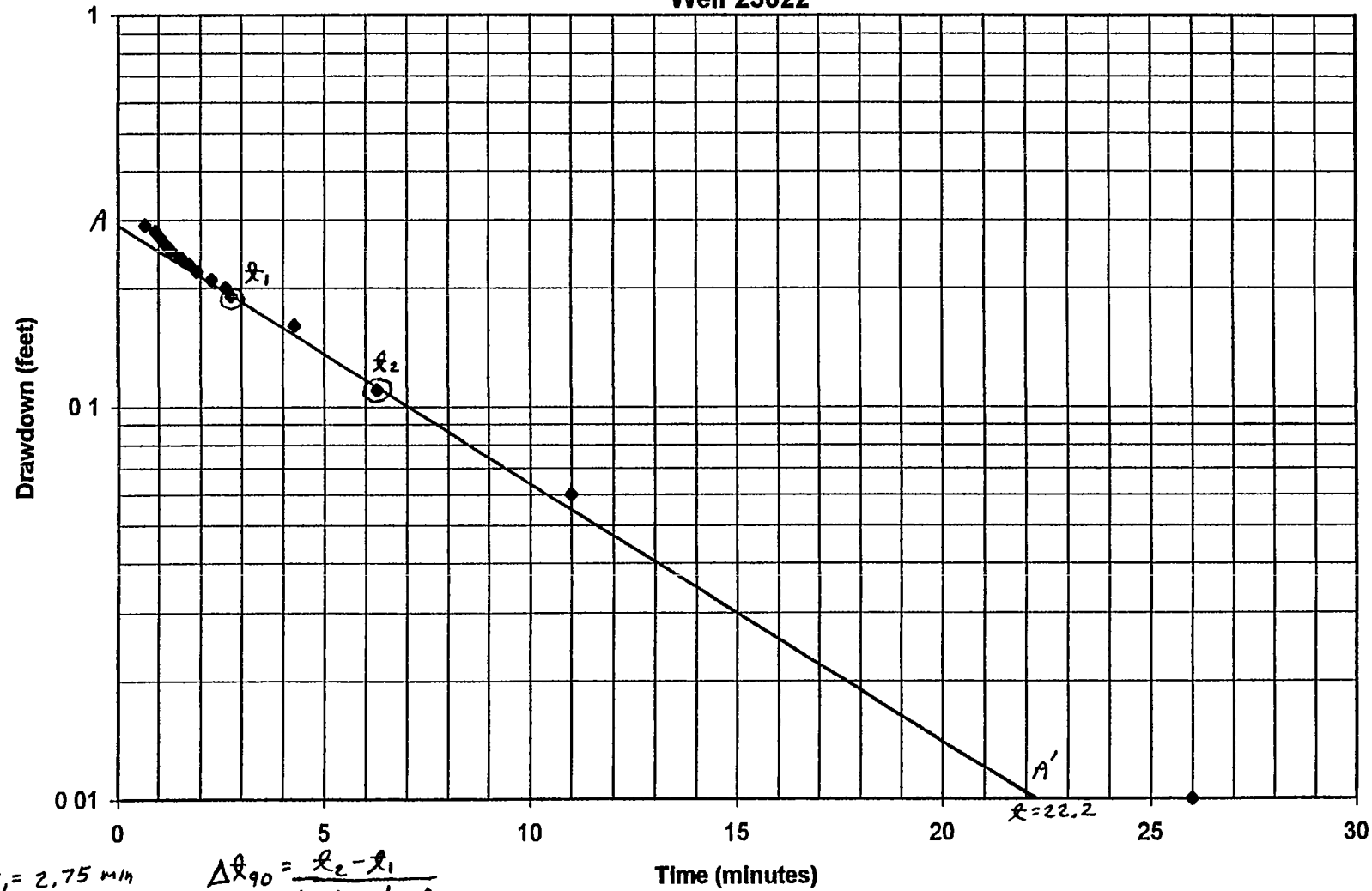

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25066
Water-level Elevation (feet)
5179 1
5179
5178 9
5178 8
5178 7
5178 6
5178 5
5178 4
5178 3
5178 2
-100
-50
0
50
100
150
200
250
300
Time (minutes)

Figure A3.8

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25022



t_1 = 2.75 min
t_2 = 6.28 min
s_1 = 0.19 ft
s_2 = 0.11 ft

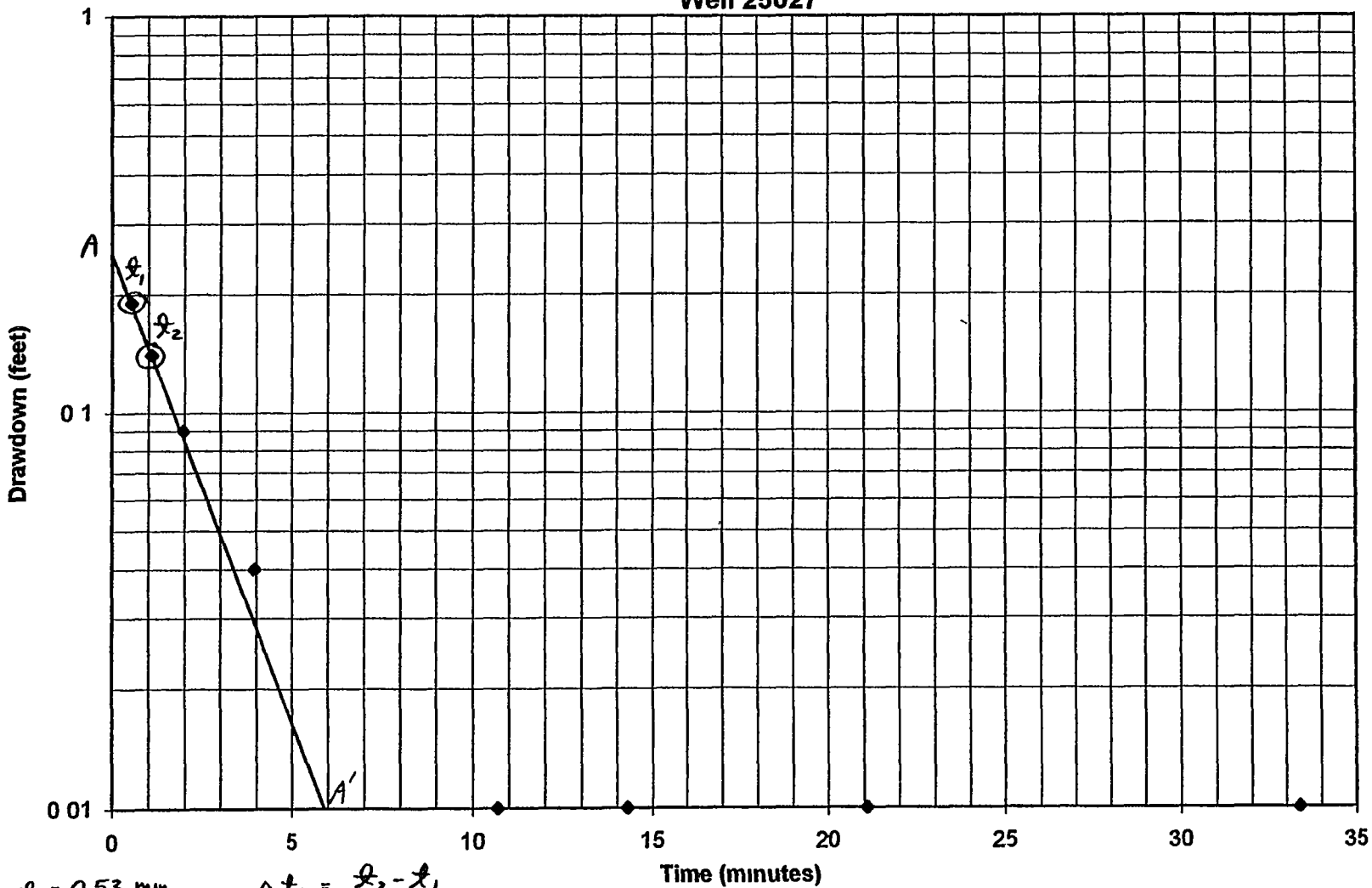
$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

$$\Delta t_{90} = \frac{6.28 - 2.75}{\log 0.19 - \log 0.11}$$

Δt_{90} = 14.87 minutes

Figure A3.9

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25027



$t_1 = 0.53$ min
$t_2 = 1.08$ min
$s_1 = 0.19$ ft
$s_2 = 0.14$ ft

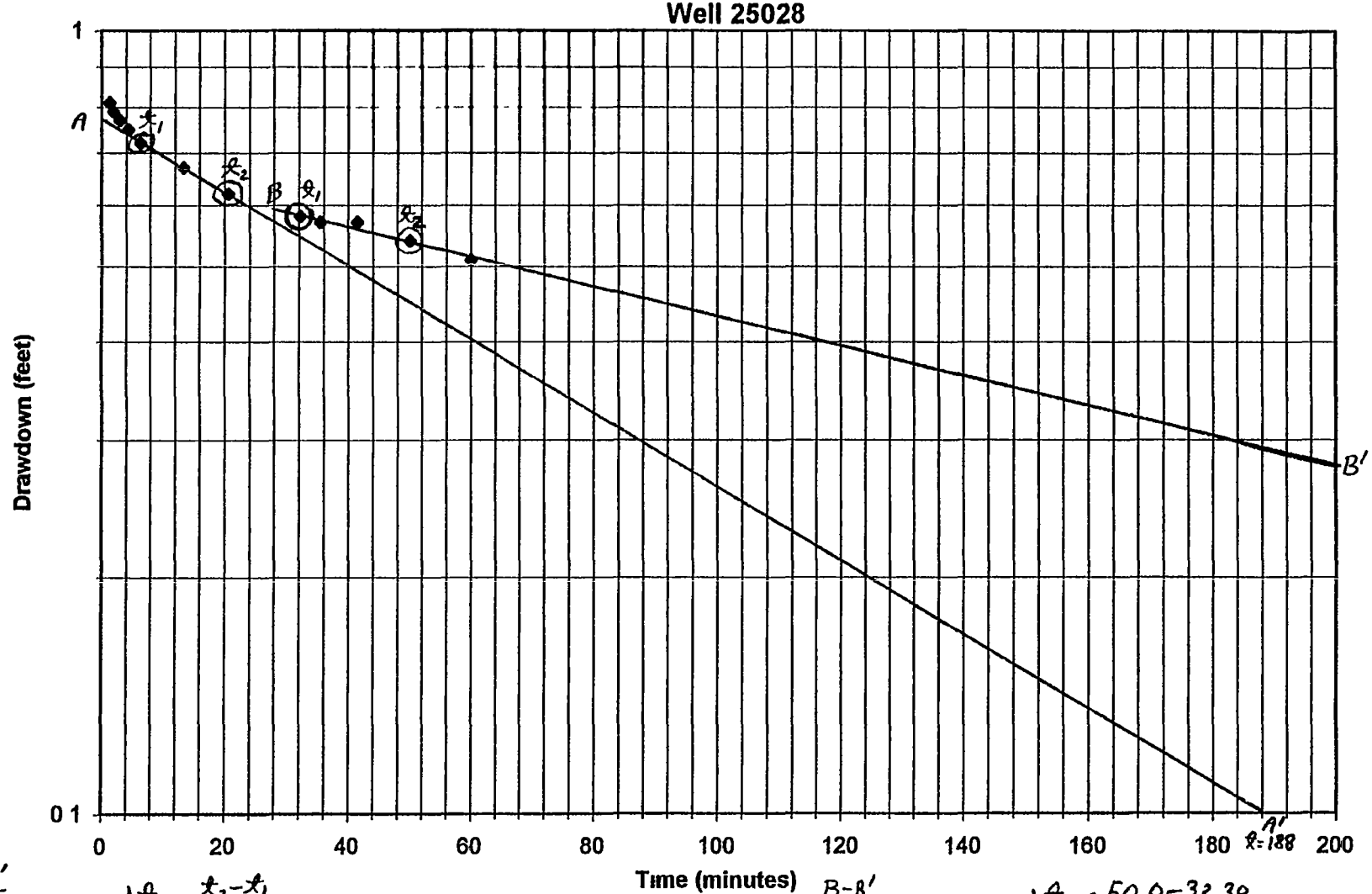
$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

$$\Delta t_{90} = \frac{1.08 - 0.53}{\log 0.19 - \log 0.14}$$

$\Delta t_{90} = 4.15$ minutes

Figure A3.10

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25028



A-A'
$t_1 = 6.35$ min
$t_2 = 20.6$ min
$s_1 = 0.72$ ft
$s_2 = 0.62$ ft

$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

$$\Delta t_{90} = \frac{20.6 - 6.35}{\log 0.72 - \log 0.62}$$

$\Delta t_{90} = 219$ min

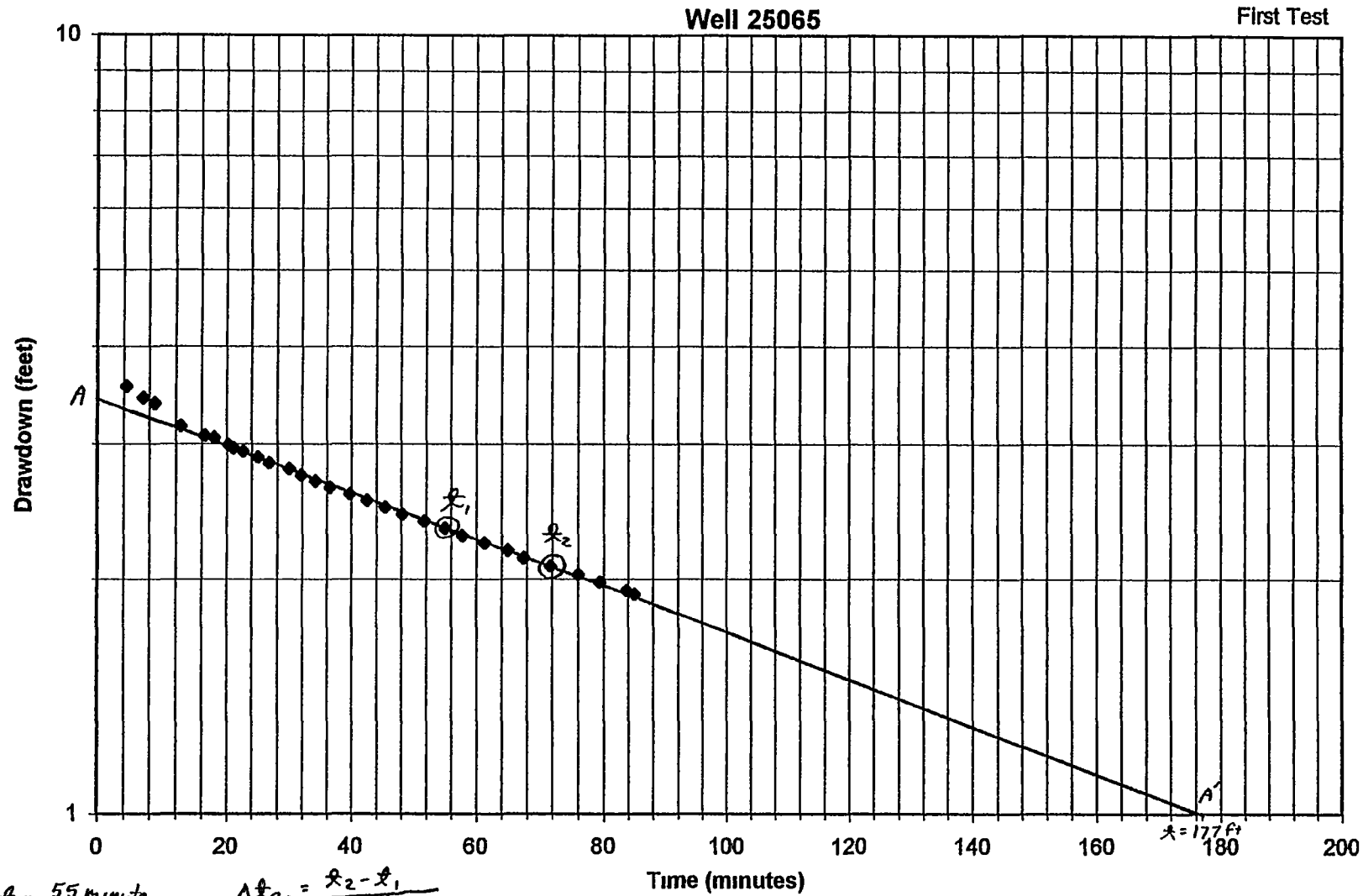
B-B'
$t_1 = 32.30$ min
$t_2 = 50.0$ min
$s_1 = 0.58$ ft
$s_2 = 0.54$ ft

$$\Delta t_{90} = \frac{50.0 - 32.30}{\log 0.58 - \log 0.54}$$

$\Delta t_{90} = 570.34$ min

Figure A3.11

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25065



$t_1 = 55$ minute

$t_2 = 71.7$ minute

$s_1 = 2.33$ ft

$s_2 = 2.08$ ft

$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

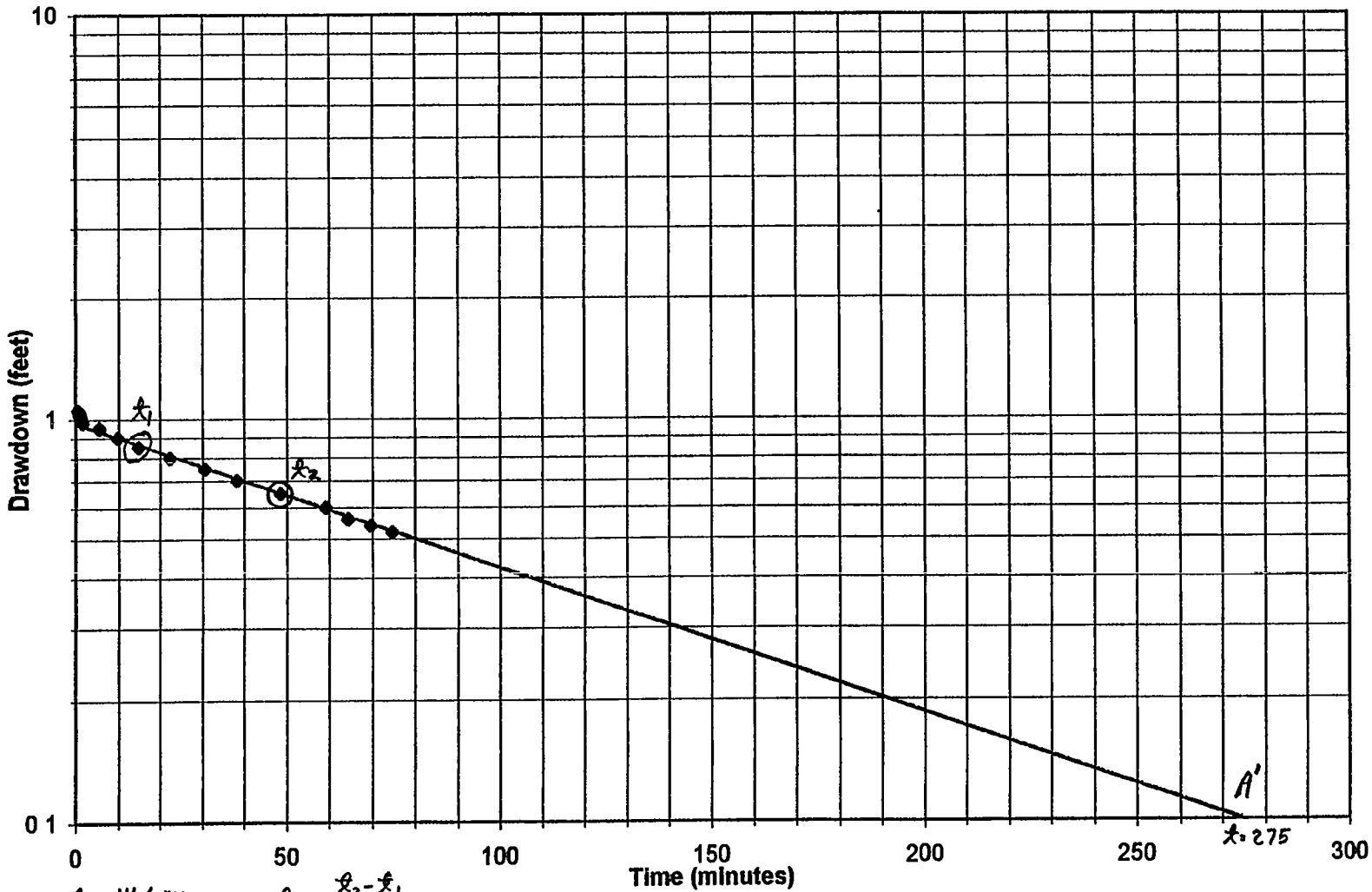
$$\Delta t_{90} = \frac{71.7 - 55}{\log 2.33 - \log 2.08}$$

$$\Delta t_{90} = 338.79 \text{ minutes}$$

Figure A3.12

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25065

Second Test



$t_1 = 14.6$ min
$t_2 = 48.5$ min
$h_1 = 0.85$ ft
$h_2 = 0.65$ ft

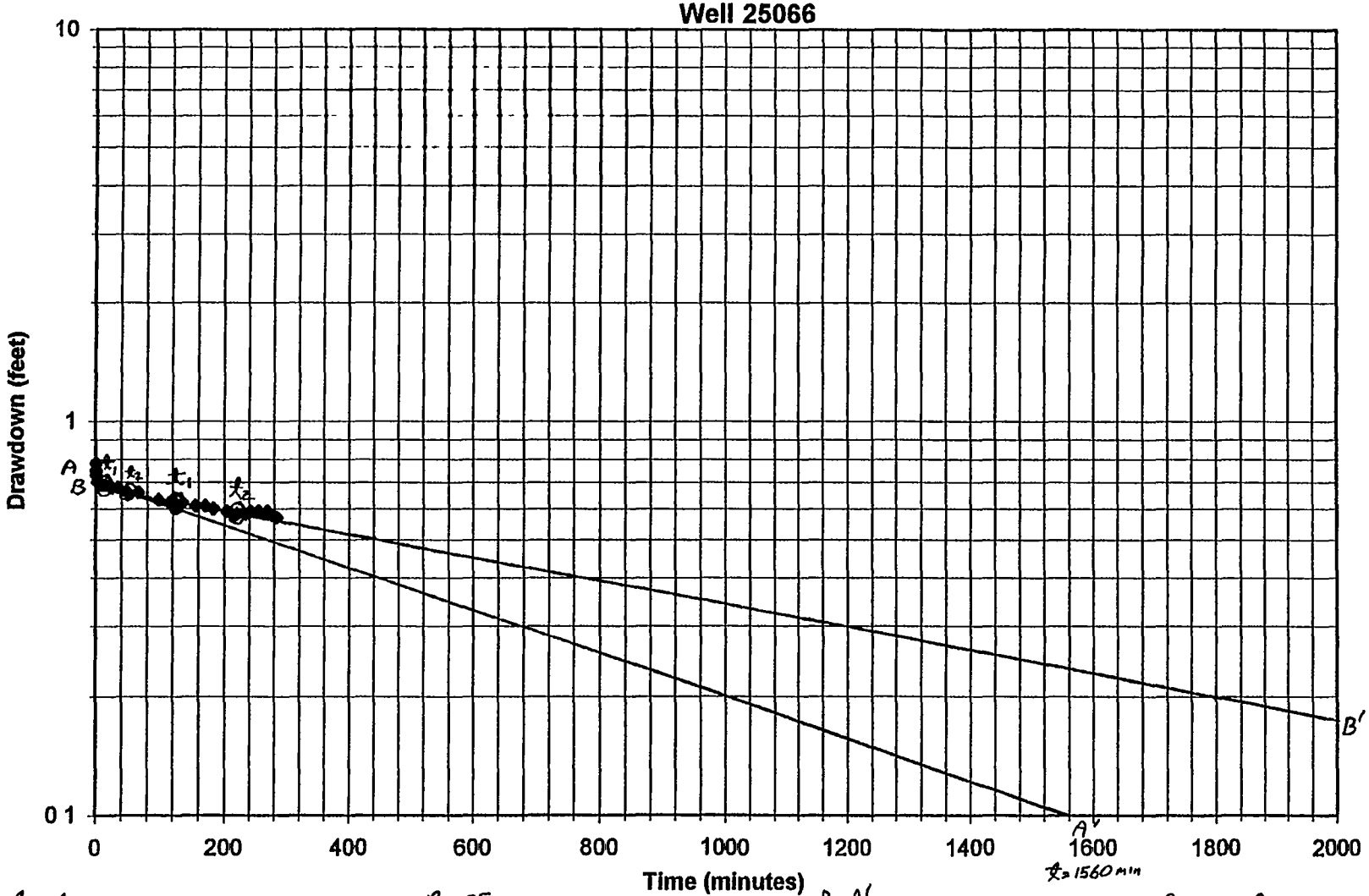
$$\Delta t_{90} = \frac{t_2 - t_1}{\log h_1 - \log h_2}$$

$$\Delta t_{90} = \frac{48.5 - 14.6}{\log 0.85 - \log 0.65}$$

$\Delta t_{90} = 290.97$ minutes

Figure A3.13

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25066



A-A'

$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2} = \frac{50-25}{\log 0.68 - \log 0.66}$$

Δt_{90} = 1928.27 minutes

t_1 = 25 min
t_2 = 50 min
s_1 = 0.68 ft
s_2 = 0.66 ft

B-B'

$$\Delta t_{90} = \frac{219.5 - 123.9}{\log 0.62 - \log 0.58}$$

Δt_{90} = 3300.68 minutes

t_1 = 123.9 min
t_2 = 219.5 min
s_1 = 0.62 ft
s_2 = 0.58 ft

Figure A3.14

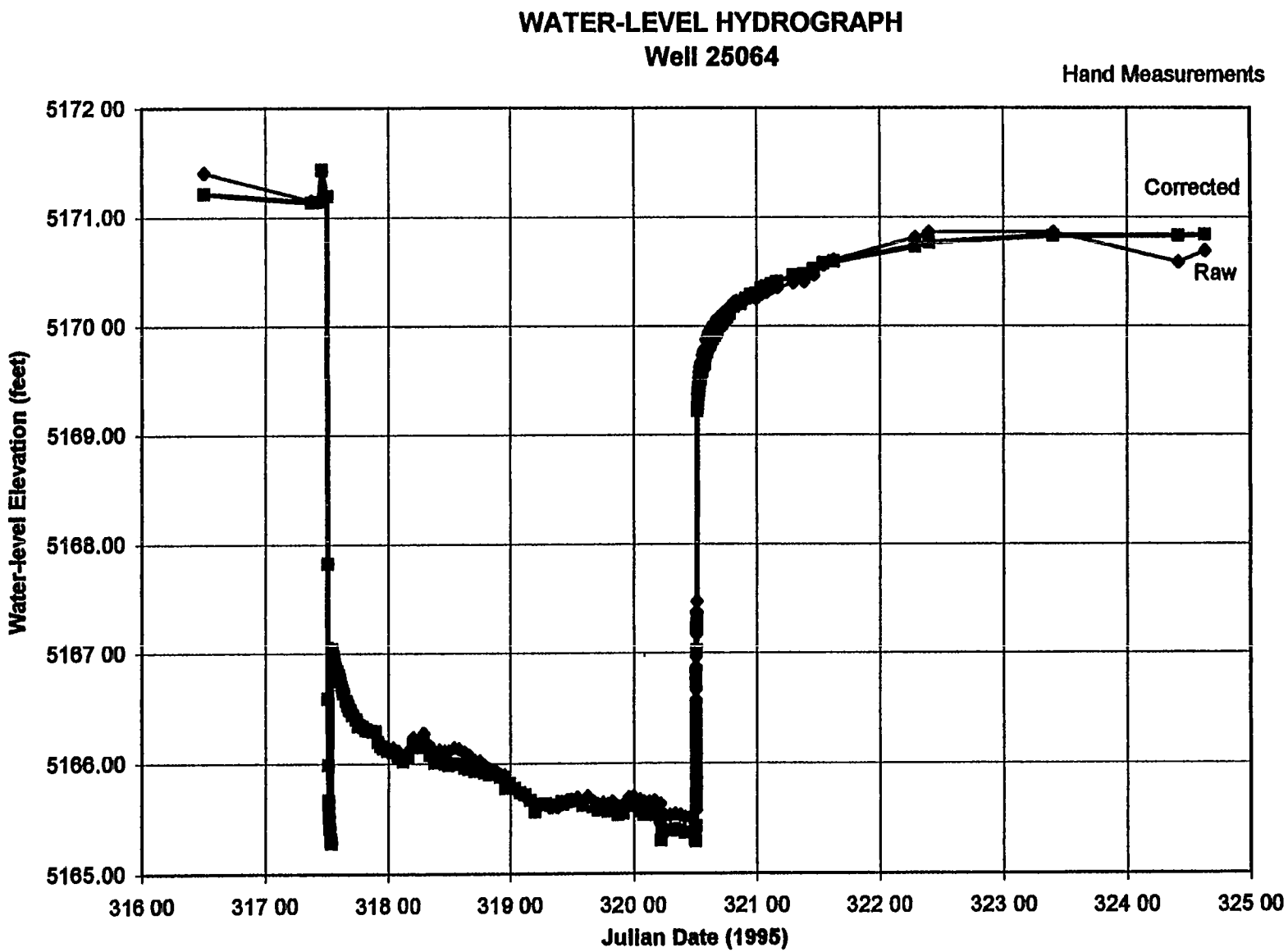

WATER-LEVEL HYDROGRAPH
Well 25064
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171.00
5170 00
5169.00
5168.00
5167 00
5166.00
5165.00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.15

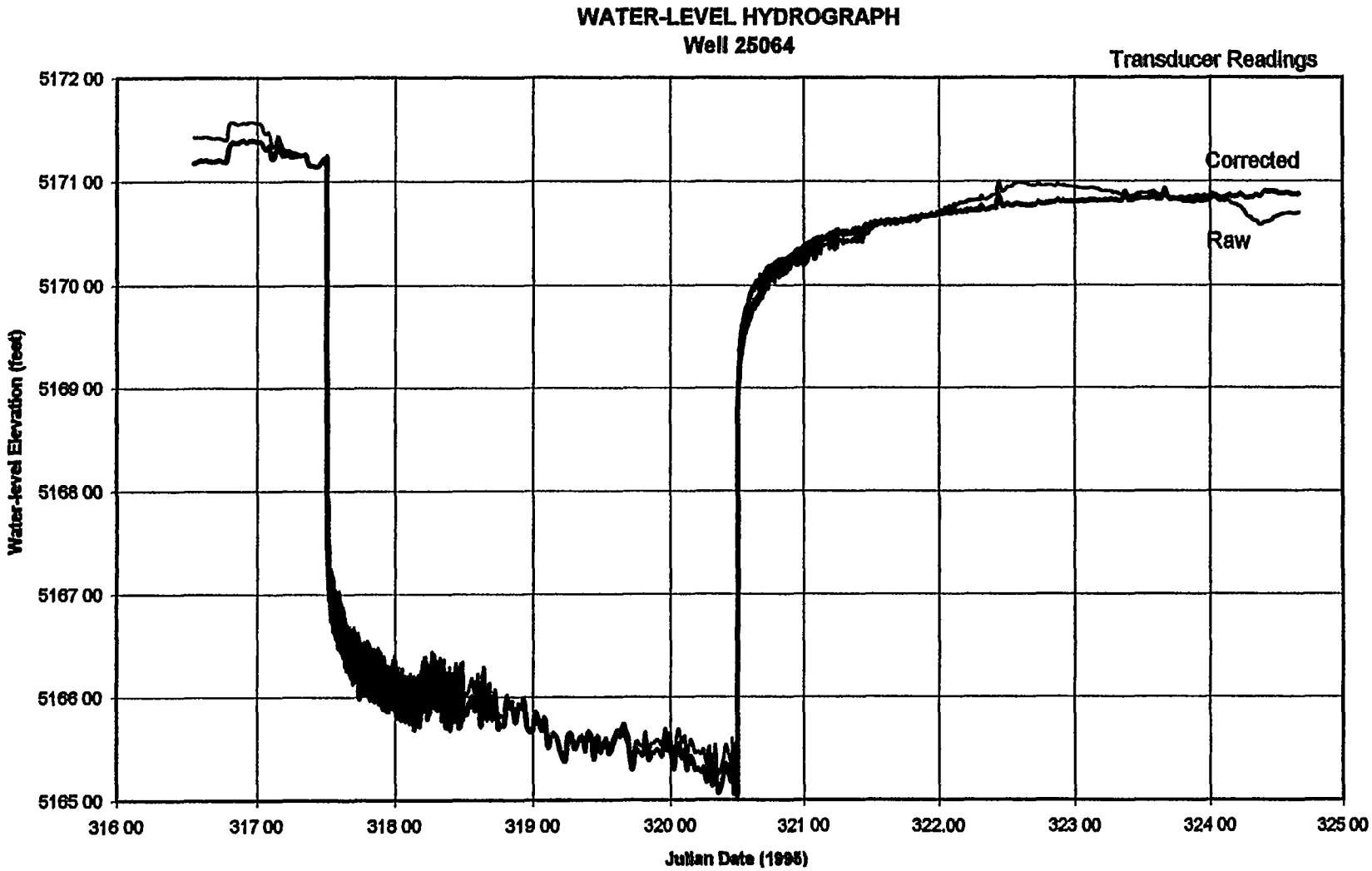

WATER-LEVEL HYDROGRAPH
Well 25064
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 00
5170 00
5169 00
5168 00
5167 00
5166 00
5165 00
316 00
317 00
318 00
319 00
320 00
321 00
322.00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.16

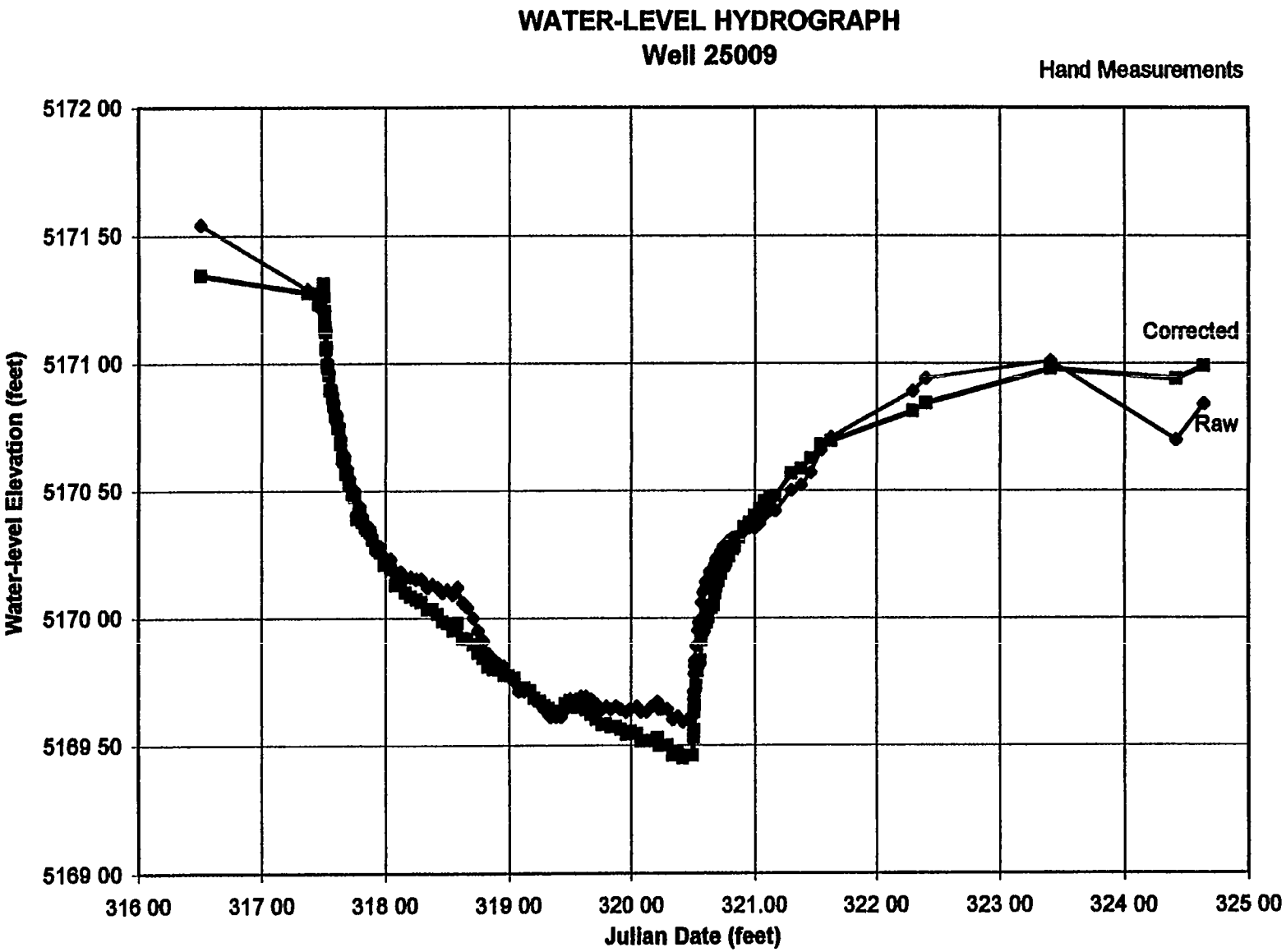

WATER-LEVEL HYDROGRAPH
Well 25009
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 50
5171 00
5170 50
5170 00
5169 50
5169 00
316 00
317 00
318 00
319 00
320 00
321.00
322 00
323 00
324 00
325 00
Julian Date (feet)

Figure A3.17

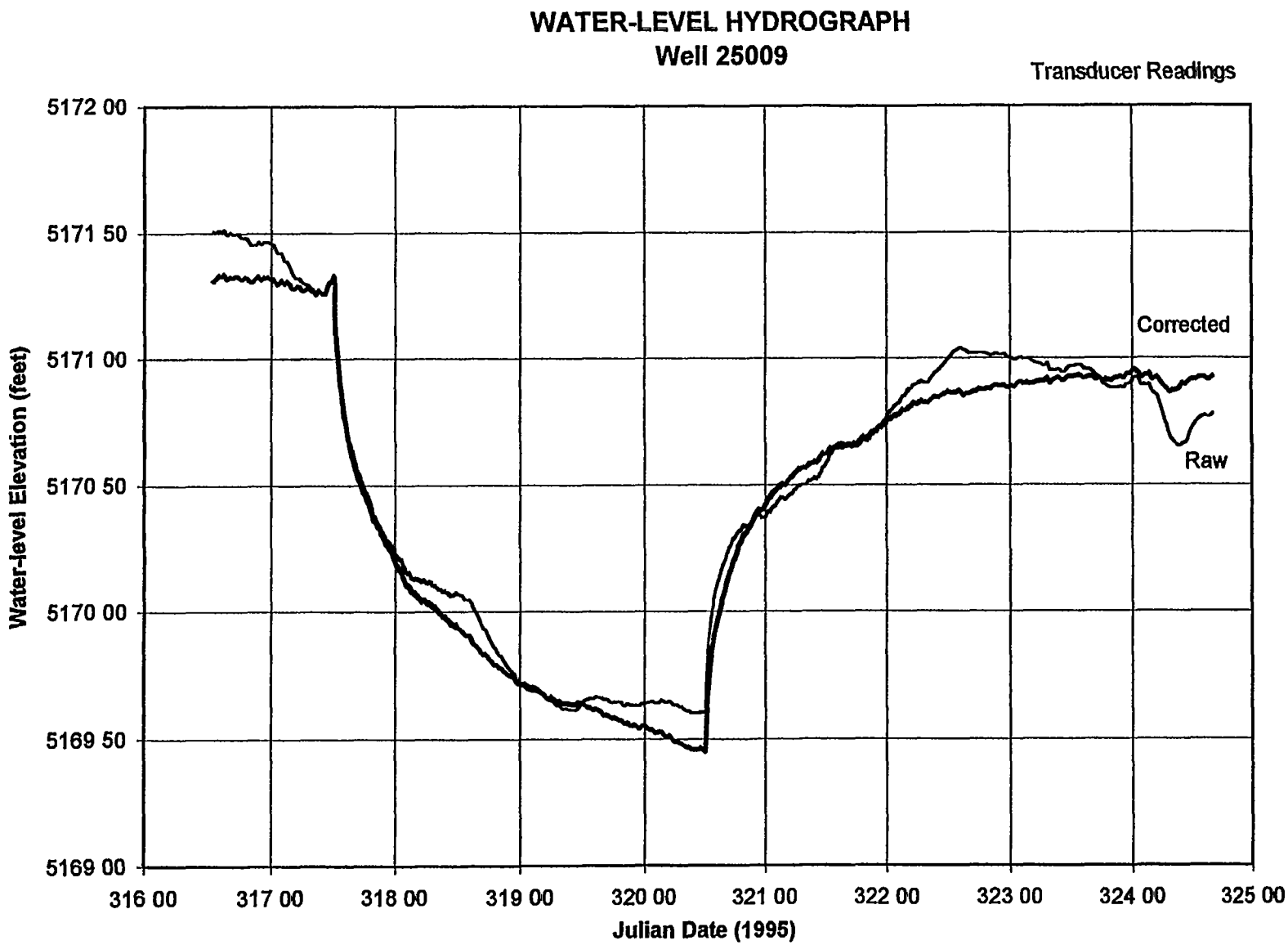

WATER-LEVEL HYDROGRAPH
Well 25009
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 50
5171 00
5170 50
5170 00
5169 50
5169 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.18

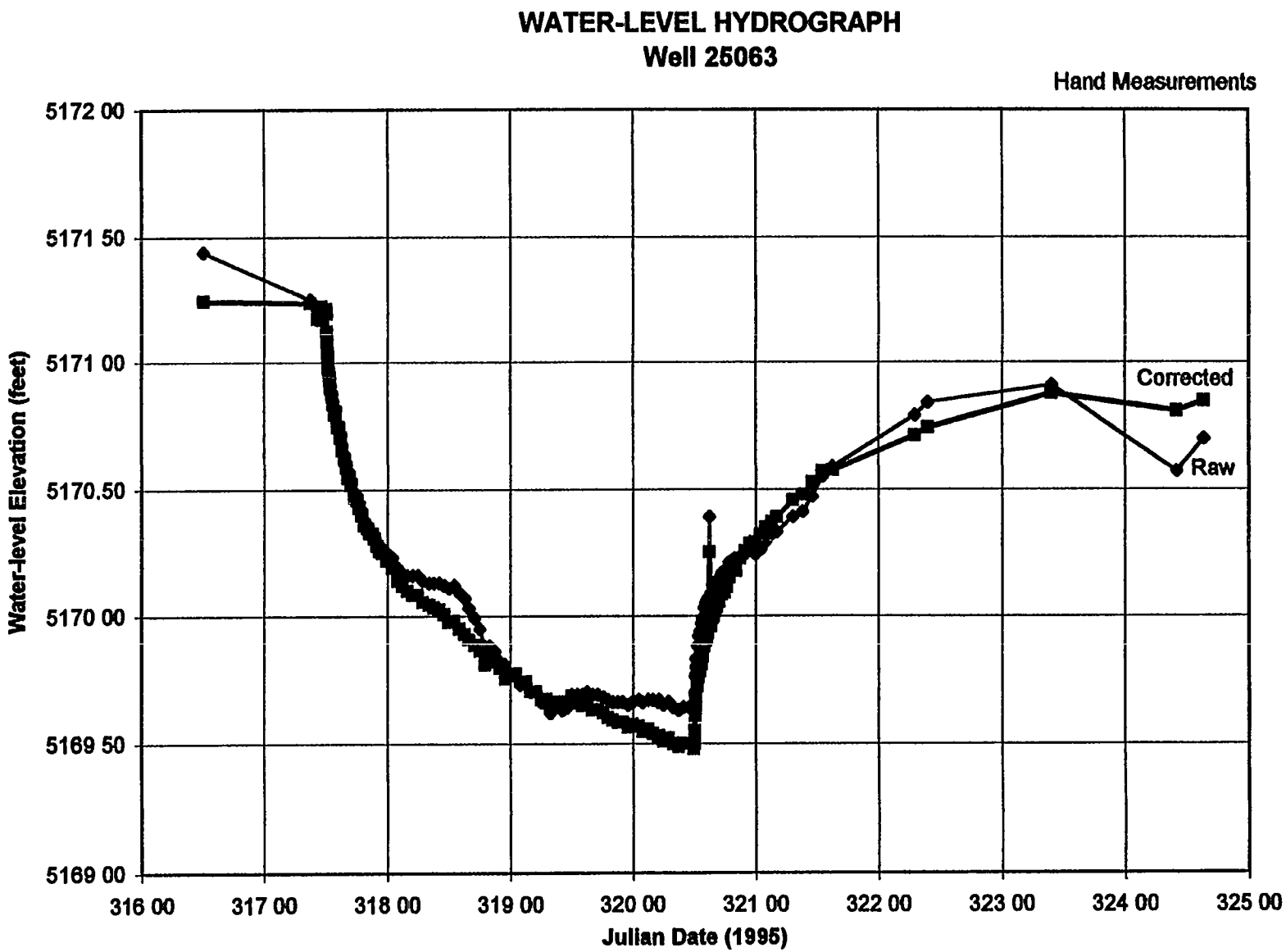

WATER-LEVEL HYDROGRAPH
Well 25063
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 50
5171 00
5170.50
5170 00
5169 50
5169 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.19

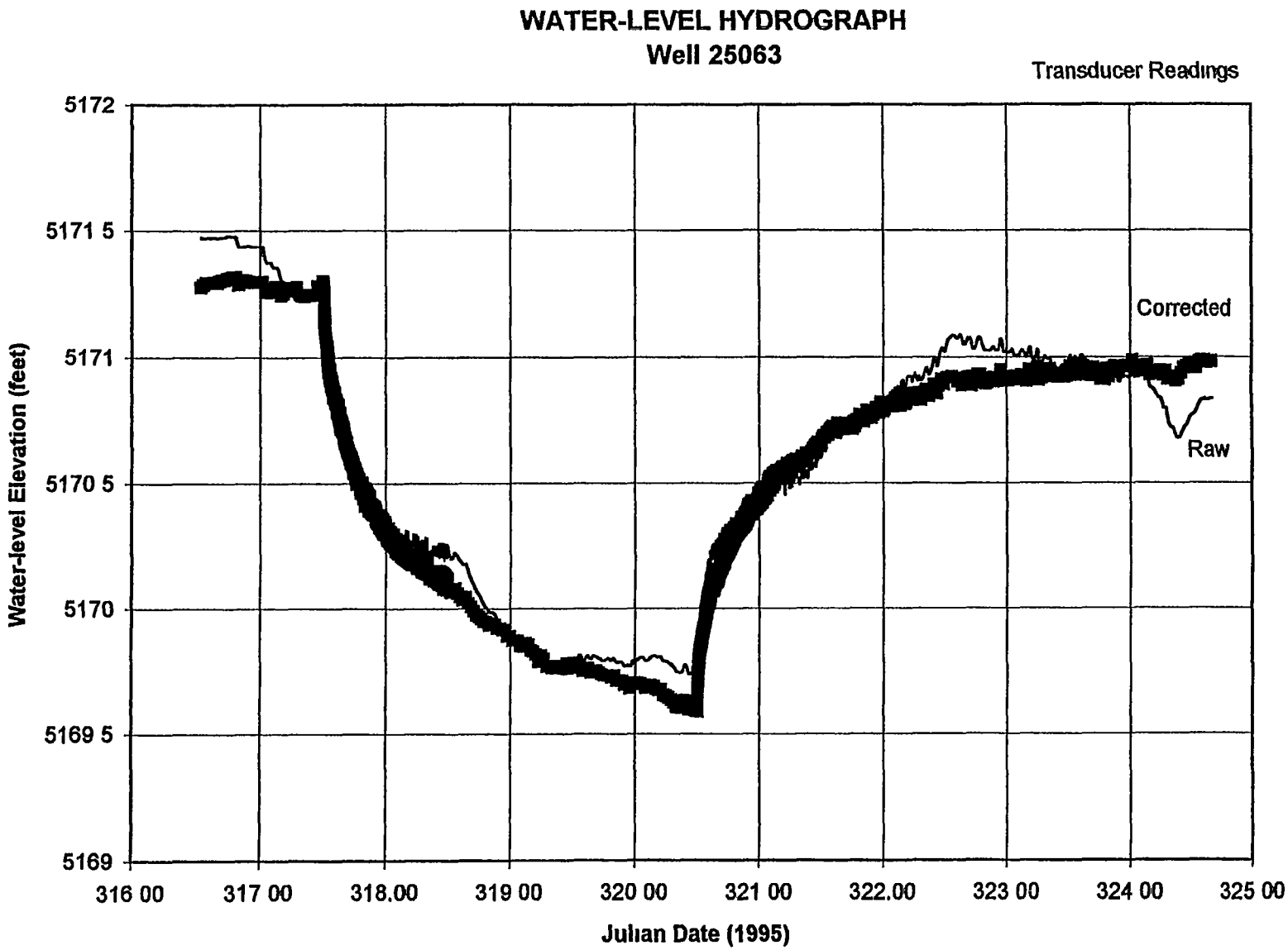

WATER-LEVEL HYDROGRAPH
Well 25063
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5172
5171 5
5171
5170 5
5170
5169 5
5169
316 00
317 00
318.00
319 00
320 00
321 00
322.00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.20

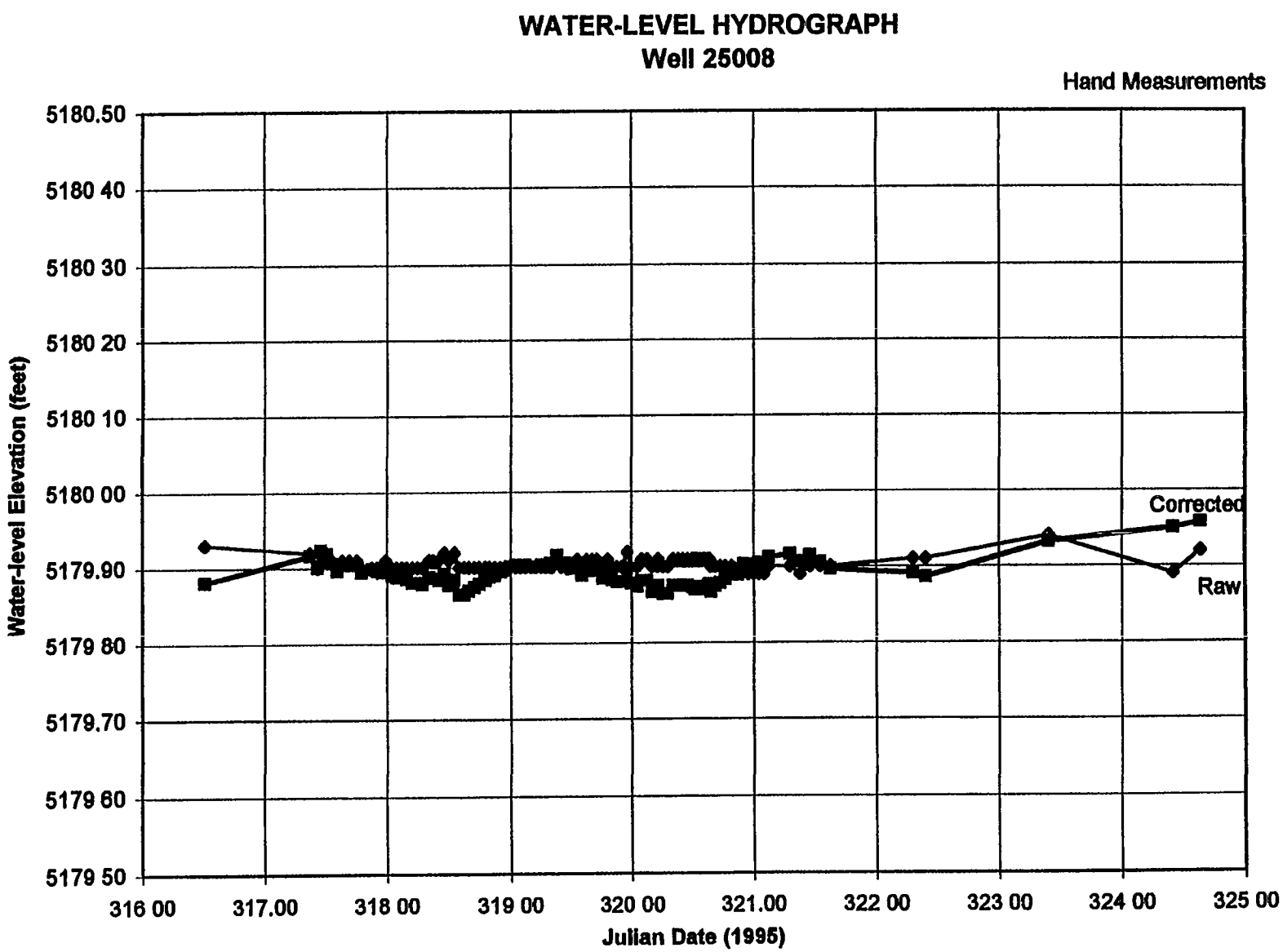

WATER-LEVEL HYDROGRAPH
Well 25008
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5180.50
5180 40
5180 30
5180 20
5180 10
5180 00
5179.90
5179 80
5179.70
5179 60
5179 50
316 00
317.00
318 00
319 00
320 00
321.00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.21

WATER-LEVEL HYDROGRAPH
Well 25008

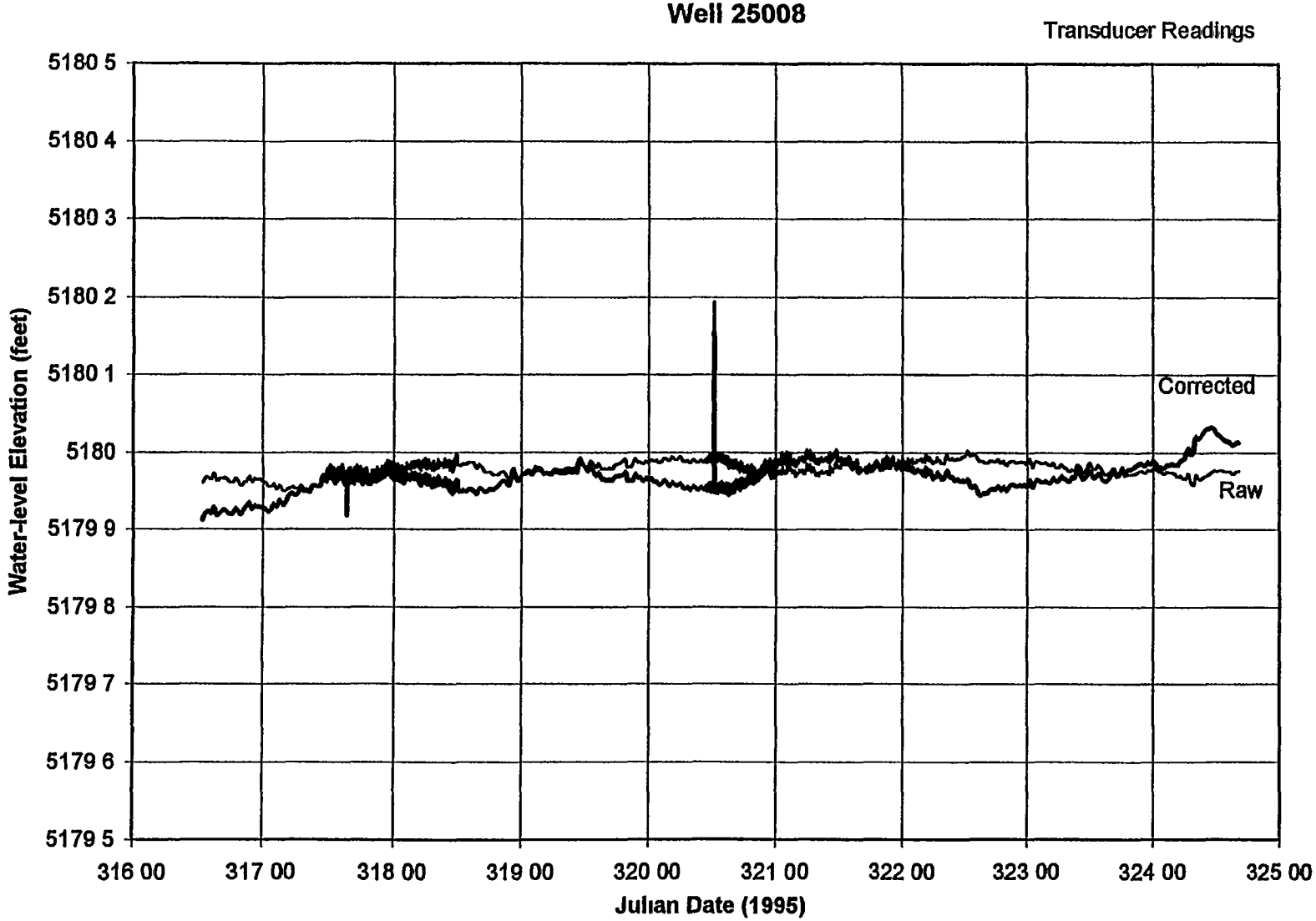


Figure A3.22

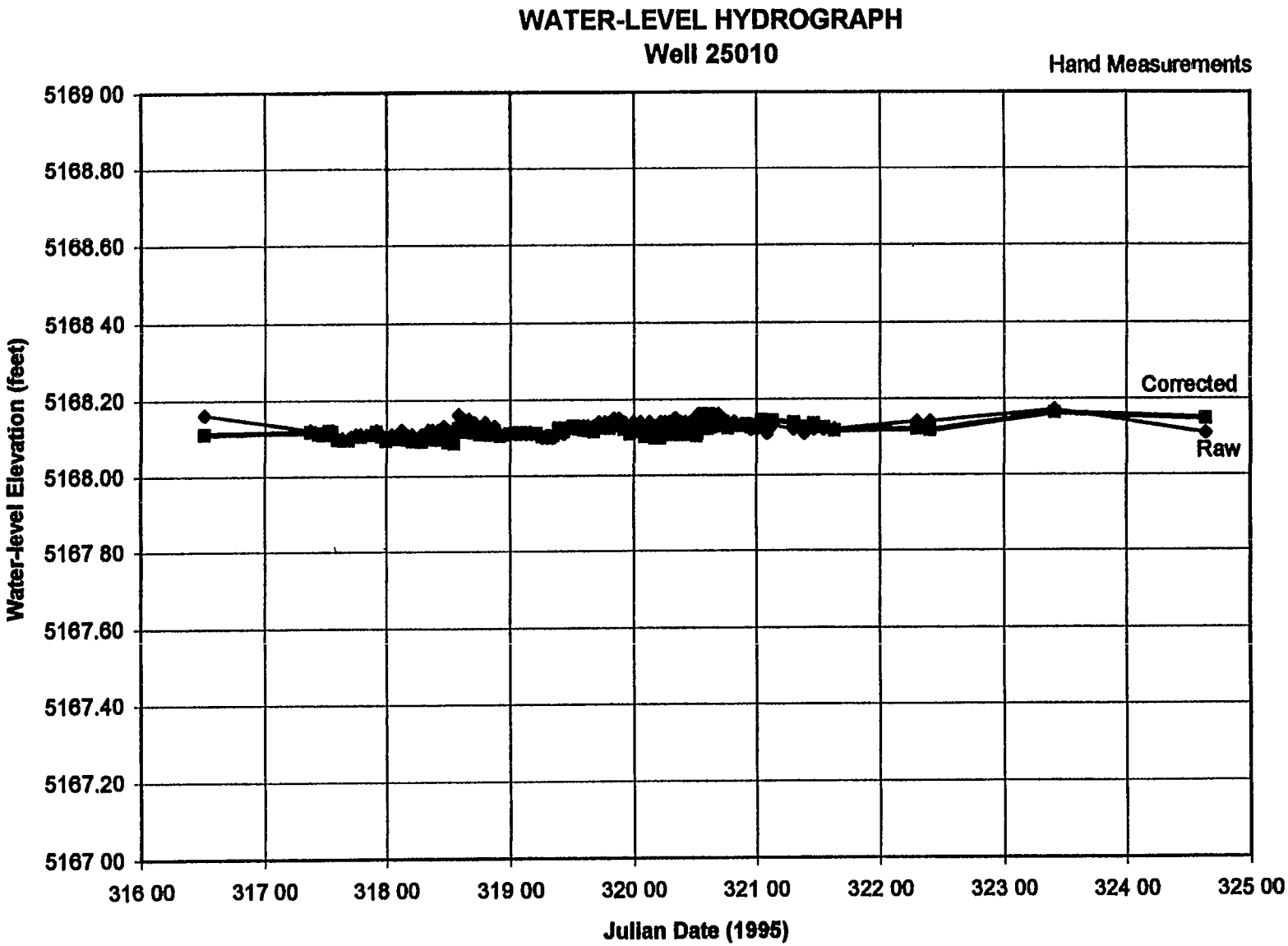

WATER-LEVEL HYDROGRAPH
Well 25010
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5169 00
5168.80
5168.60
5168 40
5168.20
5168.00
5167 80
5167.60
5167.40
5167.20
5167 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.23

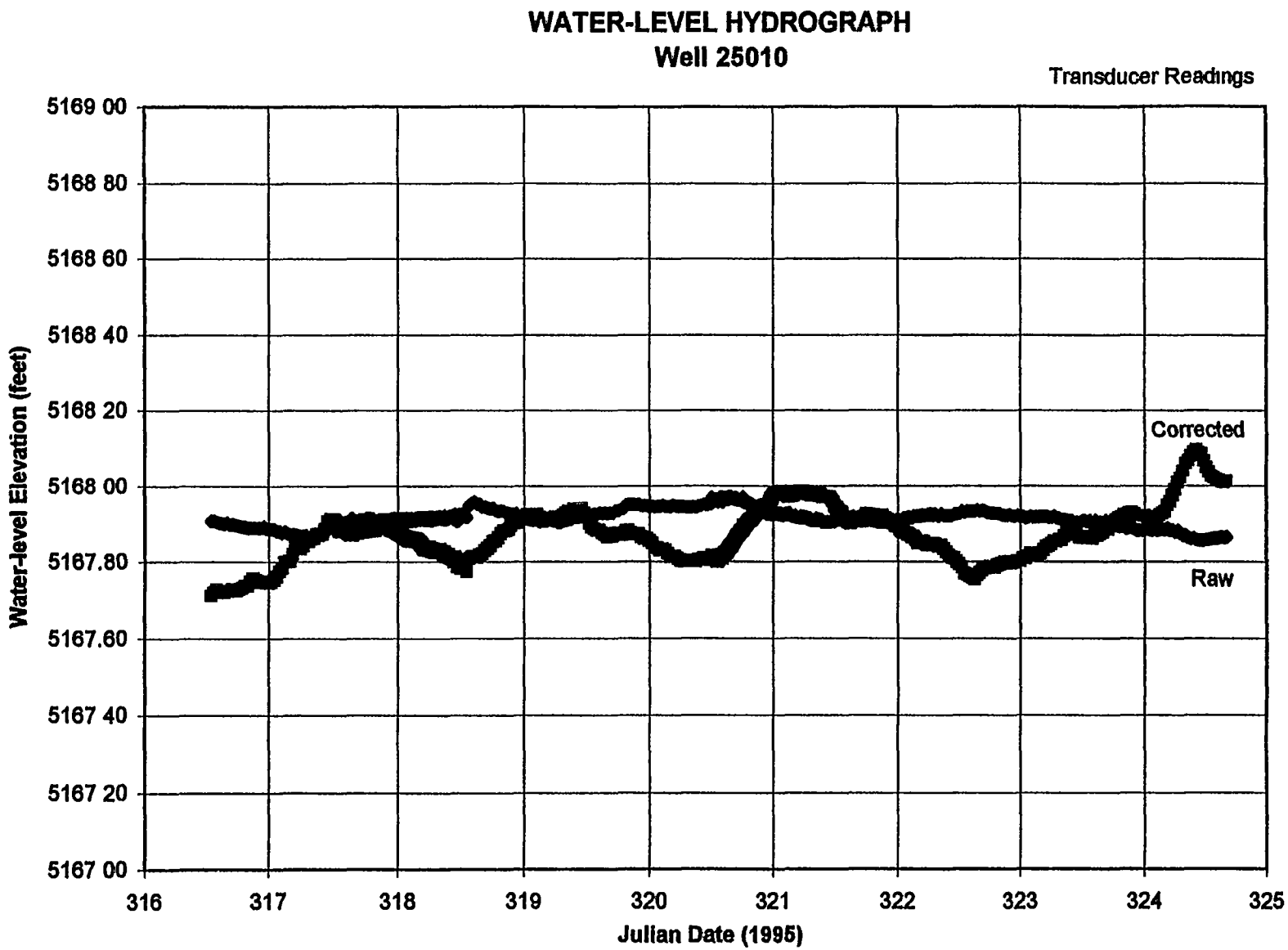

WATER-LEVEL HYDROGRAPH
Well 25010
Transducer Readings
Water-level Elevation (feet)
5169 00
5168 80
5168 60
5168 40
5168 20
5168 00
5167.80
5167.60
5167 40
5167 20
5167 00
316
317
318
319
320
321
322
323
324
325
Julian Date (1995)
Corrected
Raw

Figure A3.24

WATER-LEVEL HYDROGRAPH
Well 25026

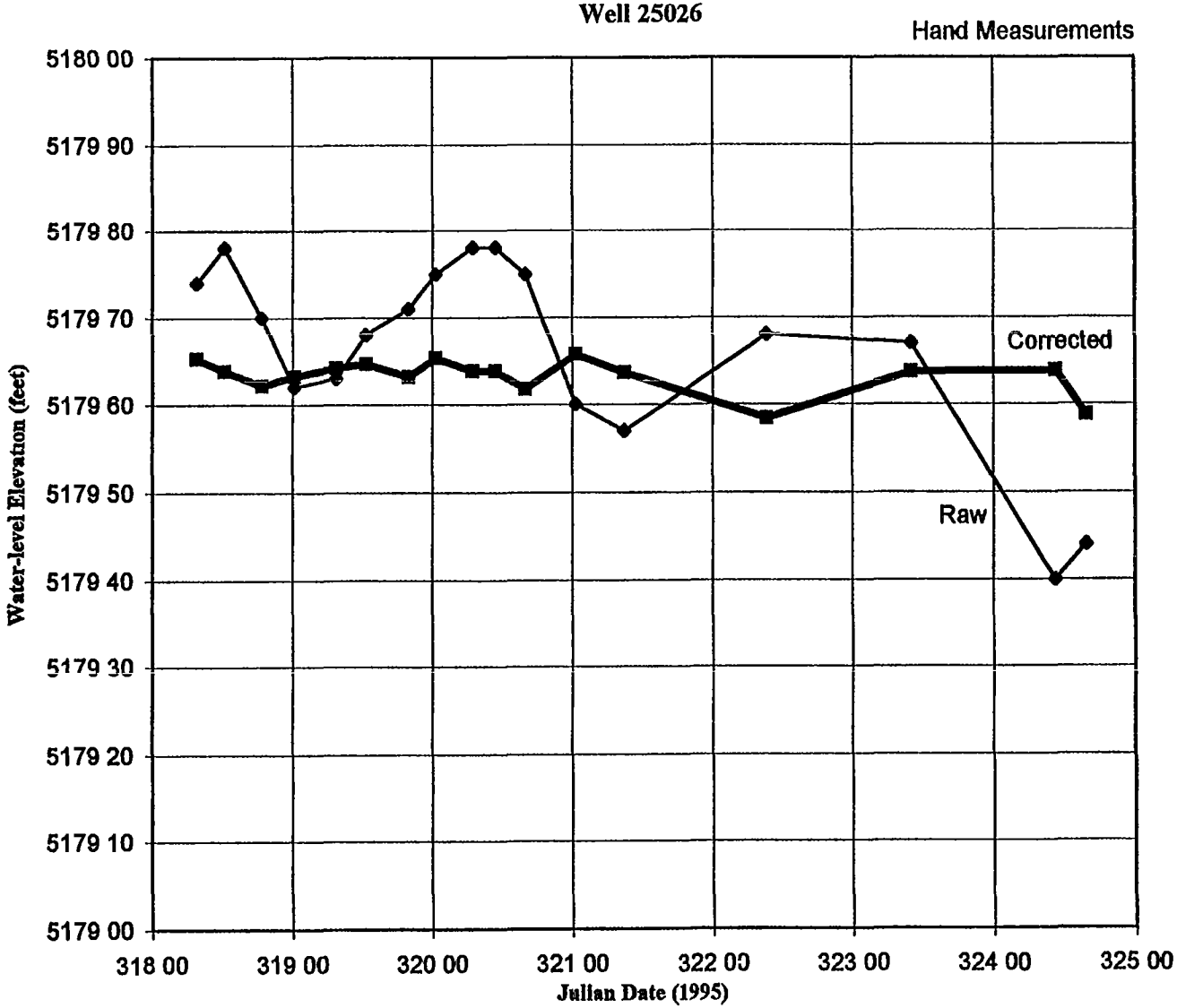


Figure A3.25

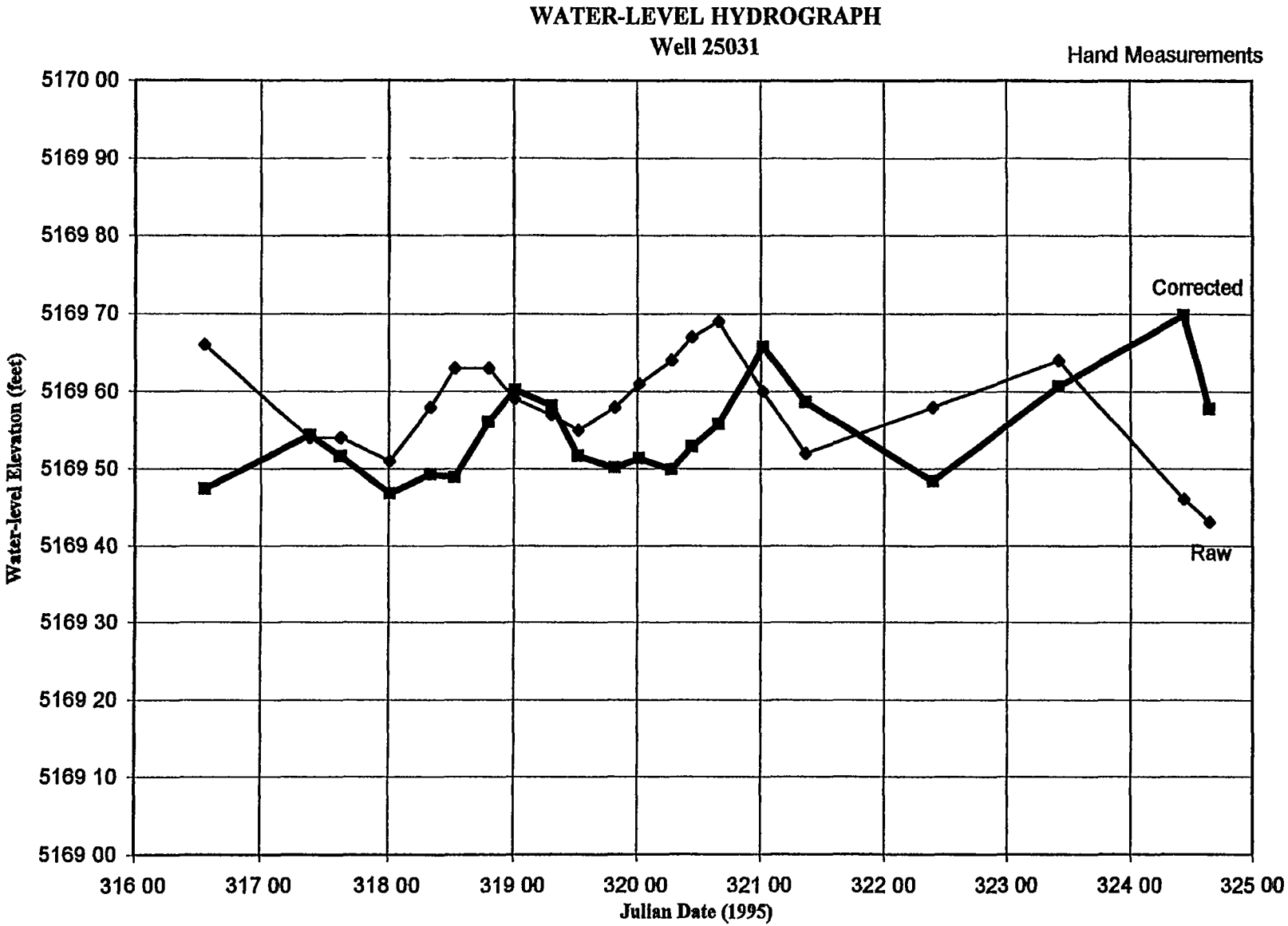

WATER-LEVEL HYDROGRAPH
Well 25031
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5170 00
5169 90
5169 80
5169 70
5169 60
5169 50
5169 40
5169 30
5169 20
5169 10
5169 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.26

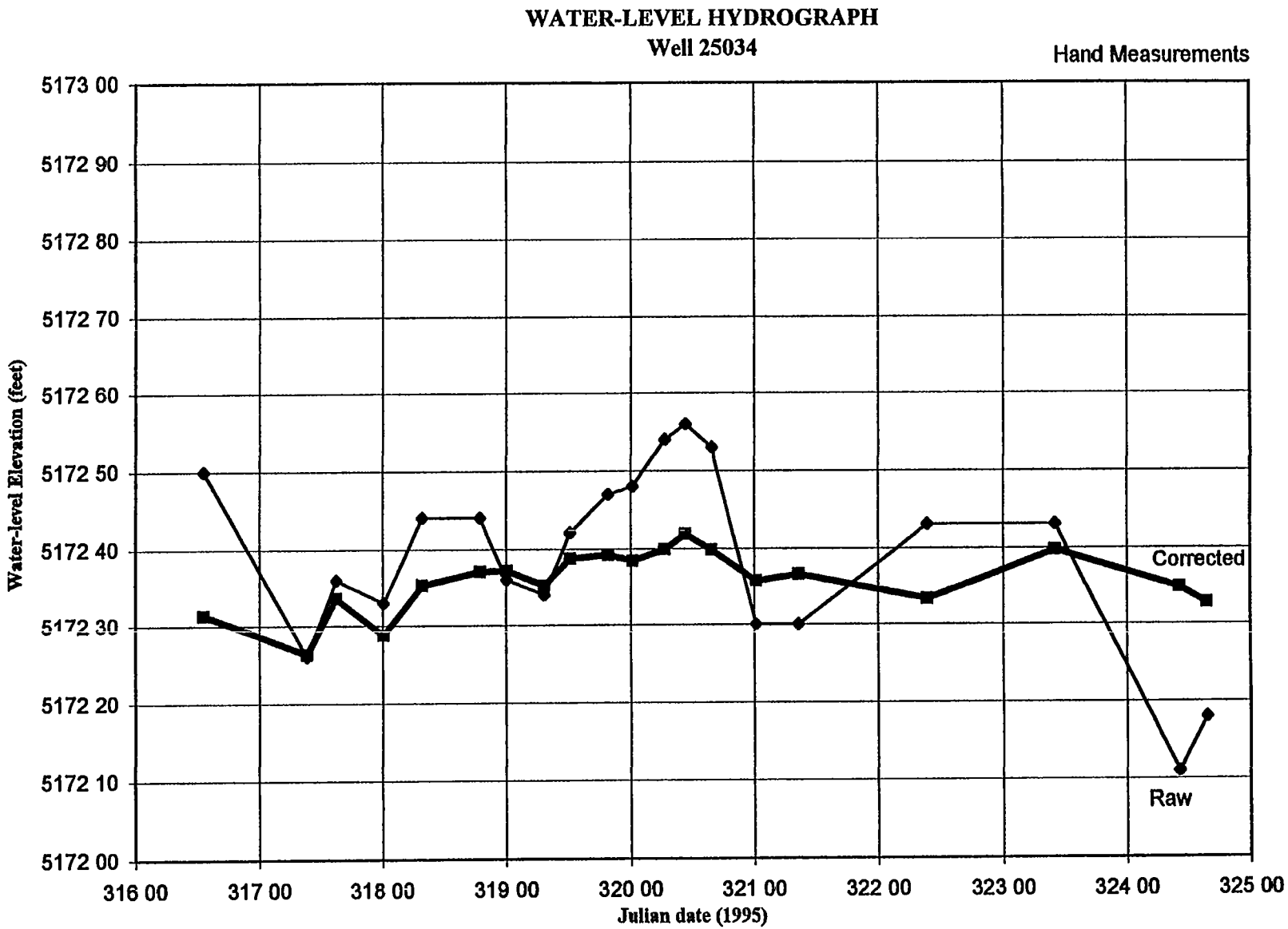

WATER-LEVEL HYDROGRAPH
Well 25034
Hand Measurements
Water-level Elevation (feet)
5173 00
5172 90
5172 80
5172 70
5172 60
5172 50
5172 40
5172 30
5172 20
5172 10
5172 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian date (1995)
Corrected
Raw

Figure A3.27

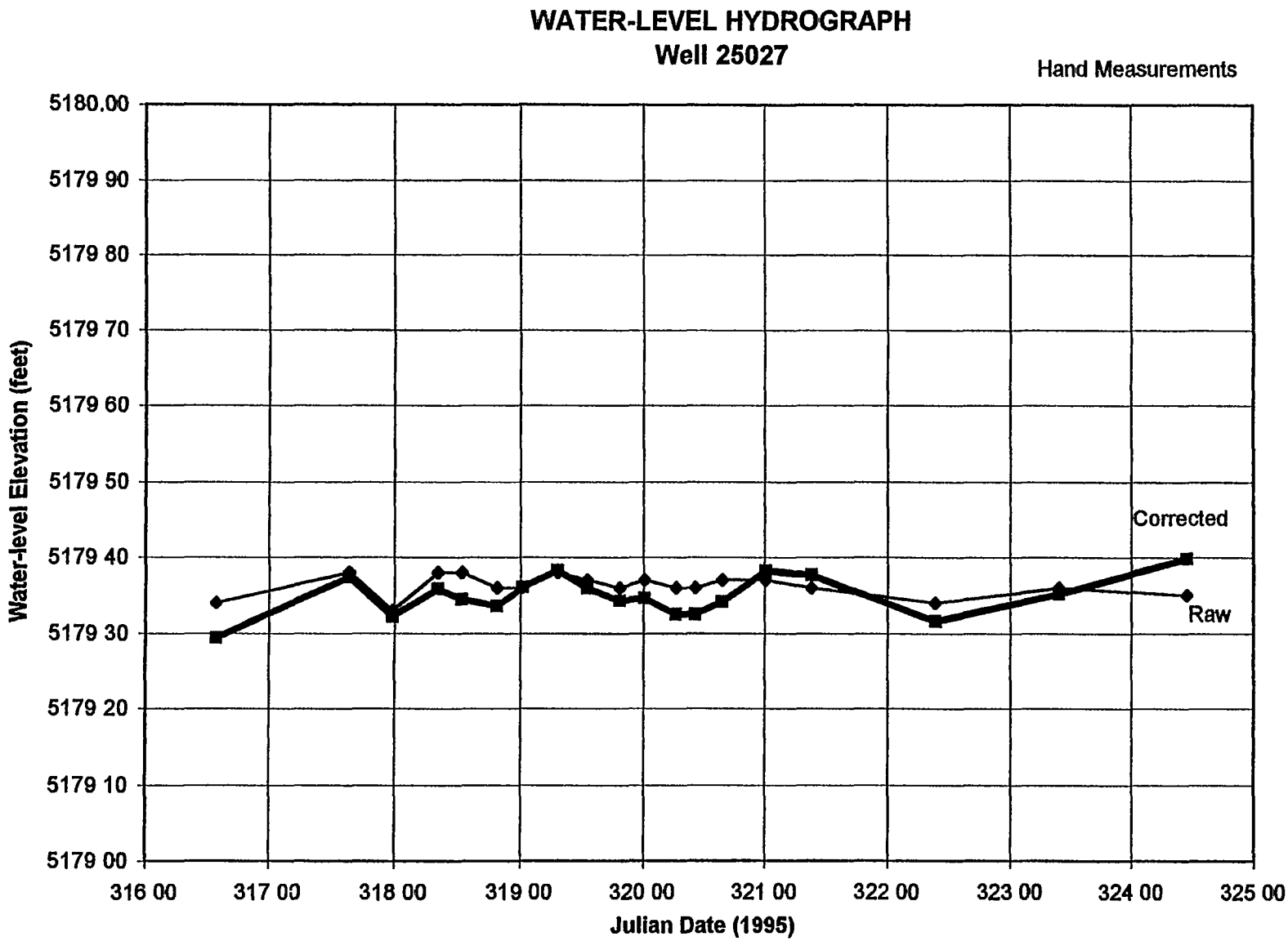

WATER-LEVEL HYDROGRAPH
Well 25027
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5180.00
5179 90
5179 80
5179 70
5179 60
5179 50
5179 40
5179 30
5179 20
5179 10
5179 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.28

WATER-LEVEL HYDROGRAPH
Well 25028

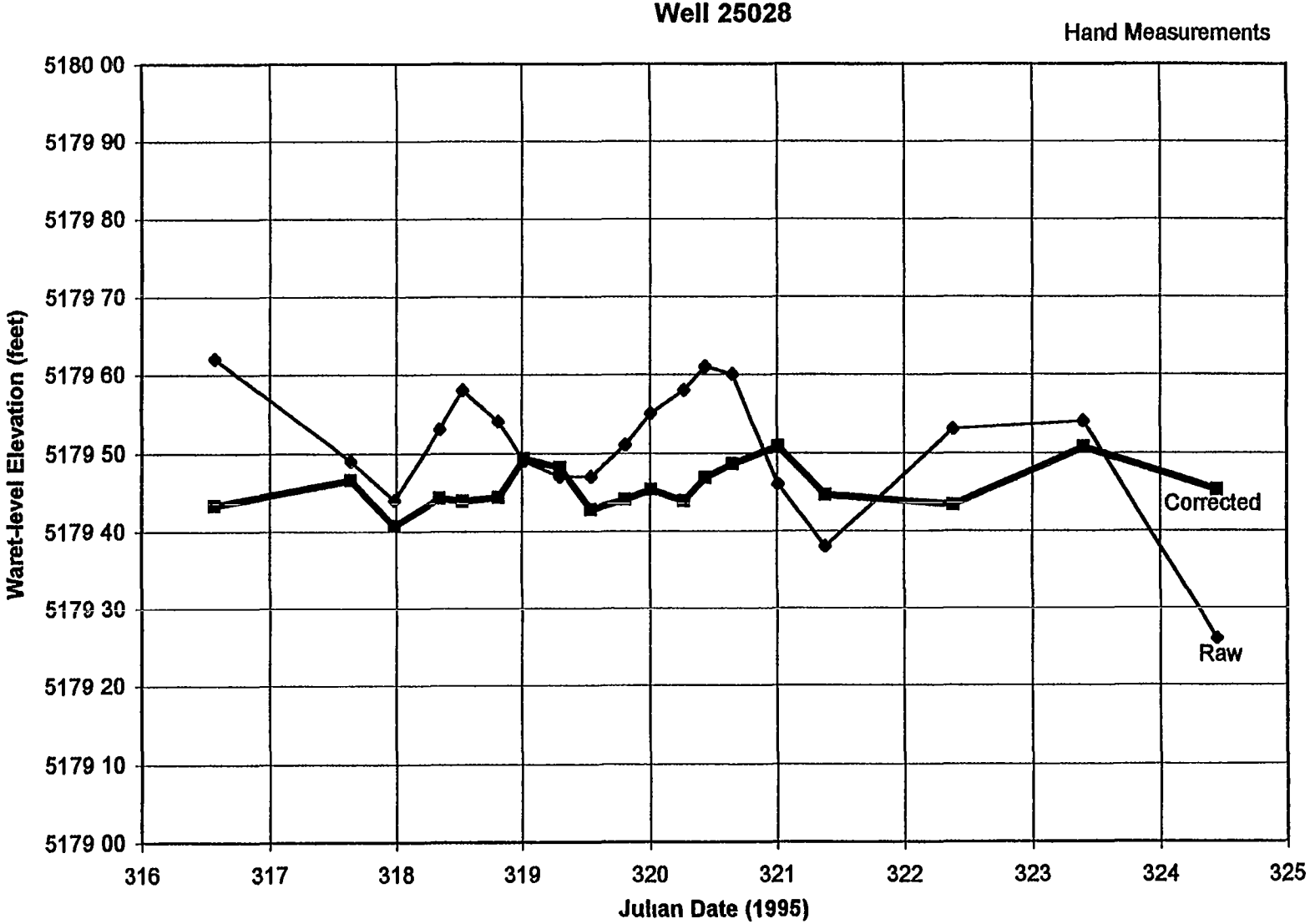


Figure A3.29

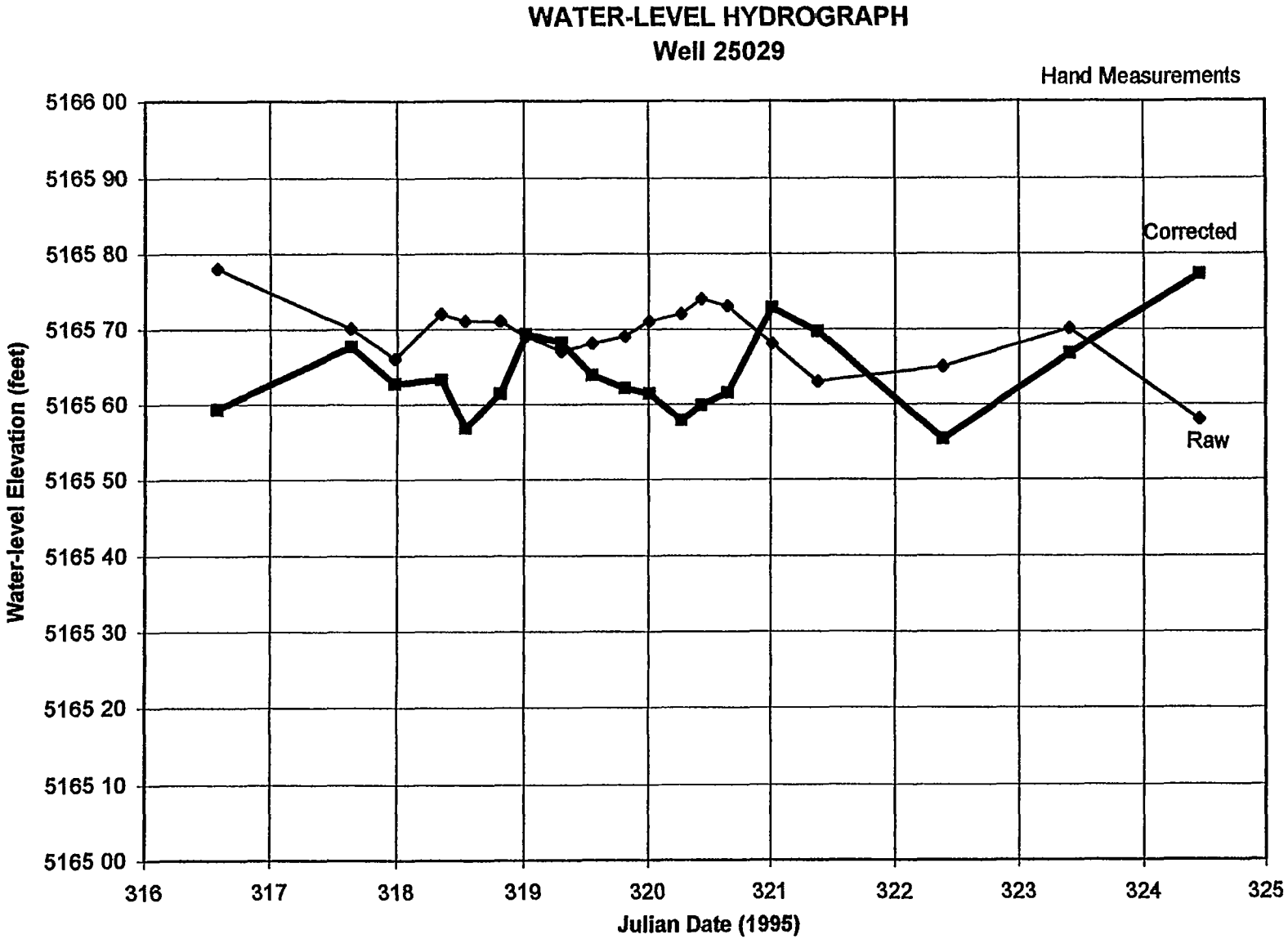

WATER-LEVEL HYDROGRAPH
Well 25029
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5166 00
5165 90
5165 80
5165 70
5165 60
5165 50
5165 40
5165 30
5165 20
5165 10
5165 00
316
317
318
319
320
321
322
323
324
325
Julian Date (1995)

Figure A3.30

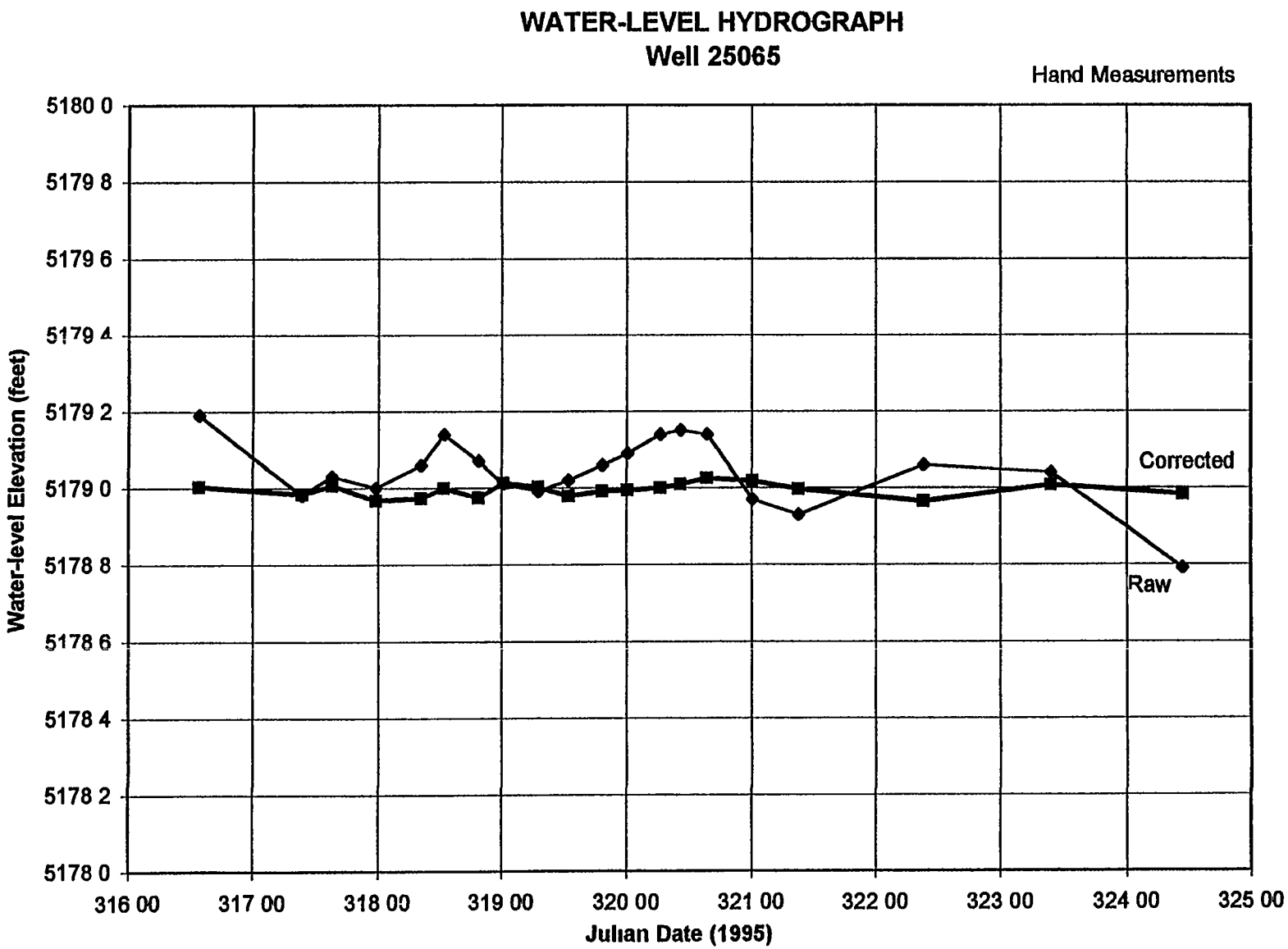

WATER-LEVEL HYDROGRAPH
Well 25065
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5180 0
5179 8
5179 6
5179 4
5179 2
5179 0
5178 8
5178 6
5178 4
5178 2
5178 0
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.31

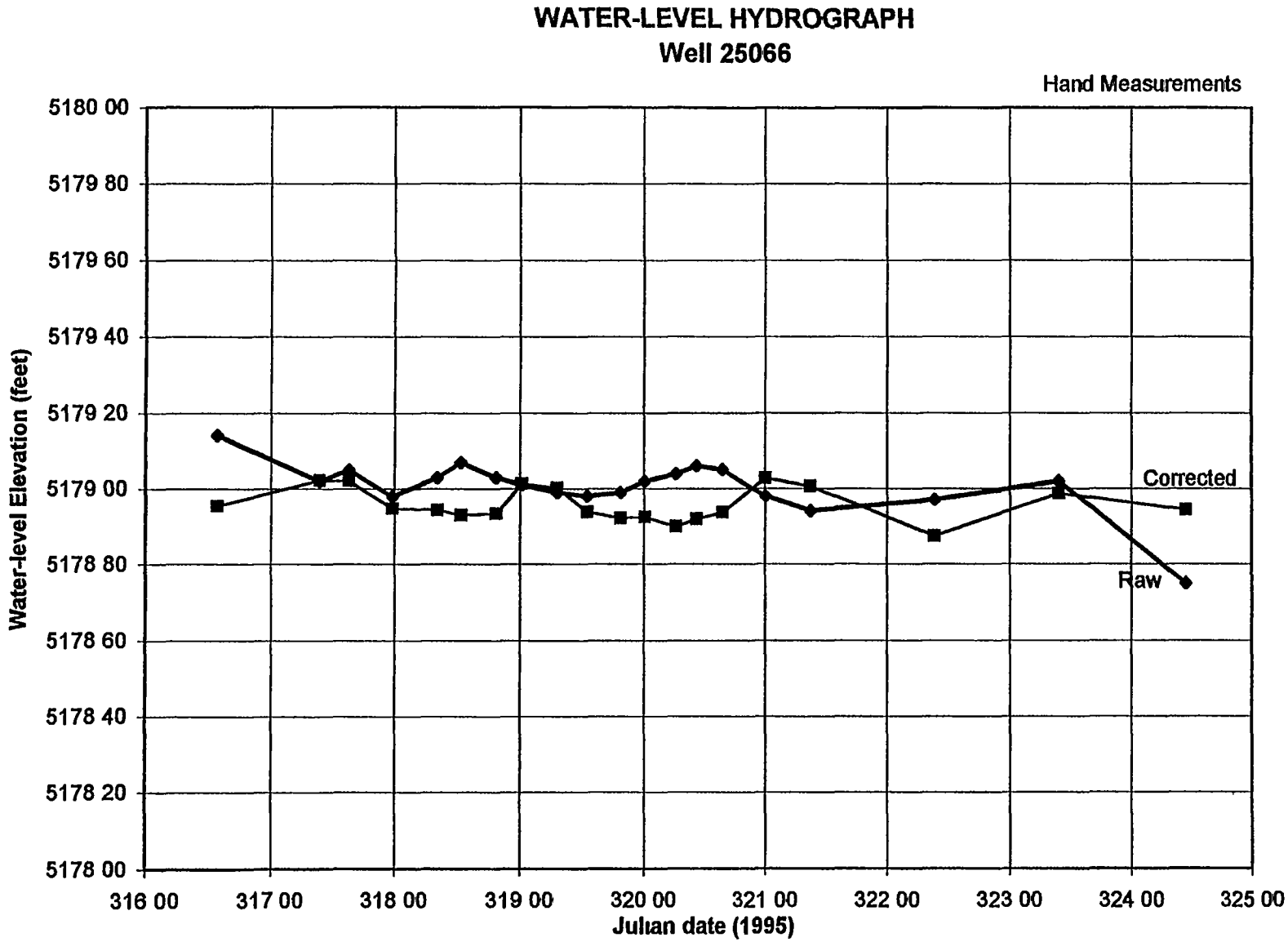

WATER-LEVEL HYDROGRAPH
Well 25066
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5180 00
5179 80
5179 60
5179 40
5179 20
5179 00
5178 80
5178 60
5178 40
5178 20
5178 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian date (1995)

Figure A3.32

BAROMETRIC PRESSURE

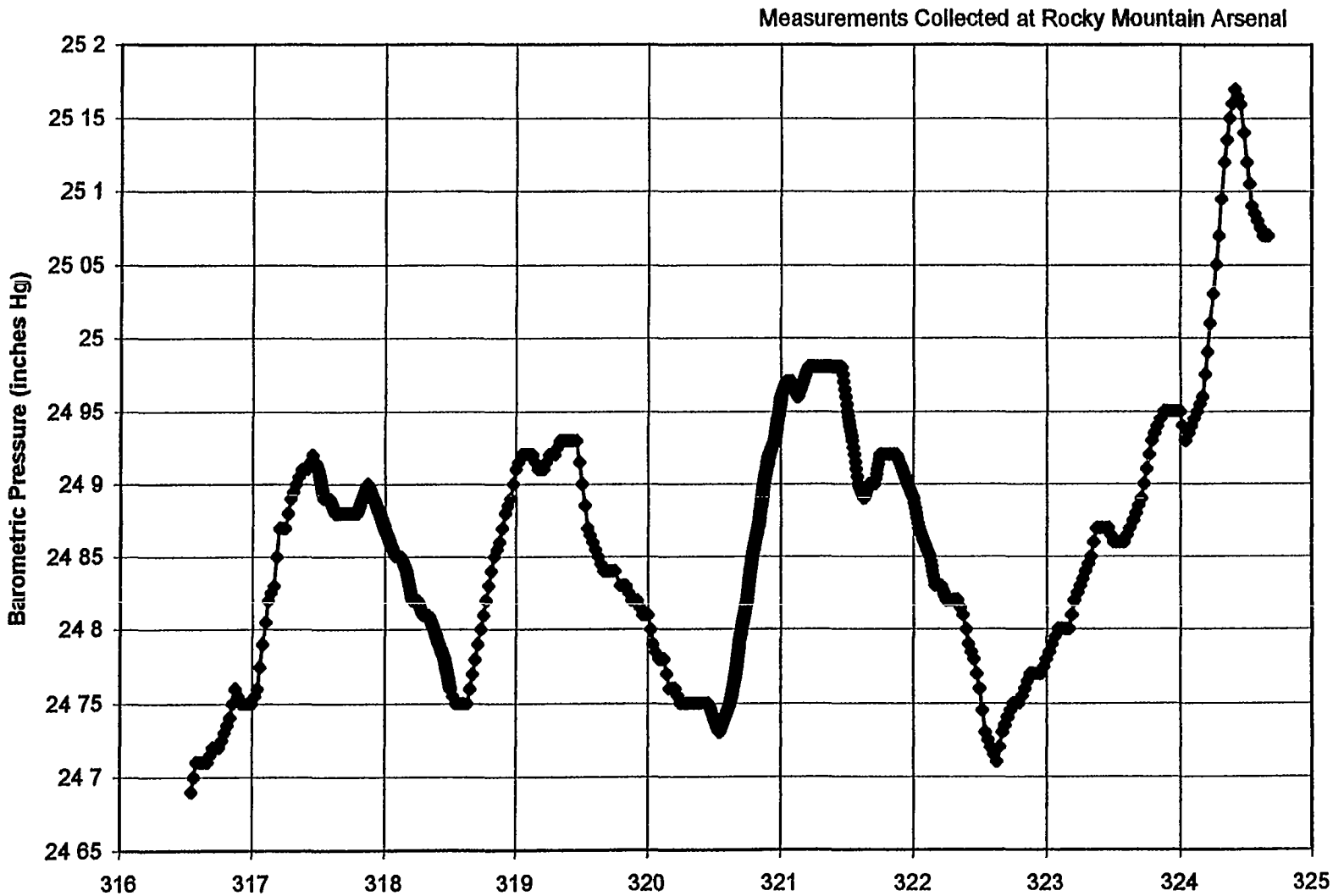


Figure J22

Figure A3.33

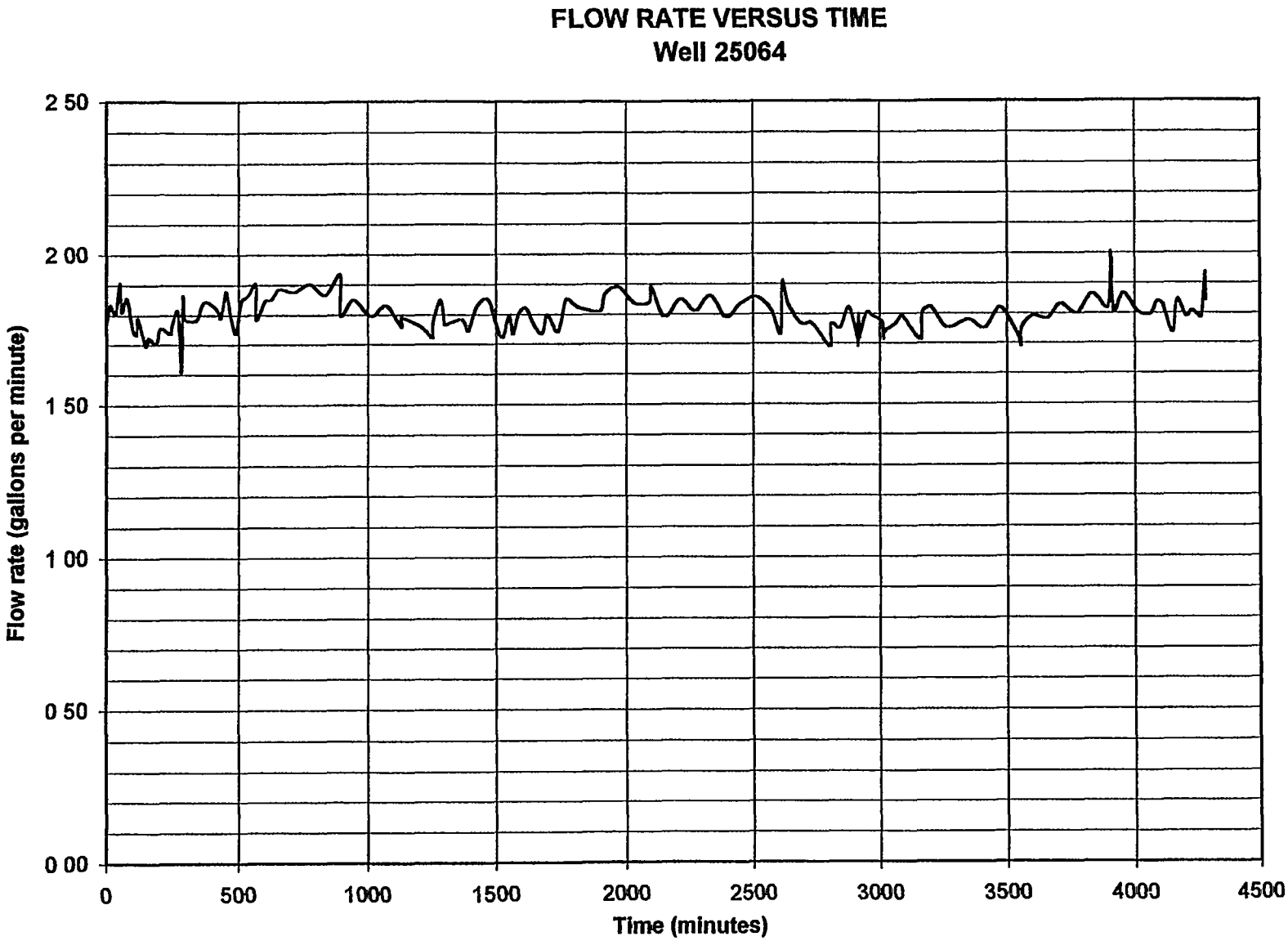
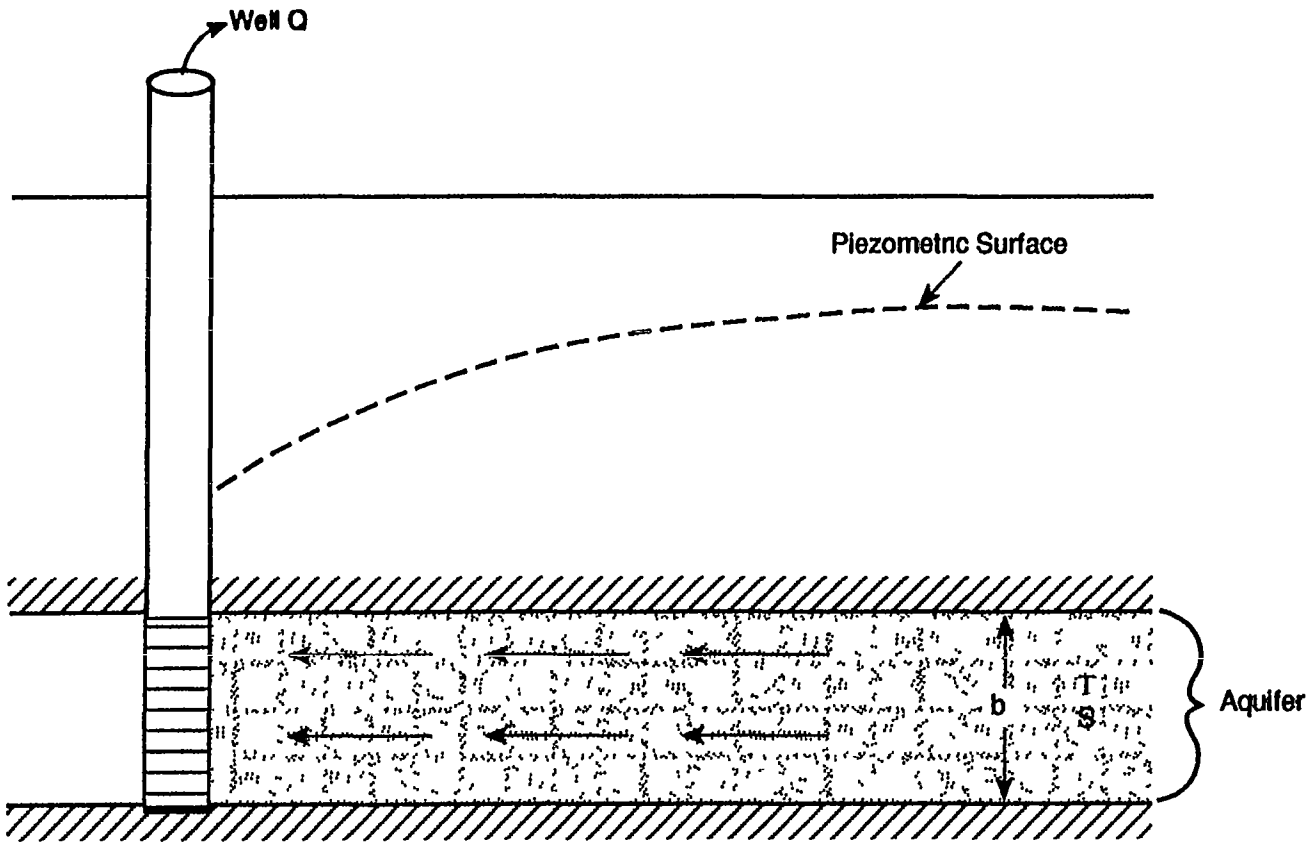

FLOW RATE VERSUS TIME
Well 25064
Flow rate (gallons per minute)
2 50
2 00
1 50
1 00
0 50
0 00
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Time (minutes)

Figure A3.34

PHYSICAL MODEL FOR IDEAL AQUIFER



T = Transmissivity

S = Storativity

b = Saturated thickness

Q = Discharge

Figure A3.35

THEIS TYPE-CURVE ANALYSIS METHOD

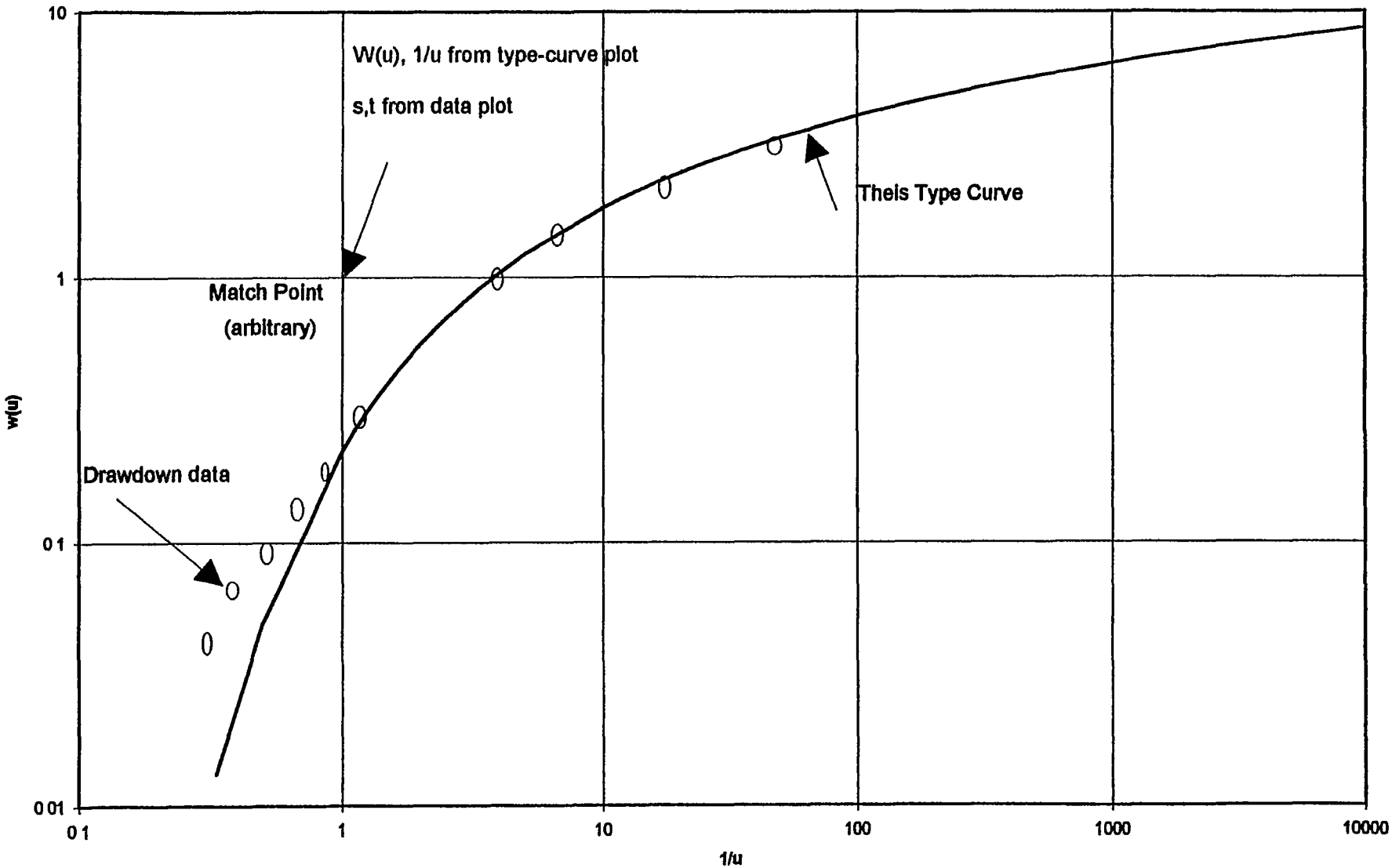


Figure A3.36

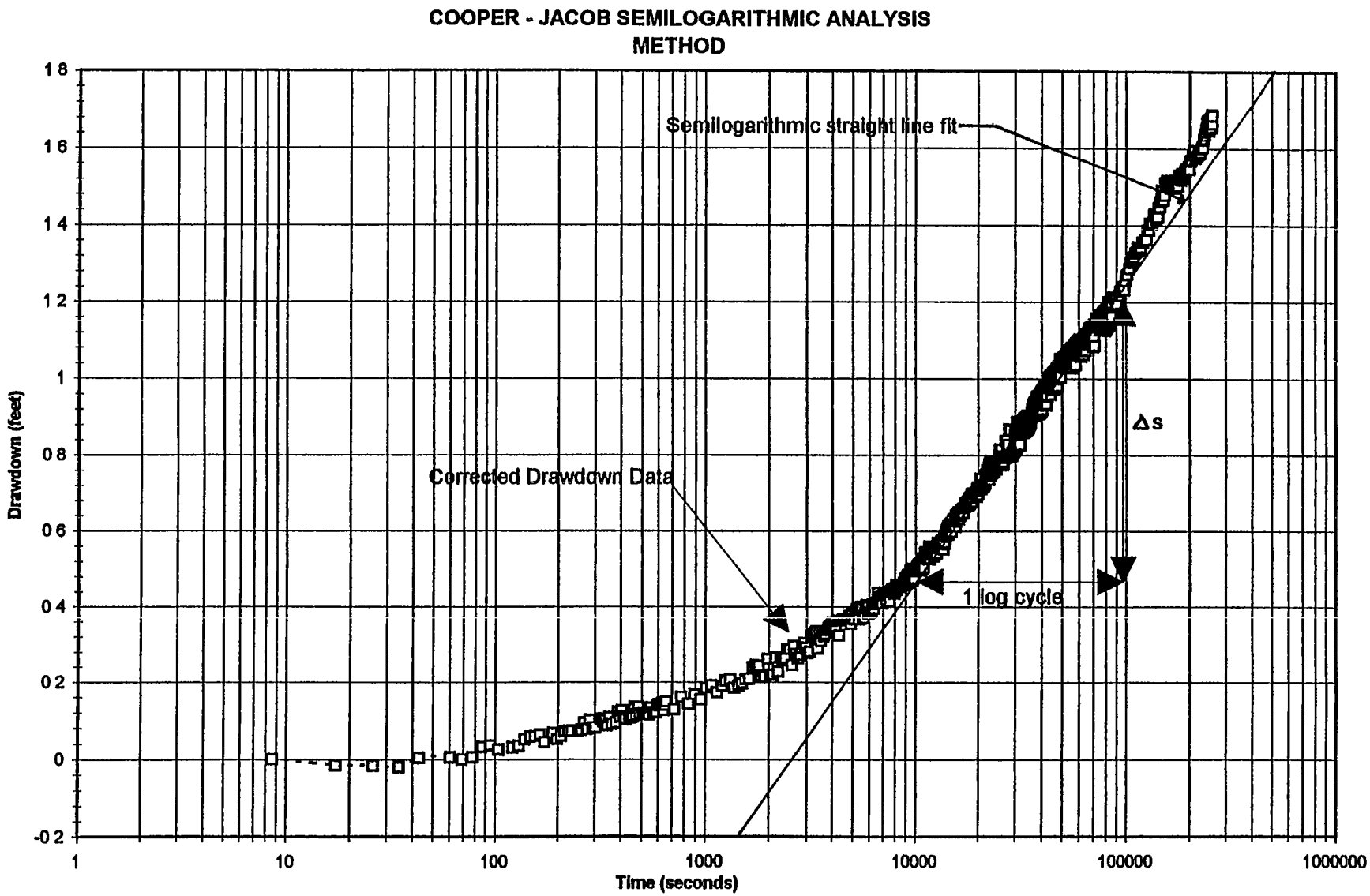

COOPER - JACOB SEMILOGARITHMIC ANALYSIS METHOD
Semilogarithmic straight line fit
Corrected Drawdown Data
1 log cycle
Δs
Drawdown (feet)
Time (seconds)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1
10
100
1000
10000
100000
1000000

Figure A3.37

THEIS RECOVERY ANALYSIS METHOD

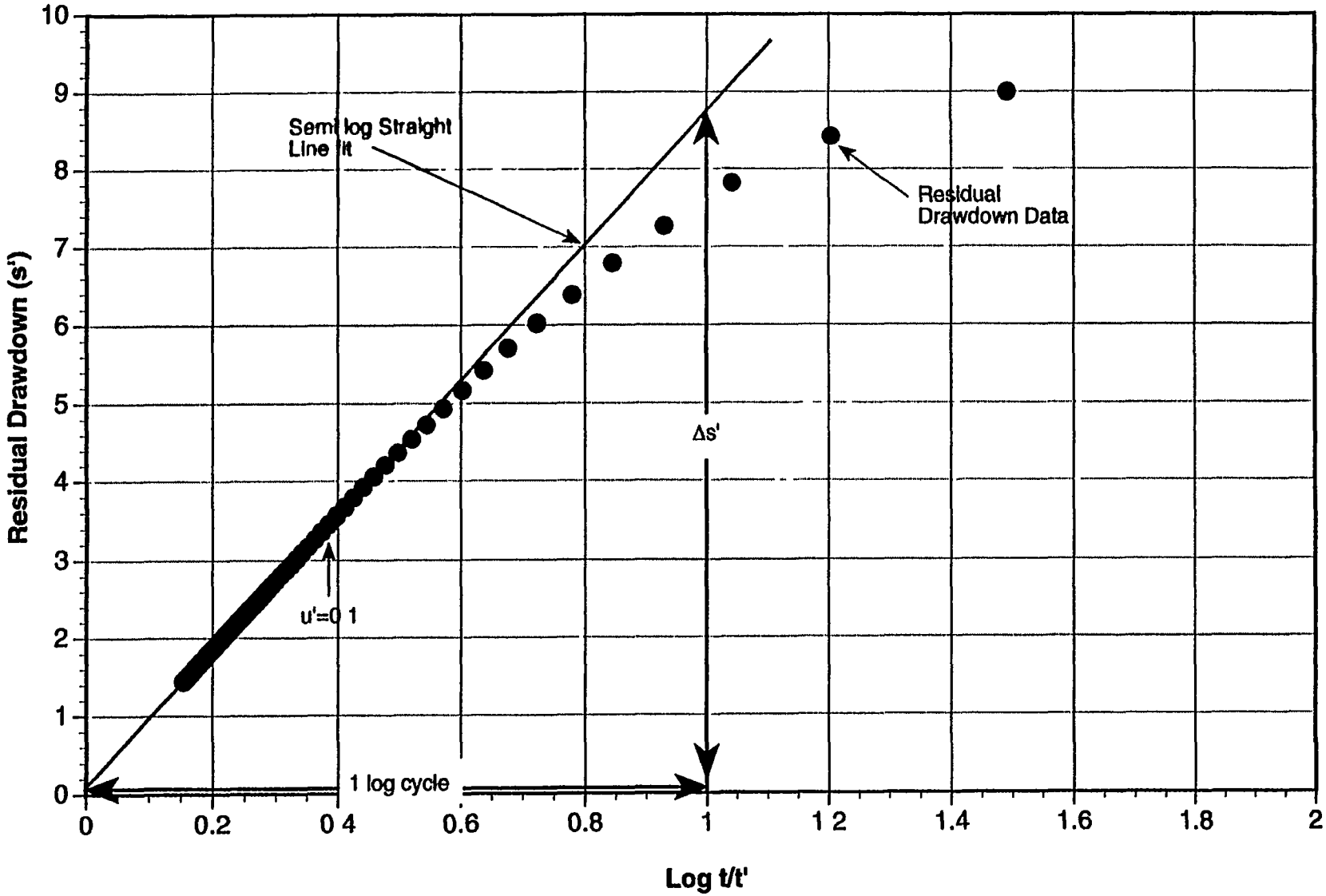
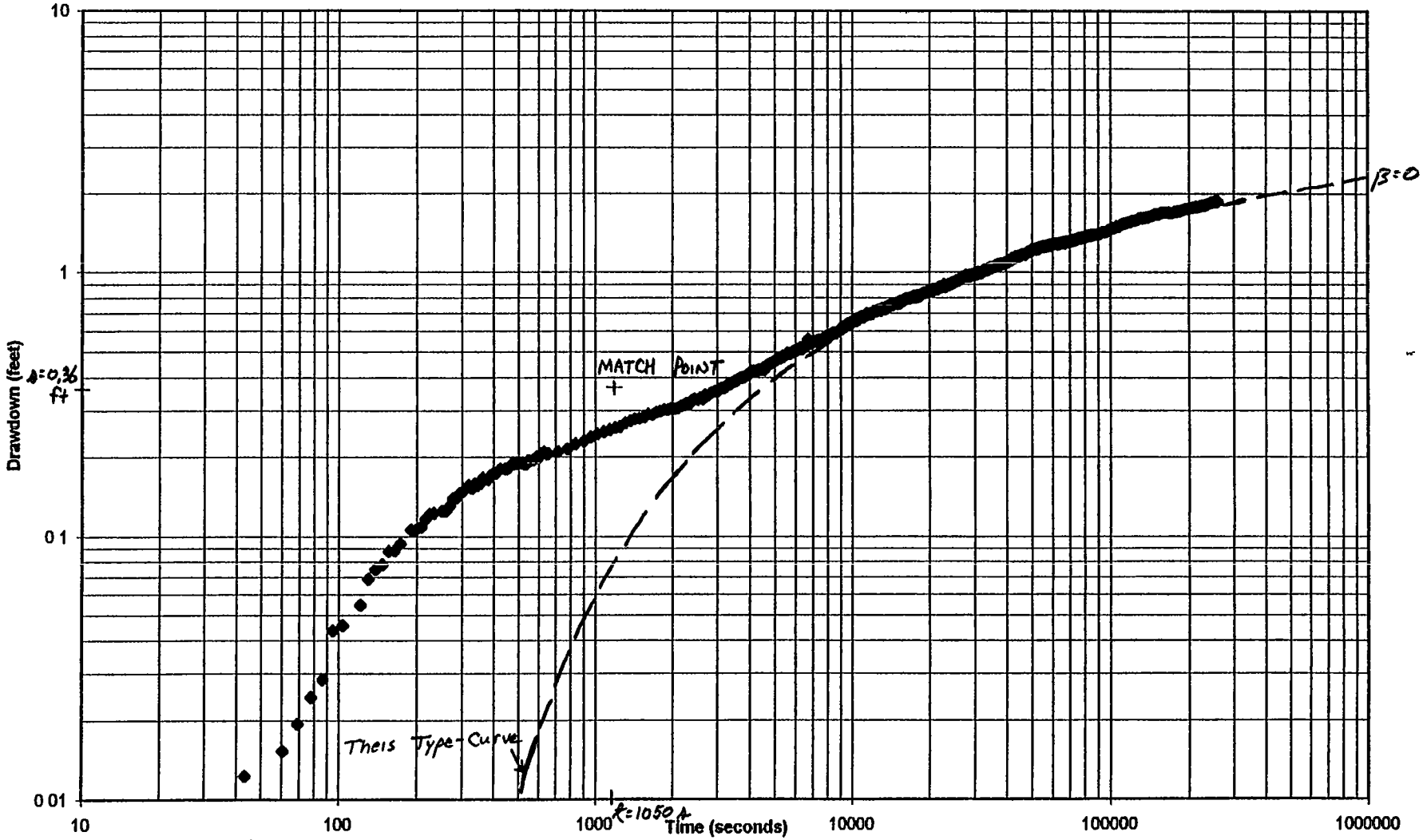


Figure A3.38

THEIS TYPE CURVE ANALYSIS
Well 25009



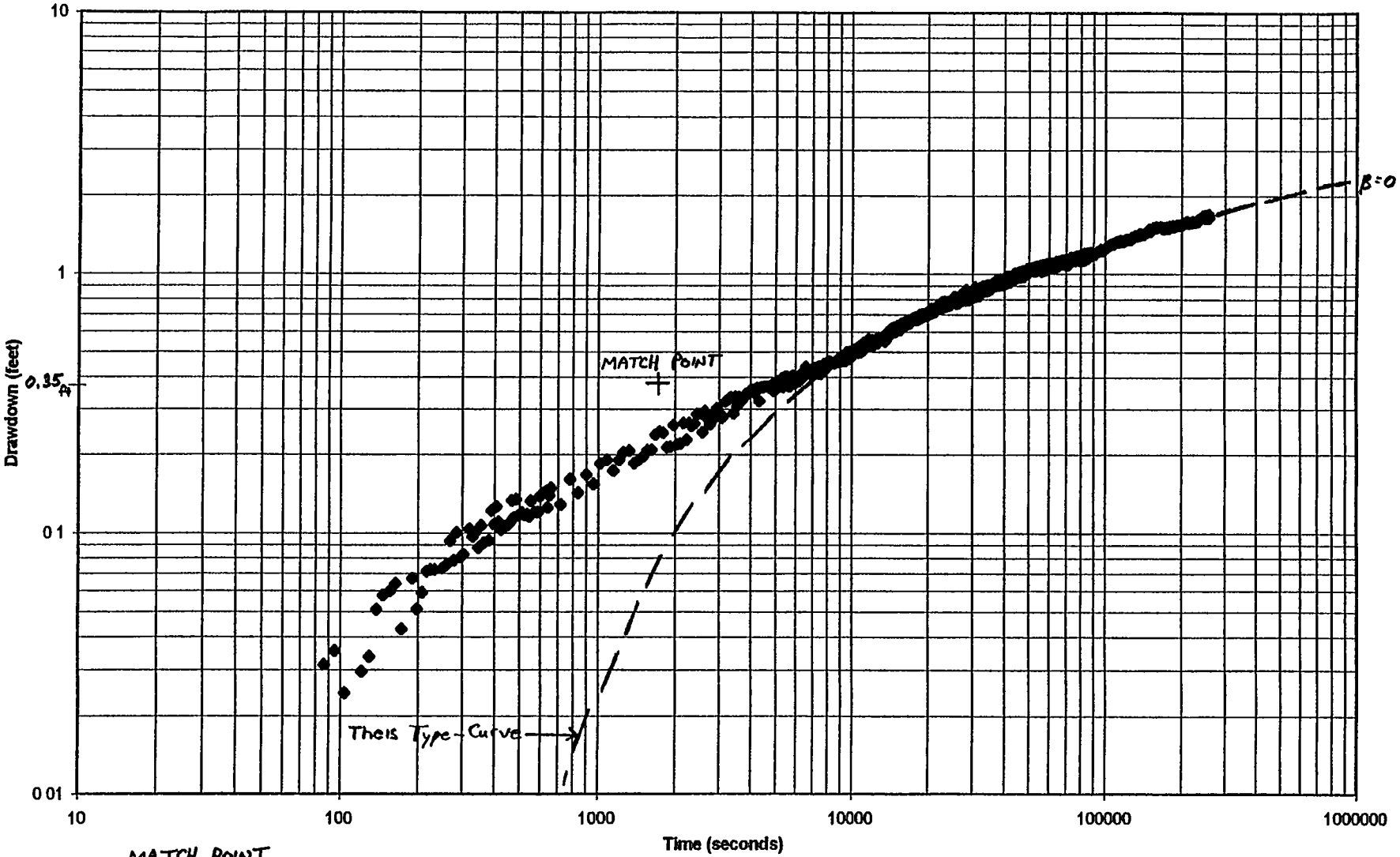
MATCH POINT

$\frac{1}{u} = 1$ $t = 1050$ s

$W(u) = 1$ $s = 0.36$ ft

Figure A3.39

THEIS TYPE CURVE ANALYSIS
Well 25063



MATCH POINT

$\frac{1}{u} = 1$ $t = 1500$ s

$W(u) = 1$ $s = 0.35$ ft

Figure A3.40

COOPER - JACOB SEMILOGARITHMIC ANALYSIS
Well 25009

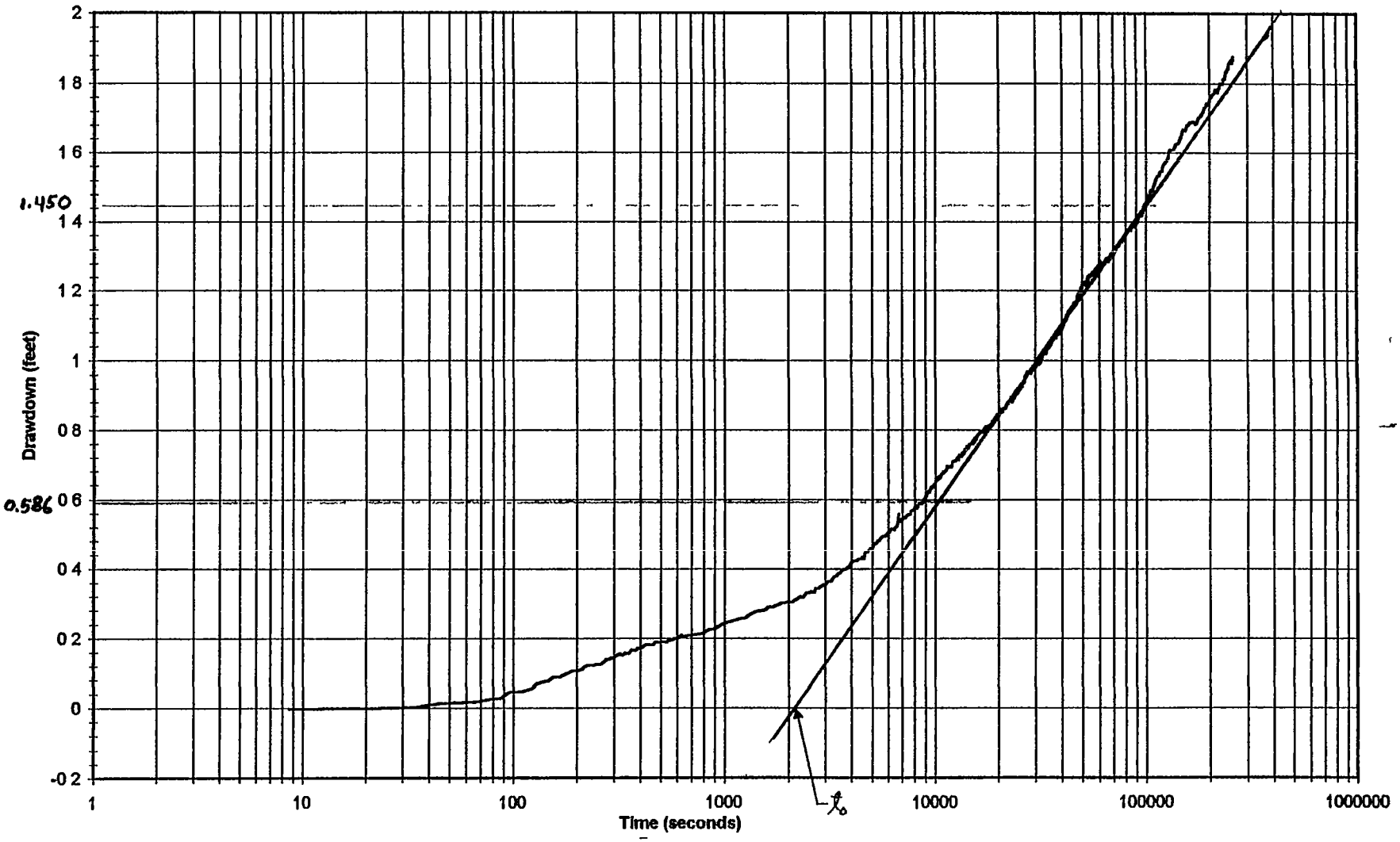
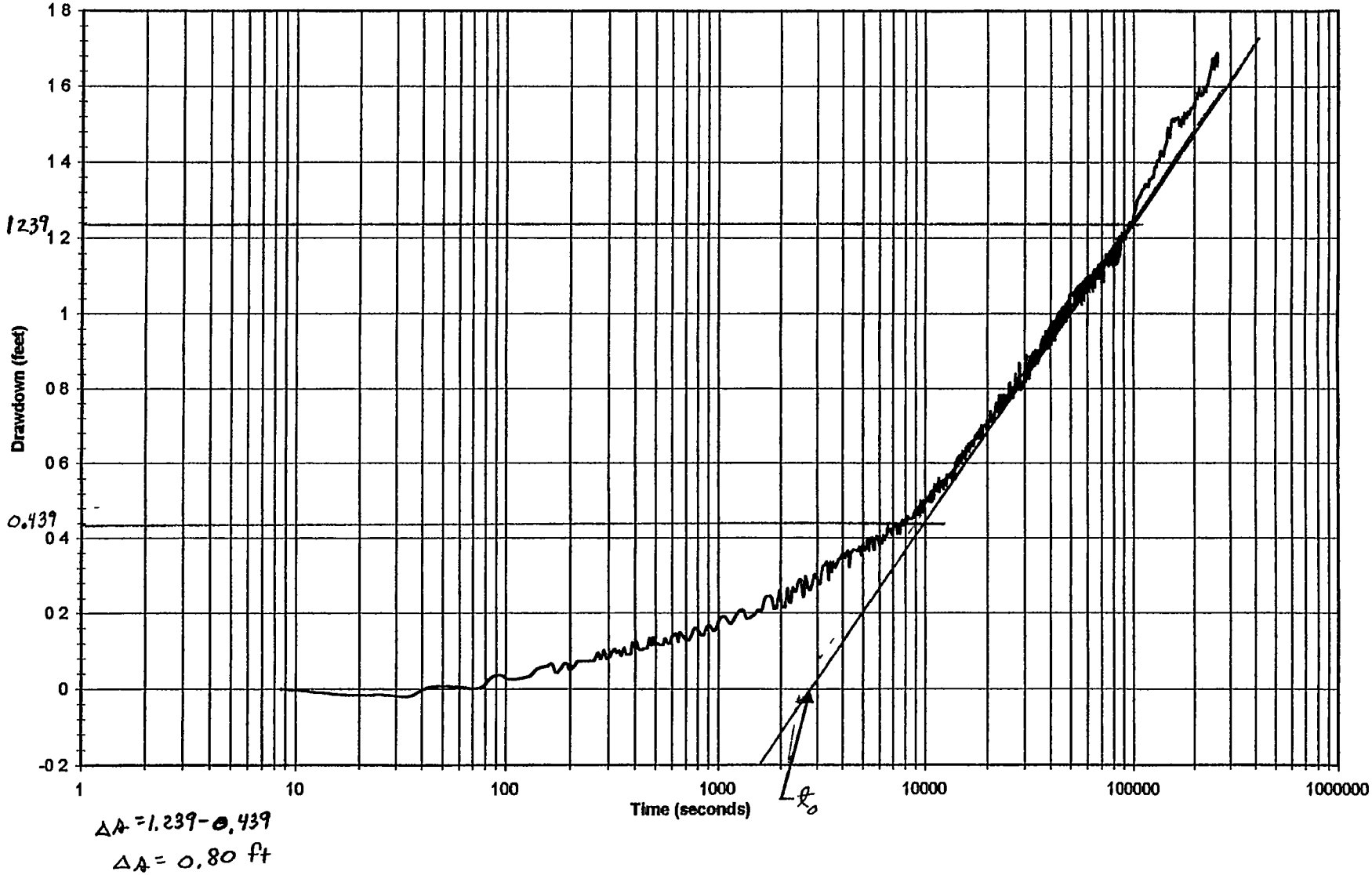


Figure A3.41

COOPER - JACOB SEMILOGARITHMIC ANALYSIS
Well 25063

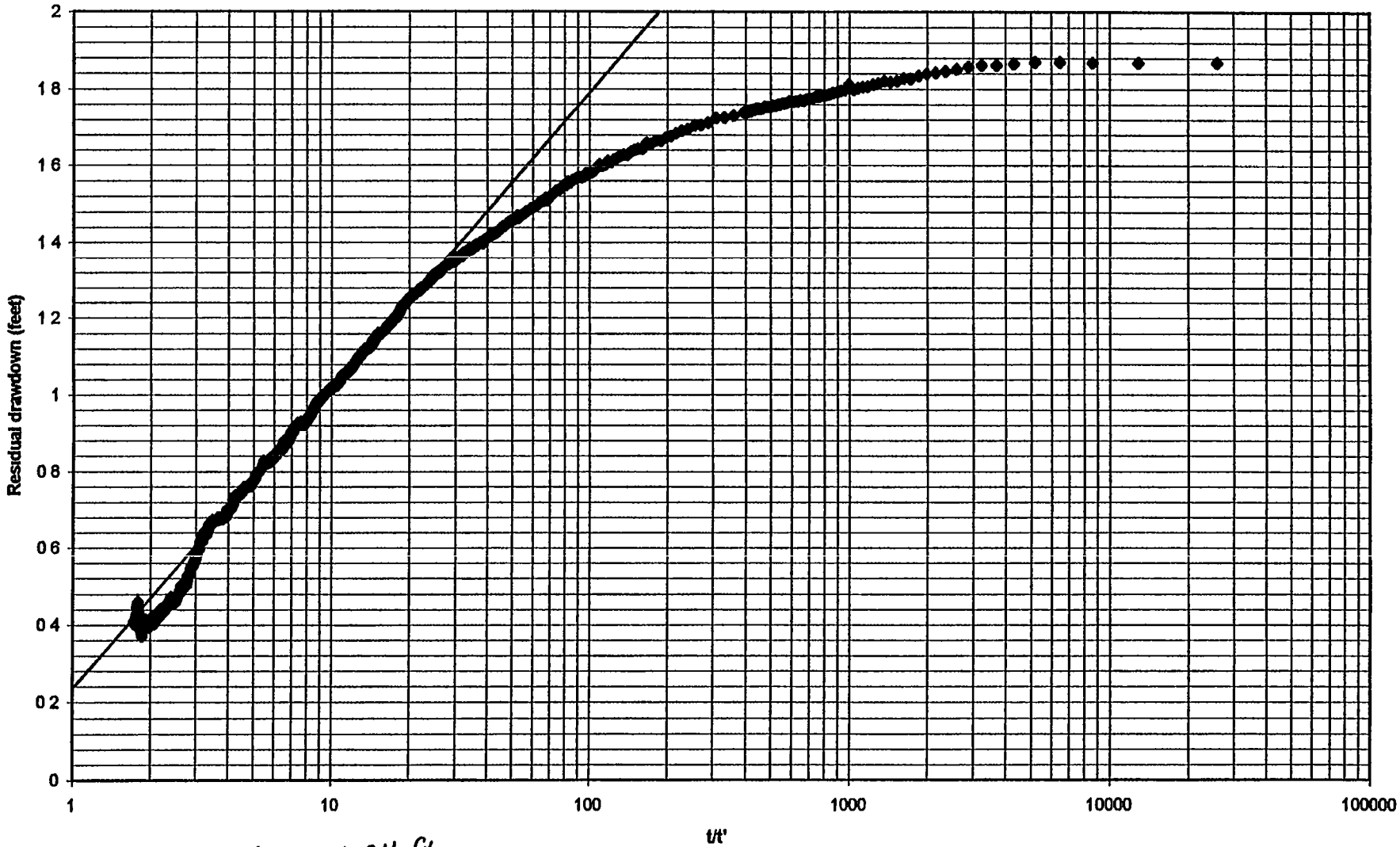


$\Delta s = 1.239 - 0.439$

$\Delta s = 0.80$ ft

Figure A3.42

THEIS RECOVERY ANALYSIS
Well 25009



$\Delta s = 1.02 - 0.24$ ft

$\Delta s = 0.78$ ft

Figure A3.43

THEIS RECOVERY ANALYSIS
Well 25063

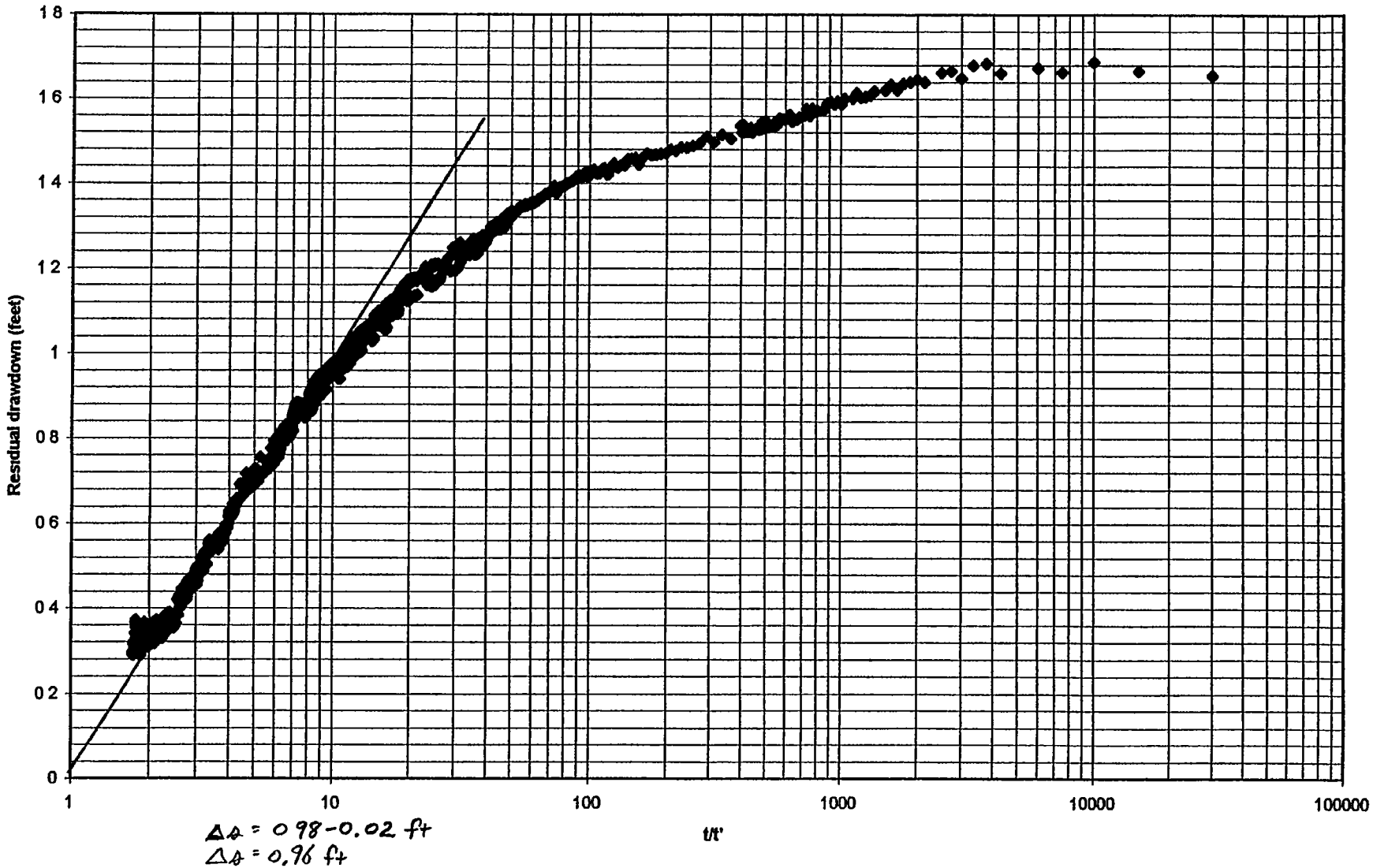


Figure A3.44

THEIS RECOVERY ANALYSIS
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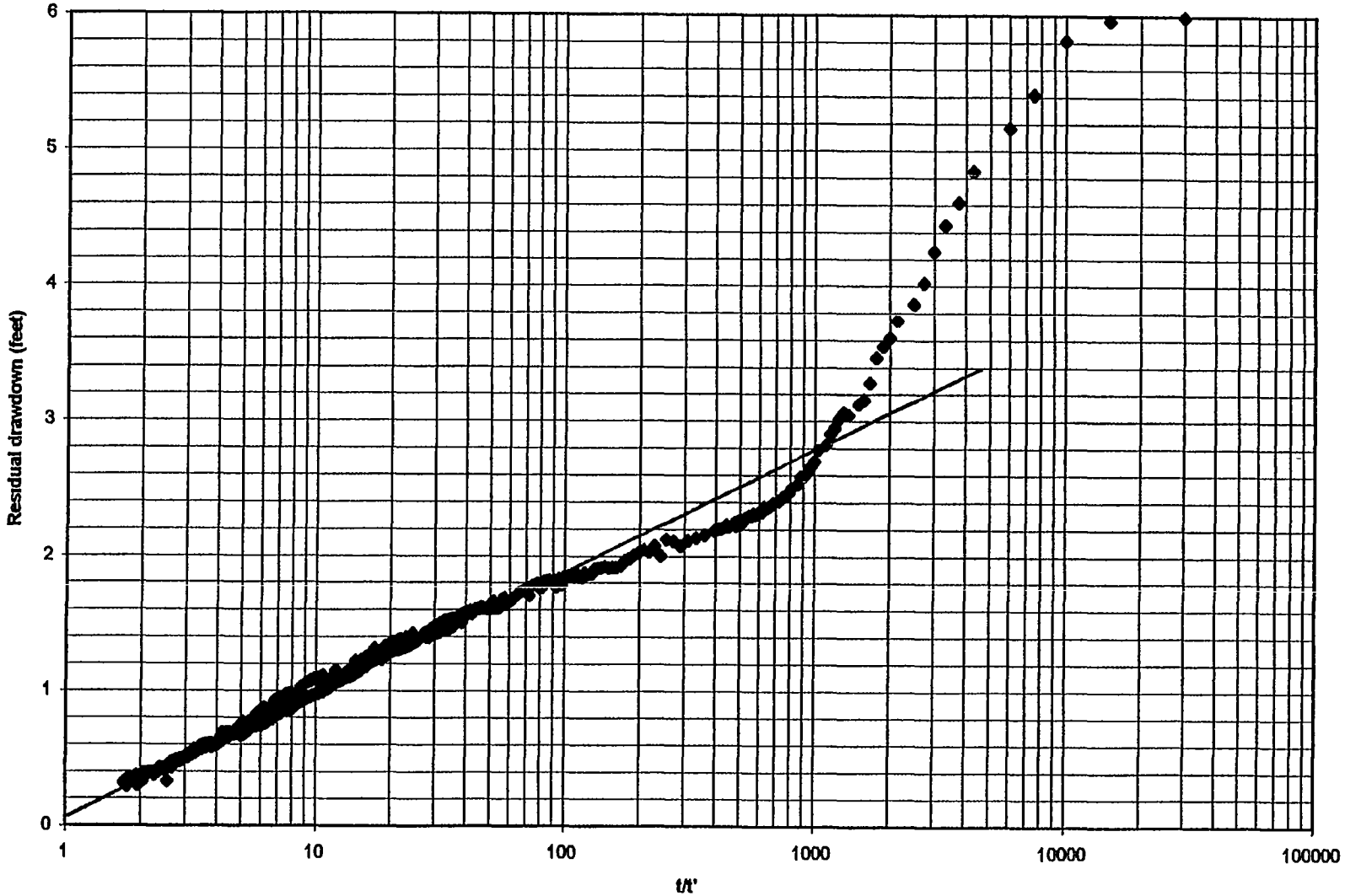

$\Delta s = 0.98 - 0.08$ ft

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1.0 INTRODUCTION

This Design Narrative has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3 The CDD has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Background

In June 1995, an Agreement for a Conceptual Remedy (the Conceptual Remedy) for the Cleanup of RMA among the State, U S Environmental Protection Agency (EPA), the Army, Shell, and the U.S Fish and Wildlife Service (FWS) was signed The Conceptual Remedy represents agreement by the parties relative to specific components of the remedy for the final cleanup of RMA These components of the remedy are included in the (1) Proposed Plan for the RMA Onpost Operable Unit and (2) Final Detailed Analysis of Alternatives Report (DAA) (Foster Wheeler, 1995) The Conceptual Remedy, the Proposed Plan for the Onpost Operable Unit, and the DAA are documents prepared under various authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) The Conceptual Remedy calls for the construction and operation of a new onsite hazardous waste landfill for disposal of principal

threat and human health exceedance soil and debris as those categories of contamination are defined in the DAA

In the On-Post Operable Unit Detailed Analysis of Alternatives Dispute Resolution Agreement dated October 16, 1995, it was agreed that the future hazardous waste landfill area, the Basin F Waste Pile drying Unit, and the appropriate waste staging and/or management area(s) will be included within a CAMU. The CAMU will be designated in accordance with the provisions of Section 264.552 of the 6 Code of Colorado Regulations (CCR) 1007-3.

The area of the CAMU intended for the state-of-the-art hazardous waste Landfill is located in portions of Section 25 and 26 between Former Basin F and North Plants (See Figure Bl). Double-lined cells within the landfill will receive principal threat and human health exceedance materials, as defined in the DAA, from 17 contaminated areas of RMA. In addition. drum wastes generated as a result of RI/FS activities may also be disposed in the landfill. **A triple-lined cell** will be constructed to receive principal threat **and human health exceedance** soils from the Basin F Waste Pile and **Former Basin F, human health exceedance soils from Sand Creek Lateral, and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.** The total volume of waste to be placed in the landfill is estimated to be 1,855,000 cubic yards, of which approximately 655,000 cubic yards are to be placed in the triple-lined cells. It is estimated that the total volume of the landfill including daily cover will exceed 2 million cubic yards

In addition to the landfill and the Basin F Waste Pile drying Unit, the CAMU will include waste staging/consolidation areas and decontamination facilities. The waste staging/consolidation areas may include areas within the CAMU that will be used for the temporary storage, consolidation, and processing of wastes after excavation from various source areas and prior to placement within the landfill. Processing waste may consist of the bulking and/or sizing of the waste as necessary to enhance landfill operations. The staging/consolidation areas may be located near the Basin F Waste Pile excavation, near the area of the Basin F drying Unit, or near the landfill. The drying Unit will be located on or near the Basin F Waste Pile. At least one decontamination facility will be located near the landfill,

and another may be located near the Basin F Waste Pile The landfill area will be located within the western half of Section 25 and the eastern half of Section 26 A leachate storage/offloading area may be included in the vicinity of the landfill area.

Working sessions were conducted prior to and throughout the preparation of this document Working session participants included the Army, Shell, Colorado Department of Public Health and Environment (CDPHE), FWS, EPA, Adams County, Tri-County Health Department, and the U S Corps of Engineers (COE) During these working sessions, proposed design criteria and landfill liner system components, as well as the level of detail to be included in the CDD, were presented and discussed To the extent applicable, this document incorporates the results of the working sessions and the Army's technical position on the CAMU design-related issues

1.2 Purpose and Scope

This document has been prepared as an appendix to the CDD The CDD will be submitted to CDPHE to respond to the design components of 6CCR 1007-3 Section 264 552(e)(2)

Section 264 552 (a)(3) of 6 CCR 1007-3 specifies that when the remediation waste placed into a CAMU is classified as hazardous and is to remain in place after closure, the CAMU shall comply with the requirements for siting of hazardous waste disposal sites found in 6 CCR 1007-2, Part 2 (Part 2) Section 2 4 and 2 5 of Part 2 address design performance criteria and requirements for design of a hazardous waste landfill

The primary performance goal, stated within Sections 2 4 and 2.5 of Part 2, is that the landfill is designed and built to assure long-term protection of human health and the environment. Section 2 5 3 of Part 2 requires that the design performance of engineered barriers within a hazardous waste landfill, combined with the geological and hydrological conditions of the landfill area, shall be such that reasonable assurance is provided that the hazardous waste will be isolated for 1,000 years within the disposal area and away from natural environmental pathways that could expose the public

Section 264 552(e)(2) requires that the CAMU designation specify the design and operation requirements applicable to the remediation waste management that are to take place within the CAMU This design narrative has been developed so that, after review and approval by CDPHE, it can be incorporated into the CAMU designation as the requirements for design of the landfill and other CAMU components

This design narrative provides performance standards, design guidance, design parameter demonstration, and resultant design criteria for the components of the landfill systems These terms are defined as follows

- Performance Standard An objective for design that is based on a regulatory requirement, regulatory guidance, and/or standard practice.
- Design Guidance Standard engineering reference manuals and design elements that have been identified in regulatory guidance or have been demonstrated by past practice to meet the performance standards
- Design Parameter Demonstration Analysis required to demonstrate that the design criteria will provide for conformance with the design guidance and the performance standard
- Resultant Design Criteria Specific elements of the design that have been shown by supporting analytical demonstration to meet the related performance standard

Collectively, these terms are referred to as design parameters in the CDD Where applicable, the types of engineering analyses that may be performed during the design to document conformance with the performance standards are presented

1.3 Guidance Documents

EPA guidance and other published documents were used as references to prepare this document. Those references used are listed in Section 11 0, Bibliography The general format and guidance given in the EPA document entitled "Guide to Technical Resources for the Design of Land Disposal Facilities" (EPA, 1988) was incorporated into the landfill-related sections (Section 3 0 and 4 0) below Application of the approach presented in these sections during design will provide a "road map" to verify, through an EPA published reference, that the landfill design submitted for CDPHE approval contains the EPA-recommended level of detail using appropriate EPA-recommended references In some cases, it was necessary

to update the information given in this seven-year-old EPA document to reflect technological advances and regulation changes that have occurred since its publication During the design of the landfill, current references, methodologies, and design approaches will be reviewed and used, as applicable, to provide a "state of the art" landfill design.

1.4 Organization

The remainder of this document is divided into 10 sections Section 2 0 describes the development of the overall CAMU layout The necessary components and considerations for the design of the CAMU components are discussed as follows

- Section 3.0 Landfill Foundation and Lining Systems
- Section 4 0 Landfill Cover Systems
- Section 5 0 Run-on/Runoff Control Systems
- Section 6 0 Waste Staging/Consolidation Areas
- Section 7.0 Leachate Management Systems
- Section 8 0 Decontamination Facilities
- Section 9 0 Basin F Waste Pile Drying Unit

Section 10 0 presents the acronyms used in this document and Section 11 0 provides the bibliography In addition to the main body of this appendix, conceptual drawings of the landfill area are included as Attachment B1 and conceptual foundation and slope stability analyses are included as Attachment B2

The conceptual drawings show a landfill concept that is considered to be a feasible design that could accomplish the goals for the landfill as outlined in the Conceptual Remedy under CERCLA This concept may undergo revision during design but the concept is accurate enough to define the CAMU footprint and make the appropriate siting demonstrations The drawings show the concept's plan views, cross sections, and selected details of the landfill cell geometry, landfill lining systems, cover systems, and run-on/runoff control systems

In the development of Table B1, certain geotechnical analyses were performed on the conceptual design shown in Attachment B1 and the results included as a component of this design narrative These analyses are included in Attachment B2

The following geotechnical analyses were performed

- Foundation settlement
- Foundation bearing capacity
- Potential for excess hydrostatic pressure on the foundation
- Excavated slope stability, including seismic considerations
- Cover slope stability, including seismic considerations

The results of these individual conceptual analyses indicate that the conceptual design will not be severely constrained by these design considerations The design of the landfill will include a more comprehensive evaluation of these and other design considerations

During the working sessions, design parameter tables were presented and discussed The results of these discussions have been consolidated into the CAMU Landfill Design Parameters table presented in Table B1 This table presents the design items for the CAMU landfill and characterizes each related design component as performance standards, design guidance, design parameter demonstration, and/or resultant design criteria. The design demonstrations referenced in Table B1 will be completed during the design process

2.0 CAMU DEVELOPMENT PLAN

During the initial working sessions, various conceptual CAMU development plans were presented In later working sessions, it was agreed that a CAMU development plan would not be included in the CDD Therefore, completion of a preliminary CAMU development plan is planned as the initial task in the CAMU design. The preparation of a preliminary CAMU development plan will enable the designer to proceed more efficiently with the detailed design tasks discussed in later sections of this document The preparation of the CAMU development plan can be divided into three subtasks

- Individual landfill cell layout alternative and final plan preparation
- Comprehensive CAMU layout plan preparation
- Phased construction document preparation

These subtasks are described in this section.

Figure B1 shows the landfill area boundary, the conceptual locations of the other CAMU facilities, and the overall CAMU boundary The individual landfill cells are to be located within the areal extent of the landfill portion of the CAMU The remaining CAMU facilities may or may not be located where shown in Figure B1, however, they will be located within the overall CAMU boundary These facilities may include, but are not be limited to the following

- Decontamination facilities
- Basin F Waste Pile drying unit
- Waste staging/consolidation areas
- Leachate storage/offloading area

The subsections below discuss the recommended methodology for development of a preliminary CAMU development plan.

2.1 Landfill Cell Layout Alternative and Final Plan

The initial step in preparing a CAMU development plan will be to develop a preliminary plan for the layout of the individual landfill cells. The individual cells are divided into two groups: double-lined cells and triple-lined cells. The triple-lined cells will contain waste from the Basin F Waste Pile and **Former Basin F, Sand Creek Lateral soil and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.** The double-lined cells will contain the remaining waste identified for landfilling in the Detailed Analysis of Alternatives (DAA) (Foster-Wheeler, 1995). The DAA is a CERCLA document.

2.1.1 Design Parameters

During the CAMU working sessions, the design parameters for the layout of the landfill cells were discussed. The layout design parameters arc presented in Table Bl with the exception for those related to the excavated surface geology. The surface of an excavated landfill cell will likely contain alluvial sandy soil or sand unit subcrops of the Denver Formation. The potential for piping and infiltration of surface water behind and below the liner as a result of sand outcrops at the surface and adjacent excavation perimeter will be evaluated during the design and addressed accordingly. As a design guidance, the base of the excavated surface located within soil classified as coarser than SM by the Unified Soil Classification System (USCS) will be over excavated a minimum of 3 feet and backfilled with structural fill that classifies finer than SM. The over excavation requirements for portions of excavated side slopes located within soil classified as coarser than SM will be determined during design.

2.2 Comprehensive CAMU Layout Plan Preparation

After completion of the individual cell layout, the next step in preparing the CAMU development plan will be to calculate the area required for each of the various remediation waste handling facilities to be constructed within the CAMU. The conceptual facility locations shown in Figure Bl are only for designating a potential use within the indicated CAMU boundary. The need for each facility along with its size and location will be determined during design. In all cases, the facilities

must be located within the CAMU boundary shown in Figure B1 Once the required areal extent of the CAMU facilities has been calculated, phased construction requirements will be analyzed

2.3 Phased Construction Document Preparation

The individual CAMU cells and facilities will be constructed over a multi-year period and the individual construction-level design drawings will be prepared and submitted to CDPHE for approval over the same multi-year time period The design will typically include a series of drawings to show the phased development of the CAMU from initial construction through final closure The phased construction drawings will contain sufficient detail to determine the required areas and location of the various CAMU facilities (cells, roadways, treatment units, drainage channels, etc) These phased development drawings will typically show the facilities to be constructed or closed as part of a given phase and the pertinent run-on/runoff controls for that phase

3.0 LANDFILL FOUNDATION AND LINING SYSTEMS

This section outlines significant design considerations for the design of the landfill foundations and lining systems Design parameters for foundations and lining systems are presented in Table B1 This section does not include landfill cover system design, which is discussed in Section 4 0 This section follows the format of Section 2 0, 3 0, and 4 0 of the previously referenced "Guide to Technical Resources for the Design of Land Disposal Facilities (EPA, 1988) "

3.1 Foundations

The landfill foundation design will include (as appropriate) an assessment for, and calculated estimates of settlement, compression, consolidation, bearing capacity, shear failure, uplifts, liquefaction of the foundation soil, and the effect, if any, of hydraulic and gas pressures on the foundation This analysis will include pertinent geologic, geotechnical, hydrogeologic, and seismic information Foundation design will address the potential for soft-spots or unsuitable soil in foundation subgrade areas Subgrade evaluations will be performed, methodologies may include proof rolling, visual observation and soil mapping The subsections below provide additional detail on the type of information typically needed and the individual analyses typically performed

3.1.1 Design Parameters

The design of the individual landfill cells will include an analysis of the expected foundation conditions and the potential effect of foundation movement on the landfill components The design parameters for the foundation design are presented in Table B1

3.1.2 Site Investigation and Laboratory Testing

An adequate site investigation is necessary to ensure that the foundation design will accommodate the expected foundation conditions A comprehensive site investigation, including field and laboratory work, was performed by HLA and was described in the report entitled "Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program" (FS Report) (HLA, 1995a) The FS

Report is attached to the CDD as Appendix R Also, additional field data are included in Appendix A, Part 2, Siting Compliance Demonstration

The available geotechnical, geological, and hydrogeological data should be reviewed during design to evaluate whether additional field and laboratory data are required to complete the foundation design If a geotechnical investigation is necessary to complete design, a work plan will be prepared and submitted to CDPHE for approval

3.1.3 Design Considerations

Design considerations relative to the landfill foundation design are presented below These considerations are discussed according to waste and structure, settlement, seepage and hydrostatic pressures, and bearing capacity

3.1.3.1 Waste and Structure

The majority of the foundation analyses will be a function of the foundation soil/bedrock properties, but the results of the analyses can be significantly influenced by the loadings assumed in the analyses The expected maximum loading on a landfill foundation is a function of the density of the waste/daily cover and lining components and the maximum height of the waste/daily cover and lining components placed over the foundation The actual waste density may vary significantly from waste stream to waste stream Because some of the landfill cells may contain significantly different waste than other cells, it is conceivable that the loadings, and thus the analytical results, may vary significantly from one cell to another The foundation design analysis will include estimates of the loadings, the landfill configuration, and the estimated waste characteristics and volumes

3.1.3.2 Settlement

An analysis of the total and differential settlement due to the maximum loadings will be performed as part of the foundation design The results of this analysis will then be used to evaluate the ability of the landfill components to maintain their integrity due to the additional stresses induced as a

result of the settlement/compression. In calculating the estimated settlements, evaluations of the settlements due to primary consolidation and secondary compression will be performed

Settlement analyses will be performed to assess the downward soil movement due to the stresses caused by the overlying landfill components (embankments, waste, liners, etc) Total settlements will typically be calculated for the toe, center, crest, and any other critical points of the load distributions for each distinct soil layer being loaded The settlements for each layer will then be summed to attain the total settlement at a particular point Differential settlements will then be calculated by subtracting the settlements between points

A conceptual settlement analysis of the foundation soil was performed to evaluate if the landfill can be designed to account for foundation settlement. This analysis was performed using available site data and assumptions using published data Conservative assumptions were used for the type of foundation soil, the height of the water table, and the premise that the water table may drop in the future The assumptions used in the analysis included

- Landfill cells will be excavated 30 feet below the natural ground surface
- Waste and cover components will be placed 30 feet above the natural ground surface
- Foundation soil will consist of 30 feet of clay overlying bedrock.
- Groundwater will be initially at the base of excavation and then drop 30 feet

The results of the analysis indicate that foundation settlement is expected to be less than 2 inches under the areas of maximum loading Thus, the estimated differential settlement within the foundation soil will be 2 inches or less The landfill components can be designed to account for this amount of differential settlement The complete calculation package, including assumptions and references, is included in Attachment B2

3.1.3.3 Seepage and Hydrostatic Pressures

Seepage into the landfill from groundwater is not anticipated due to the minimum groundwater separation of 20 feet. The results of the analysis conducted in Appendix A shows that the rate of advective movement of water from the landfill is negligible (<0 007 inches per year) The design will include an evaluation of whether the maximum leakage through the bottom liner (included in Appendix A) can provide pathways that may eventually result in failures from excessive differential settlement due to piping and soft spots Although not expected, if this evaluation results in an unacceptable conclusion, additional enhancements will be designed and incorporated into the construction requirements

The conceptual engineering analyses included in Attachment B2 include an analysis of the possible effect of excess hydrostatic pressure. The result of this analysis indicates that the groundwater will have to rise to a level approximately two times the liner thickness above the liner for the buoyancy effect of the hydrostatic pressure to be greater then the overburden pressure of the liner system As waste is placed over the liner system and the overburden pressure increased, the groundwater must rise even higher to have an effect. The potential impacts of hydrostatic pressures resulting from infiltration of surface water through piping channels will be evaluated and addressed, if applicable, during design

3.1.3.4 Bearing Capacity

For landfill cells, differential settlement is the major foundation concern. However, for specific components, primarily the sump areas and riser pipe pads, the bearing capacity of the underlying soil is also of concern An accurate estimate of the bearing capacity of the landfill foundation soil is necessary to properly estimate the amount of settlement to be expected under a given load distribution The foundation will be designed to ensure that the actual bearing stress is less than the bearing capacity of the foundation.

The analyses included in Attachment B2 includes a conceptual analysis of the calculated bearing capacity and the calculated loading using the assumptions developed as part of the conceptual foundation settlement analysis The results of this conceptual analysis indicate that the factor of safety against bearing capacity failure is 2 6

3.2 Embankment Integrity and Slope Stability

The individual CAMU landfill cells will likely be constructed above and below grade in the general configuration shown on Drawing C-7 in Attachment B1 Drawing C-7 does not currently reflect the construction of earthen embankments (dikes) as part of the landfill foundation. However, embankment construction may be incorporated into the design to some extent to meet the layout criteria described in Section 2 0 and to account for surface topography changes The landfill cell excavated slopes and embankments (if used) will be designed to ensure that they will be stable during the construction, operation, closure, and postclosure periods

The conceptual analyses included in Attachment B2 also include a slope stability analysis of the excavated cell slopes shown on the Drawings in Attachment B1 This analysis was performed using the computer program PCSTABLE5M developed by Purdue University and available site and published data The results of this analysis indicates factors of safety of 1 8 under static loads and 1 5 under pseudo-static (static and seismic) loads are obtainable Attachment B2 includes the data parameters, computer printouts, and assumptions of this analysis

Acceptable methodology for the analysis of the stability of the excavated slopes and embankments is discussed in the subsections below

3.2.1 Design Parameters

The design of the individual landfill cells will include an analysis of the stability of slopes and the integrity of earthen embankments constructed as part of a landfill cell foundation. The design

parameters for the analysis are incorporated in the general and foundation design parameters in Table B1

3.2.2 Site Investigation and Laboratory Testing

As discussed in Section 3 1 2, a site investigation and laboratory testing program has been performed and additional field and laboratory work may be performed to complete the detailed design of the landfill cells within the CAMU areal configuration. Appendix I to the CDD describes a laboratory testing program to be implemented for the construction and testing of a clay liner test fill Also, a report identifying potential borrow materials and their engineering properties entitled, "Final Feasibility Study Soils Support Program Report" (Borrow Study Report) (HLA, 1995b) is available for review at RMA Interface shear testing between the various components of the landfill lining system and various index and shear strength tests of the soil expected to be part of the landfill construction may also be performed This collective data will provide the designer with the necessary site-specific information to perform the stability analyses

3.2.3 Design Considerations

The stability of a slope is a function of the properties of the soil and other materials, such as geosynthetics, that comprise the slope, the configuration of the slope, and the hydraulic conditions of the slope The slopes designed for the landfill will typically be analyzed for stability against circular and translational failure Circular failure is movement about a curved slip surface approximated by a circle Translational failure is movement along one or more planes of weakness in a slope Additionally, the embankments and slopes will be analyzed as appropriate for stability against failure due to differential settlement, seepage-induced piping failure, and soft spots

Translational failure analyses will include both planar and wedge-type failures Both planar and wedge-type failure analyses will be performed for the lining systems on the slopes As discussed in Section 3 2 2, critical geosynthetic interfaces, soil/geosynthetic interfaces, and soil internal strengths may be estimated in the laboratory using site-specific materials The results of these tests, along with

published parameters, will be used in this analysis. The results of the analysis will be used in selecting the final type of geosynthetic (i.e., geocomposite or geotextile overlying geonet), grade of geosynthetic (i.e., textured or smooth geomembrane), and anchor trench/runout length design.

3.3 Lining Systems

The landfill lining systems will consist of the following from top to bottom:

- Protective soil layer
- A leachate collection system (LCS)
- An uppermost composite liner (FML overlying a CCL)
- A leak detection system (IDS)
- A lowermost composite liner
- A tertiary IDS (triple-lined cells only)
- A tertiary composite liner (triple-lined cells only)

The design parameters and methodology for theses components are discussed in the subsections below.

3.3.1 Design Parameters

As stated in Section 2.0, the Landfill CAMU boundary will contain one or more individual double-lined cells and **one triple-lined cell**. Conceptual cross sections of the double-and triple-lined cell lining components are shown on Drawing C-3 in Attachment Bl. The design parameters for lining systems are presented in Table Bl.

3.3.2 Design Considerations

The components of the double- and triple-lined cell lining systems can be divided into three groups, compacted clay liners (CCLs), flexible membrane liners (FMLs), and LCSs/LDSs. LCSs and LDSs are grouped together because the LCS and LDS performance standards and materials of construction are similar. The subsections below describes the purpose, design configuration and calculations, and material specification considerations for each of these groups.

3.3.2.1 Compacted Clay Liners

The design of CCLs can be divided into five groups site and material selection, thickness, hydraulic conductivity, strength and bearing capacity, and slope stability Site selection consists of selecting both the site on which the CCL will be constructed and the site from where the clay for the CCL will be obtained

The preliminary selection of the CCL material borrow sites and the required material properties have been completed and the results are summarized in the FS Report and the Borrow Study Report The Test Fill Construction Program presented in Appendix I, when completed, will finalize selection of the clay borrow site(s) and the CCL material property requirements The minimum overall thickness of the CCLs used in the cell lining systems will be 6 feet

The in situ hydraulic conductivity is the most important property of a CCL It is also the property that is the most dependent on construction procedures Appendix I presents a typical program for evaluating and establishing the required material properties and construction procedures Also, the hydraulic conductivity of CCLs using leachate of the quality expected in the landfill will be assessed as discussed in Section 3 3 3

The strength, bearing capacity, and slope stability of the CCLs and the foundations over which they are placed will be analyzed as part of the design to verify stability of the CCLs under the expected conditions Typical analyses for these parameters are discussed in Section 3 1 and 3.2

3.3.2.2 Flexible Membrane Liners

The results of the foundation analysis, slope stability analysis, CCL design, and the chemical compatibility testing will be used to select an appropriate FML and its required properties The chosen FML will demonstrate low permeability, chemical compatibility, and the required physical properties to meet the performance standards set forth in Table B1 The FML used will likely be a high density polyethylene (HDPE) liner due to its ability to meet the physical and chemical property

requirements and its proven performance history in similar applications Polyethylene FMLs with lower densities may be considered due to their elongation properties and lower coefficients of thermal expansion. An additional criterion in selecting the FML is the its ability to be installed (deployed, seamed, tested, repaired, and covered) with a high confidence in the quality of installation.

Chemical compatibility testing and evaluation using leachate of the quality expected for the landfill will be performed on the selected FML prior to completion of design. The procedures to be used are discussed in Section 3 4

The required physical properties, including thickness, strength, and frictional characteristics, will be selected through analysis The maximum differential settlements will be used to evaluate the required elongation properties The slope stability requirements will be used to select the minimum frictional characteristics and tensile strengths The expected installation and covering procedures, type of cover materials, magnitude and distribution of loadings (during construction, operation, and closure), along with the results of the foundation and slope stability analyses will be used to select the minimum thickness and associated strength properties

3.3.2.3 LCSs/LDSs

The LCS and LDS for each landfill cell will include the following

- A base sloped at a minimum of one percent
- A high permeability drainage layer consisting of either a granular layer or a geonet layer overlain by a filter geotextile
- Separate collection sump or sumps for each LCS and LDS that provide access for removal of any collected liquids
- Consideration of system flushing capabilities

The initial step in designing the LCS and LDS is typically to layout the components within the landfill cell Drawings C-3, C-4, and C-5 of Attachment B1 show typical LCS and LDS design

configurations Using the drawings and dimensions from the landfill layout plan, the dimensions, extent, and slopes for the system being designed, can be selected The expected settlement of the foundation and underlying CCLs will be analyzed to verify that the base slope will not be less than one percent at any time during the operational and postclosure period Adjustments will then be made to the base slope based on this analysis

The overall stability of side wall slopes using the expected system components will be analyzed and the stability of the individual system components will also be considered under the expected range of loading conditions Considerations for creep and collapse of geonets (if used) will be included in this analysis

As presented in Table B1, the performance standard for the LCS and LDS requires that these systems maintain less than 1 foot of leachate depth on top of each liner system throughout the active life and post-closure period The depth of liquid over the liner is a function of the impingement (percolation) rate into the liner, the base slope, the spacing of collection pipes (if used), and the LCS's and LDS's drainage capability (hydraulic conductivity or transmissivity) The ultimate design of the LDS to achieve this performance standard will allow calculation of the action leachate rate (ALR) for any given cell The ALR is the maximum design flow rate that the LDS can remove without fluid head on the bottom liner exceeding 1 foot The ALR will be included in a Response Action Plan (see Outline in Appendix N)

The impingement rate onto the LCS will be obtained from the Hydrologic Evaluation of Landfill Performance (HELP) computer model or similar computer program The other variables will be obtained from the layout of the LCS as discussed above These variables will then be used to analyze and modify the LCS design The HELP model may also be used to estimate head buildup above the uppermost composite liner for a variety of designs, time periods, and storm events The results will

then be used to verify that the head limitation will not be exceeded for the expected range of conditions

The LDS will be designed to collect and remove consolidation water from the overlying CCL, any potential leakage from the overlying liner, and to meet the general performance standards of the LCS The design of the LDS will be nearly identical to the LCS design except that the impingement rate will be a function of the amount of consolidation water plus the potential leakage rate estimated from the HELP or similar computer model As previously discussed, laboratory geotechnical testing will be performed as necessary to obtain the appropriate parameters to estimate the amount of consolidation water to be collected in the LDS As a precaution, the maximum flow capacity of the LDS will be equal to or greater than the maximum flow capacity of the LCS

The required strength of the components of the systems (both LCS and LDS) will also be analyzed under the expected range of loading conditions (including equipment loadings with minimal cover and material loadings after closure) The effects of the compressive loads on the drainage capability of the drainage layers and piping will be estimated prior to the specification of materials and construction procedures Transmissivity tests will be performed under the expected field conditions (boundary materials, loads, gradient) to confirm the design transmissivity value for the drainage layer Piping will be sized and specified based on the required flow capacity and the necessary strength requirements for the range of loading conditions The piping system will be designed to account for clogging potential

Perforated piping may be included in the LCS for rapid collection and removal of leachate and to provide the capability to flush the LCS Piping may also be incorporated into the LDS design if granular material is used as the drainage layer If granular materials are used, pipe perforations and/or filters will be designed to mitigate clogging of the pipe Adequate flow velocities for the piping will be designed to promote self-cleaning The design and selection of filter geotextile

properties will also be performed to minimize the potential for clogging from both physical and chemical processes

3.3.3 Chemical Compatibility

Chemical compatibility testing will be conducted for liner, leachate collection system, and sump materials The chemical compatibility of landfill components to leachate will be a consideration for the long-term integrity of the landfill Prior to development of the chemical compatibility testing program, the existing manufacturer's information and data from testing performed on the Pond A HDPE primary liner during closure of Pond A will be evaluated Initial assessment of material compatibility will be based on a review of existing leachate data and demonstrated properties of the landfill component being tested Standard testing protocols to assess the chemical effect on the hydraulic characteristics of geotextiles and geonets have not been developed Appropriate hydraulic chemical compatibility testing procedures for these materials will be developed and implemented during design General protocols provided below will be implemented for the mechanical chemical compatibility testing of geosynthetics and the hydraulic chemical compatibility testing of earthen materials prior to construction

Compatibility testing will typically consist of performing EPA Method 9090A testing on geosynthetic components (including pipes) and EPA Method 9100 testing on soil components EPA Method 9090A is performed by immersing an FML in a representative sample of leachate over a 120-day period and periodically measuring the physical properties of the test sample to analyze for deterioration due to the leachate immersion Although this test method was written for FMLs, the setup and immersion procedures can also be used for other geosynthetics In addition to measuring the physical properties, the testing program may be developed based on testing of the design function of the geosynthetic

Several of the EPA Method 9090A parameters have become outdated and even inappropriate for some FMLs, including HDPE FMLs Some laboratories recommend performing the test using modifications

or replacements to EPA Method 9090A. An alternate procedure is ASTM D5747-95 "Standard Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids "

EPA Method 9100 is performed by hydrating low permeability earthen materials (CCLs or geosynthetic clay liners [GCLs]) with representative leachate to access the effect of the leachate on hydraulic conductivity An alternate method is ASTM D5084-90 "Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter " GCLs and CCLs will typically be tested in accordance with the general guidelines of EPA Method 9100 and/or ASTM D5084 to ascertain the effect of leachate on the hydraulic conductivity of these materials Typically, the test will consist of hydrating the test sample with water, obtaining a hydraulic conductivity value for water only, and then passing a minimum of two pore volumes of leachate through the test sample and obtaining a hydraulic conductivity value for leachate This method will typically allow the designer to evaluate the effect of leachate on the hydraulic conductivity of the test sample Testing may also be performed using leachate as the only permeate to assess the leachate's effect on the swelling ability of the test sample

3.4 Construction Specifications

The design will set forth the material and procedural requirements for each component of the landfill construction These data will be incorporated into detailed construction specifications Typical earthwork and geosynthetic specifications are presented in Appendix P These typical specifications are provided to demonstrate that materials and methods are available for potential use that meet the design performance requirements outlined in this appendix. The specifications in Appendix P present the general content and format that will be included in the construction specifications During design, detailed construction specifications will be prepared based on engineering evaluations, additional data collection, and relevant technical considerations

The construction specifications will typically include material requirements, including quality control requirements for borrow soil, subgrade, geosynthetics, and other landfill components,

performance requirements during construction (such as compacted soil moisture/density requirements and seam strength requirements), and the procedural requirements during construction (e g , all seams will be nondestructively tested) Construction specifications will be submitted to CDPHE for approval prior to implementation

3.5 Construction Quality Assurance

An effective Construction Quality Assurance (CQA) program will be implemented to verify that the landfill is constructed as designed The CQA program will be described in a CQA Plan that will be completed prior to construction. The CQA plan will be submitted to CDPHE for approval prior to implementation

The CQA Plan will describe the CQA inspection and monitoring requirements, the CQA testing frequencies, the documentation requirements during construction, and the certification report requirements for each component of the landfill Appendix H presents an outline of a typical CQA Plan for the construction of the landfill portion of the CAMU This typical CQA Plan outline is intended to provide the reviewer with an example of the level of detail to be included in the CQA Plan developed prior to construction.

4.0 LANDFILL COVER SYSTEMS

This section presents the design parameters and general design considerations to be used for the design of the landfill cover systems Design parameters for the landfill cover systems are presented in Table B1 The landfill cover system will be a multi-layered system comprised of earthen and synthetic materials The design will incorporate erosion control, water balance, and biotic and infiltration barriers as the primary components The components and methodology described below may be modified during design Any modifications to the components and methodology described below will be subject to review and approval by CDPHE prior to implementation

Drawing C-8 shows the conceptual cover section that was agreed upon during the CAMU working sessions Each component of the cover system will perform a unique function and in some cases one component may serve multiple functions The components of the cover system are listed below from top to bottom

- Upper Soil Layer consisting of a
  - Vegetative/erosion protection layer overlying a
  - Water storage layer
- Biota Barrier/Capillary Break Layer
- Drainage Layer and/or Cushion Layer
- Composite Hydraulic Barrier
- Gas Venting System (if necessary)
- Prepared Subgrade

4.1 Design Parameters

The design parameters for the cover system are presented in Table B1

4.2 Design Considerations

Design considerations related to the cover system are presented in the following sections

4.2.1 Settlement

EPA guidance states that cover settlement is caused by primary consolidation and secondary compression Considerations for the settlement analysis will include the magnitude and distributions of the loadings, the expected percent of void space within the cell configuration of waste, the waste placement and compaction procedures, and the waste composition and structure (soil, containers, etc) The minimum slope of the cover system will be designed to account for settlement to maintain positive outward drainage The results of the settlement analysis will be used to select cover slopes, and configurations and to prepare the construction specifications

4.2.2 Slope Stability

The stability of the slope will be evaluated using the same procedure previously described for the cell lining systems The results of the stability analysis will also be used to select materials and slopes and to prepare the construction specifications

A conceptual analysis of the cover system slope stability under static and pseudo-static (static and seismic) loads using the computer program PCSTABLE5M was performed The results of this analysis indicated factors of safety of 2 8 for static loads and 2 2 for pseudo-static loads are obtainable Attachment B2 includes the data parameters, computer printouts, and assumptions of this analysis

4.2.3 Vegetation

The Conceptual Remedy states that the entire surface of the cover systems will be vegetated In some cases it may be necessary to use erosion control materials in conjunction with vegetation prior to vegetation of the entire surface The vegetated surface will be designed to provide surface stabilization/erosion control, enhanced transpiration and impact wildlife in a manner consistent with guidance from the FWS

The selection of vegetation species for the cover systems will be based on a mixture of desired characteristics based on input from the FWS and Soil Conservation Service (SCS) The selected vegetation species will provide an adequate root mass with a variation of root depths to remove moisture at differing levels of infiltration and will include some species that are drought resistant and some that resist damage from wind and water erosion Consideration will be given to species that establish rapidly in the spring to provide early protection and transpiration while other species are developing

4.2.4 Erosion Control Materials

Erosion control materials may be necessary prior to or during vegetation establishment and/or on steepened side slopes where the erosion analysis (discussed below) indicates that the soil/gravel admixture and vegetation together will not provide adequate long-term protection Erosion control materials may consist of gravel armoring, mats, or meshes using a combination of synthetic, earthen, or vegetative materials The erosion control materials are of significant benefit during the vegetation establishment period to protect bare slopes and prevent seed washout The erosion control materials will reduce erosion damage to barren slopes before vegetation establishes, but some may hinder the growth and consistency of the vegetation. This reduction in consistency of vegetation coverage may reduce the transpiration rate and the loss of root mass may reduce the long-term soil stability achieved from the root binding mechanism Therefore, after adequate initial vegetation is established, the erosion control materials may be eliminated and efforts concentrated toward the establishment of adequate long-term vegetation

4.2.5 Vegetative/Erosion Protection Layer

A preliminary analysis of the uppermost soil layer of the cover system was performed to assess its ability to resist damage from the erosive effects of wind and water This analysis assumed topsoil similar to that present in the landfill area would be used on the cover systems This preliminary analysis indicated that once consistent vegetation is established, the native soil and vegetation will provide adequate performance Because erosion control is an important consideration in the Part 2,

1,000-year demonstration (see Appendix A), natural erosion control measures for unvegetated areas should be incorporated into the design Vegetative monitoring using reference areas and statistical analysis will be performed to evaluate areas vegetated during implementation of the CAMU.

Gravel mixed with topsoil improves erosion resistance A soil/gravel admixture will gradually lose fines, thus leaving the gravel exposed The exposed gravel forms a "desert pavement" increasing the erosion resistance of unvegetated areas of the cover systems Desert pavement formation has be attributed to three processes concentration of stones by wind deflation, concentration of stones by runoff erosion, and concentration of stones by upward migration (Waugh et al , 1988)

4.2.5.1 Erosion Resistance

The design of the cover system will include an analysis of the effects of erosion (both wind and water) on the cover surface The erosion analysis will include calculations for the estimated soil loss due to wind and water erosion over the 1,000-year design life Precipitation event data used in the analyses will be consistent with the data given in the Urban Stormwater Drainage Criteria Manual (USDCM) and/or other appropriate references (Denver Regional Council of Governments, 1969 [updated]) The cover system will be designed such that the estimated soil loss does not exceed the EPA-recommended 2-tons/acre/year and that the vegetative/erosion control layer is of sufficient thickness that a portion of this layer will remain after 1,000 years

Calculation methods that are currently available that may be used are listed below

- The total depth of soil loss due to wind erosion over 1,000 years may be calculated using the wind erosion equation and parameters given in the National Agronomy Manual, or other appropriate reference
- To calculate the total depth of soil loss due to water erosion over 1,000 years, the Revised Universal Soil Loss Equation (RUSLE), Version 1.04 or later, or other suitable method may be used RUSLE is a revision and update of the universal soil loss equation (USLE). RUSLE retains the equation structure of the USLE, but each of its factor relationships has been either updated with recent data, or new relationships have been derived based on modern erosion theory and data

- The design should also consider the vegetative layer's resistance to gully erosion for both the top and side slopes

4.2.6 Water Storage Layer

Directly below the vegetative/erosion protection layer is the water storage layer This layer consists of fine-grained soil with a primary function of providing water storage to nourish the vegetation root mass and to provide adequate soil depth for the establishment of the root system The Ascalon soil series native to RMA have an available water capacity of 0 13 to 0 15 inch per inch and the Platner soil series, also native to RMA, have an available water capacity of 0 14 to 0 18 inch per inch Both of these soil types should provide adequate water retention capabilities

The design of the water storage layer will define the optimum thickness of the water storage layer to contain extreme precipitation events for which maximum infiltration may occur The HELP model or similar program will be used to calculate the percent of the infiltrated moisture that would be retained in the top 48-inches of the cover system The results of this modeling will be used to estimate whether the retained moisture is adequate to sustain vegetation and minimize the amount of infiltration that reaches the underlying composite hydraulic barrier

For frost protection, the cover system design will provide a minimum thickness of 42 inches of cover over any CCL in the cover system For example, the minimum thickness of the upper components in the cover system shown in the conceptual cover system (Drawing C-8) is 60 inches (48-inch minimum soil layer for root growth and 12-inch minimum biota layer)

4.2.7 Geotextile

The conceptual cover (Drawing C-8) proposes a geotextile between the fine-grained soil and the underlying biota layer This geotextile serves the primary functions of filtration and separation Segregation must be maintained between the overlying fine-grained soil of the water storage layer and the underlying large rock layer in order for a capillary break to function properly

The geotextile will be selected during design based on its filtration characteristics, frictional characteristics, puncture resistance, and tensile strength The geotextile design considerations include resistance to puncture and tear because it will be placed directly over rock and subjected to equipment loadings during the construction of the remainder of the cover system

4.2.8 Biota Barrier/Capillary Break Layer

The primary functions of this layer are to deter animal intrusion into the underlying drainage layer and composite hydraulic barrier and to provide for a capillary break. A capillary break is essential in minimizing the amount of infiltration that reaches the composite hydraulic barrier A capillary break is formed when there is a large differential in air void size between two materials When soils are unsaturated, atmospheric pressures exceed the soil capillary pressures Moisture is retained in the fine-grained soil due to surface tension between the fine particles and the increased atmospheric pressure of the large voids in the rock layer The fine-grained soil must become saturated before moisture will break through the capillary barrier The composition, size, and angularity of the aggregate used in the biota barrier will be chosen based on the durability of the rock, the potential for damage to surrounding geosynthetics, and the size and burrowing habits of the local animal species The size (weight) of the rocks will be chosen based on the weight of an average animal of the species the FWS anticipates may pose a burrowing problem Angularity of the aggregate will be selected to form an interlocking-bridging action that will make it difficult for animals to burrow, yet minimize the potential for damage to adjacent geosynthetics The overall thickness of the biota barrier will be selected to allow adequate interlock

A secondary function of the biota barrier/capillary break layer will be to deter plant intrusion Research conducted at the Los Alamos National Laboratory indicates that plant roots are discouraged by the large air void spaces and lack of moisture present in this layer Roots penetrate downward in search of moisture Therefore, after reaching certain depths with no moisture reserve, the roots will be discouraged and stop growing deeper This protects the underlying drainage layer from becoming clogged from root growth.

4.2.9 Drainage Layer and/or Cushion Layer

As a redundant system, a drainage layer may be provided The biota/capillary break layer discussed in Section 4 2 8 may also serve as the drainage layer If a separate drainage layer is utilized, it will typically consist of a sloped lateral drainage layer placed above the cover system's composite hydraulic barrier (FML and overlying a CCL or GCL) and will be designed to remove infiltration from above the composite hydraulic barrier

The drainage layer will typically consist of one of the components listed in Section 3 3 2 3 The design considerations that will determine the drainage material selection include

- The frictional characteristics based on slope stability requirements
- Transmissivity/permeability based on the expected amount of infiltration and the slope of the drainage layer
- Strain characteristics based on the expected amount of differential settlement.
- The compressive, tensile, and puncture strength characteristics based on the expected construction and post-construction conditions
- The cushioning characteristics based on the expected loadings and the angularity of the biota barrier rocks

As indicated above, the biota barrier/capillary break layer may also be designed to function as a drainage layer If this option is selected by the designer, the layer discussed in this section will serve only as a cushion between the biota barrier and the FML

4.2.9.1 Cover Toe Drain

The toe drain will be designed to collect the lateral flow from the cover drainage layer and transport the flow to a point of discharge in a controlled manner The drain will be sized to carry the maximum flows anticipated over the design life

4.2.10 Flexible Membrane Liner

The FML component of the composite hydraulic barrier will provide the primary hydraulic barrier to prevent moisture migration downward The FML will be chosen to provide suitable properties over

the long-term design life of this cover system The selection of the FML will be dependent on the results of the slope stability, settlement, and other design considerations given in Section 3 3 Chemical compatibility may be a design consideration if the FML is in contact with waste material

4.2.11 Compacted Clay Liner/Geosynthetic Clay Liner

A CCL or a GCL will be the lower component of the composite hydraulic barrier The design considerations for this layer are typically the same as for CCLs or GCLs used in the cell lining systems (see Section 3 3) excluding considerations for chemical compatibility Chemical compatibility may also be a design consideration if the CCL or GCL is in contact with waste material

4.2.12 Gas Venting System

The amount of expected gas generation, if any, will be estimated during design Depending on the expected gas generation rate of the material being covered, a gas venting system may be incorporated into the cover system This system would collect and remove gases that may migrate upward through the waste The gas venting system will consist of a collection layer attached to vents that will penetrate the cover system The collection layer will typically consist of synthetic and/or earthen materials capable of capturing and directing gas flows out of the landfill Chemical compatibility of gas venting system components may be a design consideration The lateral extent of the collection layer may or may not cover the entire cell surface The lateral extent of the collection layer will be determined during design based on the expected gas generation rates

4.3 Construction Specifications

The design will set forth the material and procedural requirements for each component of the cover system construction These data will be incorporated into detailed construction specifications The cover system construction specifications may or may not be combined with the landfill construction specifications Typical earthwork and geosynthetic specifications are presented in Appendix P. These typical specifications are provided to demonstrate that materials and methods are available for potential use that meet the design performance standards outlined in this appendix The specifications in Appendix P typify the level of detail to be included in the construction specifications

The construction specifications will typically consist of material requirements, including quality control requirements for borrow soil, geosynthetics, and other cover components, performance requirements during construction (i e , compacted soil moisture/density requirements, seam strength requirements), and the procedural requirements during construction (e g , all seams will be nondestructively tested) Construction specifications will be submitted to CDPHE for approval prior to implementation

4.4 Construction Quality Assurance (CQA)

An effective CQA program will be implemented to verify that the cover system is constructed as designed The CQA program will be described in a CQA Plan that will be completed prior to construction The cover system CQA Plan may or may not be combined with the landfill construction CQA Plan. The CQA Plan will describe the CQA inspection and monitoring requirements, the CQA testing frequencies, the documentation requirements during construction, and the certification report requirements for each component of the cover system Appendix H presents an outline of a typical CQA Plan for the construction of the cover systems within the CAMU This typical CQA Plan outline is intended to provide the reviewer with an example of the level of detail to be included in the final CQA Plan The CQA Plan will be submitted to CDPHE for approval prior to implementation

5.0 RUN-ON/RUNOFF CONTROL SYSTEMS

Surface-water management within the CAMU is necessary to prevent the flow of water onto contaminated areas (run-on), the flow of water off contaminated areas (runoff), and to minimize the effect of erosion on the design performance of the CAMU Surface-water management will be provided through the use of channels, culverts, and other drainage structures This section provides the design parameters and considerations for the CAMU run-on/runoff control system Design parameters for the run-on/runoff control systems are presented in Table B1

5.1 Design Parameters

The design parameters for run-on/runoff control systems are as follows

- Performance Standards
  - Design, construct, operate and maintain
    - o A run-on control system capable of preventing flow onto the active portion of the landfill during peak discharge from at least a 100-year storm
    - o A runoff management system to collect and control at least the water volume resulting from a 24-hour, 100-year storm
- Design Guidance/Alternatives
  - Control systems should typically be sized to contain both the peak discharge of a 100-year storm (which typically results from a storm duration of less than 24 hours) and the volume of water resulting from a 100-year, 24-hour storm
  - The general methodology, parameters, and criteria given in the USDCM should be complied with in the systems design.

5.2 Design Considerations

The basis for the design of the run-on control system is to prevent drainage of surface water onto active waste management areas The active waste management areas will consist of open landfill cells, waste staging/consolidation areas, and possibly the decontamination area(s) The control system will include channels, berms, and other diversions as necessary The run-on will be directed out of the CAMU into the existing drainage near the northern boundary of the CAMU The run-on

control system will be sized to carry the peak discharge from the appropriate duration 100-year storm

The runoff control systems will be typically sized to carry the peak flows and at least the volume of water resulting from a 100-year, 24-hour storm The basis for the design of the runoff control systems is also to segregate runoff of surface water that could potentially come into contact with waste from surface runoff from uncontaminated areas The runoff control system will include channels, berms, and other diversions as necessary The potentially contaminated runoff will be directed to retention pond(s) located within the CAMU Contaminated runoff will be treated onsite or sent offsite for disposal in accordance with applicable regulations

As agreed in the CAMU working sessions, the primary design reference for the design of the run-on/ runoff control system will be USDCM (Denver Regional Council of Governments, 1969 [updated]) This comprehensive three-volume document provides methodology, criteria, and parameters specific to the Denver area for the design of surface-water management systems, including channels, culverts, retention ponds, erosion control, and other surface-water control structures

6.0 WASTE STAGING/CONSOLIDATION AREAS

Construction staging areas will be used for temporary staging, material sizing and/or storage of soil/debris between processing steps or to temporarily stockpile soil for transport The waste staging/consolidation area at the landfill may include size reduction equipment to improve handling, placement, and compaction characteristics of the waste Preliminary staging areas may be used at the Basin F Waste Pile and the landfill The locations are preliminary and may be revised during the design.

The waste staging/consolidation areas will be designed to prevent release of potentially contaminated solids, liquids and vapors to the environment through the use of liners, covers, containment systems, run-on and runoff controls, and vapor containment/treatment systems (e g , covers or temporary structures with ventilation and vapor treatment equipment) as necessary The components of the waste staging/consolidation areas will be designed to meet the regulatory requirements that are applicable to that component

7.0 LEACHATE MANAGEMENT SYSTEMS

Leachate generated from the landfill will be temporarily stored and either sent offsite for disposal or treated in an onsite treatment system in accordance with all applicable regulations The onsite storage and/or treatment system will be designed in accordance with applicable regulatory requirements

8.0 DECONTAMINATION FACILITIES

Decontamination facilities will be constructed to decontaminate construction and operation equipment Decontamination facilities will potentially be located in the vicinity of the Basin F Waste Pile and the landfill The landfill decontamination facilities will be designed to decontaminate, as necessary, equipment leaving areas of contamination and will be used over a multi-year period extending from landfill construction to closure Decontamination facilities that may be associated with the Basin F Waste Pile closure will be designed to decontaminate, as necessary, equipment leaving the excavation to transport waste to the landfill These facilities will have shorter operating lives than the landfill facility and will use materials and construction methods commensurate with their operating lifespan.

Decontamination facilities will typically be equipped with a pressure washer, mechanical scrubbing equipment (e g , brushes), concrete or geomembrane liner decontamination pad, wash water collection sump, wash water transfer equipment, and wash water storage and treatment equipment Pressure washers and brushes may be used to remove contaminated material from equipment and personnel leaving areas containing potentially contaminated material Wash water will be appropriately managed onsite or offsite Solids collected during decontamination will be dried to pass the paint filter test and placed in the landfill

Decontamination facilities will be designed to prevent release of potentially contaminated wash water to the environment through the use of containment curbs, collection sumps and splash containment Tank systems that will be designed to meet applicable regulatory requirements may include a waste water storage tank, settling tank and detergent/chemical storage tanks

9.0 BASIN F WASTE PILE DRYING UNIT

A drying unit will be constructed to dry Basin F Waste Pile solids that do not pass the paint filter test before placement into the triple-lined cell(s) of the landfill There are approximately 600,000 cubic yards (cy) of Basin F materials that will be placed into the landfill An estimated 100,000 cy of waste pile materials are assumed to require drying prior to placement in the landfill (Foster Wheeler, 1995) As described in the DAA, the drying system may consist of a direct or indirect-fired heating unit used to increase the soil temperature and drive off moisture The off-gases from the dryer will be collected and treated

The drying unit will be designed to prevent release of potentially contaminated solids, liquids, and vapors to the environment through the use of containment systems, run-on and runoff controls, and vapor treatment systems, as necessary Components of the drying unit will meet the regulatory requirements that are applicable to that particular component.

10.0 ACRONYMS

Army	U.S Department of the Army
Borrow Study Report	Final Feasibility Study Soils Support Program Report
CAMU	Corrective Action Management Unit
CCL	Compacted clay liner
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
cm/s	centimeters per second
COE	U S Army Corps of Engineers
Conceptual Remedy	Agreement for the Cleanup of Rocky Mountain Arsenal
CQA	Construction Quality Assurance
cy	Cubic yards
DAA	Final Detailed Analysis of Alternatives
EPA	U.S Environmental Protection Agency
EPA Design Resource Guide	Guide to Technical Resources for the Design of Land Disposal Facilities
FFA	Federal Facilities Agreement
FML	Flexible membrane liner
FS Report	Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program
FWS	U S Fish and Wildlife Service
GCL	Geosynthetic clay liner
HELP	Hydrologic Evaluation of Landfill Performance
HLA	Harding Lawson Associates
LCS	Leachate Collection System
LDS	Leak Detection System
RMA	Rocky Mountain Arsenal
RUSLE	Revised Universal Soil Loss Equation

Shell	Shell Chemical Company
SCS	Soil Conservation Service
State	State of Colorado
USCS	Unified Soils Classification System
USDCM	Urban Stormwater Drainage Criteria Manual
USLE	Universal Soil Loss Equation

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Table B1: CAMU Landfill Design Parameters

	Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
1	**Layout of CAMU Landfill Development Area**	Individual cell layout and size	Balance minimizing land area on which waste will remain after closure and maintaining minimum 20-foot depth to groundwater Provide compatible scheduling of landfill capacity versus waste generation Provide for flexible expansion of landfill cell volume within the defined CAMU footprint	Applicable portions of the Conceptual Remedy and CAMU regulations	Technical feasibility and review of layout concepts by the parties, followed by detailed design analysis of the selected layout configuration	To be determined following design analysis
2	**Foundations**	Site geology/ engineering characterization			Geotechnical index parameters, geological profiles, representative construction drawings (plans and specifications)	
		Settlement (total and differential)/ consolidation	Prevent failure of the liner and other landfill components due to settlement and subsidence	Address the potential for a falling groundwater table	Engineering analysis	Allowable settlement to be selected following analysis
		Bearing capacity	Prevent failure of the liner and other landfill components from failure due to loading		Engineering analysis	Allowable settlement to be selected following analysis
		Potential for excess hydrostatic pressure	Prevent failures due to hydrostatic pressure	Evaluate hydrostatic pressure caused by groundwater or infiltration of surface water as applicable	Engineering analysis	To be selected following analysis
		Seismic considerations	Building and earthen structures will withstand seismic stresses		Engineering analysis	To be selected following analysis
3	**Slope Stability**	Cover slopes	Prevent failure of the landfill cover components.		Engineering analysis	To be selected following analysis
		Excavated and constructed slopes	Prevent slope failure during excavation cell construction and waste placement		Engineering analysis	To be selected following analysis.

Table B1 (continued)

	Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
4	Landfill Liner Systems (also see requirements for (2) foundations and (3) slope stability)	Composite liners general	Reduce potential for contaminant transport from the landfill and design leachate removal components to maintain a leachate depth less than 1 foot over the liner Provide natural and synthetic materials that are compatible with expected waste generated leachate	Double or triple lined cells as outlined in the applicable portions of the Conceptual Remedy	Standard practice and engineering analysis Compatibility testing.	The total cumulative thickness of CCL within the multiple liner system will be a minimum of 6 feet thick Two composite liners, each of which consists of a minimum 3 feet thick CCL and 60-mil minimum FML on top will be provided An alternative design thickness for the top CCL may be allowed with supporting equivalence demonstration if the total minimum CCL thickness remains 6 feet and if the minimum thickness of the bottom CCL remains 3 feet
		Lowermost composite liner				Composite liner will consist of a minimum 3 foot thick CCL with a minimum 60-mil FMI on top
		Uppermost composite liner				Composite liner will consist of a minimum 3 foot thick CCL with a minimum 60 mil FML on top An alternative design thickness for the top CCL may be allowed with supporting equivalence demonstration if the total minimum CCL thickness remains 6-feet and if the minimum thickness of the bottom CCL remains 3 feet
		Tertiary composite liner				Composite liner shall consist of a minimum 3 feet thick CCL with a minimum 60-mil FML on top An alternative material and thickness in lieu of CCL, may be considered based on a supporting demonstration of engineering performance
		Borrow/clay liner material	Provide sufficient quantity of satisfactory material at a rate that is sufficient to meet the construction schedule. Provide material that is compatible with leachate	$K \leq 1 \times 10^{-7}$ cm/s Geotechnical index parameters for the clay liner materials will fall within a range considered by the test fill analysis	Index testing. Testfill analysis for conductivity constructability water content alterations, scarification requirements, and methods of amending soil if required Engineering analysis of bearing capacity, settlement, and slope stability, compatibility testing, and evaluation.	To be selected following analysis

Table B1 (continued)

Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
	Subgrade (excavated sideslopes)	Provide stable foundation capable of providing support to the lining system and resistance to pressure above and below the liner to prevent liner system failure due to settlement, compression, or uplift	Evaluate the potential for and develop, if necessary, methods to prevent hydrostatic failure during construction and waste placement Provide a suitable subgrade free of soft spots, organics, or unsuitable materials Subgrade evaluations will be performed Methods such as proof rolling, visual observation or soil mapping may be employed to evaluate subgrade condition	Engineering analysis of slope stability, bearing capacity, constructability, hydrostatic failure, and suitability of subgrade materials. Subgrade and borrow source suitability will be verified using methods identified during design that may include soil mapping, soil classification, and grain size analysis	To be selected following analysis
	Subgrade (bottom)	Provide stable foundation capable of providing support to the lining system and resistance to pressure above and below the liner to prevent liner system failure due to settlement, compression, or uplift	Evaluate the potential for hydrostatic failure Develop if necessary, methods to prevent foundation failure due to excess hydrostatic pressure during construction and waste placement Provide a suitable subgrade free of soft spots, organics, or unsuitable materials Subgrade evaluations will be performed Methods such as proof rolling, visual observation, or soil mapping may be employed to evaluate subgrade condition Provide materials for backfill that are finer than SM Abandoned wells and borings should be addressed to remove a potential migration pathway Recompacted backfill in the subgrade should be placed to provide a surface with adequate settlement and bearing capacity properties	Engineering analysis of settlement, bearing capacity, buildup of hydrostatic pressure and suitability of subgrade materials	Remove a minimum of 3 feet of soil coarser than SM and replace with structural fill that classifies as finer than SM
	Leachate collection system, general	Maintain less than 1 foot of leachate on the underlying liners throughout the active life and postclosure period Prevent failure of the LCS due to settlement, loading, waste incompatibility and clogging throughout the active life and post closure period	Design system to maintain minimum 1 percent slope and control clogging. Approaches to mitigate clogging will be evaluated during design and may include filtration, flushing, etc	Engineering analysis Chemical compatibility evaluation and testing of leachate collection system components to demonstrate long-term performance	To be selected following analysis.
	Leachate collection system, granular material	Maintain less than 1 foot of leachate on the immediate underlying FML.	Provide granular material which has a hydraulic conductivity ≥0.01 cm/s.	Engineering analysis Demonstrate selected granular material will provide adequate drainage under surcharge	To be selected following analysis.

Table B1 (continued)

Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
	Leachate collection system synthetic material	Maintain less than 1 foot of leachate on the immediate underlying FML	Use of a geotextile to prevent silting Use of a geonet with a transmissivity $\geq 3x10^{-4}$ sq m/s	Engineering analysis Performance of synthetics as the only drainage material will require a demonstration that synthetic drainage material provides equivalent performance to granular material Demonstrate adequate performance under surcharge	To be selected following analysis
	Leachate collection system, piping system	To the extent necessary to drain the LCS to maintain less than 1 foot of leachate on the immediate underlying FML, provide for drainage of the granular or synthetic drainage media	Prevent clogging through design and maintenance of self flushing flow velocities	Engineering analysis of leachate flow velocities	To be selected following analysis
	Leachate collection system sump	Allow for removal and measurement of leachate		Engineering analysis of leachate flow velocities, accessibility and constructability	To be selected following analysis
	Leak detection system	Meet the above performance standards for the leachate collection system	Applicable guidance presented above for the leachate collection system	Applicable engineering analysis presented above for the leachate collection system.	To be selected following analysis
	FML	Reduce the area on which the leachate head pressure is imposed on the underlying CCL. Provide material that is compatible with the leachate	60-mil minimum thickness	Engineering analysis of material properties to match the design stresses Compatibility evaluation and testing.	To be selected following analysis Minimum 60-mil thickness
	Protective soil layer	Protect the liner from frost and construction damage	Thickness $\geq$42 inches for frost protection in Colorado, may consist of contaminated soil that is free of deleterious substances		To be selected following analysis.
5 Covers	General	Accommodate settlement to maintain cover integrity and promote gravity drainage to the perimeter Maintain final slopes and vegetative covers	EPA Cover Guidance	Engineering analysis of slope stability settlement, bearing capacity, seismic pressures, gas migration, erosional effects (wind and water), to evaluate long-term performance	Configuration to be finalized following analysis
	Vegetation	Final cover slopes will be revegetated	Appropriate portions of the conceptual remedy Select species to provide for adaptive, even distribution of vegetation with long term resistance to disease and plant succession.	Identification of vegetation that meets requirements	To be selected following analysis

Table B1 (continued)

Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
	Upper vegetative soil layer	Provide an evapotranspiration layer protect lower cover components from erosion effects and freeze/thaw cycles and provide for retention of infiltration	Appropriate portions of the Conceptual Remedy and DAA (minimum thickness of 48 inches)	Engineering analysis of vegetation evapotranspiration, erosion, and water storage	To be selected following analysis
	Biota barrier/ capillary break	Minimize burrowing animal and plant root intrusion into underlying layers of the cover Provide a capillary break to reduce the amount of infiltration reaching the drainage layer and increase moisture retention in the water storage layer		Material composition to be selected through engineering analysis of cover material	To be selected following analysis
	Drainage layer	Maximize gravity drainage of infiltration from the cover Protect cover FML from biota barrier during construction	$K \geq 1x10^{2}$ cm/s	Engineering analysis of drainage through cover Engineering analysis to demonstrate flow velocities in piping will promote self cleaning and reduce clogging Combine with biota barrier if engineering analysis indicates that biota layer will function adequately as a drainage layer	To be selected following analysis
	FML	See standards for liner system Compatibility evaluations may be required			
	Clay liner	Minimize infiltration into the underlying waste	Minimum 2 feet of clay with $K \leq 1x10^{7}$ cm/s	Engineering analysis to determine suitability of clay material	To be selected following analysis An alternative for the clay in the low permeability layer may be considered based on a demonstration acceptable to the CDPHE that engineering performance of alternative materials is equivalent to cover designs using a CCL/FML composite design
	Gas venting system	Prevent the development of landfill gas pressure that would impact the integrity of the landfill cover		Engineering analysis of gas production rates and required gas permeability of the venting system	To be selected following analysis
	Cover subgrade	Provide a stable surface for installation of the cover		Engineering analysis to select required thickness and material	To be selected following analysis

Table B1 (continued)

	Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
6	Run On/Runoff	General	Provide run on control system capable of preventing flow onto the active portion of the landfill during peak discharge from at least a 100-year storm Provide a runoff management system to collect and control at least the water volume resulting from a 24 hour 100 year storm		Engineering drawings profiles and calculations to size system including estimates of peak flow rates erosion potential management of water systems separation of run-on and runoff provisions for retention of runoff	To be selected following analysis

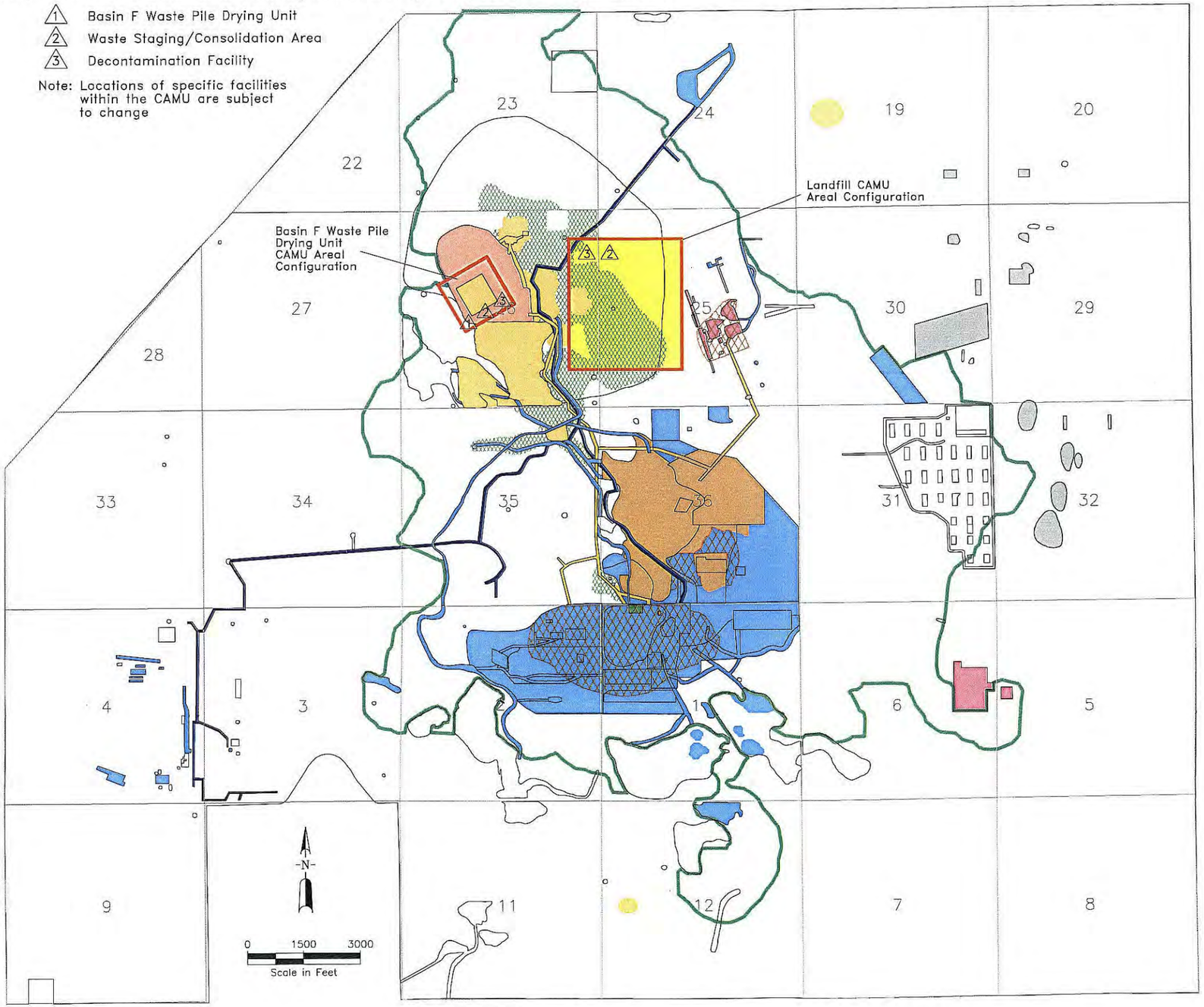
CAMU Corrective Action Management Unit
CCL Compacted clay liner
CDPHE Colorado Department of Public Health and Environment
cm/s Centimeters per second
DAA Detailed Analysis of Alternatives Version 4 1 Foster Wheeler, October 1995
FML Flexible membrane liner
ft Feet
K Hydraulic conductivity
LCS Leachate collection system
SM Silty sand (Unified Soil Classification System)
sq m/s Square meters per second

a Performance standard an objective for design that is based on a regulatory requirement regulatory guidance and/or standard practice
b Design guidance standard engineering practice reference manuals and design elements that have been identified in regulatory guidance or have been demonstrated by past practice to meet the performance standards
c Design parameter demonstration analysis required to demonstrate that the design criteria will provide for conformance with the design guidance and the performance standard
d. Resultant design criteria specific elements of design that have been shown by supporting analytical demonstration to meet the related performance standard

Facilities within Corrective Action Management Unit (CAMU) Areal Configuration

1 Basin F Waste Pile Drying Unit
2 Waste Staging/Consolidation Area
3 Decontamination Facility

Note: Locations of specific facilities within the CAMU are subject to change



Explanation

- Arsenal Boundary
- Study Area Report Boundary
- Area of Contamination Boundary
- CAMU Areal Configuration
- Landfill Principal Threat Volume; RCRA–Equivalent Cap
- Caps/Covers
- Direct Solidification/Stabilization
- Hex Pit Excavation
- Landfill Human Health Soil,[1] Consolidation of Biota Soil
- Landfill Human Health Soil[2]
- Landfill Site
- Soil Covers
- Agent Screening Area (Caustic wash/landfill)
- Unexploded Ordnance Screening Area (Detonation/landfill)
- Surficial Soil Consolidation
- Access Restrictions
- 5 Section Number

[1] Refuse from the Sanitary Landfills Medium Group will be consolidated

[2] Wastepile material will be dried prior to landfilling if paint filter test is failed

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by: Tetra Tech EC Inc.

Figure B1

Proposed Corrrective Action Management Unit Areal Configuration
Rocky Mountain Arsenal

Attachment B1

CONCEPTUAL DESIGN DRAWINGS

ROCKY MOUNTAIN ARSENAL
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS
TASK 93-03

ADAMS COUNTY, COLORADO

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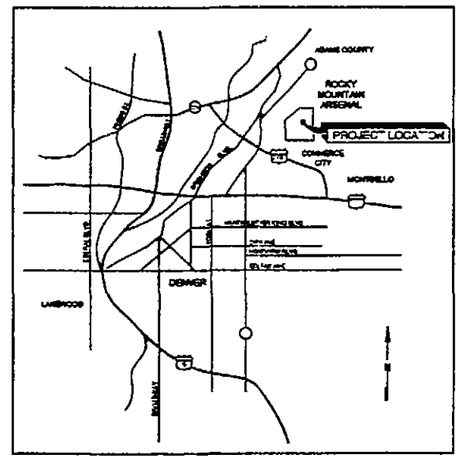
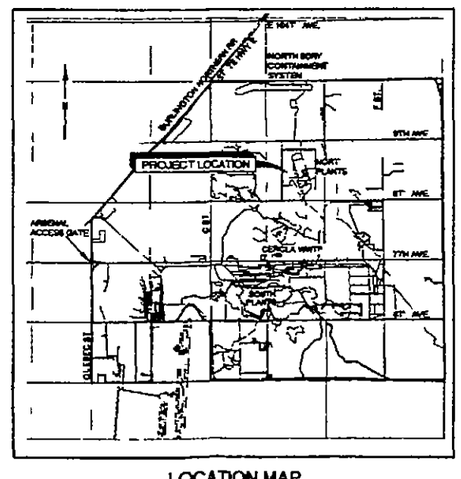


VICINITY MAP
NTS



LOCATION MAP
NTS

PREPARED FOR

PROGRAM MANAGER FOR
ROCKY MOUNTAIN ARSENAL
BUILDING 111
COMMERCE CITY, COLORADO 80022

PREPARED BY

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PRIMARY CONTACT RICK L KINSHELLA, P E
SECONDARY CONTACT ROBERT A FARRIS

DRAWING INDEX

DRAWING NO.	TITLE	SHEET NO
GENERAL		
G-1	COVER SHEET (TITLE, MAPS, DRAWING INDEX, CONTACTS)	1 OF 11
CIVIL		
C-1	1995 EXISTING SITE CONDITIONS AND CAMU BOUNDARY	2 OF 11
C-2	TYPICAL CELL PLAN	3 OF 11
C-3	TYPICAL CELL LINER SYSTEM SECTIONS AND DETAILS	4 OF 11
C-4	TYPICAL LEACHATE COLLECTION SYSTEM SECTIONS AND DETAILS	5 OF 11
C-5	TYPICAL LEACHATE COLLECTION SYSTEM SECTIONS AND DETAILS	6 OF 11
C-6	TYPICAL FINAL COVER PLAN	7 OF 11
C-7	TYPICAL CELL AND COVER CROSS-SECTIONS	8 OF 11
C-8	TYPICAL COVER SECTION	9 OF 11
C-9	TYPICAL SITE DRAINAGE PLAN	10 OF 11
C-10	TYPICAL SITE DRAINAGE PLANS, SECTIONS AND DETAILS	11 OF 11

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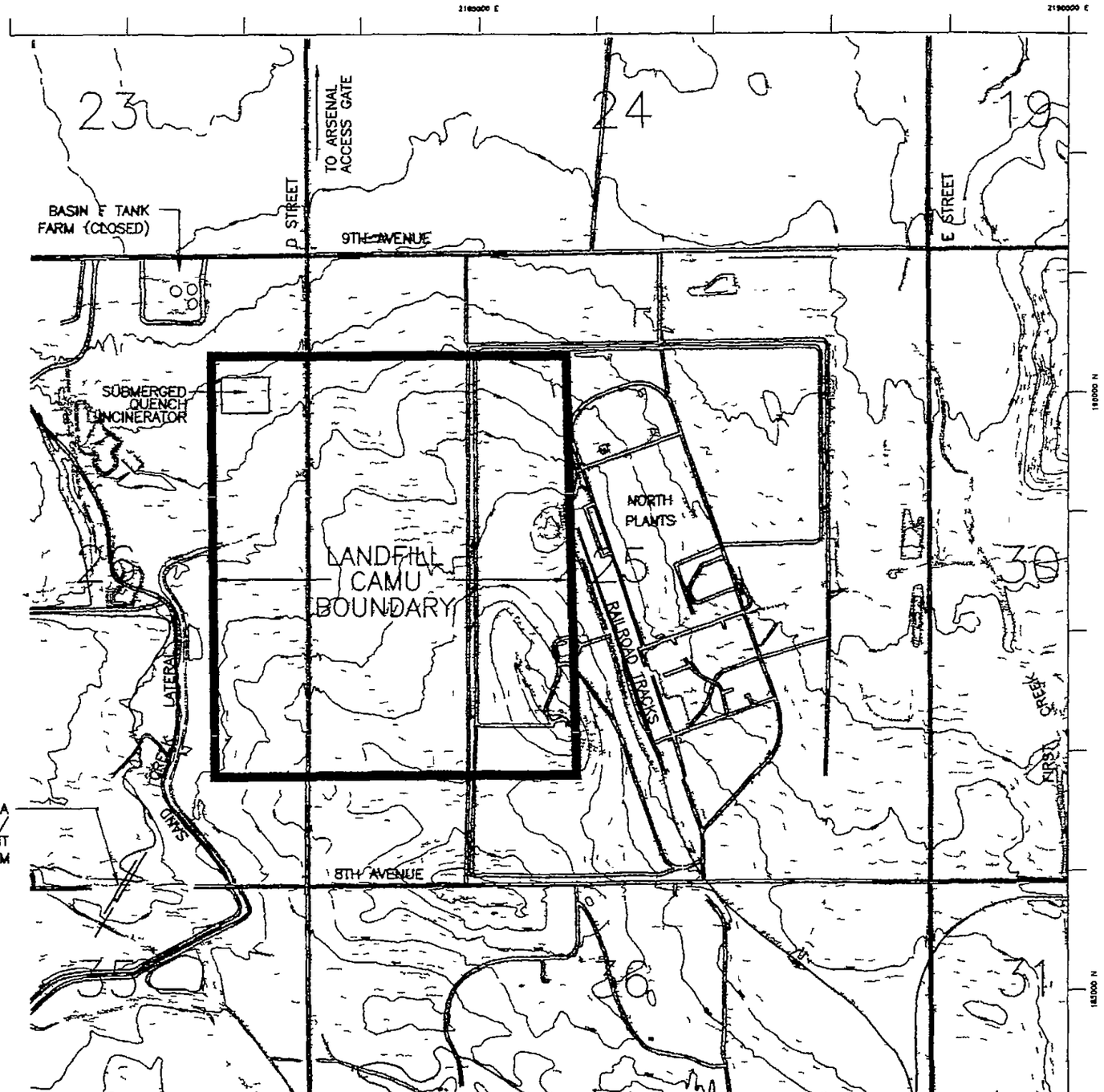
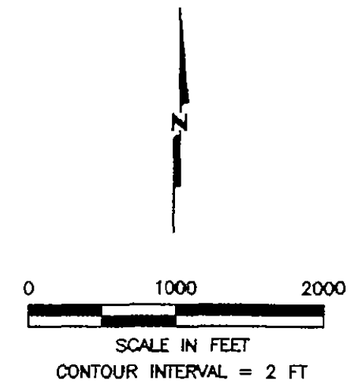
DRAWING NO.
G-1
1 / 11





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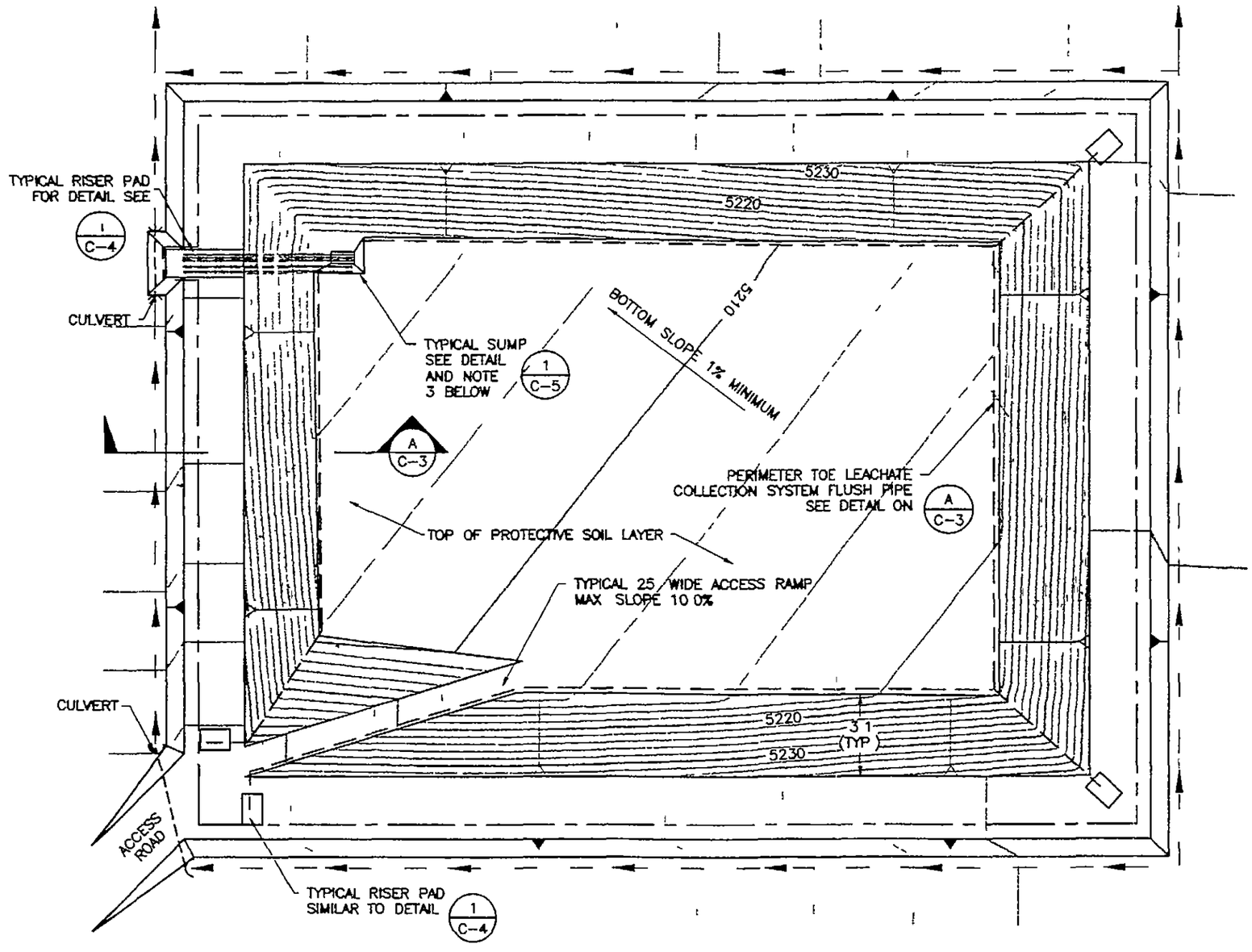
ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

1995 EXISTING SITE CONDITIONS AND CAMU BOUNDARY

DRAWING NO: C-1

2/11



N

0 100 200

SCALE IN FEET

CONTOUR INTERVAL = 2 FT

LEGEND

- LCS COLLECTION/FLUSH PIPING
- ANCHOR TRENCH
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- DRAINAGE CHANNEL

CUT FILL

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NOTES.

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3 LEACHATE REMOVAL, SUMP ACCESS FLUSHING OPERATIONS AND ASSOCIATED FUNCTIONS WILL BE CAREFULLY ANALYZED DURING DESIGN WITH CONSIDERATION GIVEN TO THE OPERATING KNOWLEDGE GAINED FROM THE BASIN F WASTE PILE. GEOTEXTILE FILTER FABRICS SHOULD BE CHOSEN TO HAVE ADEQUATE FILTRATION CHARACTERISTICS TO AVOID CLOGGING ALTERNATIVE SUMP DESIGNS MAY BE REQUIRED

4 ALL DETAILS SECTIONS AND PLANS REPRESENT TRIPLE-LINED SYSTEMS UNLESS OTHERWISE NOTED

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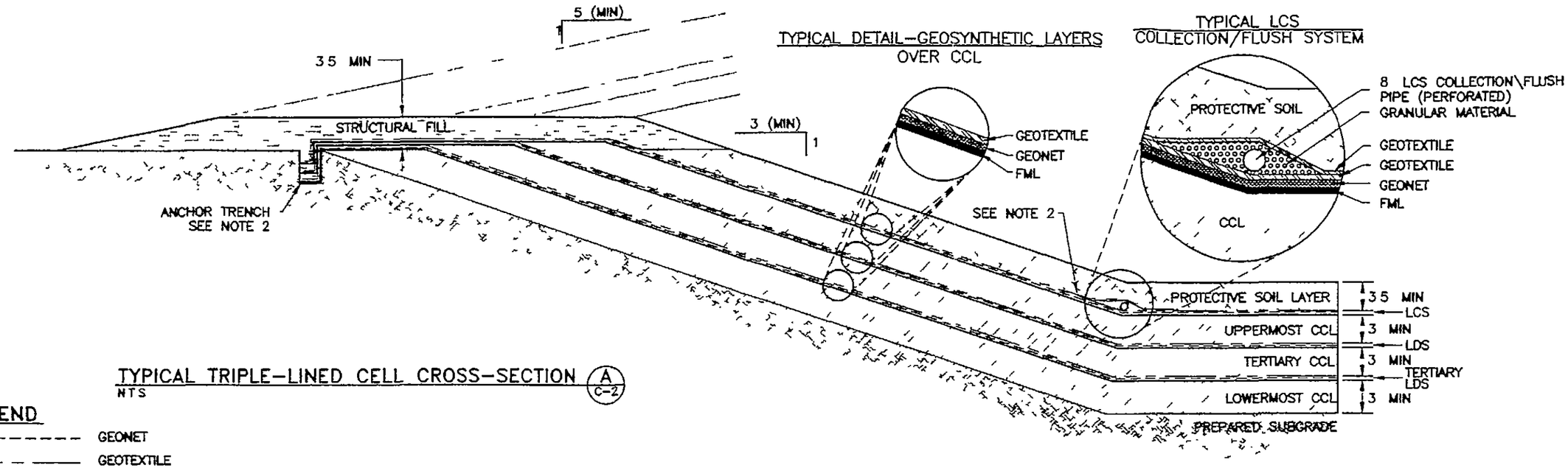
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL CELL PLAN

DRAWING NO: C-2

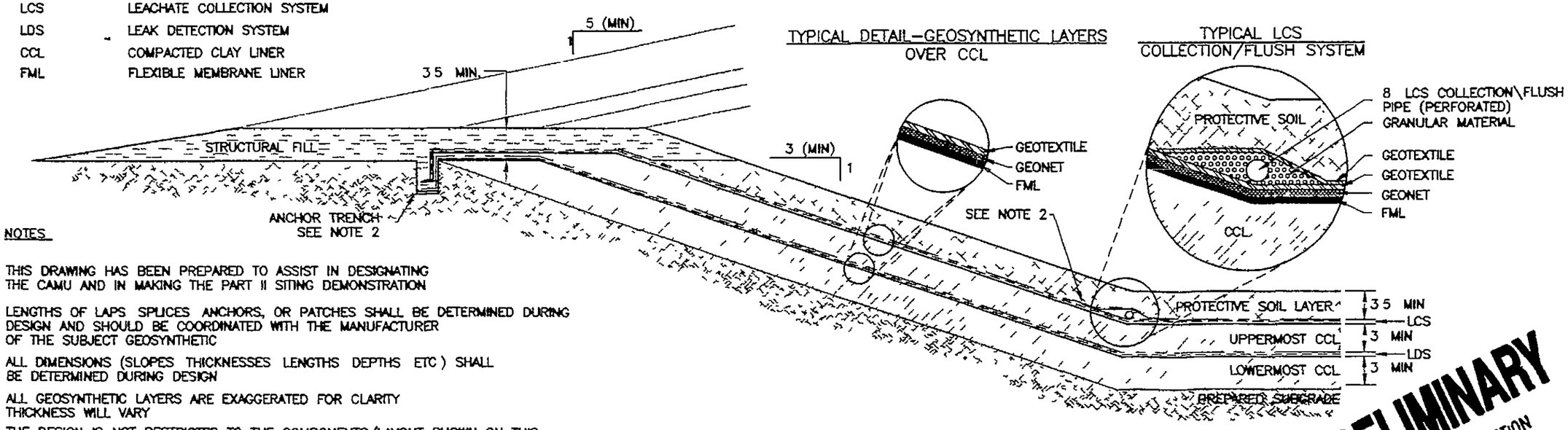
3/11



TYPICAL TRIPLE–LINED CELL CROSS–SECTION (A / C-2)
NTS

LEGEND

- - - - - - - -	GEONET
— — — —	GEOTEXTILE
————	FLEXIBLE MEMBRANE LINER
LCS	LEACHATE COLLECTION SYSTEM
LDS	LEAK DETECTION SYSTEM
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER



NOTES

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2. LENGTHS OF LAPS SPLICES ANCHORS, OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC
3. ALL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN
4. ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY
5. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

TYPICAL DOUBLE–LINED CELL CROSS–SECTION (B / TYP)
N.T.S.

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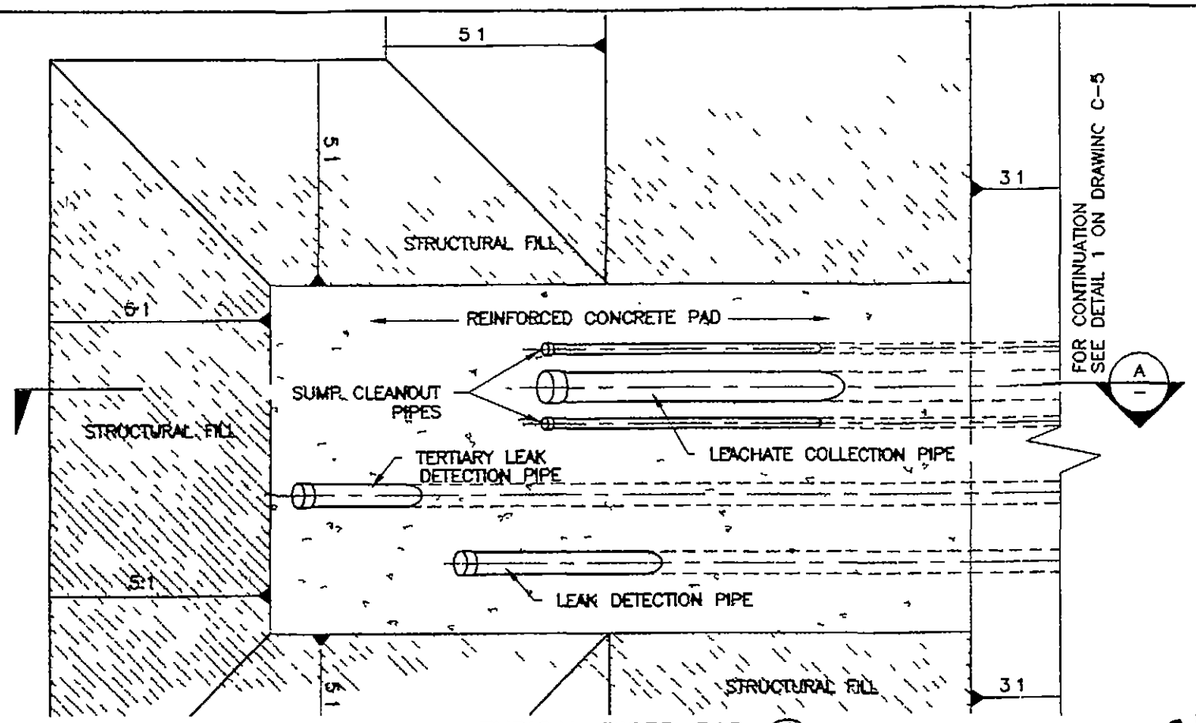
TASK 93-03
COMMERCE CITY COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

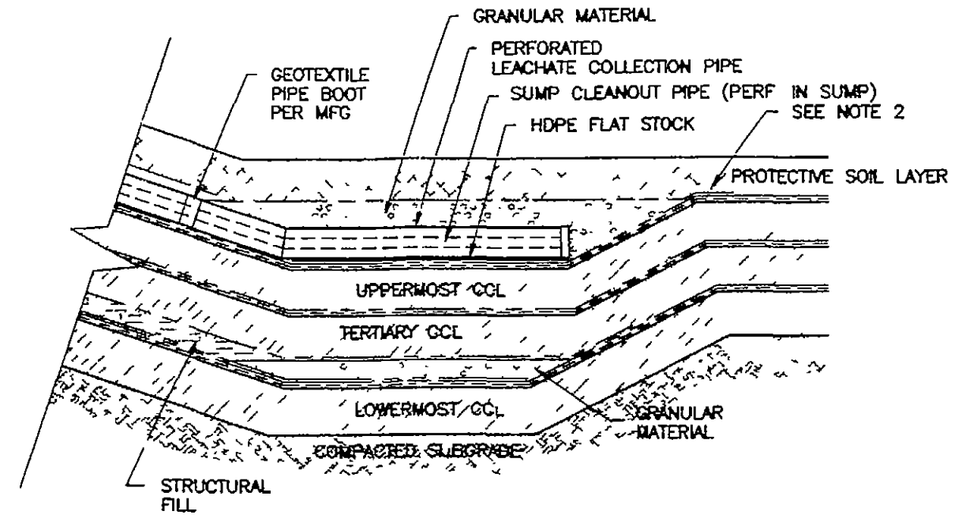
TYPICAL CELL LINER SYSTEM
SECTIONS AND DETAILS

DRAWING NO: C-3

4/11



TYPICAL RISER PAD (1 / C-2)
N.T.S



TYPICAL SUMP CROSS-SECTION (B / C-5)
N.T.S.

LEGEND

	GEONET
	GEOTEXTILE
	FLEXIBLE MEMBRANE LINER
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER

CUT FILL

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4 ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY

5. LEACHATE REMOVAL, SUMP ACCESS FLUSHING OPERATIONS AND ASSOCIATED FUNCTIONS WILL BE CAREFULLY ANALYZED DURING DESIGN WITH CONSIDERATION GIVEN TO THE OPERATING KNOWLEDGE GAINED FROM THE BASIN F WASTE PILE GEOTEXTILE FILTER FABRICS SHOULD BE CHOSEN TO HAVE ADEQUATE FILTRATION CHARACTERISTICS TO AVOID CLOGGING ALTERNATIVE SUMP DESIGNS MAY BE REQUIRED PROVISIONS FOR SUMP/PIPING CLEAN-OUT SHALL BE PROVIDED DURING DESIGN

6 ALL DETAILS AND SECTIONS REPRESENT TRIPLE-LINED SYSTEMS UNLESS OTHERWISE NOTED

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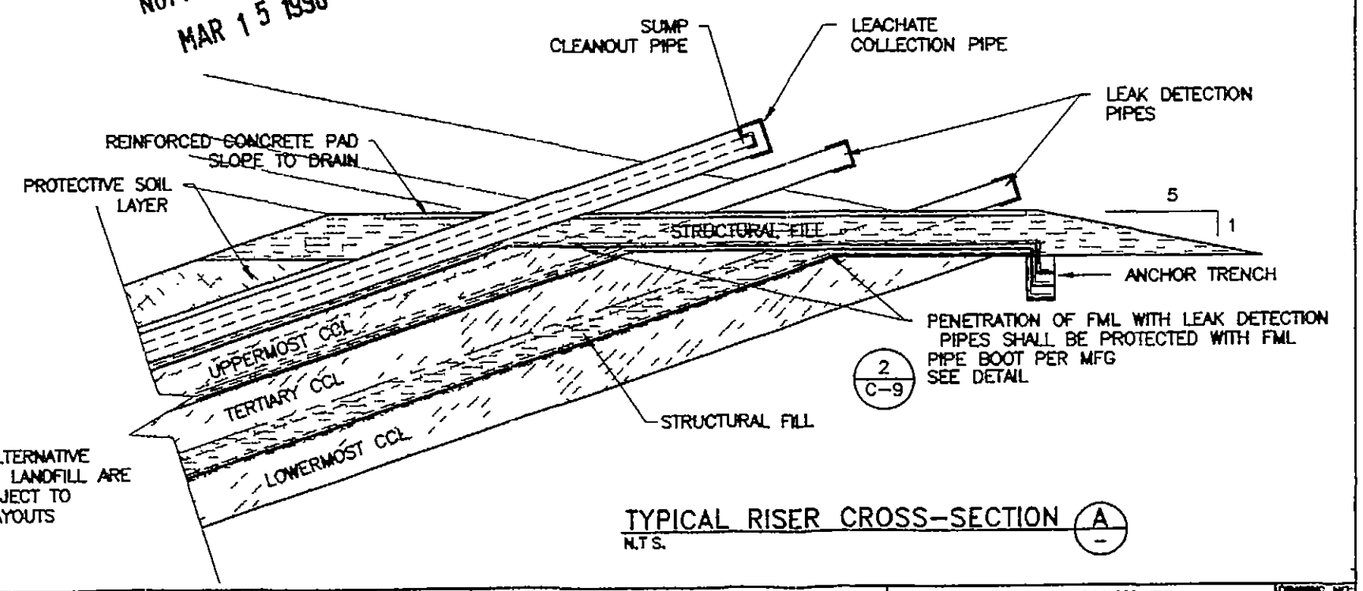

TYPICAL RISER CROSS-SECTION (A)
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ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY COLORADO

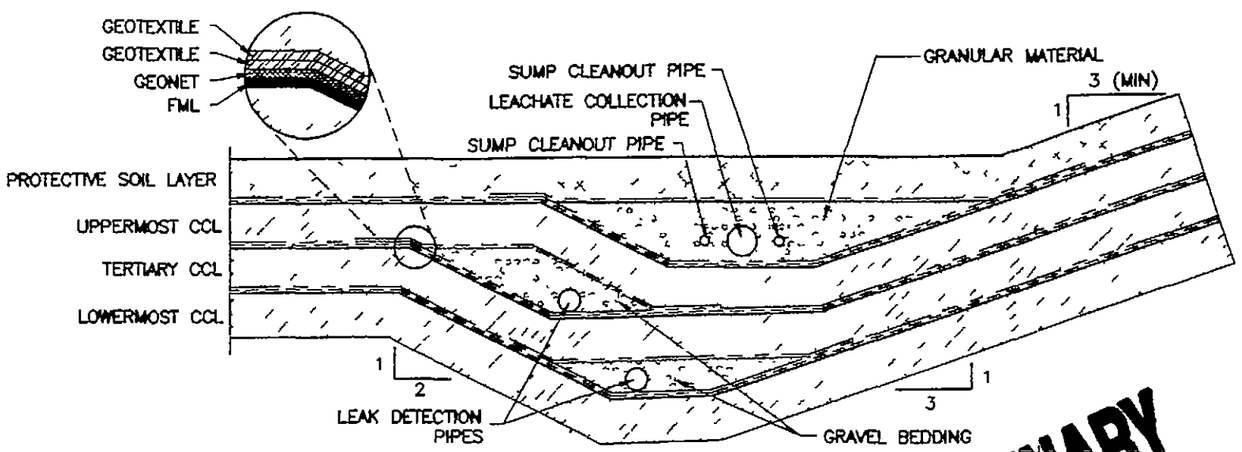
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL LEACHATE COLLECTION SYSTEM - SECTIONS AND DETAILS

DRAWING NO: C-4

5 / 11

TYPICAL DETAIL–GEOSYNTHETIC LAYERS OVER CCL



TYPICAL SUMP CROSS-SECTION (A)

N.T.S

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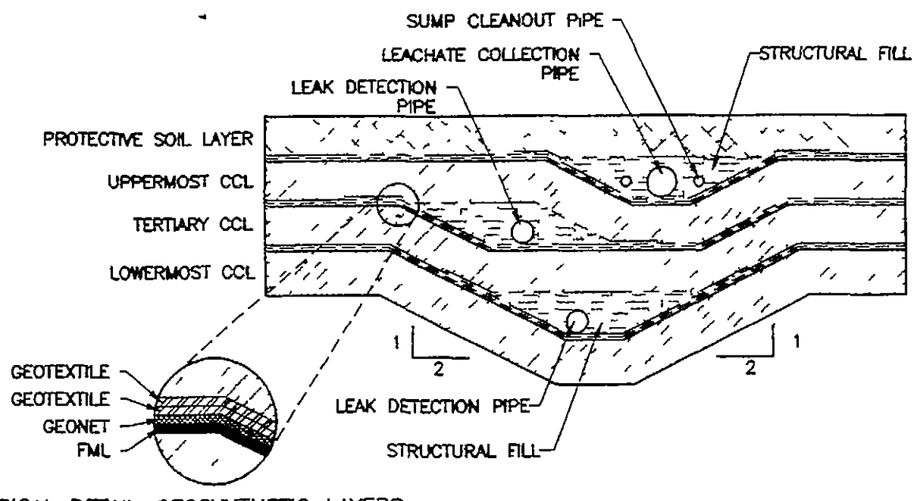


TYPICAL DETAIL–GEOSYNTHETIC LAYERS OVER CCL

TYPICAL RISER TRENCH CROSS-SECTION (B)

N.T.S

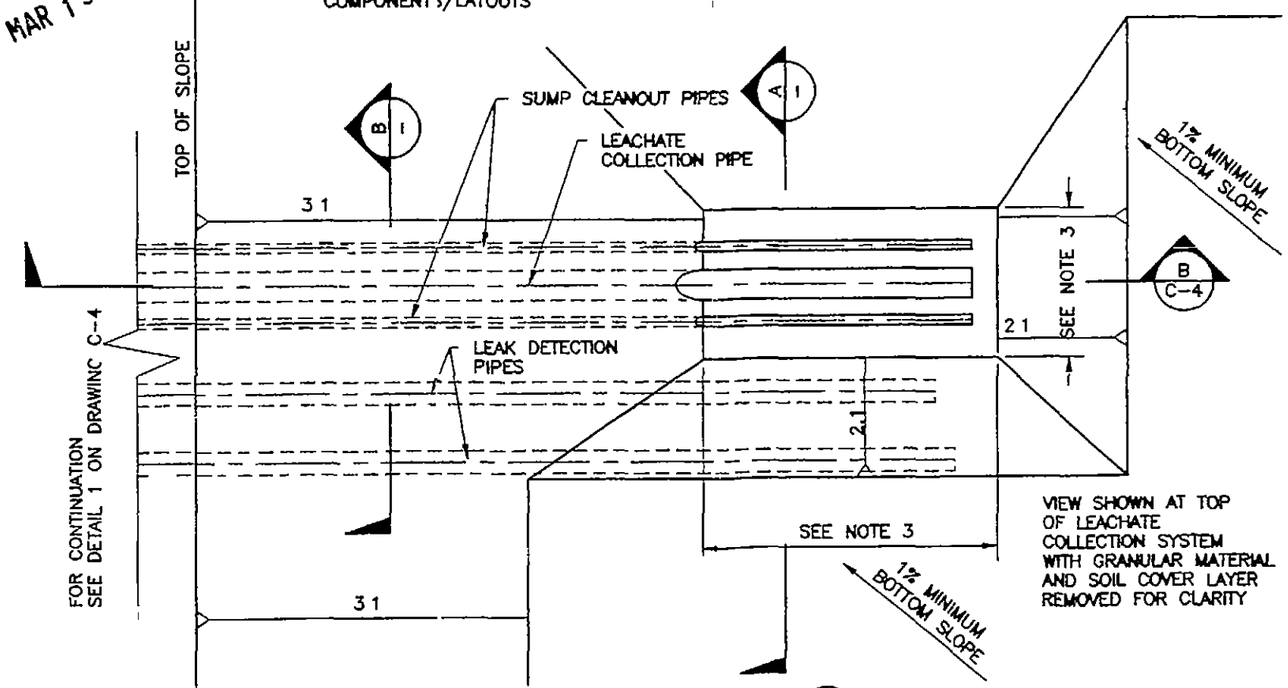
LEGEND

— — — — — —	GEONET
— — — — — —	GEOTEXTILE
——— ———	FLEXIBLE MEMBRANE LINER
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER

CUT FILL

NOTES

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. LENGTHS OF LAPS SPLICES OR PATCHES SHALL BE DETERMINED DURING FINAL DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC
3. ALL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN
4. ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY
5. LEACHATE REMOVAL, SUMP ACCESS, FLUSHING OPERATIONS AND ASSOCIATED FUNCTIONS WILL BE CAREFULLY ANALYZED DURING DESIGN WITH CONSIDERATION GIVEN TO THE OPERATING KNOWLEDGE GAINED FROM THE BASIN F WASTE PILE GEOTEXTILE FILTER FABRICS SHOULD BE CHOSEN TO HAVE ADEQUATE FILTRATION CHARACTERISTICS TO AVOID CLOGGING ALTERNATIVE SUMP DESIGNS MAY BE REQUIRED PROVISIONS FOR SUMP/PIPING CLEAN-OUT SHALL BE PROVIDED DURING DESIGN
6. ALL DETAILS AND SECTIONS REPRESENT TRIPLE-LINED SYSTEMS UNLESS OTHERWISE NOTED
7. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS



TYPICAL SUMP PLAN (1 / C-2)

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TASK 93-03
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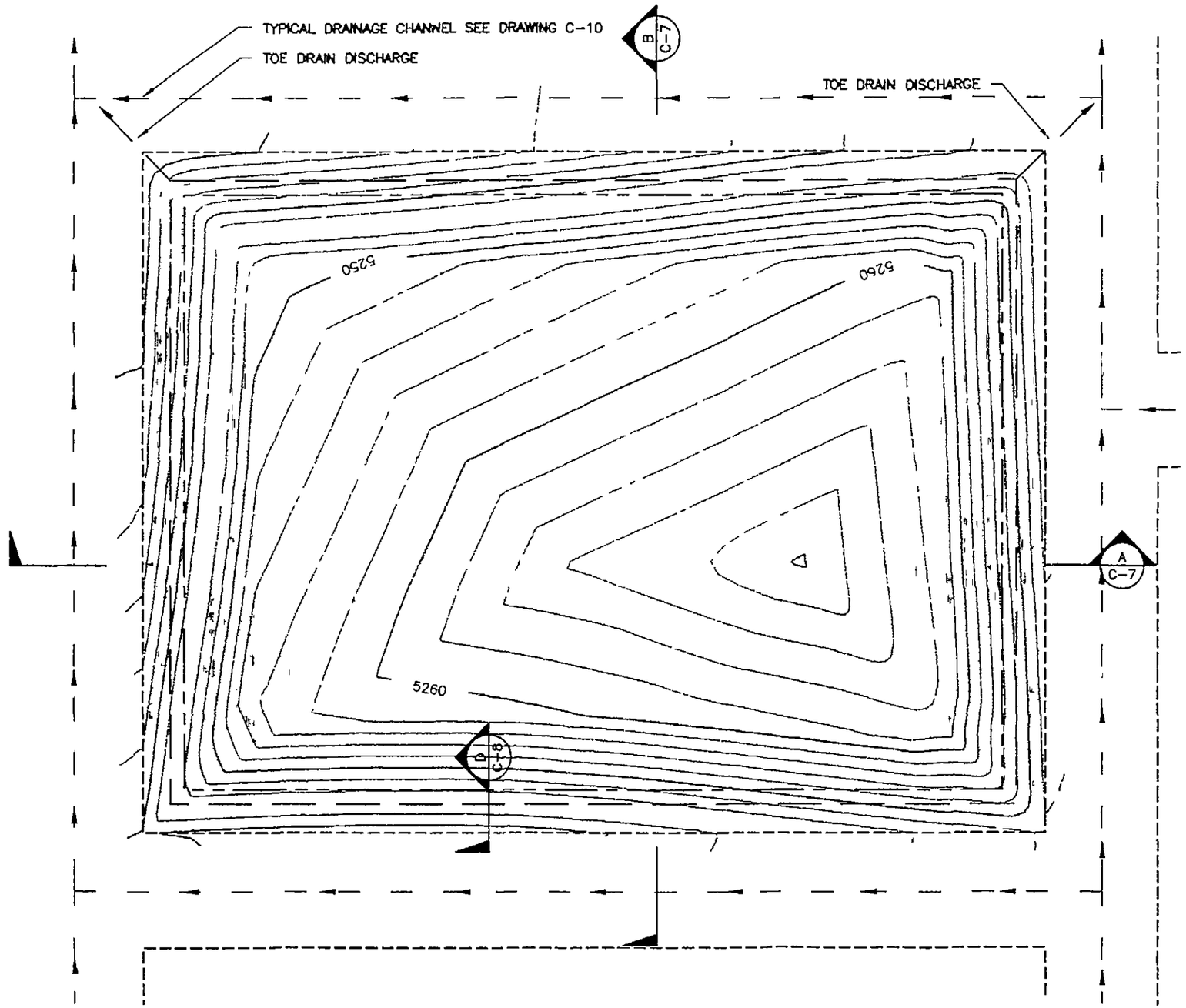
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL LEACHATE COLLECTION SYSTEM – SECTIONS AND DETAILS

DRAWING NO: C-5

6 / 11



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N

0 100 200
SCALE IN FEET
CONTOUR INTERVAL = 2 FT

LEGEND

- APPROXIMATE LIMITS OF WASTE
- FINAL COVER TOE DRAIN
- DRAINAGE CHANNEL
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- APPROX LIMITS OF FINAL COVER

NOTES.

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2 THE CONTOURING PLAN SHOWN IS AN EXAMPLE LAYOUT THE ACTUAL COVER SLOPES AND OVERALL CONFIGURATIONS WILL BE DETERMINED DURING DESIGN

3 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

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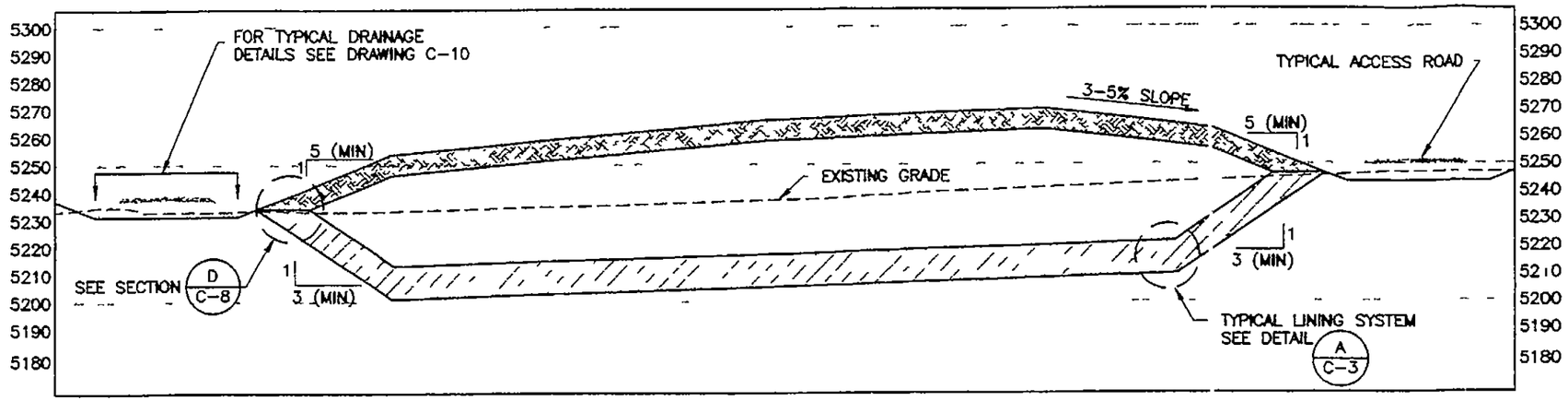
TYPICAL FINAL COVER PLAN

DRAWING NO: C-6

7/11



TYPICAL TRIPLE-LINED CELL AND COVER CROSS-SECTION A C-7
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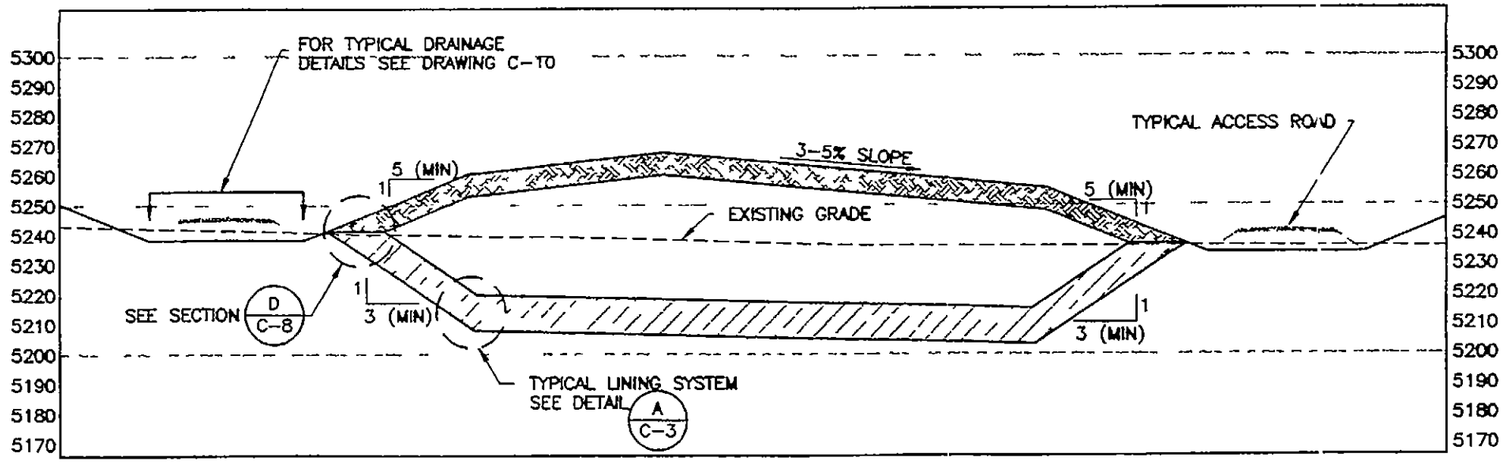
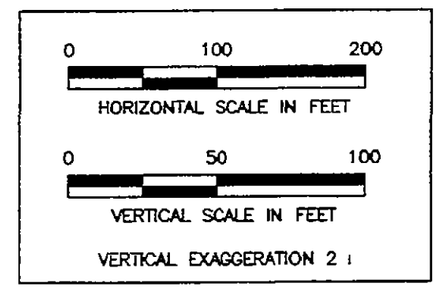
MAR 15 1996



TYPICAL TRIPLE-LINED CELL AND COVER CROSS-SECTION B C-6
N.T.S.



NOTES

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2. ALL FINAL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ELEVATIONS ETC) SHALL BE DETERMINED DURING DESIGN

3 ACCESS ROAD AREAS MAY BE REGRADED DURING DESIGN TO DEVELOP DRAINAGE CHANNELS. SEE SHEET C-10

4 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

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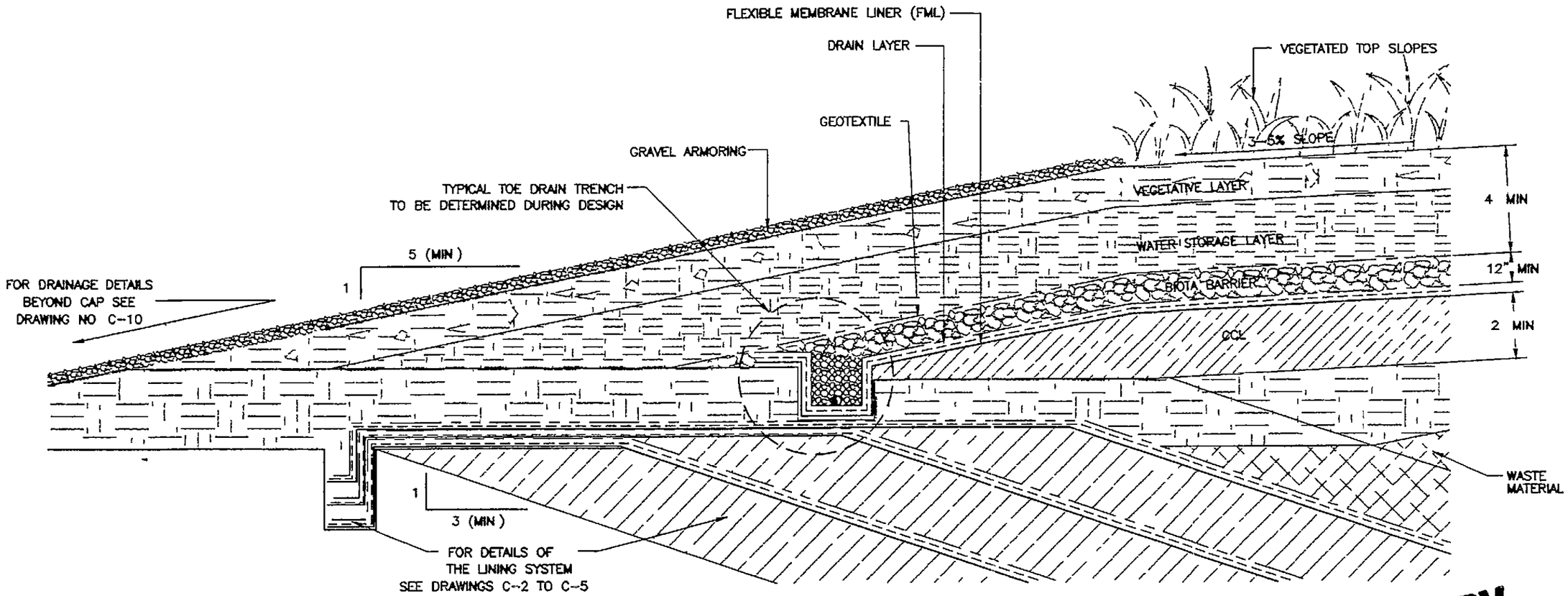
DESIGNATION LEVEL DRAWINGS

TYPICAL CELL AND COVER CROSS-SECTIONS

DRAWING NO: C-7
8/11



TYPICAL COVER SECTION (D / C-6)

NTS.

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MAR 15 1996

LEGEND

- GEONET
- GEOTEXTILE
- FLEXIBLE MEMBRANE LINER (FML)
- CCL — COMPACTED CLAY LINER

NOTES

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. TOE DRAIN TRENCH SHALL BE DESIGNED TO POSITIVE DRAIN AND CONSTRUCTED TO AVOID DAMAGE TO THE UNDERLYING GEOSYNTHETIC MATERIALS DIMENSIONS ARE TO BE DETERMINED DURING DESIGN
3. LENGTHS OF LAPS, SPLICES OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC.
4. ALL FINAL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN
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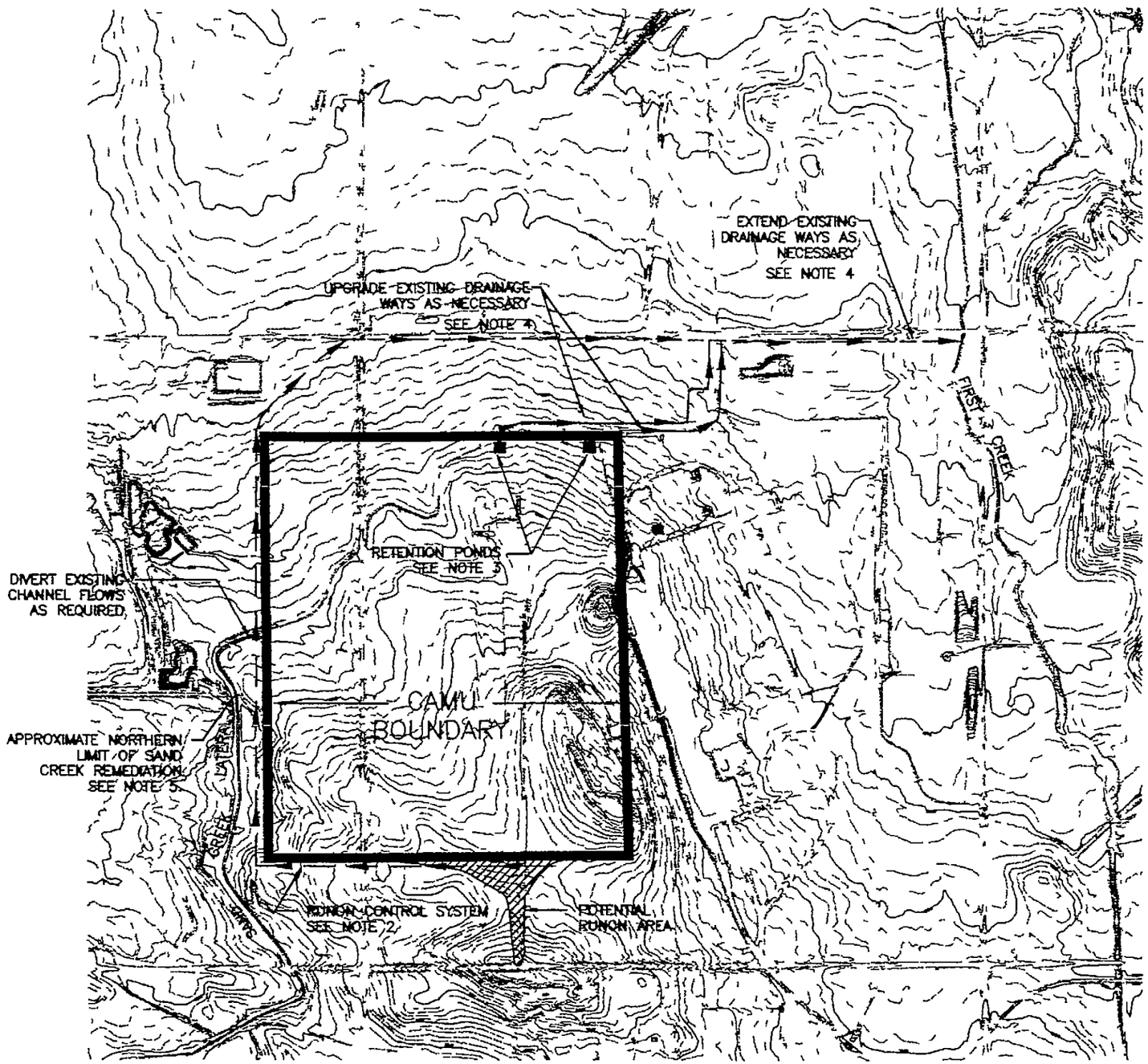
DESIGNATION LEVEL DRAWINGS

TYPICAL COVER SECTION

DRAWING NO: C-8

9 / 11



N

0 1000 2000

SCALE IN FEET

CONTOUR INTERVAL = 2 FT

LEGEND

- CAMU BOUNDARY
- RUNON CONTROLS
- EXISTING DRAINAGE WAYS
- EXISTING DRAINAGE WAYS PROPOSED FOR USAGE
- NEW/EXTENDED DRAINAGE WAYS
- INDEX CONTOURS (10)
- INTERMEDIATE CONTOURS (2)

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MAR 15 1996

NOTES.

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2. RUN-ON CONTROLS SUCH AS DITCHES BERMS SWALES ETC SHALL BE IMPLEMENTED PRIOR TO CONSTRUCTION OPERATIONS TO DIVERT RUNON AWAY FROM ACTIVE WASTE MANAGEMENT AREAS WASTE MANAGEMENT AREAS MAY INCLUDE LANDFILL CELLS WASTE TREATMENT AREAS AND DECONTAMINATION FACILITIES THESE DIVERTED FLOWS SHALL BE DIRECTED IN A CONTROLLED MANNER TO EXISTING DRAINAGE WAYS

3 DURING OPEN CELL OPERATIONS RUNOFF CONTROLS SHALL BE INSTALLED AND MAINTAINED TO COLLECT FLOWS FROM THE LANDFILL CELL AREA, AND OTHER WASTE TREATMENT/HANDLING AREAS. THIS COLLECTED RUNOFF SHALL BE CHANNELED TO RETENTION PONDS AND HANDLED AS DISCUSSED IN THE DESIGN NARRATIVE. ONCE THE CELLS ARE COVERED COLLECTED FLOWS FROM WITHIN THESE AREAS MAY BYPASS THE RETENTION PONDS AND BE DIRECTLY DISCHARGED TO EXISTING DRAINAGE WAYS

4 EXISTING DRAINAGE WAYS DESIGNATED TO RECEIVE FLOWS FROM THE CAMU OR ASSOCIATED DIVERSIONS SHALL BE ANALYZED FOR ADEQUATE CAPACITY SOME ENHANCEMENTS MAY BE REQUIRED EXTENSIONS TO EXISTING DRAINAGE WAYS MAY ALSO BE NECESSARY

5 FOR ADDITIONAL INFORMATION ON THE SAND CREEK LATERAL REMEDIATION SEE THE DETAILED ANALYSIS OF ALTERNATIVES VOLUME III CHAPTER 18

6 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

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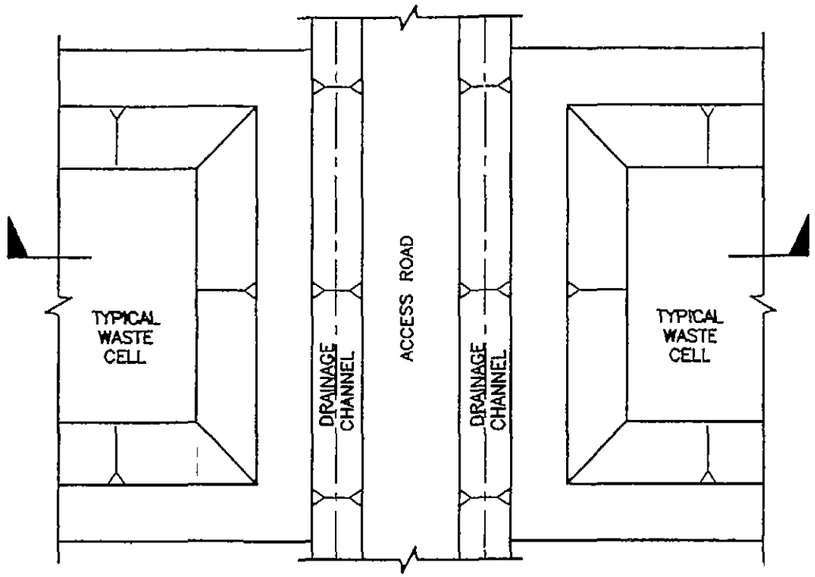
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

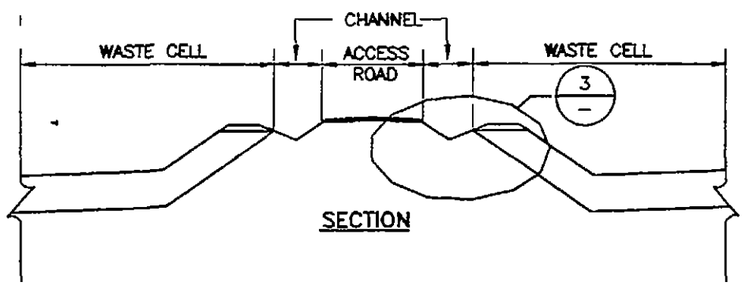
TYPICAL SITE DRAINAGE PLAN

DRAWING NO: C-9

10/11



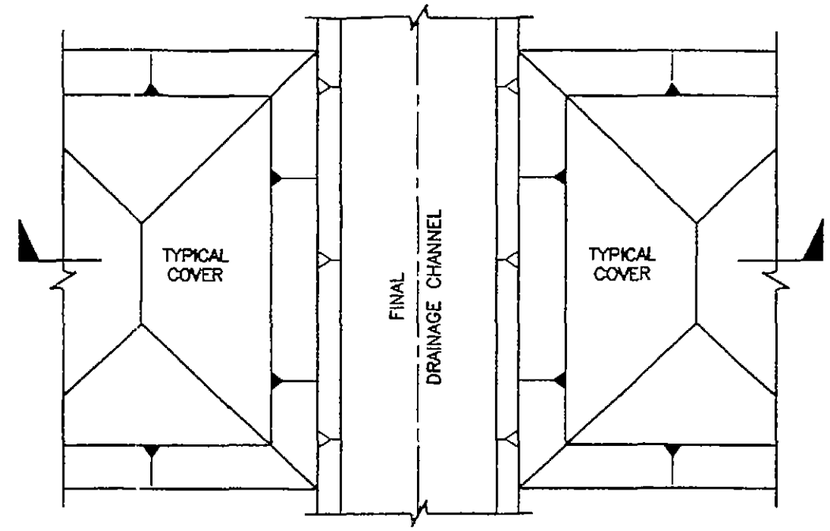
PLAN



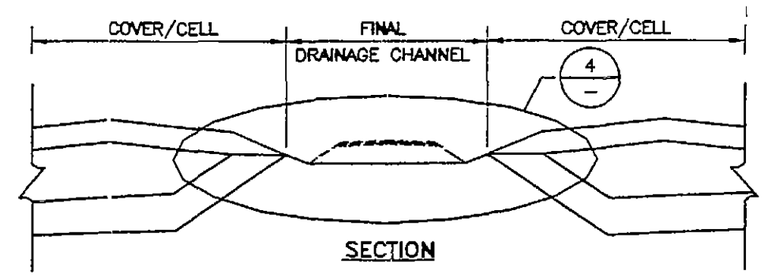
SECTION

TYPICAL CELLS DURING OPERATION (1/—)

N.T.S.



PLAN



SECTION

TYPICAL COVER/CELLS AFTER CLOSURE (2/—)

N.T.S.

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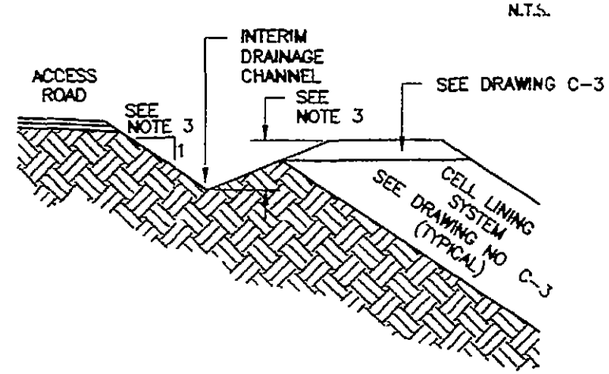
NOTES.

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2 REGRADE ACCESS THE ROAD/INTERIM SWALE AREA TO DEVELOP ADEQUATE FLOW AREA FOR THE FINAL DRAINAGE DITCH SYSTEM

3 ALL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) AND PROVISIONS FOR EROSION CONTROL SHALL BE DETERMINED DURING DESIGN

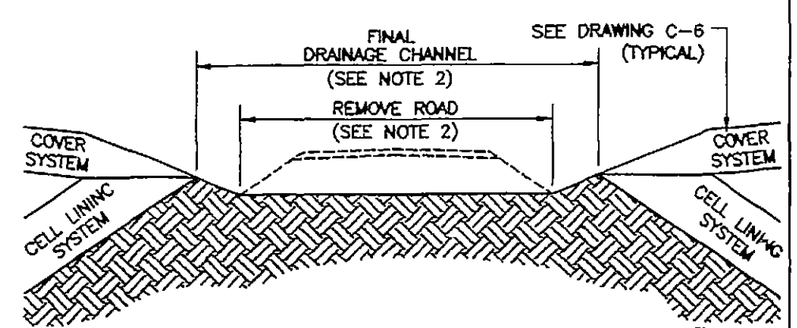
4 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS.



TYPICAL CHANNEL DETAIL BETWEEN CELLS (3/—)

N.T.S.

DURING OPEN CELL OPERATIONS



TYPICAL CHANNEL DETAIL BETWEEN CELLS (4/—)

N.T.S.

AFTER CLOSURE

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CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL SITE DRAINAGE PLANS
SECTIONS AND DETAILS

DRAWING NO: C-10

11 / 11

Attachment B2

CONCEPTUAL ENGINEERING ANALYSES

In the development of Table B1, CDPHE requested that certain conceptual engineering analyses be performed on the conceptual design shown in Attachment B1 and included a component of this design narrative These analyses are included in Attachment B2

The following conceptual engineering analyses were performed

- Foundation settlement
- Foundation bearing capacity
- Potential for excess hydrostatic pressure on the foundation
- Excavated slope stability, including seismic considerations
- Cover slope stability including seismic considerations

The results of these individual conceptual analyses indicate that the conceptual design will not be severely constrained by these design considerations The design of the landfill will include a more comprehensive evaluation of these and other design considerations

CONCEPTUAL FOUNDATION SETTLEMENT ANALYSIS

SETTLEMENT EVALUATION

Purpose: Evaluate settlement of foundation soils to assess impact to composite liner system. Settlement will result from loads associated with the new liner, waste fill, and cover soil.

Idealized Soil Profile:

Appendix R* indicates, that the soil profile consists of 5' to 58' of Alluvium over Rock. The Alluvium consists of 65% clay (CL/CH), 35% Clayey Sand (SC), and 5% other soil types. Appendix B indicates that approximately the upper 30' of soil will be excavated to construct the disposal cells. Review of 33 boring logs in Appendix R indicate that 24 logs encountered rock at a depth less than 30'. Therefore, from a settlement standpoint, the worst case would consist of approximately 30' of clay underlying the new cells.

Appendix K, states that the groundwater level is 20' to 70' below existing grades. The shallow groundwater level may be due to a leaking watermain. The design assumption is that groundwater will be at least 20' below the liner bottom. From a settlement standpoint, assume the initial water table is at a depth of the proposed liner bottom and that it is lowered below the depth of soil after liner construction; this is a conservative assumption.

* HLA, 1996. Proposed Corrective Management Unit Design Document, Rocky Mountain Arsenal, Commerce City, Co. Vol I and II. January 12.

Clay Properties:

The following data was taken from information in Appendix R:

- Liquid Limit 25-88, Avg ≈ 45 (LL)
- Plasticity Index 5-75, Avg ≈ 30 (PI)
- Water Content Avg ≈ 18% for clays (W_n) below 30' (92 samples)
- Blow Counts Avg 20 to 30 blows/FT (BPF)

From this data & published correlations settlement parameters were derived as follows:

- Compression Index, C_{cc}

  A chart of C_{cc} vs W_n indicates $C_{cc} \approx 0.05$ for a $W_n \approx 18\%$.

- Recompression Index, C_{cr}

  experience on HLA

  The C_{cr} is known to be equal to approximately $\frac{1}{10}$ to $\frac{1}{20}$ of C_{cc}.

  Assume $C_{cr} = \frac{1}{10} C_{cc} = 0.005$

- Unit Weight, γ_T

  No data may be high

  For Clays and Clayey Sands assume a total unit weight of 130 pcf

- Preconsolidation Pressure, P_c'

  $P_c' = P_o'(OCR)$

  where P_o' = insitu effective stress
  OCR = Overconsolidation Ratio

(Ladd et al. 1977) (+ Schmertmann 1977)

$$(OCR)^{0.8} = \frac{(S_u/P_o')_{overconsolidated}}{(S_u/P_o')_{normally\ consolidated}}$$

Lambe & Whitman (1969)
Soil Mechanics

pg 3 of 67

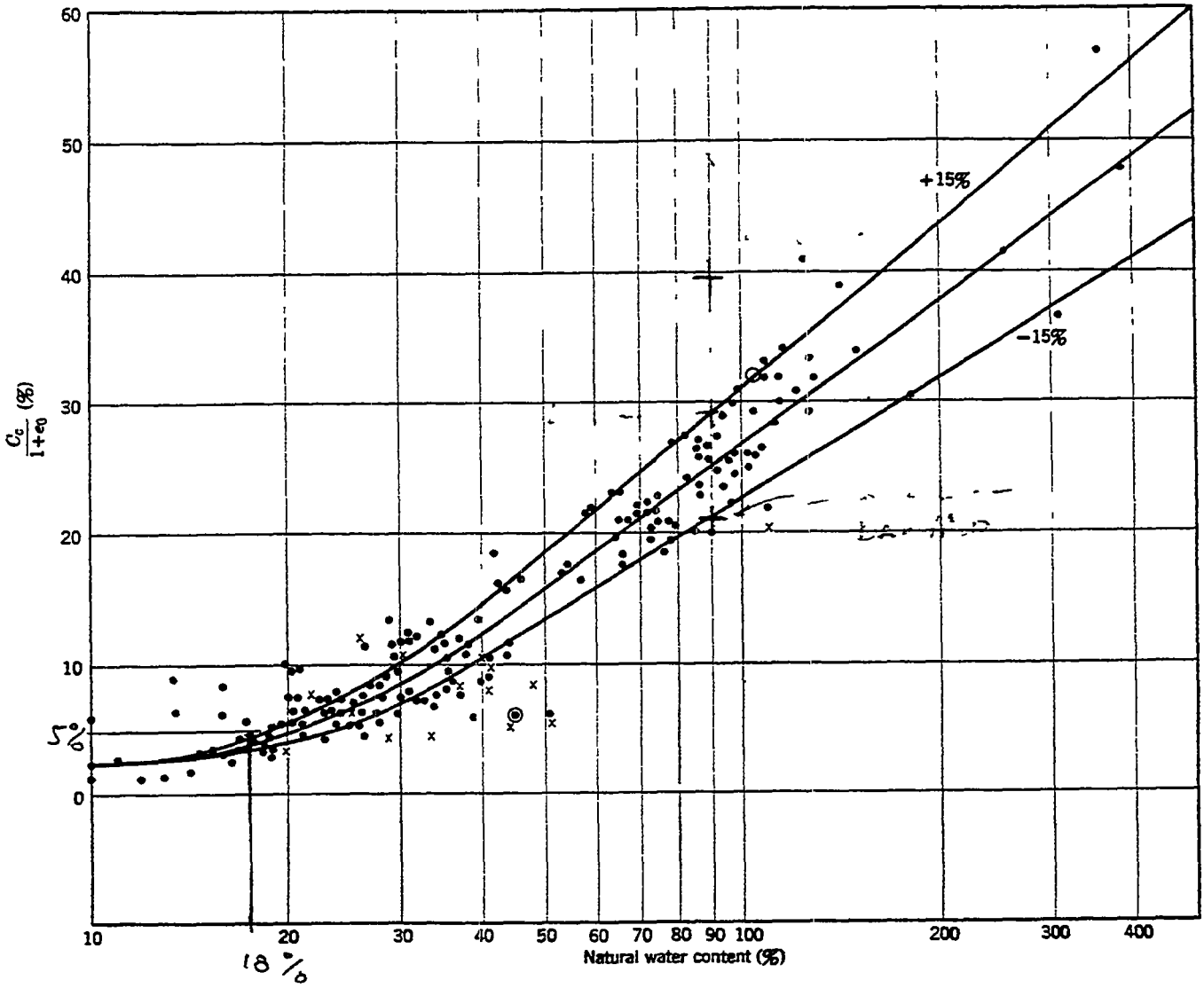


Fig 22 1(c)

Unloading

Upon unloading a soil sample in confined compression the sample expands, as illustrated in Fig 20.5. The parameter most commonly used to measure the expansion is

$$C_s = \text{swell index} = \frac{-\Delta e}{\Delta \log \bar{\sigma}_v} \qquad (22\ 1)$$

C_s is always much smaller than C_c for virgin compression. This is illustrated by the data in Table 22 1 By consolidating a series of specimens to different maximum vertical stresses $\bar{\sigma}_{vm}$ before unloading, a series of expansion curves are obtained Such expansion curves tend to be parallel. Note, for example, in Fig. 20.5 that the unload portion from the first cycle and that from the second cycle are approximately parallel. Thus C_s is more or less the same for all $\bar{\sigma}_{vm}$

In Fig 22.2 values of swell index have been plotted against the corresponding liquid limit. C_s increases with increasing liquid limit, but any relation between C_s and w_l will be only approximate.

Reloading

If a clay is subjected to many cycles of load and unload, the compression and recompression curves tend toward each other, i.e , C_c for recompression approximately equals C_s.

The compressibility of a soil depends very much on the stress level in relation to the stress history For example, we can see from Fig 20 5 that the compressibility of the Cambridge clay is much greater in the virgin compression range than it is in the recompression range; this means the compression index above $\bar{\sigma}_{vm}$ is much greater than below $\bar{\sigma}_{vm}$. This important fact presents the engineer

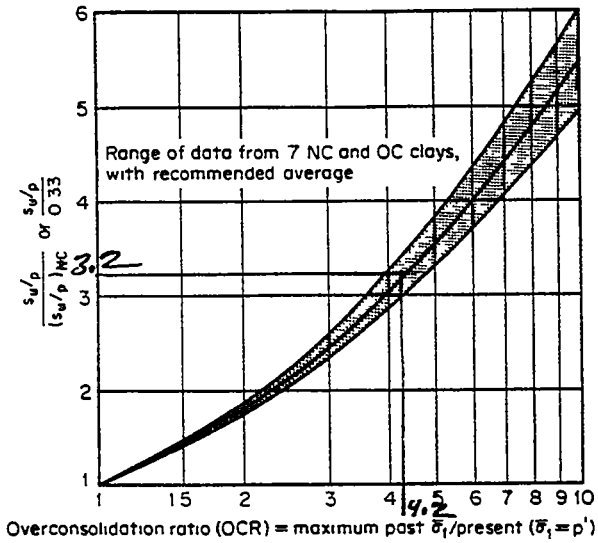


FIG 3 71 Normalized s_u/p' ratio vs OCR for use in estimating OCR from q_c in clays. [*From Schmertmann (1977)*[78] *Reprinted with permission of the Federal Highway Administration.*]

Compression in Sands

Sands and other cohesionless granular materials undergo a decrease in void volume under applied stress, caused primarily by rearrangement of grains (Art 3 5 4) Small elastic compression of quartz grains may occur In most cases the greater portion of compression is essentially immediate upon application of load

Expansion

An increase in volume occurs as a result of reduction in applied stress, increase in moisture content or mineralogical changes in certain soil and rock materials *(see Arts 3.5 4 and 10 6)*

3 5 3 ROCK DEFORMATION MEASUREMENTS

Methods Summarized

Laboratory Testing

Intact specimens are statically tested in the laboratory in the triaxial and unconfined compression apparatus, dynamic properties are measured with the resonant column device or by ultrasonic testing (ASTM 2845) A summary of parameters measured, apparatus description, and test performance is given on Table 3 36

The data are normally used for correlations with in situ test data

In Situ Testing

IMPORTANCE In situ testing provides the most reliable data on the deformation characteristics of rock masses because of the usual necessity to account for the effects of mass defects from discontinuities and decomposition

REQUIREMENTS Determination of moduli in situ requires that the deformation and the stress producing it are measurable and that an analytical method of describing the geometry of the stress deformation relationship is available

Analytical methods are governed by the testing method Modulus is the ratio of stress to strain, and since strain is the change in length per total length, the deflection that is measured during in situ testing must be related to the depth of the stressed zone to determine strain The depth of the stressed zone may be determined by instrumentation *(see Chap 4)*, or the Boussinesq equations may be used to determine stress distributions The values for the modulus E are given in terms of the test geometry, the applied pressure, the deflection, and Poisson's ratio

STATIC MODULI Determined from plate-jack tests, radial jacking and pressure tunnel tests, flat-jack tests, borehole tests (dilatometer and Goodman jack), and triaxial compression tests

DYNAMIC MODULI Determined from seismic direct velocity tests *(see Art 2 3.2)* and the 3-D velocity probe (sonic logger) *(see Art. 2 3 6)* Relationships between seismic velocities and dynamic moduli are given on Table 3 35 In moduli computations the shear-wave velocity V_s is used rather than the compression-wave velocity V_p because water in rock fractures does not affect V_s, whereas it couples the seismic energy across joint openings, allowing much shorter travel times for P waves than if an air gap existed Dynamic moduli are always higher than static moduli because the seismic pulse is of short duration and very low stress level,

Where $\left(\frac{S_u}{P_o'}\right)_{overconsol}$ is the ratio of the undrained shear strength of the clay divided by its insitu effective stress and $\left(\frac{S_u}{P_o'}\right)_{normally\ consol.}$ is the ratio if the clay were normally consolidated (OCR = 1.0).

$S_{u\ over\ consol} \approx 120 \times BPF = 120 \times 25 = 3000\ psf$

$P_{o\ insitu\ @D=45'}' = 130 \times 20' + (130-62.4)25' = 4290\ psf \approx 4300\ psf$

$\therefore \left(\frac{S_u}{P_o'}\right)_{over\ consol} = \frac{3000}{4300} = 0.70$

Skempton 1954 $\rightarrow$ $\left(\frac{S_u}{P_o'}\right)_{Normally\ Consol} = 0.11 + 0.0037\ PI$

$= 0.11 + 0.0037(30)$

$= 0.22$

$(OCR)^{0.8} = \frac{0.70}{0.22} = 3.2$ $\therefore OCR = 4.2$

$P_{c\ @D=45'}' = P_o'(OCR) = 4300 \times 4.2 \approx 18{,}000\ psf$

Load Changes:

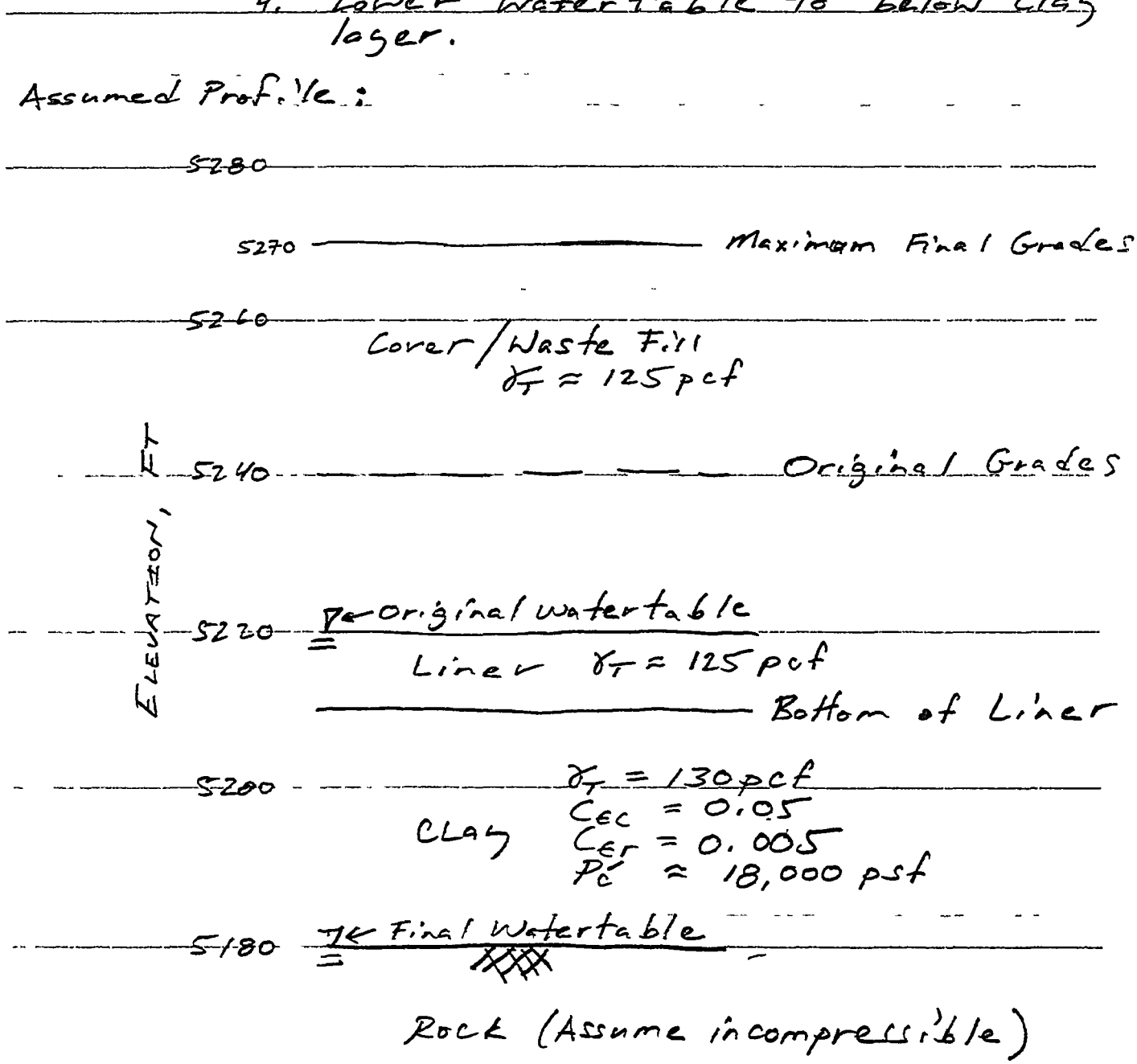
Load changes during construction will occur as follows:

1. Remove 30' of overburden
2. Construct $9\frac{1}{2}'$ to $12\frac{1}{2}'$ thick liner. γ_T liner from Appendix R $\approx$ 125 pcf.
3. Place waste fill to height up to 30' above original grades

(Appendix B, Dwg C-7). Assume $\gamma_T = 125$ pcf.

4. Lower watertable to below clay layer.

Assumed Profile:



Settlement Calculations:

The data indicates that settlement will only be associated with recompression of the clay and that the loads will not be large enough to exceed the preconsolidation pressure. Therefore:

$$S = H C_{\epsilon r} \log\left(\frac{P_f'}{P_i'}\right)$$

where P_f' = the final effective stress after adding the new waste fill, liner, and cover, and after lowering the water-table.

P_i' = the initial effective stress taken as that occurring after excavation to conservatively account for rebound during unloading; assume that the waterfable is at the bottom of the excavation.

See the attached spread sheet printout for the results of the settlement calculations.

Summary of Result:

Thickness of New Fill (FT)	Settlement (inches)	
	Ignoring Water-Table Change	With Waterfabe Change
30	1.4	1.5
60	1.9	1.9

CONSOLIDATION SETTLEMENT CALCULATIONS
RMA 93-03/CDD
HLA Project No 21907-705011 1
February 13, 1996
By A. Heriache Reviewed By

I Neglecting Watertable Change

New Fill Thickness (Feet) 60
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet) Top	Bottom	Average	Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf) New Fill	Water-Table Change	Final Effective Stress (Psf)	Compression Ratio Rebound Cer	Virgin Cec	Vertical Strain Recompress	Virgin	Change in Thickness (Inches)
1	0 0	5 0	2 5	5 0	169	18000	7500	0	7669	0 005	0 050	0 006	0 000	0 5
2	5 0	10 0	7 5	5 0	507	18000	7500	0	8007	0 005	0 050	0 006	0 000	0 4
3	10 0	15 0	12 5	5 0	845	18000	7500	0	8345	0 005	0 050	0 005	0 000	0 3
4	15 0	20 0	17 5	5 0	1183	18000	7500	0	8683	0 005	0 050	0 004	0 000	0 3
5	20 0	25 0	22 5	5 0	1521	18000	7500	0	9021	0 005	0 050	0 004	0 000	0 2
6	25 0	30 0	27 5	5 0	1859	18000	7500	0	9359	0 005	0 050	0 004	0 000	0 2
Total				30 0										1.9

II Accounting for Watertable Change

New Fill Thickness (Feet) 60
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet) Top	Bottom	Average	Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf) New Fill	Water-Table Change	Final Effective Stress (Psf)	Compression Ratio Rebound Cer	Virgin Cec	Vertical Strain Recompress	Virgin	Change in Thickness (Inches)
1	0 0	5 0	2 5	5 0	169	18000	7500	156	7825	0 005	0 050	0 006	0 000	0 5
2	5 0	10 0	7.5	5 0	507	18000	7500	468	8475	0 005	0 050	0 006	0 000	0 4
3	10 0	15 0	12.5	5 0	845	18000	7500	780	9125	0 005	0 050	0 005	0 000	0.3
4	15 0	20 0	17.5	5 0	1183	18000	7500	1092	9775	0 005	0 050	0 005	0 000	0.3
5	20 0	25 0	22.5	5 0	1521	18000	7500	1404	10425	0 005	0 050	0 004	0 000	0 3
6	25 0	30 0	27.5	5 0	1859	18000	7500	1716	11075	0 005	0 050	0 004	0 000	0 2
Total				30 0										1.9

CONSOLIDATION SETTLEMENT CALCULATIONS
RMA 93-03/CDD
HLA Project No 21907-705011 1
February 13, 1996
By A Heriache Reviewed By

I Neglecting Watertable Change

New Fill Thickness (Feet) 30
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet)			Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf)		Final Effective Stress (Psf)	Compression Ratio		Vertical Strain		Change In Thickness (Inches)
	Top	Bottom	Average				New Fill	Water-Table Change		Rebound Cer	Virgin Cec	Recompress	Virgin	
1	0 0	5 0	2 5	5 0	169	18000	3750	0	3919	0 005	0 050	0 007	0 000	0 4
2	5 0	10 0	7 5	5 0	507	18000	3750	0	4257	0 005	0 050	0 005	0 000	0 3
3	10 0	15 0	12 5	5 0	845	18000	3750	0	4595	0 005	0 050	0 004	0 000	0 2
4	15 0	20 0	17 5	5 0	1183	18000	3750	0	4933	0 005	0 050	0 003	0 000	0 2
5	20 0	25 0	22 5	5 0	1521	18000	3750	0	5271	0 005	0 050	0 003	0 000	0 2
6	25 0	30 0	27 5	5 0	1859	18000	3750	0	5609	0 005	0 050	0 002	0 000	0 1
Total				30 0										1 4

II Accounting for Watertable Change

New Fill Thickness (Feet) 30
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet)			Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf)		Final Effective Stress (Psf)	Compression Ratio		Vertical Strain		Change In Thickness (Inches)
	Top	Bottom	Average				New Fill	Water-Table Change		Rebound Cer	Virgin Cec	Recompress	Virgin	
1	0 0	5 0	2 5	5 0	169	18000	3750	156	4075	0 005	0 050	0 007	0 000	0 4
2	5 0	10 0	7 5	5 0	507	18000	3750	468	4725	0 005	0 050	0 005	0 000	0 3
3	10 0	15 0	12 5	5 0	845	18000	3750	780	5375	0 005	0 050	0 004	0 000	0 2
4	15 0	20 0	17 5	5 0	1183	18000	3750	1092	6025	0 005	0 050	0 004	0 000	0 2
5	20 0	25 0	22 5	5 0	1521	18000	3750	1404	6675	0 005	0 050	0 003	0 000	0 2
6	25 0	30 0	27 5	5 0	1859	18000	3750	1716	7325	0 005	0 050	0 003	0 000	0 2
Total				30 0										1 5

Conclusions:

The results indicate that the worst case settlement will be less than 2 inches. I most cases the liner system will be placed directly on rock; for this situation the settlement will be much smaller (likely less than ½ inch).

We judge that the liner system can be designed to accommodate these relatively low values of settlement.

Harding Lawson Associates
Engineering and Environmental Services

SHEET 1 OF 2
JOB NO 21907 705011.1
DATE 3/12/96
PROJECT BMA 93-03
COMPUTED BY BAC
SUBJECT Settlement Evaluation II
CHECKED BY WGM

SUPPLEMENT TO CONCEPTUAL SETTLEMENT EVALUATION

THE SETTLEMENT EVALUATION (P. 2 of 67 through p. 10 of 67, dated 2/13/96) CALCULATED VERY LITTLE SETTLEMENT FOR THE PARAMETERS USED. (≈1.9 in). Although the parameters used in the evaluation are considered highly conservative, an additional level of conservatism can be introduced by lowering the average number of blows/foot (penetration resistance) used in the original evaluation from 25 bpf to 17 bpf (a 1/3 reduction in assumed penetration resistance).

From p 2 of 67

$P_c' = P_o'(OCR)$ where P_c' is the preconsolidation pressure
P_o' is the insitu effective stress
OCR is the overconsolidation ratio

and

$OCR^{(.8)} = \dfrac{(S_u/P_o')_{overconsolidated}}{(S_u/P_o')_{normally\ consolidated}}$ where S_u is the undrained shear strength
$P_o' = 4300$ psf (from p5 of 67)

$S_u \approx 120 \times BPF$ (from p 5 of 67)

$\therefore S_u = 120 \times 17 = \underline{2{,}040 \text{ psf}}$

$\left(\dfrac{S_u}{P_o'}\right)_{OVER\ CONSOL} = \dfrac{2{,}040}{4300} = 0.4744$ and $\left(\dfrac{S_u}{P_o'}\right)_{normal\ consol} = 0.22$ (from p5 of 67)

$OCR^{0.8} = \dfrac{0.47}{0.22} = 2.14 \qquad OCR = 2.6 \therefore$

P_c' @ D=45' $= P_o'(OCR) = 4300(2.6) = \underline{\underline{11{,}180 \text{ psf}}}$

Harding Lawson Associates
Engineering and
Environmental Services

SHEET 2 OF 2
JOB NO 21907 705011.1
DATE 3/12/96
COMPUTED BY BAC
CHECKED BY [illegible]

PROJECT RMA 93-03
SUBJECT Settlement Evaluation II

The preconsolidation pressure used for the original evaluation (dated 2/13/96) was recalculated by reducing the estimated number of blows per foot by approx. 1/3 (25 bpf to 17 bpf). The reduction in BPF resulted in the following parameter changes

	Original Eval.	This Eval.
BPF	25	17
S_u	3000 psf	2040 psf
OCR	4.2	2.6
P_o'	18,000 psf	11,180 psf

Conclusion

The preconsolidation pressure recalculated based on a 1/3 reduction in penetration resistance is still higher than the maximum final effective stresses shown p. 8 & 9 of 67. This means that settlement of the foundation will follow the recompression portion of the consolidation curve and will still be approx. 2 inches for the parameters used. A review of the blow counts given on the logs in App. R shows the 17 BPF value to be conservative (ave BPF is higher) for clays in the landfill area from 10' to 30' deep.

CONCEPTUAL FOUNDATION BEARING CAPACITY ANALYSIS

BEARING CAPACITY

Purpose: Check bearing capacity of landfill foundation to assess impact to liner or other landfill components

Idealized Soil Profile:

As indicated under the settlement calcs, the landfill will typically be underlain by rock; however, localized areas may be underlain by up to 30 feet of clays and clayey sands.

Groundwater will be at least 20 feet below the bottom of the liner system.

Material Properties:

Based on data in Appendix R:

- Undrained Shear Strength, Su

  $S_u = 3000$ psf (See Pg 4)

- Unit Weight, γ_{TN}

  $\gamma_T = 130$ pcf

- New Fill (Liner, Waste, Cover)

  $\gamma_{TF} = 125$ pcf

Calculations:

Ult. Bearing Capacity = $5.14\,S_u + \gamma_{TN} H$

Depth of assumed footing = height of native soil adjacent to the disposal cell

$= 5.14(3000) + (130 \times 30') = 19{,}320$ psf

Load = (Height of Liner + waste + Cover) γ_{TT} =

= 60' x 125

= 7,500 psf

$$FS = \frac{19320}{7,500} = 2.6$$

OK

Conclusions:

The calculations show that the factor of safety against bearing failure is at least 2.6. These calcs include several very conservative assumptions including ignoring the presents of the rock below the clay soils, neglecting the shear strength of the soil above the bottom of the liner, and neglecting the fact that the landfill edges are sloped. Therefore, bearing capacity of the foundation soils is not a concern.

CONCEPTUAL ANALYSIS FOR EXCESS HYDROSTATIC PRESSURE ON THE LANDFILL FOUNDATION

POTENTIAL FOR EXCESS HYDROSTATIC PRESSURE

Purpose: To evaluate the potential for hydrostatic uplift on the bottom of the liner.

Groundwater Conditions:

Groundwater has been reported at a depth of 20 to 70 feet below existing grades. The shallower groundwater depth is believed do to a leaking watermain which will be repaired. The design assumptions state that the groundwater level will maintained at a depth of at least 20 feet below the bottom of the liner.

Conclusions:

The groundwater level is anticipated to be below the bottom of the liner at all times. Therefore, uplift associated with excess hydrostatic pressure is not a concern.

If the groundwater rises above the bottom of the liner, it would have to rise to a height approximately equal to twice the liner thickness above the bottom of the liner before the bouyancy effect would equal the liner weight. Once the waste is placed on the liner, it could resist higher uplift forces.

CONCEPTUAL EXCAVATED SLOPE STABILITY ANALYSIS

SLOPE STABILITY - LINER SYSTEM / EXCAVATED SLOPES

Purpose: To evaluate the stability of the excavated slopes and the liner system prior to filling the disposal cells with waste. This is a temporary condition. Based on the strength of the native soils, the critical surface will be above the native soils.

Slope Geometry:

A cross-section of the eastern slope was analyzed as shown on the attached Drawing No. C-2. The detailed geometry of the liner system is shown on Drawing No. C-3. We analyzed the double-lined cell configuration which can also be used to infer information regarding the stability of the Triple-Lined cell configuration.

Material Properties:

The following material properties were selected based on published literature:

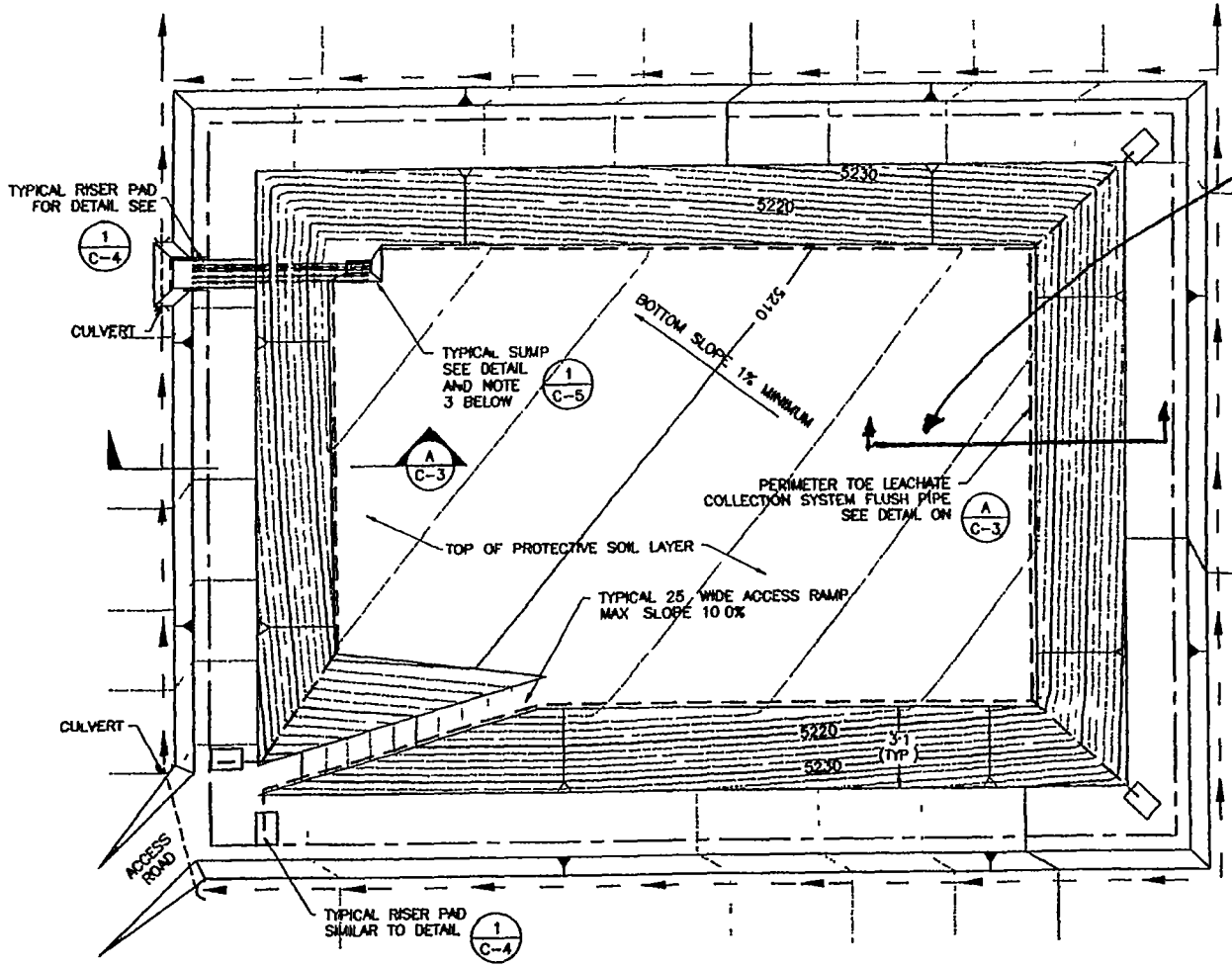
- Protective Soil Layer / Structural Fill
  Assume compacted sand
  $\phi = 35°$
  $c = 0$
  $\gamma_T = 115$ pcf

- Geosynthetic Layers Interface
  Assume textured HDPE for FML
  $\phi = 12°$
  $c = 0$

- CCL
  $\phi = 0$
  $c = 700$ psf
  $\gamma_T = 125$ pcf

CROSS SECTION USED FOR SLOPE STABILITY ANALYSES

PRELIMINARY
NOT FOR CONSTRUCTION
JAN 12 1996



0 100 200
SCALE IN FEET
CONTOUR INTERVAL = 2 FT

LEGEND

- LCS COLLECTION/FLUSH PIPING
- ANCHOR TRENCH
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- DRAINAGE CHANNEL

CUT FILL

NOTES.

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. THE CONTOURING PLAN SHOWN IS AN EXAMPLE LAYOUT ALL FINAL DIMENSIONS (SLOPES THICKNESS LENGTHS, DEPTHS, ETC) SHALL BE DETERMINED DURING DESIGN
3. LEACHATE REMOVAL SUMP ACCESS FLUSHING OPERATIONS AND ASSOCIATED FUNCTIONS WILL BE CAREFULLY ANALYZED DURING DESIGN WITH CONSIDERATION GIVEN TO THE OPERATING KNOWLEDGE GAINED FROM THE BASIN F WASTE PILE. GEOTEXTILE FILTER FABRICS SHOULD BE CHOSEN TO HAVE ADEQUATE FILTRATION CHARACTERISTICS TO AVOID CLOGGING ALTERNATIVE SUMP DESIGNS MAY BE REQUIRED.
4. ALL DETAILS SECTIONS, AND PLANS REPRESENT TRIPLE-LINED SYSTEMS UNLESS OTHERWISE NOTED
5. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING. ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE

NO.	DATE	REVISIONS	BY	CHK

DRAWN: MJK
DESIGNED: MCS
CHECKED: BAC
DATE:
PROJECT NO: 21907
SCALE: AS NOTED
APPROVED: RZK
DATE:

Harding Lawson Associates
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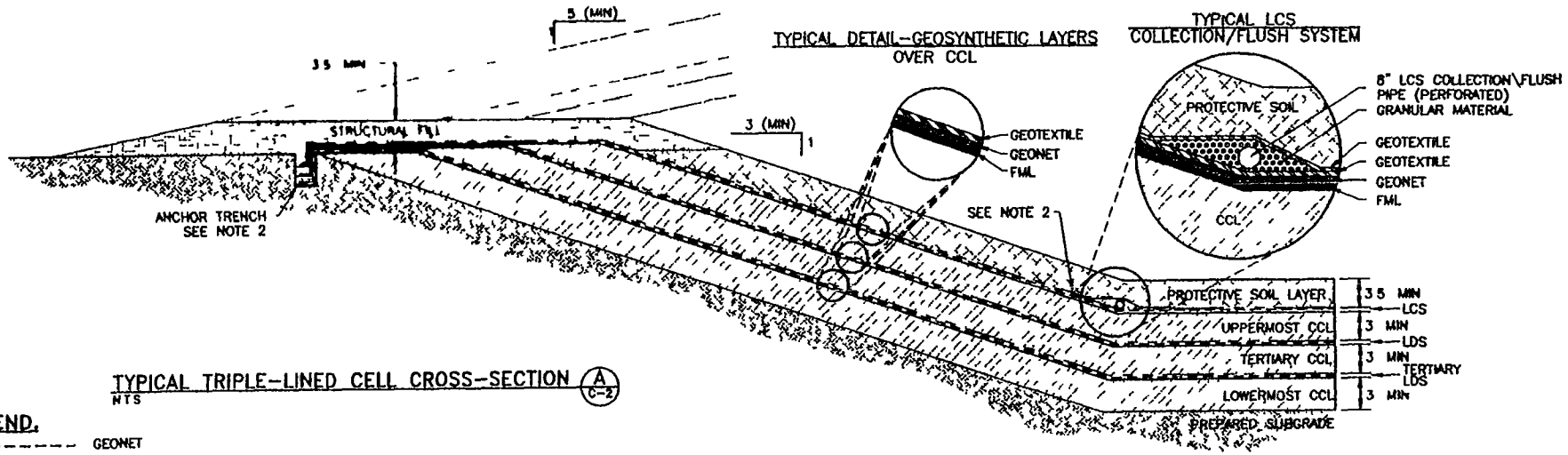
ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL CELL P1

DRAWING NO. C-2
3/11

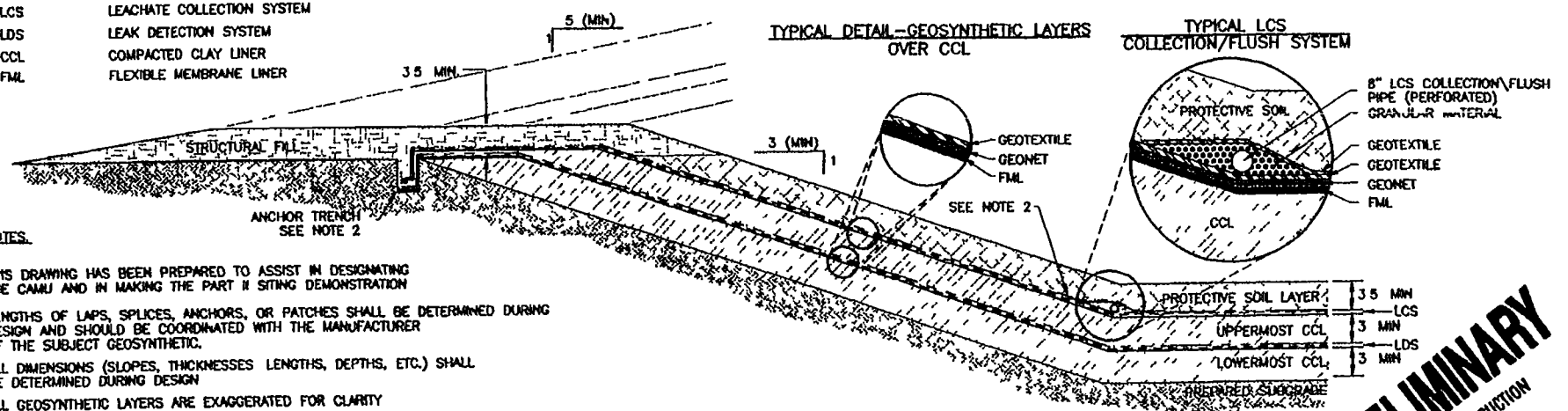
Pg 40 of 67



TYPICAL TRIPLE-LINED CELL CROSS-SECTION (A / C-2)
NTS

LEGEND.

- - - - - - - -	GEONET
— — — —	GEOTEXTILE
————	FLEXIBLE MEMBRANE LINER
LCS	LEACHATE COLLECTION SYSTEM
LDS	LEAK DETECTION SYSTEM
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER



TYPICAL DOUBLE-LINED CELL CROSS-SECTION (B / TYP)
N.T.S.

NOTES.

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. LENGTHS OF LAPS, SPLICES, ANCHORS, OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC.
3. ALL DIMENSIONS (SLOPES, THICKNESSES LENGTHS, DEPTHS, ETC.) SHALL BE DETERMINED DURING DESIGN
4. ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY
5. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE.

PRELIMINARY
NOT FOR CONSTRUCTION
JAN 12 1996

NO.	DATE	REVISIONS	BY	CHK

DRAWN: MJK | PROJECT NO: 21997
ENGINEER: BCS | SCALE: AS NOTED
CHECKED: BAC | APPROVED: RZK
DATE: | DATE:

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ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL CELL LINER SYSTEM
SECTIONS AND DETAILS

DRAWING NO. C-3
4 / 11

- Alluvial (Native) Soil

$\phi = 0$
$C = 3000$ psf
$\gamma_T = 130$ pcf

Calculations:

The slope stability calculations were performed using the same methodology as was used to evaluate the cover system.

We first analyzed the stability under static loads. A search for the critical surface yielded a factor of safety = 1.8. The critical failure surface was along the shallowest geosynthetic layer. We performed another analysis forcing the failure surface through the deeper geosynthetic layer and the factor of safety rose to 2.5.

We then performed a pseudo-static analysis using the same seismic coefficient as was used to analyze the cover system. The analysis yielded a minimum factor of safety of 1.5.

The attached output presents the results of the stability analyses.

Conclusions:

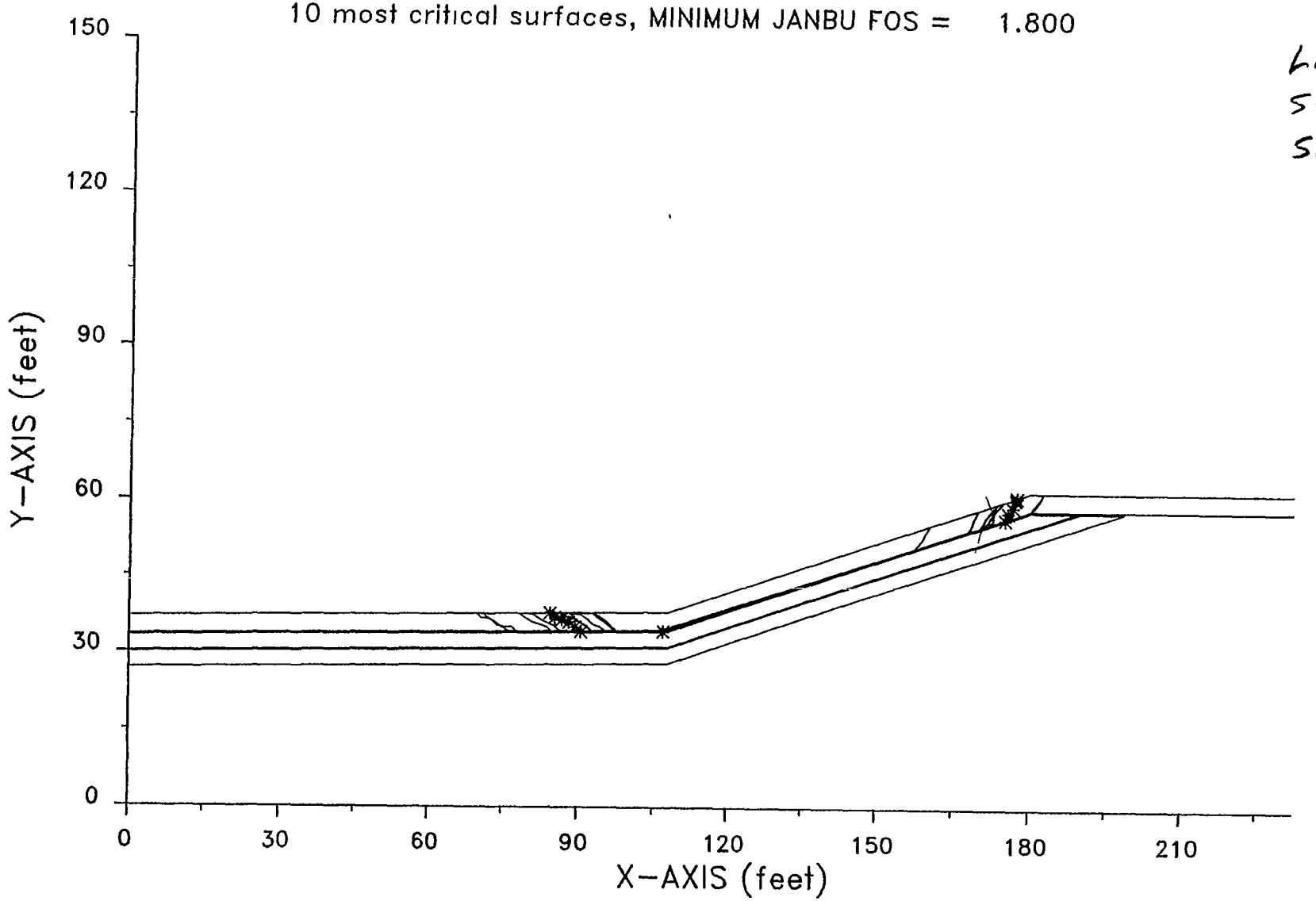
The calculated factors of safety for both static and seismic loading are at or above the commonly accepted factor of safety of 1.5. Therefore, the stability of the liner system on excavated slopes is acceptable.

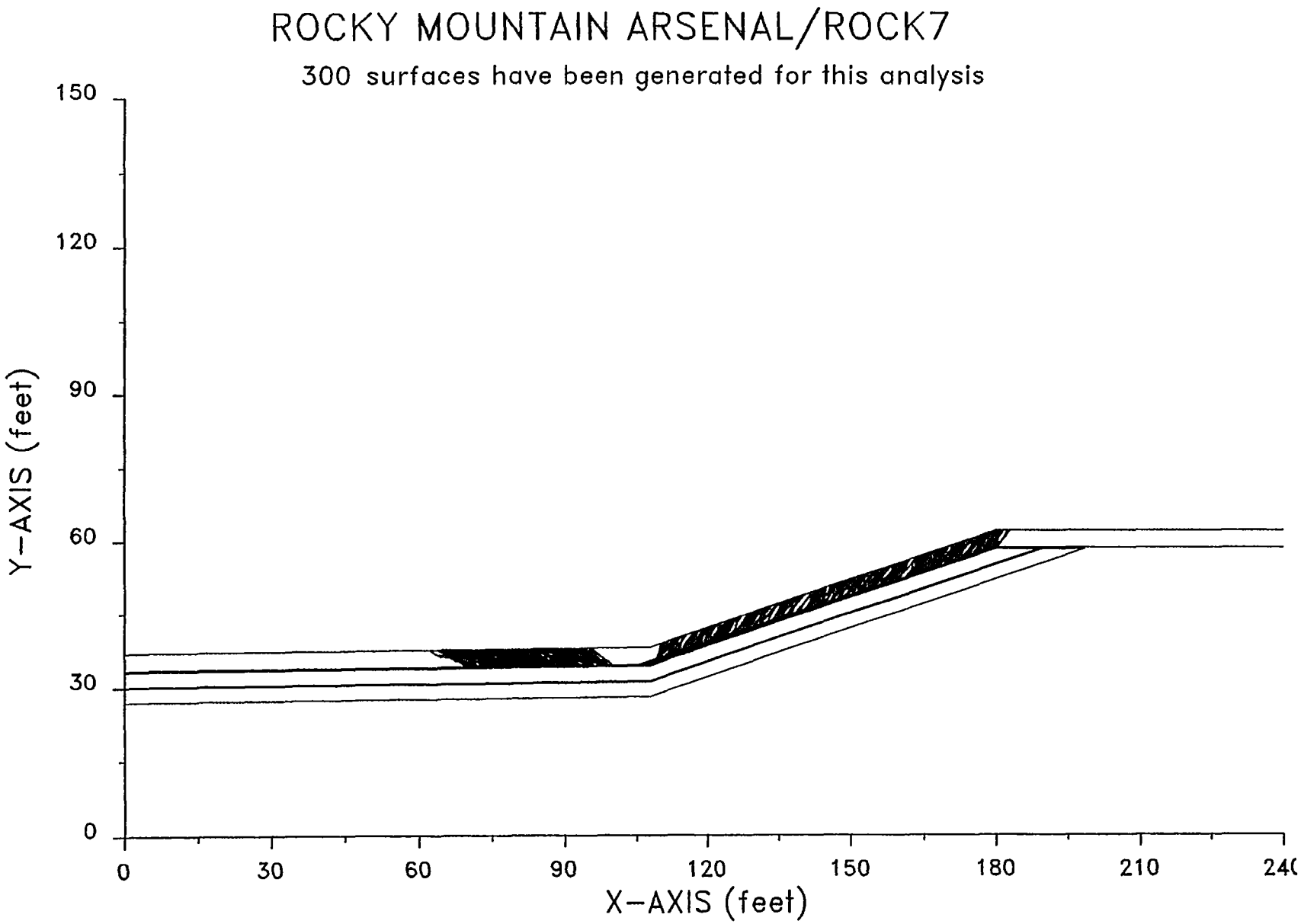
Prepared by: MDeLussey
Checked by LO

ROCKY MOUNTAIN ARSENAL/ROCK7

10 most critical surfaces, MINIMUM JANBU FOS = 1.800

Liner
Static
Shallow Layer




ROCKY MOUNTAIN ARSENAL/ROCK7
300 surfaces have been generated for this analysis
Y-AXIS (feet)
150
120
90
60
30
0
0
30
60
90
120
150
180
210
240
X-AXIS (feet)

```
*****************************************
*                XSTABL                 *
*                                       *
*     Slope Stability Analysis using    *
*   Simplified BISHOP or JANBU methods  *
*                                       *
*          Copyright (C) 1990           *
*   Interactive Software Designs, Inc.  *
*         All Rights Reserved           *
*                                       *
*          Jean Lou Chameau             *
*          Purdue University            *
*        W. Lafayette,  IN 47907        *
*                                       *
*  Ver. 3.00                      1002  *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	36.90	108.00	38.00	1
2	108.00	38.00	180.00	62.00	1
3	180.00	62.00	240.00	62.00	1

16 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	33.40	108.00	34.50	2
2	108.00	34.50	180.00	58.50	2
3	180.00	58.50	198.70	58.50	2
4	198.70	58.50	240.00	58.50	4
5	0.00	33.15	108.00	34.25	3
6	108.00	34.25	180.00	58.25	3
7	180.00	58.25	189.00	58.25	3
8	189.00	58.25	189.70	58.25	2
9	189.70	58.25	198.50	58.25	3
10	198.50	58.25	198.70	58.50	4
11	0.00	30.15	108.00	31.25	2
12	108.00	31.25	189.00	58.25	2
13	0.00	29.90	108.00	31.00	3
14	108.00	31.00	189.70	58.25	3
15	0.00	26.90	108.00	28.00	4
16	108.00	28.00	198.50	58.25	4

ISOTROPIC Soil Parameters

4 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	35.0	0.000	0.0	1
2	10.0	10.0	0.0	12.0	0.000	0.0	1
3	125.0	125.0	700.0	0.0	0.000	0.0	1
4	130.0	130.0	3000.0	0.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

3 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	70.00	33.97	100.00	34.28	0.20
2	105.00	34.33	107.00	34.35	0.20
3	108.00	34.30	180.00	58.40	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	84.49	37.76
2	85.44	37.03
3	86.84	36.49

4	88.26	35.99	
5	89.45	35.08	
6	90.67	34.20	
7	106.95	34.26	
8	175.09	56.75	5686
9	175.72	58.12	
10	176.72	59.24	
11	177.17	60.67	
12	177.44	61.15	

** Corrected JANBU FOS = 1.800 ** (Fo factor =1.025)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	71.11	37.62
2	71.54	37.26
3	72.80	36.46
4	73.86	35.40
5	75.33	35.06
6	76.82	35.00
7	77.91	33.96
8	106.85	34.29
9	174.87	56.58
10	175.92	57.65
11	176.77	58.89
12	177.16	60.34
13	177.96	61.32

5083
5021
6082
345

** Corrected JANBU FOS = 1.892 ** (Fo factor =1.027)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.30	37.85
2	94.09	37.24
3	95.33	36.40
4	96.44	35.39
5	97.50	34.33
6	106.99	34.42
7	169.77	54.92
8	170.70	56.09
9	171.38	57.43
10	172.38	58.55
11	173.42	59.63
12	173.69	59.90

** Corrected JANBU FOS = 1.910 ** (Fo factor =1.023)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	80.00	37.71
2	81.18	37.53
3	82.41	36.66
4	83.72	35.94
5	85.13	35.43
6	86.21	34.39
7	87.71	34.22
8	89.20	34.19
9	106.91	34.40
10	171.65	55.53
11	172.63	56.66
12	172.83	58.15
13	173.24	59.59
14	173.27	59.76

** Corrected JANBU FOS = 2.023 ** (Fo factor =1.026)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	88.39	37.80
2	89.15	37.16
3	90.21	36.10
4	91.54	35.41
5	92.67	34.42
6	94.14	34.17
7	106.39	34.30
8	170.70	55.23
9	171.68	56.37
10	172.49	57.63
11	173.42	58.81
12	174.47	59.88
13	174.56	60.19

** Corrected JANBU FOS = 2.037 ** (Fo factor =1.024)

Failure surface No. 6 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.02	37.85
2	93.84	37.07
3	95.05	36.18
4	96.25	35.28
5	97.31	34.22
6	105.96	34.32
7	179.90	58.27
8	180.74	59.51
9	181.79	60.58
10	182.38	61.96
11	182.40	62.00

** Corrected JANBU FOS = 2.054 ** (Fo factor =1.020)

Failure surface No. 7 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	69.80	37.61
2	70.72	36.78
3	72.22	36.73
4	73.54	36.03
5	74.75	35.14
6	76.03	34.35
7	77.50	34.04
8	106.96	34.42
9	179.95	58.31
10	181.01	59.37
11	181.63	60.74
12	182.50	61.96
13	182.53	62.00

** Corrected JANBU FOS = 2.085 ** (Fo factor =1.026)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	78.46	37.70
2	78.47	37.69
3	79.67	36.79
4	80.98	36.07
5	82.38	35.54
6	83.79	35.01
7	84.97	34.08
8	106.65	34.31
9	167.42	54.14
10	168.38	55.29
11	168.91	56.70
12	169.49	58.08
13	169.89	58.63

** Corrected JANBU FOS = 2.088 ** (Fo factor =1.027)

Failure surface No. 9 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	88.95	37.81
2	89.09	37.66
3	90.59	37.53
4	91.83	36.69
5	92.89	35.63
6	94.31	35.12
7	95.54	34.27
8	106.18	34.39
9	176.05	56.98
10	176.70	58.33

11	176.93	59.81
12	177.98	60.88
13	178.50	61.50

** Corrected JANBU FOS = 2.089 ** (Fo factor =1.023)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	87.03	37.79
2	87.58	37.27
3	89.02	36.88
4	90.29	36.07
5	91.59	35.33
6	92.66	34.27
7	94.16	34.21
8	95.66	34.19
9	106.86	34.26
10	157.07	50.77
11	158.09	51.87
12	159.07	53.01
13	159.68	54.38
14	160.52	55.51

** Corrected JANBU FOS = 2.094 ** (Fo factor =1.028)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	1.800	1.025	84.49	177.44	9193.
2.	1.892	1.027	71.11	177.96	9277.
3.	1.910	1.023	93.30	173.69	8414.
4.	2.023	1.026	80.00	173.27	8622.
5.	2.037	1.024	88.39	174.56	8509.
6.	2.054	1.020	93.02	182.40	9249.
7.	2.085	1.026	69.80	182.53	9595.
8.	2.088	1.027	78.46	169.89	8106.
9.	2.089	1.023	88.95	178.50	8898.
10.	2.094	1.028	87.03	160.52	6846.

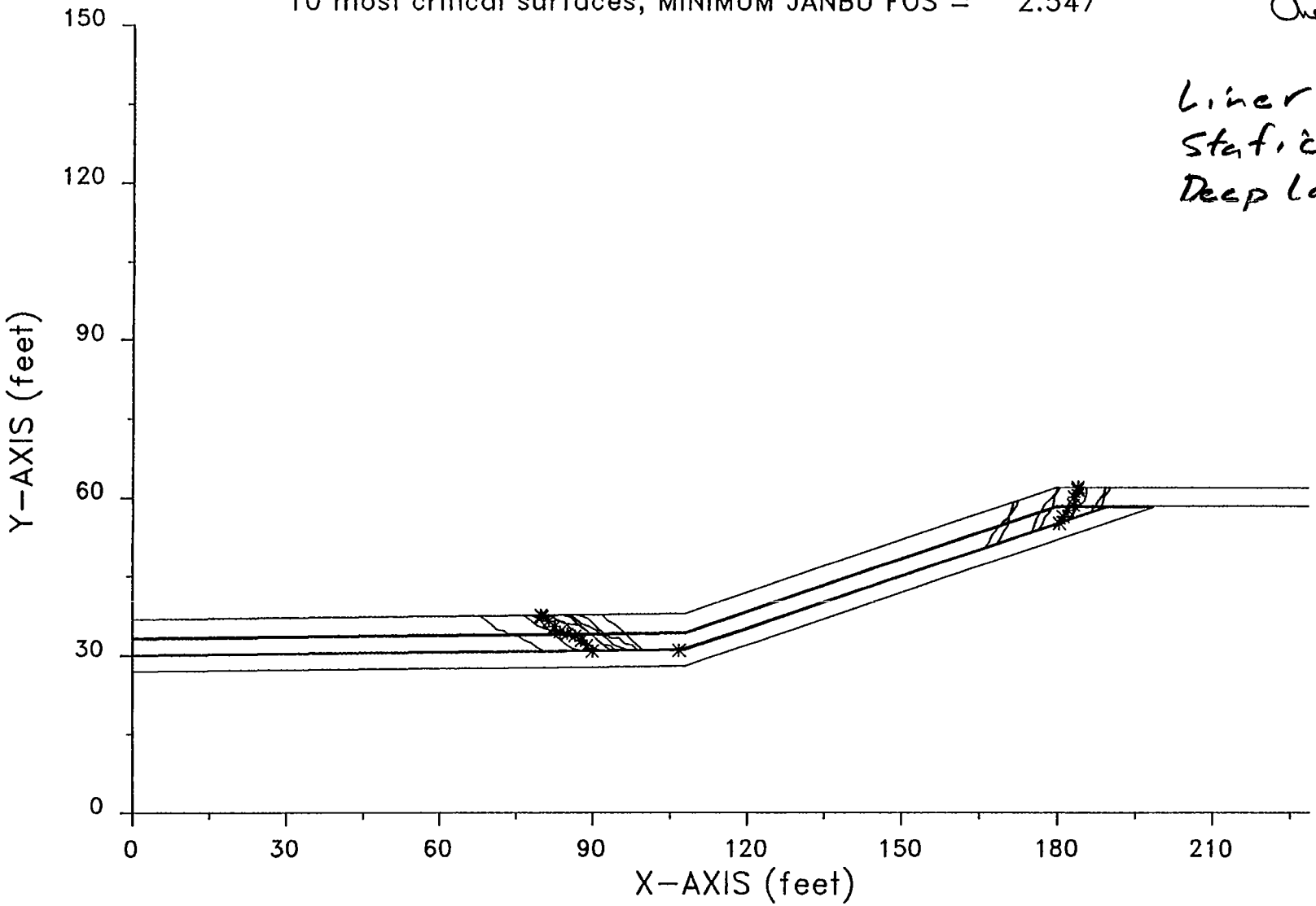
* * * END OF FILE * * *

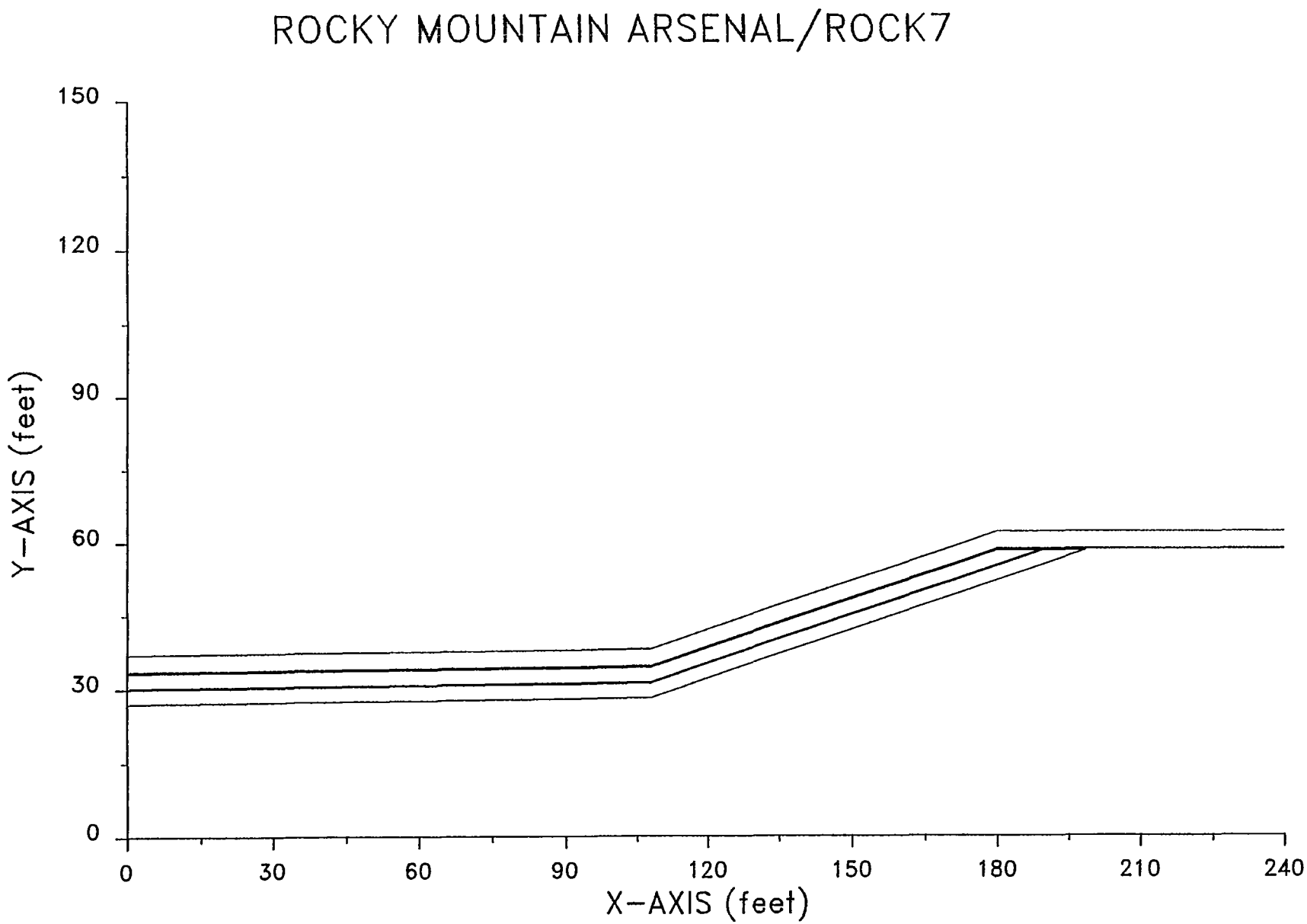
ROCKY MOUNTAIN ARSENAL/ROCK10A

10 most critical surfaces, MINIMUM JANBU FOS = 2.547

Prepared by Maria Flessas
Checked by L.O.

Liner
Static
Deep layer




ROCKY MOUNTAIN ARSENAL/ROCK7
Y-AXIS (feet)
150
120
90
60
30
0
X-AXIS (feet)
0
30
60
90
120
150
180
210
240

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*          Jean Lou Chameau             *
*          Purdue University            *
*        W. Lafayette,  IN 47907        *
*                                       *
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```

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK10A

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	36.90	108.00	38.00	1
2	108.00	38.00	180.00	62.00	1
3	180.00	62.00	240.00	62.00	1

16 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	33.40	108.00	34.50	2
2	108.00	34.50	180.00	58.50	2
3	180.00	58.50	198.70	58.50	2
4	198.70	58.50	240.00	58.50	4
5	0.00	33.15	108.00	34.25	3
6	108.00	34.25	180.00	58.25	3
7	180.00	58.25	189.00	58.25	3
8	189.00	58.25	189.70	58.25	2
9	189.70	58.25	198.50	58.25	3
10	198.50	58.25	198.70	58.50	4
11	0.00	30.15	108.00	31.25	2
12	108.00	31.25	189.00	58.25	2
13	0.00	29.90	108.00	31.00	3
14	108.00	31.00	189.70	58.25	3
15	0.00	26.90	108.00	28.00	4
16	108.00	28.00	198.50	58.25	4

ISOTROPIC Soil Parameters

4 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	35.0	0.000	0.0	1
2	10.0	10.0	0.0	12.0	0.000	0.0	1
3	125.0	125.0	700.0	0.0	0.000	0.0	1
4	130.0	130.0	3000.0	0.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

3 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	80.00	30.83	100.00	31.02	0.20
2	105.00	31.08	107.00	31.09	0.20
3	108.00	31.12	189.00	58.12	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 18 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	79.96	37.71
2	80.26	37.45
3	81.52	36.64

4	82.62	35.62	
5	83.69	34.57	
6	85.15	34.22	
7	86.60	33.84	
8	87.74	32.86	
9	88.93	31.96	
10	90.00	30.90	
11	106.78	31.01	
12	180.40	55.16	55.38 Top
13	181.12	56.48	
14	182.08	57.63	
15	183.08	58.74	
16	183.32	60.22	
17	183.94	61.59	
18	184.04	62.00	

** Corrected JANBU FOS = 2.547 ** (Fo factor =1.049)

Failure surface No. 2 specified by 20 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	87.50	37.79
2	87.63	37.66
3	89.07	37.25
4	90.16	36.22
5	91.24	35.17
6	92.40	34.23
7	93.66	33.41
8	95.16	33.40
9	96.23	32.35
10	97.69	32.03
11	98.81	31.02
12	106.82	30.99
13	175.11	53.40
14	175.60	54.82
15	176.11	56.23
16	176.88	57.52
17	177.61	58.83
18	178.67	59.89
19	179.72	60.96
20	180.34	62.00

** Corrected JANBU FOS = 2.586 ** (Fo factor =1.050)

Failure surface No. 3 specified by 18 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	76.53	37.68
2	76.70	37.62
3	77.96	36.80
4	79.13	35.86
5	80.52	35.30
6	81.97	34.94
7	83.42	34.54

8	84.72	33.80
9	86.21	33.60
10	87.39	32.68
11	88.62	31.81
12	89.79	30.88
13	106.97	31.06
14	187.81	57.67
15	188.70	58.88
16	189.04	60.34
17	190.10	61.40
18	190.20	62.00

** Corrected JANBU FOS = 2.648 ** (Fo factor =1.047)

Failure surface No. 4 specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	91.85	37.84
2	92.85	36.84
3	94.15	36.08
4	95.38	35.23
5	96.48	34.21
6	97.55	33.15
7	98.61	32.10
8	99.72	31.09
9	106.88	31.05
10	176.14	53.79
11	177.07	54.97
12	177.61	56.37
13	178.64	57.46
14	179.26	58.82
15	179.48	60.31
16	180.35	61.53
17	180.54	62.00

** Corrected JANBU FOS = 2.712 ** (Fo factor =1.048)

Failure surface No. 5 specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	84.45	37.76
2	85.73	37.40
3	86.80	36.35
4	87.97	35.42
5	89.24	34.61
6	90.37	33.63
7	91.52	32.66
8	92.58	31.60
9	93.91	30.92
10	106.74	31.03
11	179.76	54.99
12	180.72	56.14
13	181.60	57.36
14	182.15	58.76

15	182.93	60.04
16	183.96	61.12
17	184.38	62.00

** Corrected JANBU FOS = 2.785 ** (Fo factor =1.048)

Failure surface No. 6 specified by 21 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	81.62	37.73
2	81.75	37.60
3	83.11	36.97
4	84.39	36.19
5	85.88	36.06
6	87.38	35.96
7	88.63	35.13
8	89.80	34.18
9	90.87	33.13
10	91.97	32.12
11	93.46	31.94
12	94.60	30.96
13	106.91	31.02
14	168.05	51.10
15	169.06	52.21
16	169.72	53.56
17	170.52	54.83
18	170.67	56.32
19	171.13	57.74
20	171.59	59.17
21	171.61	59.20

** Corrected JANBU FOS = 2.876 ** (Fo factor =1.054)

Failure surface No. 7 specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	77.95	37.69
2	79.35	37.21
3	80.41	36.15
4	81.47	35.09
5	82.54	34.03
6	83.76	33.16
7	84.89	32.17
8	86.14	31.35
9	87.61	31.06
10	89.11	30.96
11	106.64	31.02
12	182.05	55.75
13	182.87	57.00
14	183.64	58.29
15	183.72	59.78
16	184.39	61.13
17	185.14	62.00

** Corrected JANBU FOS = 2.910 ** (Fo factor =1.049)

Failure surface No. 8 specified by 19 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	82.19	37.74
2	83.18	36.76
3	84.63	36.40
4	85.72	35.37
5	86.98	34.55
6	88.05	33.50
7	89.12	32.45
8	90.28	31.50
9	91.65	30.88
10	106.96	31.01
11	165.85	50.44
12	166.85	51.55
13	167.46	52.92
14	168.40	54.10
15	169.41	55.21
16	170.47	56.27
17	171.43	57.42
18	172.26	58.67
19	172.51	59.50

** Corrected JANBU FOS = 2.930 ** (Fo factor =1.054)

Failure surface No. 9 specified by 16 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	85.85	37.77
2	86.79	37.08
3	87.99	36.17
4	89.38	35.62
5	90.72	34.95
6	91.84	33.94
7	93.07	33.10
8	94.14	32.05
9	95.54	31.50
10	96.96	31.01
11	106.70	31.02
12	186.31	57.22
13	187.26	58.38
14	188.00	59.69
15	188.94	60.86
16	189.35	62.00

** Corrected JANBU FOS = 2.943 ** (Fo factor =1.045)

Failure surface No.10 specified by 19 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	67.92	37.59
2	68.96	37.07
3	70.11	36.11
4	71.23	35.11
5	72.71	34.84
6	73.90	33.93
7	75.40	33.87
8	76.65	33.04
9	78.06	32.54
10	79.20	31.56
11	80.54	30.89
12	82.04	30.84
13	106.85	31.03
14	182.53	55.95
15	183.27	57.25
16	184.18	58.44
17	185.22	59.52
18	185.67	60.95
19	185.69	62.00

** Corrected JANBU FOS = 2.955 ** (Fo factor =1.050)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK10A

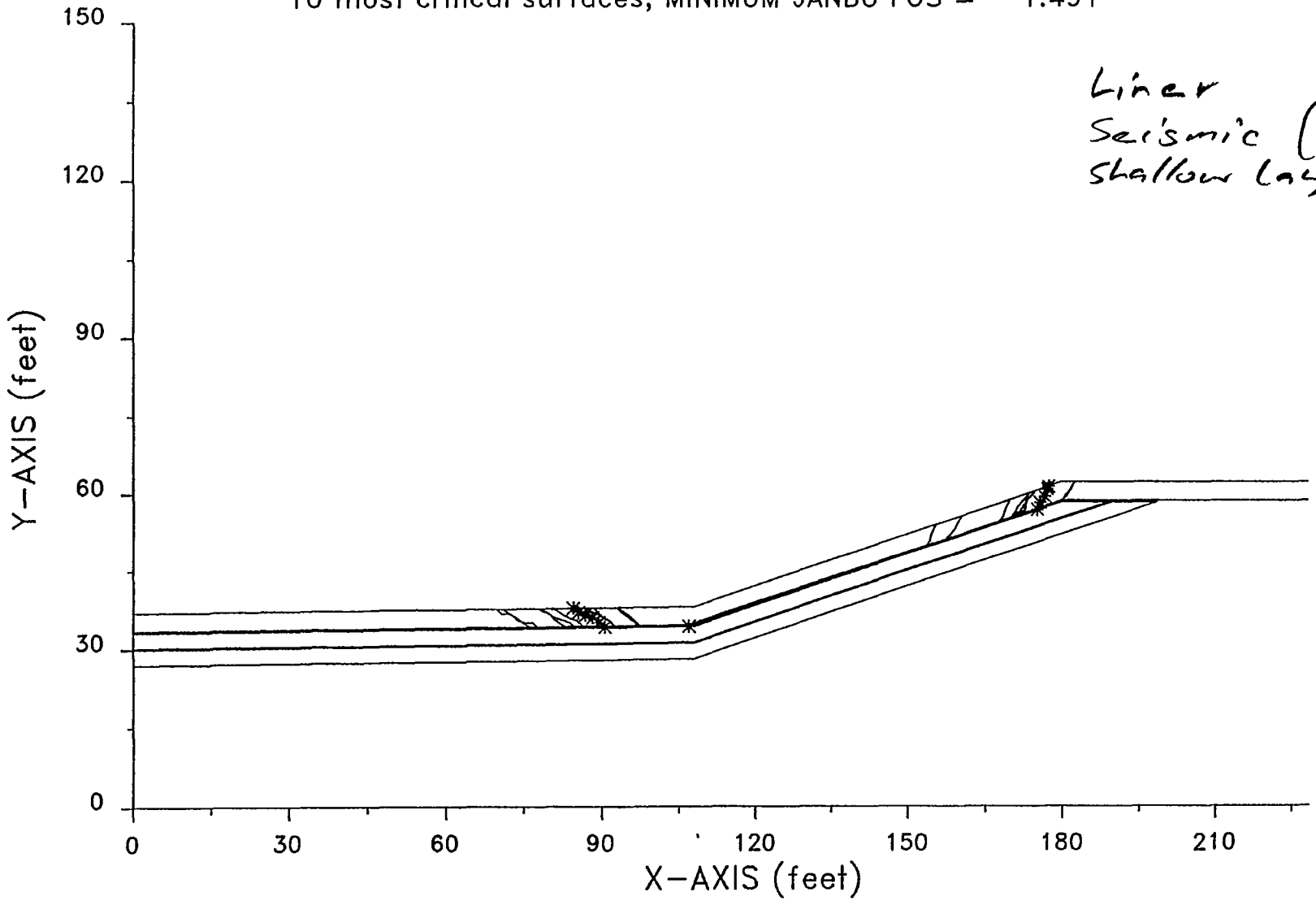
	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	2.547	1.049	79.96	184.04	188.15E+02
2.	2.586	1.050	87.50	180.34	180.66E+02
3.	2.648	1.047	76.53	190.20	187.58E+02
4.	2.712	1.048	91.85	180.54	183.39E+02
5.	2.785	1.048	84.45	184.38	187.24E+02
6.	2.876	1.054	81.62	171.61	162.97E+02
7.	2.910	1.049	77.95	185.14	187.44E+02
8.	2.930	1.054	82.19	172.51	160.51E+02
9.	2.943	1.045	85.85	189.35	186.33E+02
10.	2.955	1.050	67.92	185.69	188.50E+02

* * * END OF FILE * * *

ROCKY MOUNTAIN ARSENAL/ROCK7EQ

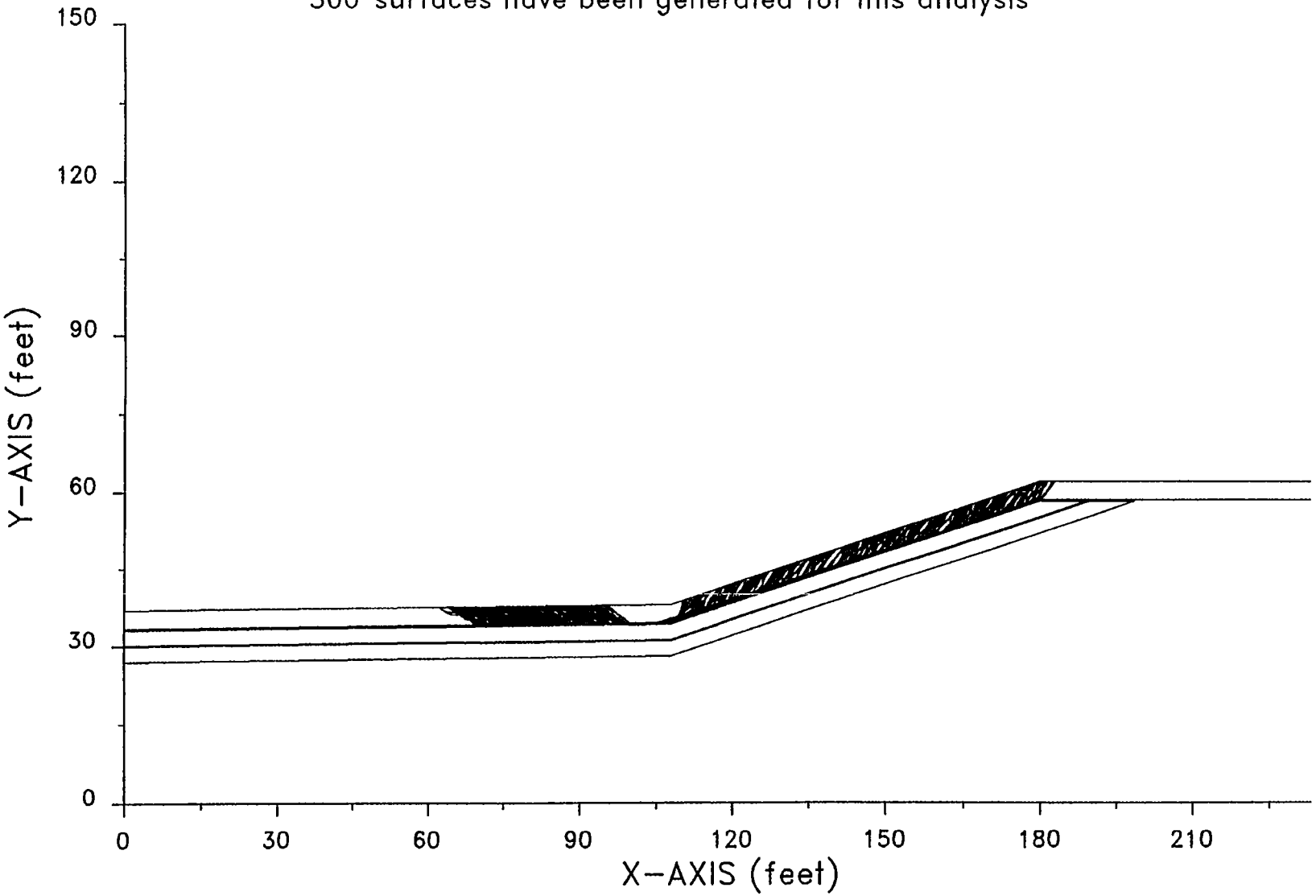
10 most critical surfaces, MINIMUM JANBU FOS = 1.491

Liner
Seismic ($K_H = 0.05g$)
Shallow Layer



ROCKY MOUNTAIN ARSENAL/ROCK7EQ

300 surfaces have been generated for this analysis



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*                                       *
*          Jean Lou Chameau             *
*          Purdue University            *
*       W. Lafayette,  IN 47907         *
*                                       *
*  Ver. 3.00                      1002  *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7EQ

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	36.90	108.00	38.00	1
2	108.00	38.00	180.00	62.00	1
3	180.00	62.00	240.00	62.00	1

15 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	33.40	108.00	34.50	2
2	108.00	34.50	180.00	58.50	2
3	180.00	58.50	198.70	58.50	2
4	198.70	58.50	240.00	58.50	4
5	0.00	33.15	108.00	34.25	3
6	108.00	34.25	180.00	58.25	3
7	180.00	58.25	189.00	58.25	3
8	189.00	58.25	189.70	58.25	2
9	189.70	58.25	198.50	58.25	3
10	198.50	58.25	198.70	58.50	4
11	0.00	30.15	108.00	31.25	2
12	108.00	31.25	189.00	58.25	2
13	0.00	29.90	108.00	31.00	3
14	108.00	31.00	189.70	58.25	3
15	0.00	26.90	108.00	28.00	4
16	108.00	28.00	198.50	58.25	4

ISOTROPIC Soil Parameters

4 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	35.0	0.000	0.0	1
2	10.0	10.0	0.0	12.0	0.000	0.0	1
3	125.0	125.0	700.0	0.0	0.000	0.0	1
4	130.0	130.0	3000.0	0.0	0.000	0.0	1

A horizontal earthquake loading coefficient
of 0.050 has been assigned

A vertical earthquake loading coefficient
of 0.000 has been assigned

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

3 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	70.00	33.97	100.00	34.28	0.20
2	105.00	34.33	107.00	34.35	0.20
3	108.00	34.30	180.00	58.40	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	84.49	37.76
2	85.44	37.03
3	86.84	36.49
4	88.26	35.99
5	89.45	35.08
6	90.67	34.20
7	106.95	34.26
8	175.09	56.75
9	175.72	58.12
10	176.72	59.24
11	177.17	60.67
12	177.44	61.15

** Corrected JANBU FOS = 1.491 ** (Fo factor =1.025)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	71.11	37.62
2	71.54	37.26
3	72.80	36.46
4	73.86	35.40
5	75.33	35.06
6	76.82	35.00
7	77.91	33.96
8	106.85	34.29
9	174.87	56.58
10	175.92	57.65
11	176.77	58.89
12	177.16	60.34
13	177.96	61.32

** Corrected JANBU FOS = 1.538 ** (Fo factor =1.027)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.30	37.85
2	94.09	37.24
3	95.33	36.40
4	96.44	35.39
5	97.50	34.33
6	106.99	34.42
7	169.77	54.92
8	170.70	56.09
9	171.38	57.43
10	172.38	58.55
11	173.42	59.63
12	173.69	59.90

** Corrected JANBU FOS = 1.609 ** (Fo factor =1.023)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	80.00	37.71
2	81.18	37.53
3	82.41	36.66
4	83.72	35.94
5	85.13	35.43
6	86.21	34.39
7	87.71	34.22
8	89.20	34.19
9	106.91	34.40
10	171.65	55.53
11	172.63	56.66
12	172.83	58.15
13	173.24	59.59
14	173.27	59.76

** Corrected JANBU FOS = 1.657 ** (Fo factor =1.026)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	69.80	37.61
2	70.72	36.78
3	72.22	36.73
4	73.54	36.03
5	74.75	35.14
6	76.03	34.35
7	77.50	34.04
8	106.96	34.42
9	179.95	58.31
10	181.01	59.37
11	181.63	60.74
12	182.50	61.96
13	182.53	62.00

** Corrected JANBU FOS = 1.681 ** (Fo factor =1.026)

Failure surface No. 6 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	77.88	37.69
2	78.41	37.35
3	79.81	36.80
4	80.87	35.74
5	82.08	34.85
6	83.40	34.15

7	106.74	34.28
8	153.26	49.39
9	154.24	50.52
10	154.57	51.99
11	155.13	53.38
12	155.53	53.84

** Corrected JANBU FOS = 1.688 ** (Fo factor =1.030)

Failure surface No. 7 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	88.39	37.80
2	89.15	37.16
3	90.21	36.10
4	91.54	35.41
5	92.67	34.42
6	94.14	34.17
7	106.39	34.30
8	170.70	55.23
9	171.68	56.37
10	172.49	57.63
11	173.42	58.81
12	174.47	59.88
13	174.56	60.19

** Corrected JANBU FOS = 1.694 ** (Fo factor =1.024)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	78.46	37.70
2	78.47	37.69
3	79.67	36.79
4	80.98	36.07
5	82.38	35.54
6	83.79	35.01
7	84.97	34.08
8	106.65	34.31
9	167.42	54.14
10	168.38	55.29
11	168.91	56.70
12	169.49	58.08
13	169.89	58.63

** Corrected JANBU FOS = 1.696 ** (Fo factor =1.027)

Failure surface No. 9 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.02	37.85

2	93.84	37.07
3	95.05	36.18
4	96.25	35.28
5	97.31	34.22
6	105.96	34.32
7	179.90	58.27
8	180.74	59.51
9	181.79	60.58
10	182.38	61.96
11	182.40	62.00

** Corrected JANBU FOS = 1.724 ** (Fo factor =1.020)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	87.03	37.79
2	87.58	37.27
3	89.02	36.88
4	90.29	36.07
5	91.59	35.33
6	92.66	34.27
7	94.16	34.21
8	95.66	34.19
9	106.86	34.26
10	157.07	50.77
11	158.09	51.87
12	159.07	53.01
13	159.68	54.38
14	160.52	55.51

** Corrected JANBU FOS = 1.728 ** (Fo factor =1.028)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7EQ

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	1.491	1.025	84.49	177.44	109.70E+02
2.	1.538	1.027	71.11	177.96	113.36E+02
3.	1.609	1.023	93.30	173.69	9919.
4.	1.657	1.026	80.00	173.27	103.90E+02
5.	1.681	1.026	69.80	182.53	117.40E+02
6.	1.688	1.030	77.88	155.53	7765.
7.	1.694	1.024	88.39	174.56	101.26E+02
8.	1.696	1.027	78.46	169.89	9841.
9.	1.724	1.020	93.02	182.40	109.14E+02
10.	1.728	1.028	87.03	160.52	8223.

* * * END OF FILE * * *

CONCEPTUAL COVER SLOPE STABILITY ANALYSIS

SLOPE STABILITY - COVER SLOPES

Purpose: To evaluate the stability of the cover system on perimeter slopes with respect to static and seismic loading.

Slope Geometry:

A cross-section of the eastern slope was analyzed as shown on the attached Drawing No. C-6. The detailed geometry of the cover system is shown on Drawing No. C-8.

Material Properties:

The following material properties were selected based on published literature

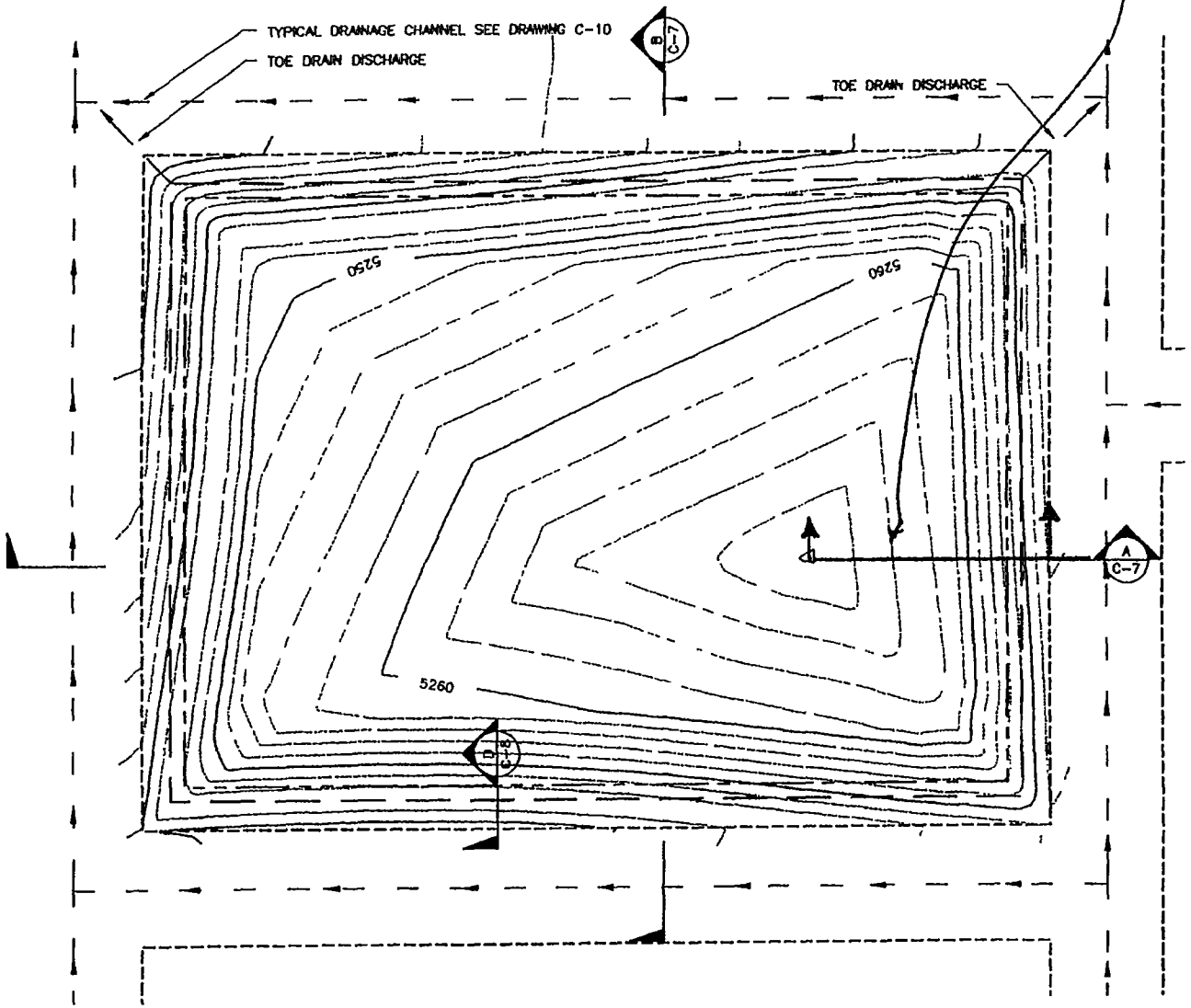
- Vegitative Layer
  Assume sandy material
  $\phi = 30°$
  $C = 0$
  $\gamma_T = 115$ pcf

- Water Storage Layer (compacted)
  Assume cohesive soil
  $\phi = 0$
  $C = 1000$ psf
  $\gamma_T = 125$ pcf

- Water Storage Layer - Geotextile - Biota Barrier Interface
  $\phi = 20°$
  $C = 0$

- Biota Barrier (Gravel)
  $\phi = 37°$
  $C = 0$
  $\phi = 120$ pcf

CROSS SECTION USED FOR SLOPE STABILITY ANALYSES



PRELIMINARY
NOT FOR CONSTRUCTION
JAN 12 1996

0 100 200
SCALE IN FEET
CONTOUR INTERVAL = 2 FT

LEGEND.

- APPROXIMATE LIMITS OF WASTE
- FINAL COVER TOE DRAIN
- DRAINAGE CHANNEL
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- APPROX LIMITS OF FINAL COVER

NOTES.

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION.
2. THE CONTOURING PLAN SHOWN IS AN EXAMPLE LAYOUT THE ACTUAL COVER SLOPES AND OVERALL CONFIGURATIONS WILL BE DETERMINED DURING DESIGN.
3. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE.

NO.	DATE	REVISIONS	BY	CHK

DRAWN: BCS
ENGINEER: BAC
CHECKED: BAC
DATE:
PROJECT NO: 21957
SCALE: AS NOTED
APPROVED: RKK
DATE:

Harding Lawson Associates
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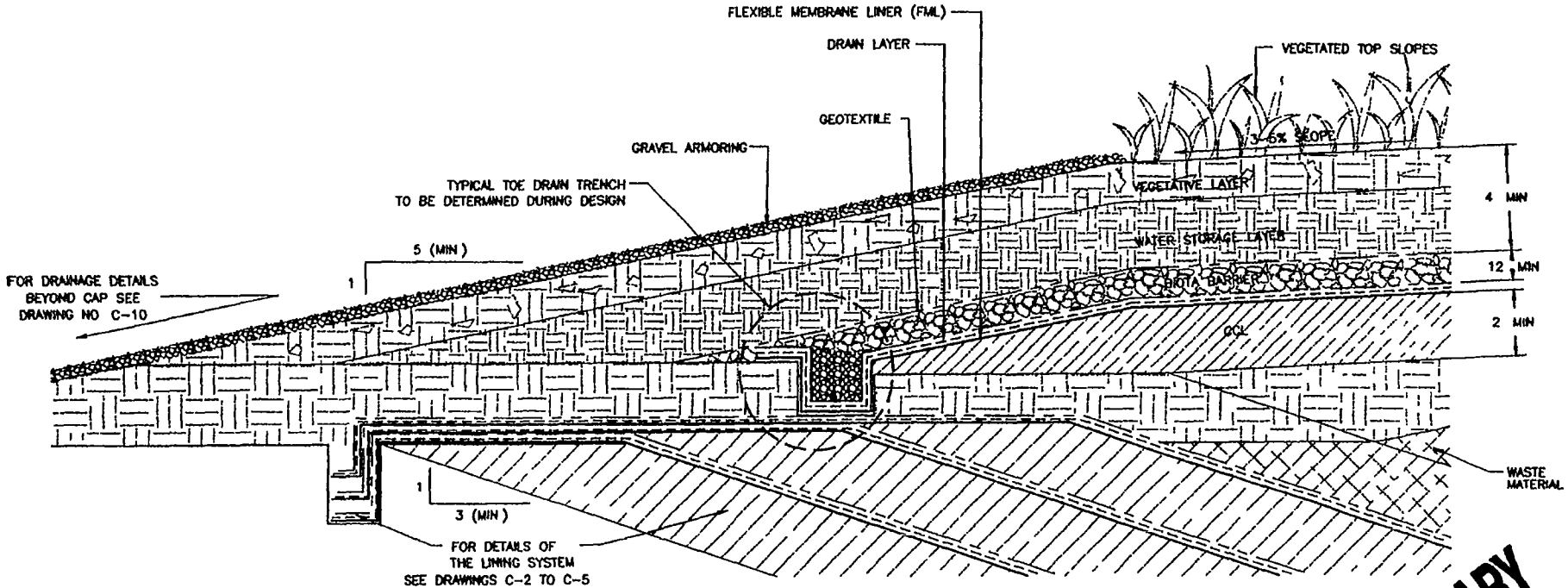
ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

CAMU DECISION DOCUMENT
DECISION LEVEL DRAWING

TYPICAL FINAL COVER PLAN

DRAWING NO. C-6
7/11

pg 15 of 67



TYPICAL COVER SECTION (D / C-6)
NTS

PRELIMINARY
NOT FOR CONSTRUCTION
JAN 12 1996

LEGEND:

- GEONET
- GEOTEXTILE
- FLEXIBLE MEMBRANE LINER (FML)
- CCL — COMPACTED CLAY LINER

NOTES.

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. TOE DRAIN TRENCH SHALL BE DESIGNED TO POSITIVE DRAIN AND CONSTRUCTED TO AVOID DAMAGE TO THE UNDERLYING GEOSYNTHETIC MATERIALS. DIMENSIONS ARE TO BE DETERMINED DURING DESIGN
3. LENGTHS OF LAPS, SPLICES OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC
4. ALL FINAL DIMENSIONS (SLOPES, THICKNESSES LENGTHS, DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN
5. ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY
6. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE

NO.	DATE	REVISIONS	BY	CHK

DRAWN: BCS
ENGINEER: BCS
CHECKED: BAC
PROJECT NO: 31997
SCALE: NONE
APPROVED: RZK
DATE:

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ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL COVER SECTION

DRAWING NO: C-8
9 / 11

- Biota Barrier - Geotextile - Geonet - FML - CCL Interface (Assume Textured HDPE)
  $\phi = 12°$ (see attached)
  $C = 0$

- CCL
  $\phi = 0$
  $C = 700$ psf
  $\gamma_T = 125$ pcf

- Waste Material
  Assume cohesive soil
  $\phi = 0$
  $C = 2000$ psf HIGH
  $\gamma_T = 125$ pcf

Calculations:

Slope stability calculations were performed using the computer program PC STABL 5M developed at Purdue University. The program uses Janbu's simplified method for noncircular slip surfaces.

The analyses was performed using the attached cross-section. We assumed that the drain layer would remove any infiltrating water so that hydrostatic pressure would not build up within the system.

We first analyzed the stability of the slope under static loading. A search for the critical surface yielded a factor of safety = 2.8. The critical surface was predominantly along the FML layer, which represents a low strength zone.

We then performed a pseudo-static analysis to simulate seismic loading conditions. We used a pseudo-static

- Sli. .g along a surface that occurs between geosynthetics This may occur when multiple geosynthetic layers are used

3.6.1 Soil Geotextile Interface Friction

The interface friction between soils and geotextiles generally has a high efficiency under both low and high normal loads The efficiency is generally higher for wovens and needle-punched nonwovens than for heat-bonded nonwovens This is probably due to the rougher surface and larger amount of soil-to-fabric interaction with the wovens and needle-punched nonwovens Other factors or trends observed in performing direct shear tests between soils and geotextiles include

- There is some indication that wetting the geotextiles decreases the shear strength (El-Fermaoui and Nowatzi, 1982, Miyamori et al , 1986)
- For woven geotextiles, the machine and cross directions produce different interface friction values, with the cross direction typically being lower (Eigenbrod and Locker, 1987)
- The density of sand may not have a significant effect on the interface friction between sands and geotextiles, especialy for woven geotextiles (Eigenbrod and Locker, 1987, Koutsourais et al , 1990)
- Adhesion between soils and geotextiles may exist due to the interlocking of the materials The adhesion is most apparent in nonwoven geotextiles (Eigenbrod and Locker, 1987)
- For clay soils and nonwoven geotextiles at intermediate and high confining stresses, the interface friction angle may increase and the adhesion decrease due to consolidation of the soil adjacent to the geotextile (Williams and Houlihan, 1987)

Since the shear strength results are highly dependent on the soil and type of geotextile, it is highly recommended that direct shear tests using the actual materials be used However, for general guidance purposes or preliminary designs, Table 3 13 presents the results of soil geotextile friction tests reported in the literature (Myles, 1982, Martin et al , 1984, Miyamori et al , 1986, Eigenbrod and Locker, 1987, Williams and Houlihan, 1987, Eigenbrod et al , 1990, Koutsourais et al , 1990) The wide variations in the results presented in Table 3 13 are due to variations in testing procedures, normal stresses, soils, and geotextiles The range also covers both peak and residual friction angles

3.6.2 Soil Geomembrane Interface Strength

Since, unlike geotextiles, geomembranes do not contain openings or pores, the interface strength between soils and geomembranes is largely dependent on whether the surface of the geomembrane is flexible or rough enough to push the failure plane into the adjacent soils If the failure plane is pushed into the adjacent soils, the

TABLE 3.13 Typical Range of Reported Soil Geotextile Fric. Angles

Geotextile	Sand Friction Angle (deg) (Efficiency)	Clay Friction Angle (deg) (Efficiency)
Woven	23–42 (0 68–1 0)	16–26 (0 61–0 93)
Nonwoven, Needle-punched	25–44 (0 67–1 0)	15–28 (0 62–0 99)
Nonwoven, resin or heat bonded	22–40 (0 56–0 91)	17–33 (0 60–0 85)

interface friction strength is generally similar to the soil strength Factors that affect the soil strength include items such as the soil type, density, moisture content, and confining stress For clays, the loading and shearing conditions, such as consolidated drained (CD), consolidated undrained (CU), or unconsolidated undrained (UU), also have significant influence

If the failure plane is not pushed into the adjacent soils, low interface friction values may result For example, the interface strength between smooth HDPE geomembranes and clay can be less than 10° This low interface friction strength can lead to significant stability problems Also, if the interface between the clay and geomembrane is wetted (i e , due to condensation of water under the geomembrane, clay swelling, or excess moisture during construction), the interface strength can be further reduced (VonPein and Prasad, 1990, Mitchell et al , 1990) It is therefore critical that interface friction tests accurately model potential field conditions

Table 3 14 summarizes soil geomembrane interface strengths based on the results reported by several researchers (Martin et al , 1984, Williams and Houlihan

TABLE 3.14 Typical Range of Reported and Recommended Soil Geomembrane Friction Angles

Geomembrane	Reported Sand Friction Angles (deg) (Efficiency)	Recommended Sand Friction Angles, δ (deg)	Reported Clay Friction Angles (deg) (Efficiency)	Recommended Clay Friction Angles, δ (deg
PVC	21–33 (0 62–0 93)	20–30	6–39 (0 53–1 0)	6–15
HDPE	17–28 (0 45–0 81)	17–25	5–29 (0 47–0 88)	5–10
Textured HDPE	30–45 (0 86–1 0)	30–40	7–35 (0 70–1 0)	9–15
VLDPE[a]	21–28 (0 62–0 67)	—	—	—

[a]Since VLDPE is a relatively new product, limited results were reported in the literature It is anticipate that the range of efficiencies for VLDPE to sand interfaces is broader than shown Blank (—) mean insufficient data at this time

From: Waste Containment Systems, Waste Stabilization, and Landfills by Sharma and Lewis 1994

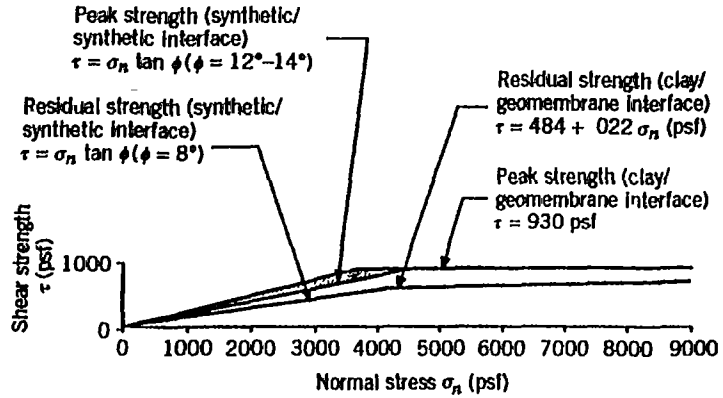


Figure 3.61 Liner strength relations (From Byrne et al , 1992 Reproduced by permission of ASCE)

1987, Soil and Material Engineers, 1987, Leach et al , 1987, Koutsourais et al , 1990, Swan et al , 1990, O'Rourke et al , 1990, Mitchell et al , 1990, Ojeshina, 1990, Druschel and O'Rourke, 1991, Somasundaram and Khilnani, 1991, Sharma and Hullings, 1993) The results are highly variable due to the large range of soil types and testing conditions Both peak and residual values are included within the reported range Table 3 14 also includes recommended soil geomembrane interface strengths

As shown in Figure 3 61, the interface strength of clay–geomembrane exhibits a linear shear strength (τ) and normal stress (σ_n) relationship at lower normal stresses The interface friction angles (δ) reported in Table 3 14 represent this behavior At higher normal loads, the interface friction angle becomes very low and for all practical purposes τ tends to become independent of σ_n The authors' experience on various low-plasticity (CL) and high-plasticity (CH) clays tested against both smooth and textured HDPE geomembrane confirms this τ–σ_n behavior Recommended values presented in Table 3 14 should be used only as a guide in feasibility studies Tests on site-specific materials and selected geomembranes should be conducted for final design purposes

3.6.3 Geosynthetic-to-Geosynthetic Shear Strength

Several researchers have tested various geosynthetic-to-geosynthetic interfaces (Martin et al , 1984, Williams and Houlihan, 1986, Koutsourais et al , 1990, Mitchell et al , 1990, Lydick and Zagorski, 1990, Ojeshina, 1990; Somasundaram and Khilnani, 1991) The results of these studies are summarized in Table 3 15 The primary components of interface friction between multiple layers of geosynthetics are sliding between layers and dilation at the geosynthetic surface (Williams and Houlihan, 1986)

TABLE 3 15 Typical Range of Reported Geosynthetic to Geosynthetic Friction Angles (Degrees)

	PVC	HDPE Smooth	HDPE Textured	Geonet
Woven Geotextile	10–28	7–11	9–17	9–18
Nonwoven, needle-punched Geotextile	16–26	8–12	15–33	10–27
Nonwoven, resin/heat-bonded Geotextile	18–21	9–11	15–16	17–21
Geonet	11–24	5–19	7–25	—

The testing conditions may also have a significant effect on results Mitchell c al (1990) noted that polishing of geomembrane surfaces by geotextiles reduce interface friction Also, the orientation of geonet strands can affect the interfac strength between geonets and geomembranes (Geotek, 1987, Mitchell et al , 1990) Site-specific tests should therefore be performed using the actual materials and an ticipated shear conditions

3.6 4 Geosynthetic Clay Liner Shear Strength

Limited information is currently available on the internal shear strength of GCLs due primarily to their relatively short history The tests that have been performe are also difficult to compare, due to the numerous variations in test condition Many of these variations, such as strain rate, normal load, sample size, and consoli dation conditions, are similar to the variations experienced when comparing shea strength testing of other geosynthetics An additional variation of GCLs, howeve is the hydrating conditions, including the hydrating liquid Hydration can occu under free swell, constrained swell, or partially constrained swell, or the sampl may be tested unhydrated Even if ' ydrated under free-swell conditions, it may b difficult to assess whether full hydration has occurred since the bentonite may b restricted from free swell by the bonded geotextiles Also, due to the large wat absorption of bentonite, most shear strength test results will incorporate some im measurable pore pressure effects unless the test is performed at extremely low di placement rates

Table 3 16 presents the results of direct shear testing performed under variou hydration conditions The tests were performed at a strain rate of 9 mm/min and normal stresses up to 60 kPa Although these test results provide some informatio on the internal shear strength of GCLs, it is highly recommended that project spe cific testing be performed

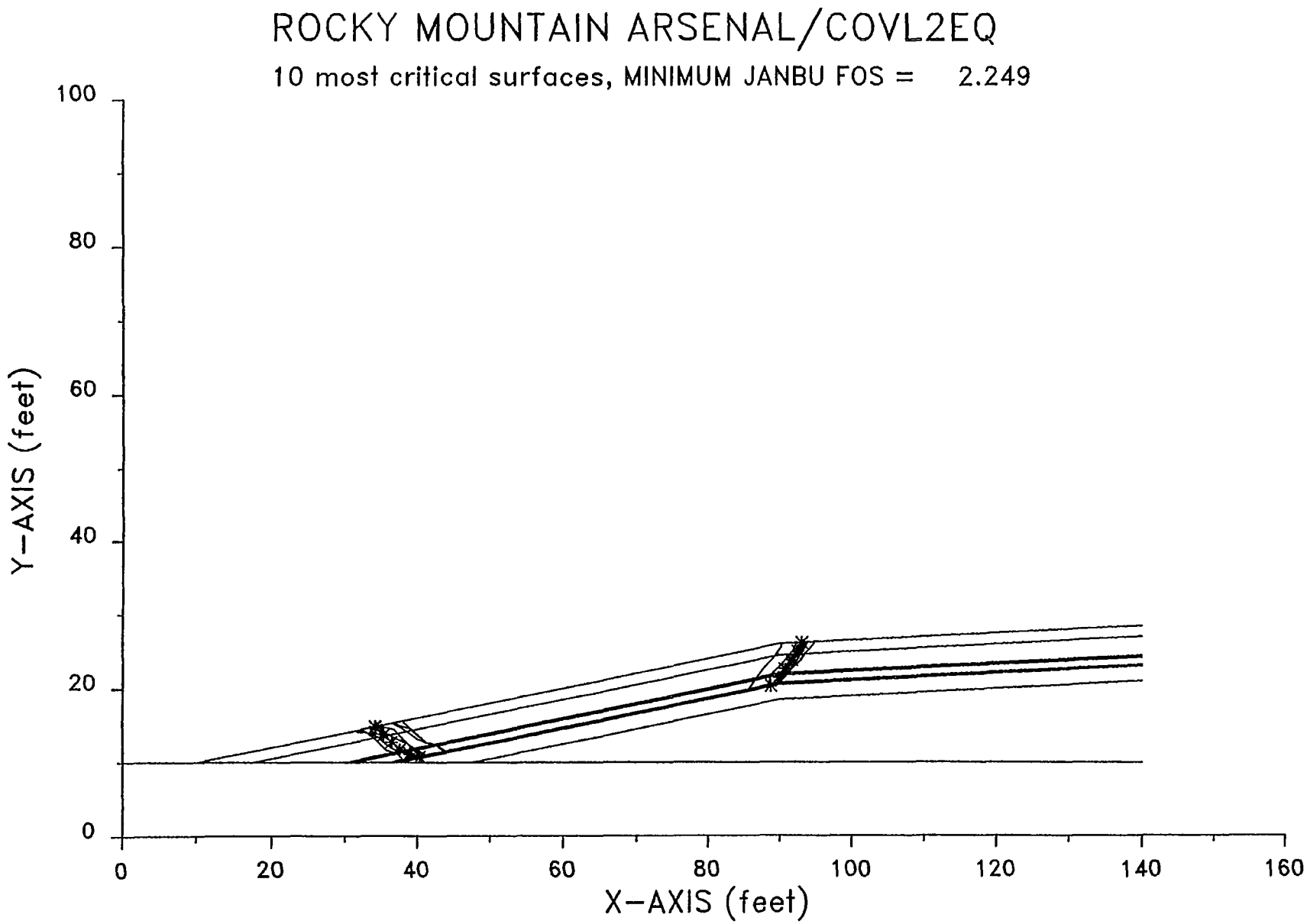
Pg 19 of 64

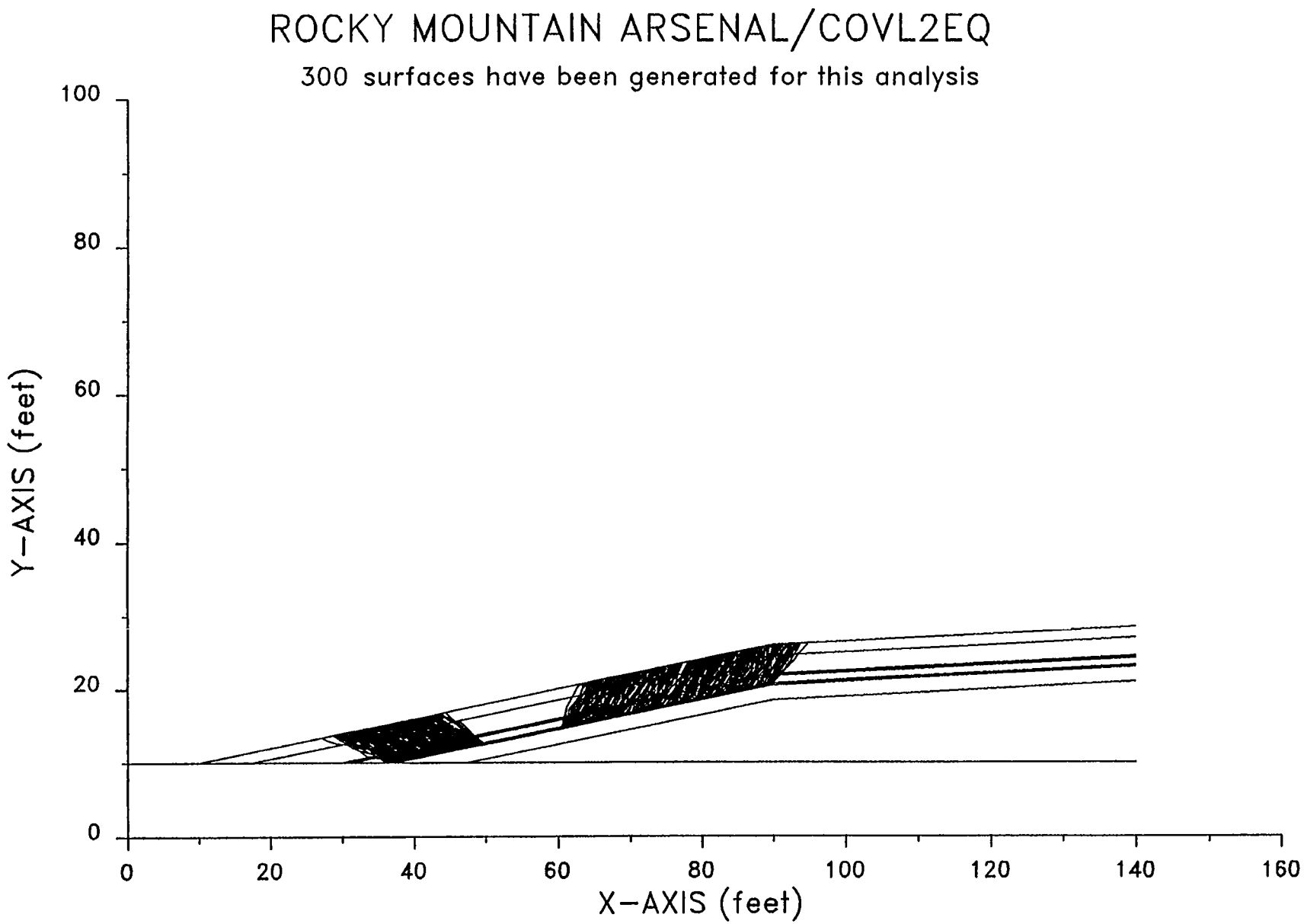
Horizontal earthquake coefficient of 0.05 gravities. The value was taken from a USGS map prepared by Algermissen, et al (1990) and represents the peak ground acceleration with a 90% chance of not being exceeded in 250 years. Typically the peak ground acceleration values are factored down to arrive at a psuedo-static coefficient for stability calculations; however, we conservatively used the peak ground acceleration value directly. The psuedo-static calculations indicated a minimum factor of safety of 2.2.

The attached output presents the results of the stability analyses.

Conclusions:

The calculated factors of safety for both static and seismic loading are above the commonly accepted factor of safety = 1.5. Therefore, the stability of the cover system on perimeter slopes is acceptable.


ROCKY MOUNTAIN ARSENAL/COVL2EQ
10 most critical surfaces, MINIMUM JANBU FOS = 2.249
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
120
140
160


ROCKY MOUNTAIN ARSENAL/COVL2EQ
300 surfaces have been generated for this analysis
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
120
140
160

XSTABL OUTPUT

```
*****************************************
*                XSTABL                 *
*                                       *
*    Slope Stability Analysis using     *
*   Simplified BISHOP or JANBU methods  *
*                                       *
*          Copyright (C) 1990           *
*   Interactive Software Designs, Inc.  *
*         All Rights Reserved           *
*                                       *
*          Jean Lou Chameau             *
*          Purdue University            *
*       W. Lafayette,  IN 47907         *
*                                       *
*  Ver. 3.00                      1002  *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	10.00	10.00	10.00	8
2	10.00	10.00	90.00	26.00	1
3	90.00	26.00	140.00	28.50	1

19 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	10.00	10.00	17.50	10.00	8
2	17.50	10.00	90.00	24.50	2
3	90.00	24.50	140.00	27.00	2
4	17.50	10.00	30.00	10.00	8
5	30.00	10.00	90.00	22.00	3
6	90.00	22.00	140.00	24.50	3
7	30.00	10.00	31.25	10.00	8
8	31.25	10.00	90.00	21.75	4
9	90.00	21.75	140.00	24.25	4
10	31.25	10.00	36.25	10.00	8
11	36.25	10.00	90.00	20.75	5
12	90.00	20.75	140.00	23.25	5
13	36.25	10.00	37.50	10.00	8
14	37.50	10.00	90.00	20.50	6
15	90.00	20.50	140.00	23.00	6
16	37.50	10.00	47.50	10.00	8
17	47.50	10.00	90.00	18.50	7

18	90.00	18.50	140.00	21.00	7
19	47.50	10.00	140.00	10.00	8

ISOTROPIC Soil Parameters

8 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	30.0	0.000	0.0	1
2	125.0	125.0	1000.0	0.0	0.000	0.0	1
3	100.0	100.0	0.0	20.0	0.000	0.0	1
4	120.0	120.0	0.0	37.0	0.000	0.0	1
5	100.0	100.0	0.0	12.0	0.000	0.0	1
6	125.0	125.0	700.0	0.0	0.000	0.0	1
7	125.0	125.0	2000.0	0.0	0.000	0.0	1
8	115.0	115.0	0.0	35.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	36.87	10.10	50.00	12.62	0.20
2	60.00	14.62	90.00	20.62	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.14	14.83
2	34.19	14.78
3	35.32	13.79
4	36.41	12.76
5	37.52	11.76
6	38.93	11.24
7	40.35	10.77
8	88.72	20.31
9	89.77	21.39
10	90.62	22.63
11	91.60	23.76
12	92.48	24.97
13	92.99	26.15

** Corrected JANBU FOS = 2.829 ** (Fo factor =1.038)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.26	14.65
2	33.85	14.07
3	35.27	13.59
4	36.52	12.75
5	37.68	11.80
6	38.79	10.79
7	40.28	10.66
8	89.62	20.45
9	90.67	21.52
10	91.57	22.72
11	92.41	23.96
12	93.21	25.24
13	93.73	26.19

** Corrected JANBU FOS = 2.834 ** (Fo factor =1.037)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	32.32	14.46
2	33.42	13.70
3	34.58	12.75
4	35.65	11.70
5	37.08	11.24
6	38.22	10.27
7	88.93	20.41
8	89.97	21.50
9	91.03	22.56
10	91.92	23.77
11	92.58	25.12
12	93.00	26.15

** Corrected JANBU FOS = 2.855 ** (Fo factor =1.037)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	36.55	15.31
2	37.52	14.82
3	38.80	14.04
4	40.02	13.16
5	41.44	12.68
6	42.85	12.19
7	44.13	11.40
8	89.60	20.45
9	90.65	21.52
10	91.67	22.62
11	92.72	23.68
12	93.62	24.89
13	94.65	25.97
14	94.73	26.24

** Corrected JANBU FOS = 2.943 ** (Fo factor =1.039)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.95	14.79
2	34.01	14.74
3	35.13	13.75
4	36.36	12.90
5	37.47	11.89
6	38.94	11.58
7	40.14	10.68
8	88.33	20.36
9	88.76	21.79
10	89.81	22.86
11	90.80	23.99
12	91.81	25.10
13	92.24	26.11

** Corrected JANBU FOS = 2.960 ** (Fo factor =1.039)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	37.01	15.40
2	37.42	14.99
3	38.88	14.64
4	40.05	13.71
5	41.15	12.69
6	42.60	12.32
7	43.82	11.44

8	88.74	20.31
9	89.78	21.39
10	90.72	22.56
11	91.58	23.79
12	92.58	24.91
13	93.57	26.03
14	93.59	26.18

** Corrected JANBU FOS = 2.984 ** (Fo factor =1.039)

Failure surface No. 7 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	31.57	14.31
2	31.73	14.19
3	33.22	14.00
4	34.61	13.42
5	35.69	12.38
6	36.96	11.59
7	38.46	11.49
8	39.61	10.53
9	85.51	19.71
10	86.38	20.93
11	87.27	22.14
12	88.22	23.30
13	89.27	24.37
14	90.14	25.59
15	90.16	26.01

** Corrected JANBU FOS = 3.023 ** (Fo factor =1.039)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.53	14.91
2	34.76	14.77
3	35.87	13.76
4	37.24	13.14
5	38.64	12.61
6	39.72	11.58
7	41.04	10.86
8	89.59	20.53
9	90.52	21.71
10	91.25	23.02
11	91.82	24.41
12	92.87	25.48
13	93.56	26.18

** Corrected JANBU FOS = 3.087 ** (Fo factor =1.038)

Failure surface No. 9 specified by 12 coordinate points

Point	x-surf	y-surf

No.	(ft)	(ft)
1	37.98	15.60
2	39.00	14.63
3	40.18	13.69
4	41.28	12.68
5	42.76	12.43
6	43.87	11.42
7	89.00	20.33
8	89.89	21.54
9	90.55	22.89
10	91.55	24.01
11	92.37	25.26
12	93.02	26.15

** Corrected JANBU FOS = 3.096 ** (Fo factor =1.040)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	29.15	13.83
2	29.48	13.51
3	30.94	13.16
4	32.06	12.17
5	33.54	11.93
6	35.03	11.79
7	36.29	10.96
8	37.56	10.17
9	86.34	19.95
10	87.10	21.24
11	88.04	22.41
12	88.71	23.75
13	89.72	24.86
14	89.83	25.97

** Corrected JANBU FOS = 3.124 ** (Fo factor =1.037)

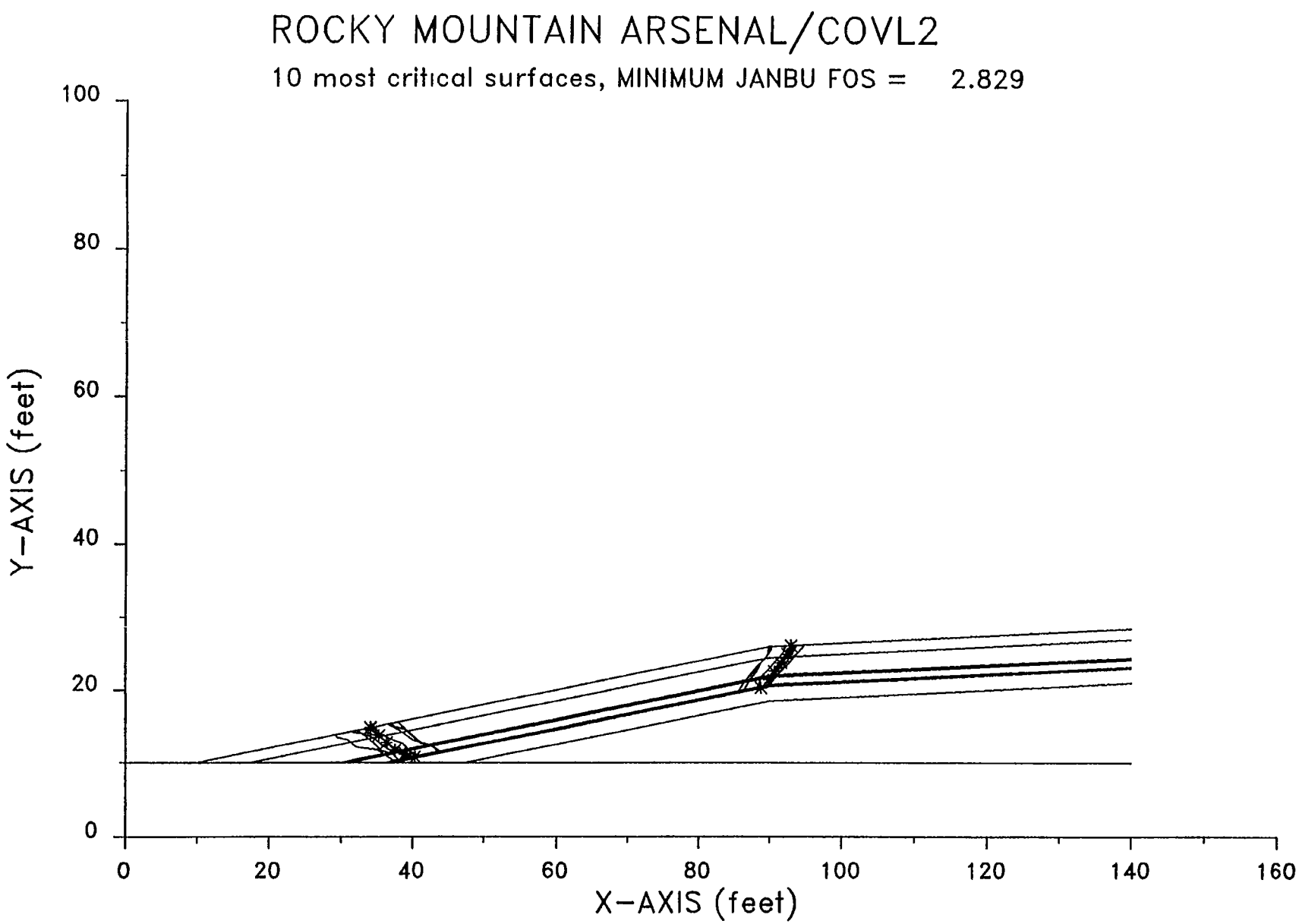
The following is a summary of the TEN most critical surfaces

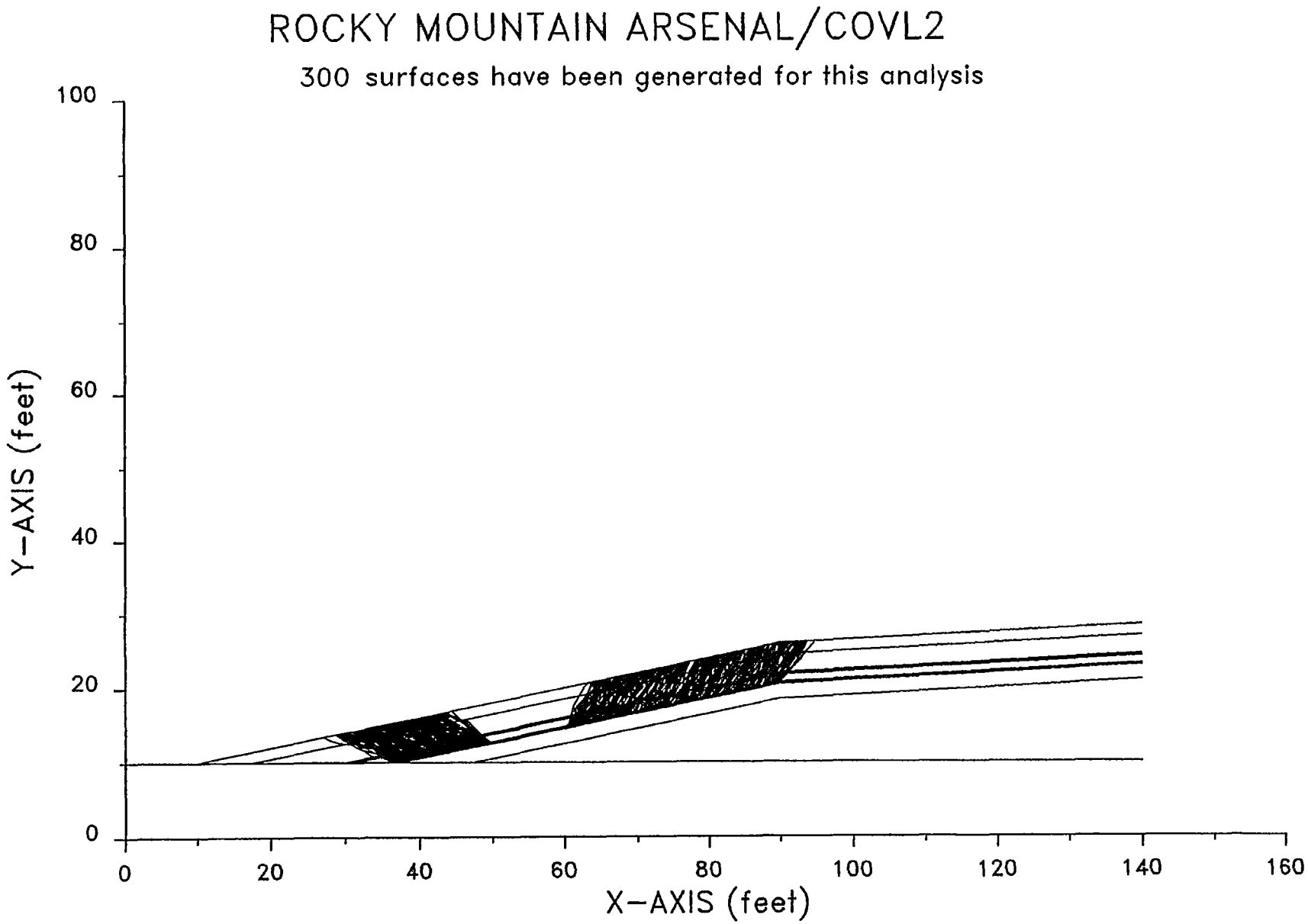
Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	2.829	1.038	34.14	92.99	6859.
2.	2.834	1.037	33.26	93.73	6998.
3.	2.855	1.037	32.32	93.00	7077.
4.	2.943	1.039	36.55	94.73	6546.
5.	2.960	1.039	33.95	92.24	6745.
6.	2.984	1.039	37.01	93.59	6402.
7.	3.023	1.039	31.57	90.16	6708.
8.	3.087	1.038	34.53	93.56	6753.

9.	3.096	1.040	37.98	93.02	6390.
10.	3.124	1.037	29.15	89.83	6997.

* * * END OF FILE * * *


ROCKY MOUNTAIN ARSENAL/COVL2
10 most critical surfaces, MINIMUM JANBU FOS = 2.829
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
120
140
160


ROCKY MOUNTAIN ARSENAL/COVL2
300 surfaces have been generated for this analysis
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
120
140
160

XSTABL OUTPUT

```
*****************************************
*                XSTABL                 *
*                                       *
*    Slope Stability Analysis using     *
*   Simplified BISHOP or JANBU methods  *
*                                       *
*          Copyright (C) 1990           *
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*          Jean Lou Chameau             *
*          Purdue University            *
*       W. Lafayette,  IN 47907         *
*                                       *
*  Ver. 3.00                      1002  *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	10.00	10.00	10.00	8
2	10.00	10.00	90.00	26.00	1
3	90.00	26.00	140.00	28.50	1

19 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	10.00	10.00	17.50	10.00	8
2	17.50	10.00	90.00	24.50	2
3	90.00	24.50	140.00	27.00	2
4	17.50	10.00	30.00	10.00	8
5	30.00	10.00	90.00	22.00	3
6	90.00	22.00	140.00	24.50	3
7	30.00	10.00	31.25	10.00	8
8	31.25	10.00	90.00	21.75	4
9	90.00	21.75	140.00	24.25	4
10	31.25	10.00	36.25	10.00	8
11	36.25	10.00	90.00	20.75	5
12	90.00	20.75	140.00	23.25	5
13	36.25	10.00	37.50	10.00	8
14	37.50	10.00	90.00	20.50	6
15	90.00	20.50	140.00	23.00	6
16	37.50	10.00	47.50	10.00	8
17	47.50	10.00	90.00	18.50	7

18	90.00	18.50	140.00	21.00	7
19	47.50	10.00	140.00	10.00	8

ISOTROPIC Soil Parameters

8 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	30.0	0.000	0.0	1
2	125.0	125.0	1000.0	0.0	0.000	0.0	1
3	100.0	100.0	0.0	20.0	0.000	0.0	1
4	120.0	120.0	0.0	37.0	0.000	0.0	1
5	100.0	100.0	0.0	12.0	0.000	0.0	1
6	125.0	125.0	700.0	0.0	0.000	0.0	1
7	125.0	125.0	2000.0	0.0	0.000	0.0	1
8	115.0	115.0	0.0	35.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	36.87	10.10	50.00	12.62	0.20
2	60.00	14.62	90.00	20.62	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.14	14.83
2	34.19	14.78
3	35.32	13.79
4	36.41	12.76
5	37.52	11.76
6	38.93	11.24
7	40.35	10.77
8	88.72	20.31
9	89.77	21.39
10	90.62	22.63
11	91.60	23.76
12	92.48	24.97
13	92.99	26.15

** Corrected JANBU FOS = 2.829 ** (Fo factor =1.038)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.26	14.65
2	33.85	14.07
3	35.27	13.59
4	36.52	12.75
5	37.68	11.80
6	38.79	10.79
7	40.28	10.66
8	89.62	20.45
9	90.67	21.52
10	91.57	22.72
11	92.41	23.96
12	93.21	25.24
13	93.73	26.19

** Corrected JANBU FOS = 2.834 ** (Fo factor =1.037)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	32.32	14.46
2	33.42	13.70
3	34.58	12.75
4	35.65	11.70
5	37.08	11.24
6	38.22	10.27
7	88.93	20.41
8	89.97	21.50
9	91.03	22.56
10	91.92	23.77
11	92.58	25.12
12	93.00	26.15

** Corrected JANBU FOS = 2.855 ** (Fo factor =1.037)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	36.55	15.31
2	37.52	14.82
3	38.80	14.04
4	40.02	13.16
5	41.44	12.68
6	42.85	12.19
7	44.13	11.40
8	89.60	20.45
9	90.65	21.52
10	91.67	22.62
11	92.72	23.68
12	93.62	24.89
13	94.65	25.97
14	94.73	26.24

** Corrected JANBU FOS = 2.943 ** (Fo factor =1.039)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.95	14.79
2	34.01	14.74
3	35.13	13.75
4	36.36	12.90
5	37.47	11.89
6	38.94	11.58
7	40.14	10.68
8	88.33	20.36
9	88.76	21.79
10	89.81	22.86
11	90.80	23.99
12	91.81	25.10
13	92.24	26.11

** Corrected JANBU FOS = 2.960 ** (Fo factor =1.039)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	37.01	15.40
2	37.42	14.99
3	38.88	14.64
4	40.05	13.71
5	41.15	12.69
6	42.60	12.32
7	43.82	11.44

8	88.74	20.31
9	89.78	21.39
10	90.72	22.56
11	91.58	23.79
12	92.58	24.91
13	93.57	26.03
14	93.59	26.18

** Corrected JANBU FOS = 2.984 ** (Fo factor =1.039)

Failure surface No. 7 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	31.57	14.31
2	31.73	14.19
3	33.22	14.00
4	34.61	13.42
5	35.69	12.38
6	36.96	11.59
7	38.46	11.49
8	39.61	10.53
9	85.51	19.71
10	86.38	20.93
11	87.27	22.14
12	88.22	23.30
13	89.27	24.37
14	90.14	25.59
15	90.16	26.01

** Corrected JANBU FOS = 3.023 ** (Fo factor =1.039)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.53	14.91
2	34.76	14.77
3	35.87	13.76
4	37.24	13.14
5	38.64	12.61
6	39.72	11.58
7	41.04	10.86
8	89.59	20.53
9	90.52	21.71
10	91.25	23.02
11	91.82	24.41
12	92.87	25.48
13	93.56	26.18

** Corrected JANBU FOS = 3.087 ** (Fo factor =1.038)

Failure surface No. 9 specified by 12 coordinate points

Point	x-surf	y-surf

No.	(ft)	(ft)
1	37.98	15.60
2	39.00	14.63
3	40.18	13.69
4	41.28	12.68
5	42.76	12.43
6	43.87	11.42
7	89.00	20.33
8	89.89	21.54
9	90.55	22.89
10	91.55	24.01
11	92.37	25.26
12	93.02	26.15

** Corrected JANBU FOS = 3.096 ** (Fo factor =1.040)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	29.15	13.83
2	29.48	13.51
3	30.94	13.16
4	32.06	12.17
5	33.54	11.93
6	35.03	11.79
7	36.29	10.96
8	37.56	10.17
9	86.34	19.95
10	87.10	21.24
11	88.04	22.41
12	88.71	23.75
13	89.72	24.86
14	89.83	25.97

** Corrected JANBU FOS = 3.124 ** (Fo factor =1.037)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	2.829	1.038	34.14	92.99	6859.
2.	2.834	1.037	33.26	93.73	6998.
3.	2.855	1.037	32.32	93.00	7077.
4.	2.943	1.039	36.55	94.73	6546.
5.	2.960	1.039	33.95	92.24	6745.
6.	2.984	1.039	37.01	93.59	6402.
7.	3.023	1.039	31.57	90.16	6708.
8.	3.087	1.038	34.53	93.56	6753.

9.	3.096	1.040	37.98	93.02	6390.
10.	3.124	1.037	29.15	89.83	6997.

* * * END OF FILE * * *

Appendix C

GUIDANCE FOR THE DEVELOPMENT OF AN OPERATIONS NARRATIVE

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1.0 INTRODUCTION

This guideline for the development of an Operations Narrative has been prepared as an appendix to the CAMU Designation Document (CDD) in support of the designation of a Corrective Action Management Unit (CAMU) as part of the remedy for the cleanup of the Rocky Mountain Arsenal (RMA) located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Purpose and Scope

This document has been prepared as a guideline for the development of an Operations Narrative for the waste management activities to be conducted as part of the CAMU Detailed operational requirements cannot be completely developed until the design of the CAMU facilities is completed. Appendix C describes the general approach, that will be utilized in the development of the Operations Narrative, for specifying remediation waste management practices for the CAMU The Operations Narrative will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0 of the CDD

Additionally, the CDD contains other appendixes that provide requirements and/or guidance for the development of additional plans that will supplement the operational requirements For clarity, the contents of these related appendixes were not included in this document. Instead, the related appendixes are intended to be used in conjunction with this document. The related appendixes include the following

- Appendix B - Design Narrative This appendix describes the design parameters and design guidelines for the design of the CAMU
- Appendix D - Waste Analysis Plan This appendix outlines the procedures for evaluating the compatibility of waste to be managed within the CAMU
- Appendix G - Inspection Plan Outline This appendix outlines the inspection requirements and frequencies during operation of the CAMU
- Appendix J - Operating Record System Plan Outline This document outlines the documentation during the operation of the CAMU
- Appendix N - Action Leakage Rate and Response Action Plan Outline This appendix provides the calculation of an action leakage rate of a landfill cell based on the amount of water collected in a leak detection system and the appropriate response actions if the action leakage rate is extended
- Appendix O - Health and Safety Plan (HASP) Outline This appendix outlines the HASP for the CAMU and includes site and program descriptions, identification of waste types and hazards, and decontamination, disposal, and emergency procedures
- Appendix Q - Contingency Plan Outline This appendix outlines the response procedures for events that potentially threaten the public health and/or environment (i.e , spills, tornados)

This appendix is organized in nine sections Section 2.0 addresses the operational requirements and procedures for the landfill Section 3 0 addresses the operational procedures and requirements for the Basin F Waste Pile drying unit. Sections 4 0 and 5 0 address the operational procedures and requirement for the decontamination facility and the waste staging/consolidation areas, respectively Section 6.0 addresses the operational procedures and requirements for the run-on/runoff control systems The operational requirements for roadways are addressed in Section 7 0 Section 8 0 addresses emergency response and preparedness Sections 9 0 and 10 0 present an acronym list and bibliography, respectively

2.0 LANDFILL

This section describes general operational procedures that are anticipated to be incorporated into the final Operations Narrative The operational procedures described below will be consistent with the operational provisions for landfills specified in 6 Code of Colorado Regulations (CCR) 1007-3, Part 264 301

2.1 Waste Placement

This section describes typical operational procedures for placement of waste within the landfill cells at RMA These procedures will be refined and incorporated into the final Operations Narrative during the landfill design phase Landfill cell construction waste placement, and closure may be performed in progression such that the three activities would be performed concurrently

2.1.1 General Waste Placement

Landfill cell construction, waste placement, and closure may be performed in progression such that these three activities would be performed concurrently Waste, may be placed within a cell once the components of the cell in the vicinity of waste placement have been completed including the liner system, operations layer, and access ramp Construction of the cap may commence once a portion of the cell has been filled

Waste placement procedures (fill sequence, lift thickness, compaction requirements) will be specified based on the requirements of the design Measures will be taken to prevent runoff from exiting the landfill cell, the generation of windblown waste, and to control odor and/or vapor emissions Transport and placement of waste in the landfill will be halted when wind speeds exceed those specified in the design. Equipment and vehicles leaving the landfill cell that have come in direct contact with waste will be externally cleaned, if necessary, at the decontamination facility (see Section 4 0)

2.1.2 Ignitable, Reactive, and Incompatible Waste Placement

If ignitable, reactive, and incompatible wastes are placed in the landfill, the wastes will be isolated and/or segregated to prevent ignition and reaction. Waste materials that potentially exhibit these properties will be tested and classified as such in accordance with the procedures developed during preparation of the final Waste Analysis Plan (WAP) Specific procedures for the isolation and/or segregation of these wastes will be developed during the design phase

2.1.3 Containerized Waste Placement

Except for very small containers, such as an ampule, containers will be either

- At least 90 percent full when placed in the landfill
- Emptied and crushed flat, shredded, or similarly reduced in volume to the maximum practical extent before placement within the landfill

Additional requirements or procedures for placement of containerized waste may be identified during the design process

2.2 Daily Cover Placement

Daily cover consisting of soil, foaming agents, a geosynthetic cover, a combination of these materials, or other materials will be placed over the waste to prevent airborne dispersion of waste particulates and for odor and/or vapor controls The possibility of using a structural cover or building to reduce leachate generation and control air emissions was discussed during the value engineering meetings held February 13 and 14, 1996 Further evaluation of the requirements for air emission and leachate generation controls will be performed during design

2.3 Leachate Collection System and Leak Detection System(s)

The leachate collection system (LCS) and leak detection system(s) (LDS) will be operated to prevent leachate accumulation over the liner in excess of 1 foot and to minimize clogging of the systems Leachate removed from these systems will be treated The detailed procedures for removal of leachate will be developed during design Monitoring and evacuation of these systems will be in accordance with

the frequencies specified within the Inspection Plan (Appendix G) The leachate removed from the LCS and LDS will be appropriately managed either onsite or offsite in accordance with applicable regulatory requirements at the time of generation Details regarding how this leachate will be managed will be determined during design.

Surface water within the landfill will typically be directed into temporary sumps on the landfill surface formed from the waste fill progression and daily cover This water will be removed using vacuum trucks and/or pumps and piping to reduce the amount of water that reaches the LCS The surface water will be managed in accordance with applicable regulatory requirements at the time it is collected. Collected surface water may be placed in a storage facility for testing prior to discharge or treatment.

The LCS and LDS may be flushed, if necessary The procedures for flushing the LCS and LDS will be determined based on the history of the Basin F Waste Pile and the requirements of the individual cell operation. The specific procedures for flushing will be developed as part of the individual cell design

2.4 Odor/Vapor Controls

The expected amount of odor and/or vapor emissions for specific waste streams to be placed within an individual cell will be estimated during the design of the specific landfill cell receiving that specific waste stream Cell-specific odor/vapor controls may be necessary for the landfill cells that will contain waste from the Basin F Waste Pile and may also be necessary for cells containing other waste streams

Odor/vapor controls may consist of one, or a combination of, the following

- Enclosures with internal air handling systems placed over the cell
- Specific types of daily cover (i e , foams)
- Specific types of placement procedures
- Specific monitoring requirements
- Other control systems developed during design

The odor/vapor control requirements will be completed as a part of design and will consider the design of the landfill cell, the work plan for the excavation, treatment (if necessary), transport of the particular waste stream, and the operating requirements of the landfills

3.0 BASIN F WASTE PILE DRYING UNIT

The Basin F Waste Pile drying unit will be constructed and operated to dry Basin F Waste Pile material that does not pass the paint filter test. The drying unit will be operated and maintained in accordance with manufacturer's instructions, applicable regulations, and other requirements identified during design. Methods and procedures for handling and placement of soils after drying to address exposure to precipitation and production of leachate will be evaluated during design.

Environmental controls including containment systems, odor/vapor controls, and run-on and runoff controls will be operated and maintained to protect human health and the environment and prevent releases that may have adverse impacts to soil, groundwater, surface water, and air The details and requirements for these systems will be determined during design

4.0 DECONTAMINATION FACILITY

Decontamination facilities will be constructed and operated to decontaminate equipment used during operation and closure of the CAMU Decontamination facilities will be operated and maintained to ensure proper functioning of equipment and achievement of design performance standards The decontamination facility will be operated in accordance with the manufacturer's instructions, applicable regulatory requirements, and the requirements of the design

Equipment leaving the active waste management areas (i e , landfill cells, waste handling/drying facility) will be visually inspected prior to leaving the area If contaminants are found during the inspection or if the vehicle or equipment has come in direct contact with contaminated materials, the equipment will be washed in a decontamination facility before leaving the active waste management areas

Rinsate collected during decontamination will be characterized and either recycled, treated, or disposed of in accordance with applicable regulations Details of how the rinsate will be managed will be determined during design.

5.0 WASTE STAGING/CONSOLIDATION AREAS

Waste staging/consolidation areas will be used during operations for temporary staging, waste sizing, and/or storage of soil/debris between processing steps or to temporarily stockpile remediation wastes for transport Waste staging areas will be located within the CAMU area Equipment, facilities, and systems at the waste staging/consolidation areas will be operated and maintained in accordance with manufacturer's recommendations, applicable regulatory requirements, and other requirements identified during design. Environmental controls and safety systems will be operated and maintained to protect human health and the environment and prevent releases that may have an adverse impact on soil, groundwater, surface water, and air

The waste staging/consolidation areas will incorporate run-on/runoff controls for the management of surface water in these areas In general, run-on will be prevented from flowing onto these areas through the use of curbs, diversion channels, grading, and other hydraulic structures Run-on will be diverted to existing drainages outside the CAMU Runoff from these areas will be collected through the use of curbs, sumps, channels, grading, and other hydraulic structures and diverted to a retention pond(s) Details of how runoff will be managed will be developed during design. Waste staged, sized, and/or stored in these areas will be managed in a manner that minimizes the potential for wind or water dispersion and excessive odor/vapor emissions This may be done through the use of one, or a combination of, the following

- Enclosures with internal air handling systems
- Covers consisting of soils, geosynthetics, or other materials
- Other control systems or strategies specified in design
- Unit-specific operating requirements
- Unit-specific inspection and monitoring requirements

6.0 RUN-ON/RUNOFF CONTROL SYSTEMS

Water collected from the run-on control system will be directed to existing drainages outside the CAMU Water collected from the runoff control system will be diverted to a retention pond(s) within the CAMU Run-on and runoff water will be managed in accordance with applicable regulatory requirements at the time of collection These systems may include drop structures, berms, channels, culverts, and curbs and will be inspected in accordance with the Inspection Plan (Appendix G) These systems will be operated and maintained to meet the design performance standards Operational activities will typically consist of grading, excavation, and general repair work to ensure the following

- The drainage structures do not become obstructed with debris or sediment
- Positive drainage is maintained and ponding does not occur
- Adequate flow capacity and freeboard are maintained in accordance with design requirements
- Excessive erosion does not occur
- Run-on system integrity is maintained to prevent flow onto active waste management areas
- Runoff system integrity is maintained to prevent the release of potentially contaminated runoff from active waste management areas

7.0 ROADWAYS

Roadways outside the active waste management areas will be operated and maintained in the same manner as other roadways at RMA Roadways within active waste management areas will be operated and maintained to verify that

- The roadways are in a good state of repair
- The roadways are safe for travel
- Runoff is properly collected and diverted to retention ponds, testing prior to release may be required
- Waste has not accumulated on the roadway

Visual inspections for obstructions, excessive cracking, and proper drainage will be performed periodically in accordance with the Inspection Plan (Appendix G) Repairs, cleanup, and maintenance will be performed as necessary to ensure that the roadways are functioning as designed

8.0 EMERGENCY RESPONSE AND PREPAREDNESS

Emergency response equipment for the CAMU will typically include alarm/communication systems, fire protection equipment, spill control equipment, and decontamination equipment The actual components of the systems necessary to provide for emergency response and preparedness will be determined during design These systems will be tested, operated, and maintained in accordance with manufacturer's instructions and applicable regulatory requirements to assure proper operation in the event of an emergency Adequate access will be maintained during operation of the CAMU to allow unobstructed movement of personnel and equipment to any area where an emergency may occur Arrangements with local authorities may be established to familiarize the authorities with the operations and facilities at the landfill and secure support in the event of an emergency A Contingency Plan (see outline in Appendix Q) specific to the CAMU will be developed and appended to the RMA Contingency Plan for implementation in the event of a release or other emergency

9.0 ACRONYMS

Army	U S Department of the Army
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWMA	Colorado Hazardous Waste Management Act
FFA	Federal Facilities Agreement
HASP	Health and Safety Plan
HLA	Harding Lawson Associates
LCS	Leachate collection system
LDS	Leak detection system
O&M	Operation and maintenance
RMA	Rocky Mountain Arsenal
State	State of Colorado
WAP	Waste Analysis Plan

10.0 BIBLIOGRAPHY

Foster Wheeler Environmental Corporation 1995. *Final detailed analysis of alternatives, Rocky Mountain Arsenal, Commerce City, Colorado version 4 1,* October

Appendix D

GUIDELINES FOR DEVELOPMENT OF A WASTE ANALYSIS PLAN

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1.0 INTRODUCTION

This guideline for the development of a Waste Analysis Plan (WAP) has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for the cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 CAMU Description

In June 1995, an Agreement for a Conceptual Remedy (the Conceptual Remedy) for the Cleanup of RMA among the State, U S Environmental Protection Agency (EPA), the Army, Shell, and the U.S Fish and Wildlife Service (FWS) was signed The Conceptual Remedy represents agreement by the parties relative to specific components of the remedy for the final cleanup of RMA. These components of the remedy are included in the (1) Proposed Plan for the RMA Onpost Operable Unit and (2) Final Detailed Analysis of Alternatives Report (DAA) (Foster Wheeler, 1995) The Conceptual Remedy, the Proposed Plan for the Onpost Operable Unit, and the DAA are documents prepared under various authorities of the Compre-

hensive Environmental Response, Compensation, and Liability Act (CERCLA). The Conceptual Remedy calls for the construction and operation of a new onsite hazardous waste landfill for disposal of principal threat and human health exceedance soil and debris (See DAA for detailed definitions of these CERCLA related terms). The portion of the CAMU that includes a state-of-the-art hazardous waste landfill is located in Sections 25 and 26 of RMA between Former Basin F and North Plants. Double-lined cells within the landfill will receive principal threat and human health exceedance material from 17 contaminated areas of RMA. In addition, **a** triple-lined **cell** will be constructed to receive principal threat and **human health exceedance** soil from the Basin F Waste Pile and **Former Basin F, human health exceedance soil from Sand Creek Lateral, and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto**. The total volume of material to be placed in the landfill will be approximately 1,200,000 cubic yards, with approximately 655,000 cubic yards to be placed in the triple-lined **cell**.

1.2 Document Objectives and Organization

This document has been prepared as a guideline for the development of a WAP for the CAMU that will be responsive to Sections 265.13 and 265.17 of 6 CCR 1007-3. The WAP will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5.0 of the CDD. The final WAP will describe procedures for obtaining and/or reviewing detailed chemical and physical analysis data for the wastes to be disposed of in the hazardous waste landfill. Detailed chemical and physical data have previously been collected during the on post remedial investigation/feasibility study (RI/FS) for the material to be disposed in the onsite CAMU. To the extent applicable, the final WAP will incorporate any existing data in developing the final procedures for characterization of disposed waste streams. The objectives of the WAP will be as follows:

- Summarize existing chemical and physical data for each of the waste streams to be disposed in the landfill area of the on post CAMU, and identify more detailed data sources for reference as necessary during disposal operations (6 CCR 265.13(a))
- Specify any restrictions and/or pre-disposal requirements for the disposed wastes (6 CCR 265.17)
- Describe additional chemical and physical analyses to complete the characterization of each waste for the purposes of disposal. These additional analyses will be performed as necessary to assess compatibility of the waste streams with potentially commingled waste streams in the landfill and with the liner/cover components. The description of additional analyses will include identification of analytical parameters and the rationale for parameter selection, (2) sampling frequency, (3) sampling methods, and (4) analytical methods (6 CCR 265.13(b)).

Existing data and reference information for the disposed waste streams used in the development of this guidance document are summarized in Section 2 0 Contemplated restrictions and pretreatment requirements for the disposed waste streams and the general approach for waste disposal are summarized in Section 3 0 Contemplated waste compatibility screening analyses to be performed on the disposed wastes, including the analytical parameters, rationale, and analytical frequency considerations, are summarized in Section 4 0 Contemplated sampling protocols and analytical methods are discussed in Sections 5 0 and 6.0, respectively Documentation of waste analysis and disposal is described in Section 7 0 A list of acronyms is presented in Section 8 0, and references are listed in Section 9 0

2.0 IDENTIFICATION AND CHARACTERIZATION OF DISPOSED WASTES

Considerable analytical data have been generated during historical onpost investigations at RMA for the designated waste streams that will be placed into the CAMU This large body of analytical data will support the general waste characterization requirements stated in Part 265 13(a) of 6 CCR 1007-3 These analytical data are summarized in the sections which follow, and references are provided to indicate additional, more detailed sources of information concerning the characteristics and composition of the disposed waste streams

2.1 Wastes Disposed in Double-Lined Cells

Table D1 identifies the waste streams designated under the Agreement for a Conceptual Remedy for disposal in double-lined cells of the onsite CAMU landfill, and summarizes the chemical composition of these wastes In general, the chemical composition information shown in Table D1 is based on analytical data collected during the onpost RI/FS as summarized in the Final Detailed Analysis of Alternatives (DAA) Report, Version 4 1 (Foster Wheeler, 1995) In addition to the waste streams listed in Table D1, the Army may dispose of drummed wastes generated during RI/FS activities in the double lined cells These wastes are currently stored in warehouses at RMA Wastes characterization data generated at the time of generation, and other RMA site characterization data will be summarized for these drummed waste in the final WAP

Preliminary surveys of physical characteristics data obtained for individual soil samples collected near or within the soil waste bodies designated for disposal were performed by HLA in preparation of this WAP HLA's surveys indicated that the soil waste streams listed in Table D1 generally were of neutral to slightly alkaline pH (6 80 to 9 73), but that pH ranged as high as 11 to 12 in soil associated with the Secondary Basins and Lime Basins Soil organic carbon content ranged from less than 500 milligrams per kilogram (mg/kg) to as high as 10,300 mg/kg in the soil waste streams, with the highest occurrences observed in the South Plants Central Processing Area Soil and the South Plants Balance of Area Soil Moisture content ranged from approximately 5 to 30 percent for the soil waste

streams to be disposed. Sources of more detailed physical characteristics information are referenced in Section 2.3.

2.2 Wastes Disposed In Triple-Lined Cells

Table D2 identifies the **three** waste streams designated under the Agreement for a Conceptual Remedy for disposal in enhanced, triple-lined cells of the onsite CAMU landfill, and summarizes the chemical composition of these wastes. In general, the chemical composition information shown in Table D2 is based on analytical data collected during the onpost RI/FS as summarized in the Final Detailed Analysis of Alternatives Report, Version 4.1 (Foster Wheeler, 1995). Additional data for the Basin F solids are from historical analyses of drummed Basin F soil.

Considerable analytical data have been generated for leachate from Basin F solids as part of the Interim Response Acton (IRA) at Basin F. A summary of these data is presented in Table D3 to provide additional information related to the Basin F Waste Pile soil to be disposed in triple-lined cells of the CAMU landfill. Table D3 also includes chemical composition data for Basin F liquid as obtained from the Rocky Mountain Arsenal Contingency Plan (Weston, 1991).

2.3 Sources of Additional Data

More detailed summaries of existing chemical data and physical characteristics data for the material comprising the waste streams will be compiled during preparation of the final WAP, as necessary to meet the general waste characterization requirements. Detailed data are available from the documents listed in Table D4. These and other documents containing detailed analytical data are available from the RMA Technical Information Center (RTIC). Chemical data for specific samples collected from the media to be disposed, as identified through review of the documents in Table D4, can also be obtained from the RMAED through DP Associates, the RMA data management subcontractor

3.0 SUMMARY OF THE WASTE DISPOSAL PROCESS

This section summarizes the process of waste disposal contemplated at the RMA onsite CAMU, including contemplated waste restrictions, pretreatment requirements, and the overall approach to landfill disposal for the waste streams identified in Section 2 0 This summary of the waste disposal process will form a basis for development of final waste analysis requirements

3.1 Waste Restrictions and Pretreatment Requirements for Disposed Wastes

The specific waste streams to be disposed in the RMA CAMU are described in Section 2 0 As these waste streams will be managed within a CAMU, land disposal restrictions defined in Part 268 of 6 CCR 1007-3 will not apply However, the following general restrictions are expected to apply to the waste streams as they are generated and disposed

- Pyrophoric materials discovered during excavation and disposal operations that are observed to react with atmospheric air or water will be neutralized prior to placement in the hazardous waste landfill
- Explosives-containing munitions discovered during excavation and disposal operations will be transported offsite for detonation at an approved facility If not considered safe for removal and transport, they will be detonated in place, prior to placement in the hazardous waste landfill
- Liquid wastes will not be disposed of in the hazardous waste landfill

In addition the conceptual remedy has specified the following requirements for disposed waste streams

- M-1 Pits principal threat and human health exceedance soil will be pretreated with a solidification technology prior to disposal
- Hex Pits principal threat soil will be treated with either an in situ or ex situ treatment technology If an ex situ process is selected, treatment of the Hex Pit soil will occur prior to disposal in the CAMU landfill
- Agent-contaminated building material and soil will be caustic washed as necessary prior to disposal
- Basin F Waste Pile soil that fails the paint filter test (U S Environmental Protection Agency [EPA] Method 9095) will be dried prior to disposal

The WAP will outline waste characterization analyses that may be required for wastes exhibiting potential compatibility concerns with other waste streams or with the disposal process Compatibility testing will be performed in accordance with Appendix B, Section 3 3 3, during the landfill design phase prior to disposal Threshold index parameters will be established as part of the compatibility testing program implemented during the design phase The threshold index parameter(s) will define screening-level analysis that may be used to confirm that waste streams to be disposed of in the landfill are not significantly different from those that were demonstrated to be compatible with liner components in the compatibility testing program conducted in conjunction with the landfill design. Thus, analysis for threshold index parameters may also occur during the landfill disposal phase If, during the disposal phase, analysis indicates that waste streams do not fall within threshold index parameter limits, additional compatibility testing will be required

3.2 Approach for Waste Disposal

Figure D1 presents a summary of the generalized conceptual approach for disposal of each waste stream from excavation through final placement in the landfill The figure identifies the major decision steps in the evaluation and clearance of each waste for final disposal As shown, preliminary clearance of each waste stream by the Program Manager for Rocky Mountain Arsenal (PMRMA) for disposal in the landfill will be based on reviews of existing data (see Section 2 0), as well as on additional data collected during the CAMU design phase Final clearance of the wastes for landfill disposal will be based on additional waste compatibility analyses that will be addressed in the WAP Information regarding compatibility testing of the waste streams and liner system components can be found in the Preliminary Scope of Work and Schedule of Design Activities for the RMA CAMU (Table 5 1) and in the Design Narrative (Appendix B, Section 3 3 3)

4.0 SPECIFIC WASTE ANALYSIS REQUIREMENTS FOR LANDFILL DISPOSAL

The disposal of principal threat and human health exceedance waste in the RMA onsite hazardous waste landfill is based on a large body of historical data as discussed in Section 2 0, which is expected to support meeting the general waste characterization requirements stated in Part 265 13a of 6 CCR 1007-3. A sampling and analysis program for the waste streams is contemplated during the design phase Additional analyses of each waste stream may occur during the disposal phase, as necessary, to assess its chemical compatibility with the liner components (e g , index testing may be conducted to verify waste stream characteristics are consistent with those found to be compatible during the design phase) Analyses conducted during waste disposal will also address the compatibility of each waste stream with commingled waste Waste compatibility screening analyses may be required for each waste stream, and will be performed if visual inspection of the waste and/or historical data reviews imply potential compatibility concerns Screening analysis data will be used to identify incompatible or reactive waste that may require segregation, pretreatment, and/or specific health and safety precautions

In addition to the compatibility screening program, some wastes will undergo field screening for Army Agents during disposal to assess whether pretreatment (i e , caustic washing) is necessary prior to placement in the landfill The general compatibility screening and agent screening analyses requirements prior to disposal are presented in the following subsections

4.1 Compatibility Screening Analyses

The WAP will specify the procedures for waste compatibility screening analysis to be conducted prior to disposal Those procedures will be similar to those presented below

For waste streams that exhibit potential compatibility concerns based on historical data review and/or inspection, initial screening will occur prior to disposal through the collection of samples from the waste body or from initial excavations of the waste These samples will be analyzed for any or all of

the parameters described below, as deemed necessary by field personnel, to assess waste compatibility A preliminary assessment of the analytical parameters and methods for waste analysis is discussed in Section 6 0

- **Corrosivity** Corrosivity shall be assessed based on the ability of the waste to corrode steel at a rate and temperature set by the National Association of Corrosive Engineers standard TM-01-69 or equal (40 CFR 261 22[1])
- **pH** pH shall be measured to further assess corrosivity and waste compatibility
- **Free Liquids** Free liquid present in the waste shall be assessed visually or by the paint filter test (EPA Method 9095) Assessments of free liquids will estimate the number of phases, volume percent of aqueous liquid, volume percent of organic liquid, and volume of sediment in the liquid phase
- **Ignition Test.** Waste materials that exhibit a positive result when tested for ignition by spark at temperatures below 140 degrees Fahrenheit (° F) shall be identified
- **Compatibility with Commingled Waste.** If a waste stream is to be mixed with other wastes during disposal, then a sample of the waste stream shall be mixed with the wastes with which it is to be commingled to determine compatibility Any reaction which generates excessive heat or liberates excessive gases will identify incompatibility Wastes shall be segregated within the landfill if incompatibility is identified and cannot be remedied
- **Threshold Index Testing**· Threshold index testing parameters developed as part of the design phase compatibility testing program will be conducted, if necessary If the established index parameters are exceeded, then appropriate liner system compatibility testing will be performed

As accumulation and disposal of each waste stream proceeds, one or more of the above tests may be repeated as necessary if physical characteristics of a waste stream are observed to change significantly and compatibility concerns are raised Any significant change in color, odor, reactivity with ambient air or water, and/or number of media or phases present (e g., free liquids) for a given waste stream as assessed by field personnel, may result in verification analyses for compatibility.

Segregation and/or pretreatment alternatives may be considered on the basis of the screening results for wastes that exhibit the following characteristics

- Observable reactivity with commingled waste
- Corrosivity as indicated by a steel degradation or by pH below 2 0 or above 12 5

- Flash as indicated by ignition below 140°F
- Free liquids Drying and/or solidification may be considered as a pretreatment step for wastes exhibiting free liquids
- Observable reactivity with liner components

4.2 Agent Screening Analyses

Of the waste streams identified for disposal in the onsite hazardous waste landfill, 10 waste streams may contain potential agent contamination as indicated in the Final DAA Report (Foster Wheeler, 1995) The preferred alternative identified by the Final DAA Report for these soil and building material waste streams is to screen for agent materials during removal of the wastes and treat any contaminated material by caustic washing prior to placement in the landfill Therefore, screening of these waste streams for the Army Agents GB, VX, mustard (H), and Lewisite (L) will occur as part of the waste analysis program during the disposal phase The screening of these wastes will occur as they are excavated or otherwise accumulated by field monitoring methods currently established by PMRMA (see Section 6 0) Any suspected field detections of agent in the waste streams will be confirmed by collecting samples from the suspect material for laboratory analysis

5.0 WASTE SAMPLING PROCEDURES

As presented in Section 2 0, the types of waste media to be sampled during disposal operations include the following

- Excavated soil and sediment
- Building material and munitions debris

The general procedures, which will be in the final WAP, for sampling these two classifications of waste media are presented below In addition, a general summary of sampling documentation and decontamination procedures are presented in this section.

5.1 Waste Sampling

Where sampling is necessary for waste compatibility screening, composite grab samples will be collected from the subject area, initial excavations of waste soil and/or sediment, initial debris accumulations, or from initial pre-processed waste streams, as appropriate Specific standard operating procedures (SOPs) for sampling of these materials will be developed during remedial design These SOPs will be designed to comply with "Test Methods for Evaluating Solid Waste" specified in 6 CCR 1007-3, 260 1 Alternative methods may be used if prior approval is obtained from CDPHE

5.2 Sample and Document Custody Procedures

Sample and document custody procedures applicable to waste sampling are summarized in the following subsections These procedures are consistent with quality assurance (QA) and documentation protocols established by PMRMA (1993) and by EPA (1986, 1992, 1994) The procedures below are considered general and are subject to alteration and refinement during the design phase

Waste samples scheduled by the PMRMA Laboratory Support Division (LSD) for offsite analysis will be delivered to the PMRMA Receiving Office, Building 618, for shipping by the Program Manager

Support Division (PMSD) to one or more laboratories contracted by the PMRMA LSD Waste samples scheduled for onsite laboratory analysis will be delivered directly to the PMRMA Environmental Analytical Laboratory (EAL)

Field Documentation

Appropriate waste sampling forms will be used to record sample and field data collection activities performed onsite At the beginning of each day, the date, start time, weather conditions, field personnel present, level of personal protective equipment (PPE) being used, and name of the person making the entry will be recorded The names of visitors and the purpose of their visit will also be recorded All information pertinent to a field survey and/or sampling event will be recorded in the waste sampling form Typically, the waste sampling form will include the following information

- Name and title of author, date and time of entry, and physical/environmental conditions during field activity
- Location of sampling or field activity
- Name(s) and title(s) of field crew
- Type of media sampled or measured
- Sample collection or measurement method
- Number and volume of samples(s) collected
- Description of measuring reference points
- Date and time of sample collection
- Sample identification numbers(s)
- Field observations and comments
- Field measurements recorded (e g , pH, photoionization detector [PID])
- Sample documentation, including dates and methods of sample shipment

An example waste sampling form is attached as Figure D2 By the end of each day, samples should be brought back to the sample handling trailer for packaging

Sample Classification, Handling, and Shipping

Sample classification is necessary to ensure the protection of personnel involved in the offsite shipment of analytical samples and to maintain the integrity of the samples When sent by common carrier, the packaging, labeling, and shipping of hazardous materials is regulated by the U S Department of Transportation (DOT)

Designated sampling personnel will contact the PMSD no later than 9 00 a m daily for assignment of courier air bill numbers Sample shipments to each laboratory will receive a unique airbill number Containers shipped by the PMRMA shipping custodian will receive a different airbill number than those shipped by RMA Security Therefore, if necessary, two airbill numbers should be requested each day for each laboratory because samples will normally be delivered to the PMRMA shipping custodian (before 4 00 p m) or to RMA Security (after 4 00 p m)

Samples will be shipped with approximately 10 percent air space so that the container is not full at 130 °F unless otherwise required by the method of analysis Glass containers used for all types of analyses will be wrapped in bubble wrap and placed inside a DOT-approved shipping container (Coleman Sample Manager®) and packed to prevent breakage Sample shipments will be preserved by cooler packs around the sample containers Any remaining space will be filled with bubble wrap or vermiculite Samples scheduled for offsite analysis will be delivered to the PMRMA Receiving Office, Building 618, until approximately 4 00 p m and to RMA Security, Building 135, from approximately 4 00 p m until 7 00 p m for shipping to the contract laboratory(ies) for analysis Samples scheduled for onsite analysis will be delivered no later than 3 00 p m to the PMRMA EAL analytical laboratory Additional details of the waste analytical program are described in Section 6 0

The chain-of-custody (COC) record for each sample shipment will be enclosed in a sealed, waterproof envelope attached to the inside of the cooler lid and for delivery to the PMRMA Receiving Office or the PMRMA EAL The Field Operations Coordinator (FOC) will be responsible for notifying the

project Quality Assurance Coordinator (QAC) of the number of samples delivered to the PMRMA Receiving Office and/or the PMRMA LSD and the time of delivery The project QAC (or designated representative) will contact the PMRMA Receiving Office and PMRMA LSD daily, as necessary, to inform them of the incoming samples, arrival time, and special handling or analytical procedures required

Required sample containers, sample preservation methods, and maximum holding times for each sample type are summarized in the RMA Chemical Quality Assurance Plan (CQAP) (PMRMA, 1993) Containers will be obtained from the PMSD supply office, based on availability, and supplied to field personnel before sampling

Sample Identification and Labeling

Sample labels and COC records will be provided to sampling personnel by the project QAC Labels will be attached to each bottle in which a sample is collected If labels are lost, voided, or damaged, the sample information will be noted on the waste sampling forms

Each sample will be identified by a separate sample label and associated tag number The information recorded on the label generally includes, but is not limited to, the following information

- Label tag number
- Site identification number
- PMRMA-approved site type code
- Date a six-digit number indicating the day, month, and year of collection
- Time a four-digit number indicating the 24-hour clock time of collection
- Media type the type of sample (e g , groundwater)
- Sample depth
- Sampler's signature
- Preservative the type of preservative used, if required

- Analysis the type of analysis requested
- The PMRMA-approved sampling technique used during collection

An example of a sample label to be used during the program is shown in Figure D3

Custody seals (evidence tape) will be used to preserve the integrity of the samples in the regular nonlocking shipping containers from the time of collection until they are opened in the laboratory Field personnel will prepare the shipping coolers with custody seals prior to releasing the samples The seal will be attached in such a way that it will break when the sample shipping container is opened Samples shipped in the Coleman Sample Manager® cooler will be sealed using wire custody seals The seals will carry the following information

- PMRMA sample shipping custodian's initials
- Date and time of sealing

Chain-of-Custody Records

To establish the documentation necessary to trace sample possession from the time of sample collection at RMA through sample analysis, a COC record will be completed and will accompany every sample This record will document sample custody transfer from the sampler, to other sampling team members (if necessary), to the laboratory, and back to RMA for disposal

For offsite analyses, the COC process will be maintained by PMRMA using a commercial shipper for shipment of bottles to the site and shipment of samples back to the laboratory The field personnel or sample custodian will write the courier airbill number on the COC record, and sign the COC record and the courier airbill form The PMRMA sample shipping custodian or RMA Security will arrange the shipping and prepare the courier airbill form

The COC record typically contains, at a minimum, the following information

- List of sampling team members
- Label identification number
- Date of sample bottle preparation and shipment
- Signature of sampler or bottle preparer
- Date and time of sample collection
- Sample location and depth
- Medium type
- Airbill number
- Sample preservation
- Type of requested analysis
- Signatures of persons involved in the chain of sample possession
- Inclusive dates of possession
- PMRMA-approved sampling technique and site type

The laboratory portion of the COC record will be completed by laboratory personnel and typically contains the following information

- Date of sample receipt by the laboratory
- Name of person receiving the sample at the laboratory
- Sample condition and temperature upon receipt at the laboratory

Samples will be appropriately packaged for shipment and will be dispatched to the laboratory for analysis with a separate COC record accompanying each shipment. The method of shipment, courier name(s), if any, and other pertinent information should be entered in the remarks section of the COC record An example COC record that will be used for water samples collected during the program is presented in Figure D4

Each COC record consists of three sheets of pressure-sensitive paper (white, yellow, and pink) After the shipping courier name and airbill have been written on the COC and the COC has been signed, additional copies of the original will be made for the Logistic Branch of the Army and the PMRMA LSD The two colored backing sheets of the COC will be removed, and the sample container with the original white COC record inside the lid will be sealed by the field personnel or sample custodian The yellow original will be retained in the sampling contractor's files, and the pink original will be retained by PMRMA

After the field COC record is signed by the laboratory, the laboratory will initiate an internal COC record to track the sample through analysis The original COC record will be retained in the laboratory's files, and a photocopy of the original COC record will accompany the unused portion of the sample back to RMA for final disposal Under no circumstances is an offsite laboratory to send extracted or spent samples to RMA for storage

Corrections to Documentation

Unless prohibited by cold weather conditions, data recorded in field logbooks, sample labels, and COC records will be completed with waterproof ink. None of the accountable, serialized documents will be destroyed or discarded, even if the documents are illegible or contain inaccuracies that require a replacement document

Errors on field documents will be corrected by drawing a line through the error and entering the correct information Errors on a field document should be corrected by the person who made the original entry, and the erroneous information should not be obliterated Corrections to documentation will be initialed and dated

5.3 Decontamination Procedures

Generalized decontamination procedures for sample collection are as follows and will be further defined as necessary during the CAMU design phase Sampling equipment including sampling

scoops, bowls, picks, and chisels will be thoroughly cleaned prior to use and between discrete sampling locations using a detergent solution (Liquinox® or equivalent) followed by a distilled water rinse and allowed to air dry Samples will be collected in laboratory-certified clean sample containers and placed on ice in insulated coolers

Decontamination water used will generally be Contracting Officer's Representative (COR)-approved or distilled water Tap water may be used instead of COR-approved water for use in steam cleaning and detergent solutions provided that distilled water is used afterward to rinse equipment COR-approved water consists of the potable water supplied to RMA that is treated with an activated carbon treatment unit. Decontamination will consist of combinations of steam cleaning and/or detergent solution (Liquinox® or equivalent) wash, water rinse, and distilled water rinse Detergent solution is prepared by mixing approximately 1 teaspoon of detergent (Liquinox® or equivalent) per 5 gallons of COR-approved water or tap water This section details decontamination procedures as well as types of equipment to be decontaminated

Decontamination Pad

A temporary mobile decontamination pad will be set up near the work area to provide onsite decontamination Each temporary pad will include a steam cleaner and a sump to collect decontamination solids and wastewater Decontamination solids and wastewater will be removed from the sump will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation

Personnel

Procedures for personnel decontamination are described in the Health and Safety Plan

6.0 WASTE ANALYTICAL PROCEDURES

It is contemplated that the WAP will specify that the PMRMA EAL will be the onsite laboratory responsible for performing waste characterization analyses Additional external laboratories may be identified by the PMRMA LSD to assist in waste sample analysis The laboratories and methods employed for waste analysis will be approved by PMRMA, and method performance and proficiency will be demonstrated prior to sample analyses in accordance with the PMRMA Chemical Quality Assurance Plan (PRMRA, 1993)

6.1 Analytical Methods

Analytical parameters and methods for waste samples that will be included within the WAP are summarized in Table D5 As shown, waste extracts to be screened and analyzed for agent parameters will be analyzed according to approved PMRMA-approved field screening methods Laboratory verification analyses to confirm suspected agent detections based on field screening results will be performed by the PMRMA EAL Analyses for the remaining parameters listed in Table D5 will be performed according to standard EPA or American Society for Testing and Materials (ASTM) screening-level methods

6.2 Quality Assurance Protocols

The WAP will specify that quality assurance and quality control (QA/QC) protocols for waste analyses and reporting will be approved by the PMRMA LSD and will be consistent with the requirements of the PMRMA CQAP (PMRMA, 1993)

7.0 DOCUMENTATION FOR WASTE ANALYSIS AND DISPOSAL

Specific documentation and data management requirements for waste analysis data during disposal operations will be developed in the operations plans of the contractors performing disposal Because the details of the CAMU design and operation are still being developed, specific documentation processes, formats, and requirements cannot be defined at the present time However, in general, the WAP will specify the following general documentation requirements will be met during disposal

Waste Analysis Data

- Management, review, and reporting of analytical data by the PMRMA LSD will conform to the requirements of the RMA CQAP (PMRMA, 1993)

- Analytical data generated prior to disposal will be reported from the PMRMA LSD to the remediation contractor, who initiated the waste compatibility characterization request (see Section 3 2) The remediation contractor will submit the historical data to the PMRMA Remedial Action Branch (RAB) and to the landfill operations contractor for evaluation and clearance of the waste. Based on initial data evaluation, the PMRMA RAB may identify additional parties to assess the waste compatibility data (e g , a pretreatment contractor)

- Official documentation of preliminary and final clearance for disposal in the onsite CAMU landfill will be transmitted from the PMRMA RAB to the excavation and landfill operation contractors (as well as appropriate pretreatment contractors) for each disposed waste stream Such documentation will include the basis for clearance for each waste stream

- A complete file of current and historical analytical data for each waste stream will be maintained by the remediation contractor, the landfill operations contractor, and PMRMA. Hardcopy data files will be maintained by PMRMA at the RMA Technical Information Center (RTIC), and electronic data will be maintained in the RMAED

Waste Disposal

- Logs may be maintained by remediation contractors for excavation, pretreatment (if necessary), and landfill disposal Excavation logs may include location information for each allotment of waste that is excavated for disposal Landfill disposal logs may include grid location information for each waste allotment in the landfill cells

- Transfer logs may be employed by the excavation, pretreatment, and landfill operations contractors to document the transfer of waste allotments and their locations within the disposal cells

Additional, more detailed requirements for documentation and reporting of waste disposal activities, including formats for logs and forms, will be defined during the design phase and will be included in the disposal operations plans

8.0 ACRONYMS

Army	U S Department of the Army
As	Arsenic
ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, xylene
CAMU	Corrective Action Management Unit
CCR	Colorado Code of Regulations
Cd	Cadmium
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHWMA	Colorado Hazardous Waste Management Act
CLC2A	Chloroacetic acid
COC	Chain of custody
COR	Contracting Officer's Representative
CPMSO	p-Chlorophenylmethyl sulfoxide
$CPMSO_2$	p-Chlorophenylmethyl sulfone
CQAP	Chemical Quality Assurance Plan
Cr	Chromium
CWTS	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Wastewater Treatment System
DAA	Detailed Analysis of Alternatives
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
DIMP	Diisopropylmethyl phosphonate

DMMP	Dimethylmethyl phosphonate
DOT	U S Department of Transportation
EAL	Environmental Analytical Laboratory
EC	Exchangeable Cations
EPA	U S Environmental Protection Agency
ESE	Environmental Science and Engineering
FFA	Federal Facilities Agreement
FOC	Field Operations Coordinator
GB	Isopropylmethylphosphonofluoridate
GC	Gas chromatography
H	Mustard
HCCPD	Hexachlorocyclopentadiene
Hg	Mercury
HLA	Harding Lawson Associates
IRA	Interim Response Action
L	Lewisite
LSD	Laboratory Support Division
mg/kg	Milligrams per kilogram
MKE	Morrison-Knudsen Environmental
NH_3	Ammonia
OCP	Organochlorine pesticide
OPC	Organophosphorous compound
OPP	Organophosphorous pesticide
OSC	Organosulfur compound
Pb	Lead
PID	Photoionization detector
PMRMA	Program Manager for Rocky Mountain Arsenal

PMSD	Program Manager Support Division
PNA	Polynuclear aromatic hydrocarbon
PPE	Personal protective equipment
ppm	Parts per million
QA/QC	Quality assurance/quality control
QAC	Quality Assurance Coordinator
RAB	Remedial Action Branch
RI/FS	Remedial Investigation/Feasibility Study
RMA	Rocky Mountain Arsenal
RMAED	RMA Environmental Database
RTIC	RMA Technical Information Center
S^2	Sulfide
SOPs	Standard Operating Procedures
State	State of Colorado
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
UXO	Unexploded ordnance
VHO	Volatile halogenated organic
VX	Ethyl S-2-diisopropylaminoethylmethylphosphorothiolate
WAP	Waste Analysis Plan
yd^3	Cubic Yard
°F	Degrees Fahrenheit

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Table D1: Summary of Wastes Disposed in Double-lined Cells at the RMA Onsite Hazardous Waste Landfill

Waste Identification	Basis for Disposal in Hazardous Waste Landfill	Chemical Composition (ppm)[a,b]	
South Plants Central Processing Area Soil	Principal Threat and Human Health Exceedance for OCPs, VHOs, DBCP, CLC2A, As, Hg, trace metals Potential agent presence[c]	OCPs	7 5 to 580
		VHOs	1 9 to 580
		DBCP	275
		CLC2A	13
		HCCPD	28
		DCPD	6 7
		As	230
		Cd	5 1
		Cr	20
		Hg	300
		Pb	310
Balance of South Plants Area Soil	Principal Threat and Human Health Exceedance for OCPs, HCCPD, As, trace metals Potential agent and UXO presence[c]	OCPs	0 53 to 33
		HCCPD	23
		Cr	62
		Hg	500
		Pb	340
Section 36 Balance of Area Soil	Human Health Exceedance for OCPs, CLC2A Potential agent and UXO presence[c]	OCPs	0 10 to 24
		CLC2A	52
		As	2 4
		Hg.	0 46
Secondary Basin Soil	Human Health Exceedance for OCPs, Cr	OCPs	0 68 to 28.2
		Cr	120[d]
North Plants Soil	Human Health Exceedance for As	As	2,800
M-1 Pits Soil	Principal Threat and Human Health Exceedance for OCPs, HCCPD, DCPD, As, Hg Potential agent presence[c]	OCPs	0 099 to 0 55
		HCCPD	44
		DCPD	195
		As	17,000
		Cd	320
		Hg	4,300
Hex Pits Soils	Principal Threat and Human Health Exceedance for OCPs, HCCPD	OCPs	1,000[d]
		HCCPD	40,000[d]
Burial Trenches Soil	Human Health Exceedance for Cr, Pb Potential agent and UXO presence[c]	Cr	20
		Pb	190

Table D1 (continued)

Waste Identification	Basis for Disposal in Hazardous Waste Landfill	Chemical Composition (ppm)[a,b]	
Sand Creek Lateral Soil	Human Health Exceedance for OCPs, CLC2A, Cr	OCPs CLC2A Cr Pb	0 04 to 27 8 230[d] 180 800
Buried Lake Sediments	Human Health Exceedance for OCPs	OCPs	0 8 to 40
South Plants Ditches Soil	Principal Threat and Human Health Exceedance for OCPs, trace metals	OCPs As Cr Hg	0 17 to 270 0 42 12 0 30
Upper Derby Lake Soil (Lake Sediments)	Human Health Exceedance for OCPs	OCPs	0 7 to 11 8
Chemical Sewer System Soil (outside of the South Plants Central Processing Area)	Human Health Exceedance for OCPs, VHOs, HCCPD, DBCP, CLC2A, As Potential agent presence[c]	OCPs VHOs HCCPD DBCP CLC2A As	20,000[d] 400[d] 4,000[d] 32,000[d] 230[d] 740[d]
Agent-contaminated Building Material	Potential agent presence[c]	Data to be obtained during building demolition prior to pretreatment	
Munitions Testing Group Debris and Nearby Soil	Toxicity characteristic as assessed by TCLP Potential UXO presence[c]	TCLP data to be generated during excavation as necessary prior to disposal	
Toxic Storage Yard	Human Health exceedence for CLC2A, Arsenic Potential agent presence[c]	CLC2A As	115 1,600
Sanitary Landfills	Human Health exceedence for OCPs, metals	OCPs Cr Pb Cd. Hg	0 02 to 3 0 18 65 5 8 0 11

Table D1 (continued)

As	Arsenic
Cd	Cadmium
Cr	Chromium
CLC2A	Chloroacetic acid
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
HCCPD	Hexachlorocyclopentadiene
Hg	Mercury
OCPs	Organochlorine pesticides
Pb	Lead
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total organic carbon
UXO	Unexploded ordnance
VHOs	Volatile halogenated organics

a Unless otherwise noted, chemical composition data have been collected from the Final Detailed Analysis of Alternatives (DAA) Report, Version 4 1 (Foster Wheeler, 1995)

b Unless otherwise noted, concentrations listed below are modeled mean concentration values in parts per million (ppm) within the human health and/or principal threat exceedence volume to be disposed

c Based on historical site use information, as noted in the Final DAA Report (Foster Wheeler, 1995)

d No modeled mean concentration reported, value represents a single detection or a modeled maximum value in an isolated area.

Table D2: Summary of Wastes Disposed in Triple-lined (Enhanced) Cells at the RMA Onsite Hazardous Waste Landfill

Waste Identification	Basis for Hazard Classification	Physical Characteristics[a]	Chemical Composition (ppm)[a,b]
Basin F Principal Threat Soil	**Principal threat exceedances for OCPs**	**Est. pH and TOC: assumed to be same as those for Basin F Waste-Pile Soil**	**OCPs: 0.1 to 23,000 DCPD: 8 to 22,000 VOCs: 40 to 2,000**
Sand Creek Lateral Soil	**Human Health Exceedance for: OCPs**	**Same as above**	**OCPs: 0.04 to 27.8 Pb: 9-1070**
Basin F Waste Pile Soil	Principal Threat and Human Health Exceedance for: OCPs, Volatiles, DCPD, CLC2A	pH: 6.38 to 8.72 density: 2022 to 2711 lb/yd^3 loadbearing: 2 5 ton/ft^2 flash point: 70 to > °F reactive: S^{2-}: C 5 ppm reactive: CN^-: < 2 ppm reactive: NH_3: 15 ppm TOC (TCLP): 420 ppm TOX (TCLP): < 5 ppm	**Total Analyses** Ammonia (as N): 9200 Cyanide: 0 581 Nitrate: 600 OCPS 0 1 to 3,100 HCCPD: 5.5 DCPD: 1,500 to 2,000 CLC2A: 110 to 760 BTEX: 0.02 to 51 PNAs: 17 to 48 Ketones: 0.5 to 3.2 Methanol: 54.3 VHOs: 0.06 to 110 **TCLP Analyses** Endrin: < 0.0001 to 0 003 Antimony: 0.036 to 0.039 Arsenic: < 0.015 to 0.134 Barium: 0.183 to 1 Cadmium: <0.005 to 0.055 Chromium: <0.006 to 0.151 Lead: < 0.030 Nickel: 0.161 to 0.324 Selenium: < 0.038 Silver: < 0.009 Thallium: < 0.110 Mercury: <0.0005 to 0.0006

BTEX	Benzene, toluene, ethylbenzene, xylene
CLC2A	Chloroacetic acid
CN	Cyanide
DCPD	Dicyclopentadiene
HCCPD	Hexachlorocyclopentadiene
HLA	Harding Lawson Associates
Ketones	Acetone, 2-butanone
Major cations	Calcium, magnesium, potassium, sodium
MKE	Morrison-Knudsen Environmental

Table D2 (continued)

NH_3	Ammonia
OCPs	Organochlorine pesticides
PNAs	Polynuclear aromatic hydrocarbons
S^2	Sulfide
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total organic carbon
TOX	Total organic halogens
VHOs	Volatile halogenated organics

a Physical characteristics data reported for Lime Basin Soil are estimates based on soil samples collected near the Lime Basins during the Phase II Onpost Feasibility Study (Woodward-Clyde, 1993b) and on lime-containing soil samples collected by HLA (HLA, 1994) Chemical composition data for Lime Basin Soil are modeled mean concentration values in parts per million (ppm) within the exceedance volume to be disposed, as presented in the Final Detailed Analysis of Alternatives (DAA) Report, Version 4 1 (Foster Wheeler, 1995)

b Physical characteristics data reported for Basin F Waste Pile Soil were collected for drummed Basin F soil by HLA (1994) Chemical composition data for Basin F Waste Pile Soil are ranges or maximum concentrations that have been condensed from the Final DAA Report (Foster Wheeler, 1995), and from data reported for drummed Basin F soil by MKE in 1989 and HLA in 1994

Table D3: Summary of Basin F Waste Pile Leachate Data and Basin F Liquid Data

Waste Identification	Physical Characteristics[a]	Chemical Composition (ppm)[a,b]
Basin F Waste Pile Soil Leachate	pH 7 92 to 9 42 TDS 0 6 to 37 2 % TSS <4 to 1721 ppm SC 217,000 to 530,000 μmhos/cm Total hardness 56,000 to 217,000 ppm TOC 18 to 49 ppm TOX 80 to 220 ppm COD 49 to 280 ppm	Sulfate 23 to 54,533 Chloride 1032 to 190,000 DMMP 0 01 to 5 6 $CPMSO_2$ 0 02 to 19 VHOs 0 026 to 1 1 BTEX 0 006 to 0 046 DIMP 0 74 to 1 3 CPMS 0 23 to 0 31 CPMSO 2 8 to 4 0 Ketones 0 005 to 15 IMPA 560 to 730 OSCs 0 007 to 580 Cyanide 0 42 to 0 87 Fluoride 32 to 36 Nitrate (as N) 870 to 930 Alkalinity 17 to 30 Ammonia nitrogen 21 to 23 Phosphorus 20 to 21 Sulfide 26 to 32 As 1 1 to 1 4 Hg 0 012 to 0 016 Trace metals 0 033 to 250 Major cations 7 0 to 100,000 OCPs 0 0002 to 0 170 OPPs 0 006 to 0 013 DCPD 0 042 to 0 050
Basin F Liquid		OCPs 0 1 to 2 9 HCCPD 1 9 OSCs 0 1 to 120 CPMSO 25 8 CPMSO2 200 OPPs 0 1 to 0 9 VHOs 0 003 to 0 1 DIMP 123 DMMP 2,000 Major cations 250 to 61,000 Trace metals 0 4 to 5,860 BTEX 0 008 to 0 01 As 3 9 Hg 340 Fluoride 170 Chloride 160,000 Sulfate 47,000

Table D3 (continued)

Waste Identification	Physical Characteristics[a]	Chemical Composition (ppm)[a,b]
Basin F Liquid (continued)		Cyanide 1 55 Nitrate 1,300 Total nitrogen 104,000 Total phosphorous 16,200

As	Arsenic
BTEX	Benzene, toluene, ethylbenzene, xylenes
CPMS	p-Chlorophenylmethyl sulfide
CPMSO	p-Chlorophenylmethyl sulfoxide
$CPMSO_2$	p-Chlorophenylmethyl sulfone
DCPD	Dicyclopentadiene
DIMP	Diisopropylmethylphosphonate
DMMP	Dimethylmethylphosphonate
HCCPD	Hexachlorocyclopentadiene
Hg	Mercury
IMPA	Isopropylmethylphosphonic acid
Ketones	Include methyl ethyl ketone, acetone, and methyl isobutyl ketone
Major cations	Calcium, magnesium, potassium, sodium
N	Nitrogen
OCPs	Organochlorine pesticides
OPCs	Organophosphorus compounds
OPPs	Organophosphorus pesticides
OSCs	Organosulfur compounds, include dithiane, benzothiazole, 1,4-oxathiane, thiodiglycol, thiodiglycolic acid, and dimethyl disulfide
ppm	Parts per million
TDS	Total dissolved solids
Trace metals	Aluminum, antimony, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, zinc
TSS	Total suspended solids
VHOs	Volatile halogenated organics

a Data for Basin F Waste Pile leachate have been condensed from the Final Basin F Waste Pile Annual Data Collection Report (HLA, 1994), the Rocky Mountain Arsenal Contingency Plan, Revision 4 0 (Weston, 1991), and from leachate data collected by HLA in March, 1994, (see Appendix A of the CDD)

b Chemical composition data for Basin F Liquid have been summarized from the Rocky Mountain Arsenal Contingency Plan, Revision 4 0 (Weston, 1991)

Table D4: References Presenting Characterization Data for Waste Streams Disposed in the Onpost CAMU at RMA

RTIC Reference Number	Document Name	Data Presented
95290R01	Final Detailed Analysis of Alternatives Report, Version 4 1, Volumes I through VII (Foster Wheeler, 1995)	Statistical summaries of target chemical characterization data for all designated waste streams (includes all waste streams designated for disposal in the onpost CAMU)
92017R01	Final Remedial Investigation Summary Report, Version 3 2, Vol I, Appendices A, C, E (Ebasco, 1992)	Summaries of target chemical characterization data for contaminated areas and media at RMA
91081R01	Soil Investigation and Inventory of RMA (J P Walsh, 1988)	Physical characterization data for RMA soil media Includes chemical indicator parameter data (pH, EC, exchangeable bases, CEC, moisture, lime content, organic carbon content) Data are reported for soil boring samples collected across the site
88344R01	Determination of Partition Coefficients for the Primary Contaminant Sources of Section 36, Version 2 2 (ESE, 1988)	Presentation of partition coefficients for RMA chemicals in contaminated soil and wastes at RMA Includes discussions of soil chemical and physical properties relating to contaminant transport
93137R02	Final Technical Report, Phase II On-Post Feasibility Study, Version 3 0, Volumes I and II, (Woodward-Clyde, 1993b)	Chemical and physical characterization data for RMA soil media Includes data for RMA target chemicals, chemical indicator parameters (CEC, extractable sulfur, pH, organic carbon), soil classification, soil testing (grain size, Atterberg limits, moisture) Data were collected for major study areas of RMA (e g , South Plants Study Area, North Plants Study Area, North Central Study Area, etc)

Table D4 (continued)

RTIC Reference Number	Document Name	Data Presented
93137R01	Final Technical Report, Phase I Feasibility Study, Version 3 1, Volumes I and II, (Woodward-Clyde, 1993a)	Chemical and physical characterization data for RMA soil media Includes data for RMA target chemicals, chemical indicator parameters (CEC, extractable sulfur, pH, organic carbon), soil classification, soil testing (grain size, Atterberg limits, moisture)
94187R01	Final Report, Feasibility Study Soil Volume Refinement Program, Version 2 0 (Ebasco, 1994)	Total and TCLP analysis results for soil boring samples from contaminated areas of RMA Analyses for agent and agent degradation products are included
93014R02	RMA Innovative Technology Studies Program, Summary Results Report for Soil Vapor Extraction Bench-scale Testing (Draft Final) (Harding Lawson Associates, 1992)	Chemical and physical characterization data for soil boring samples from former Basin F
94168R01	Final Technical Report, Task 93-04 Soil Vapor Extraction Screening Program, Rocky Mountain Arsenal, Commerce City, Colorado (Harding Lawson Associates, 1994)	Chemical and physical characterization data for soil samples from South Plants and former Basin F

CAMU Corrective Action Management Unit
CEC Cation Exchange Capacity
EC Exchangeable cations
ESE Environmental Science and Engineering
RMA Rocky Mountain Arsenal
RTIC RMA Technical Information Center
TCLP Toxicity Characteristic Leaching Procedure

Table D5: Analytical Parameters and Methods for Waste Analysis

Army Agent Analysis

1 Field Screening Analysis for GB, VX, mustard, and Lewisite by Miniature Continuous Air Monitoring Systems (MINICAMs)

2 Laboratory verification analysis for GB, VX, mustard, and Lewisite by gas chromatography (GC)

Waste Compatibility Tests

1 Corrosivity by EPA Method 1110

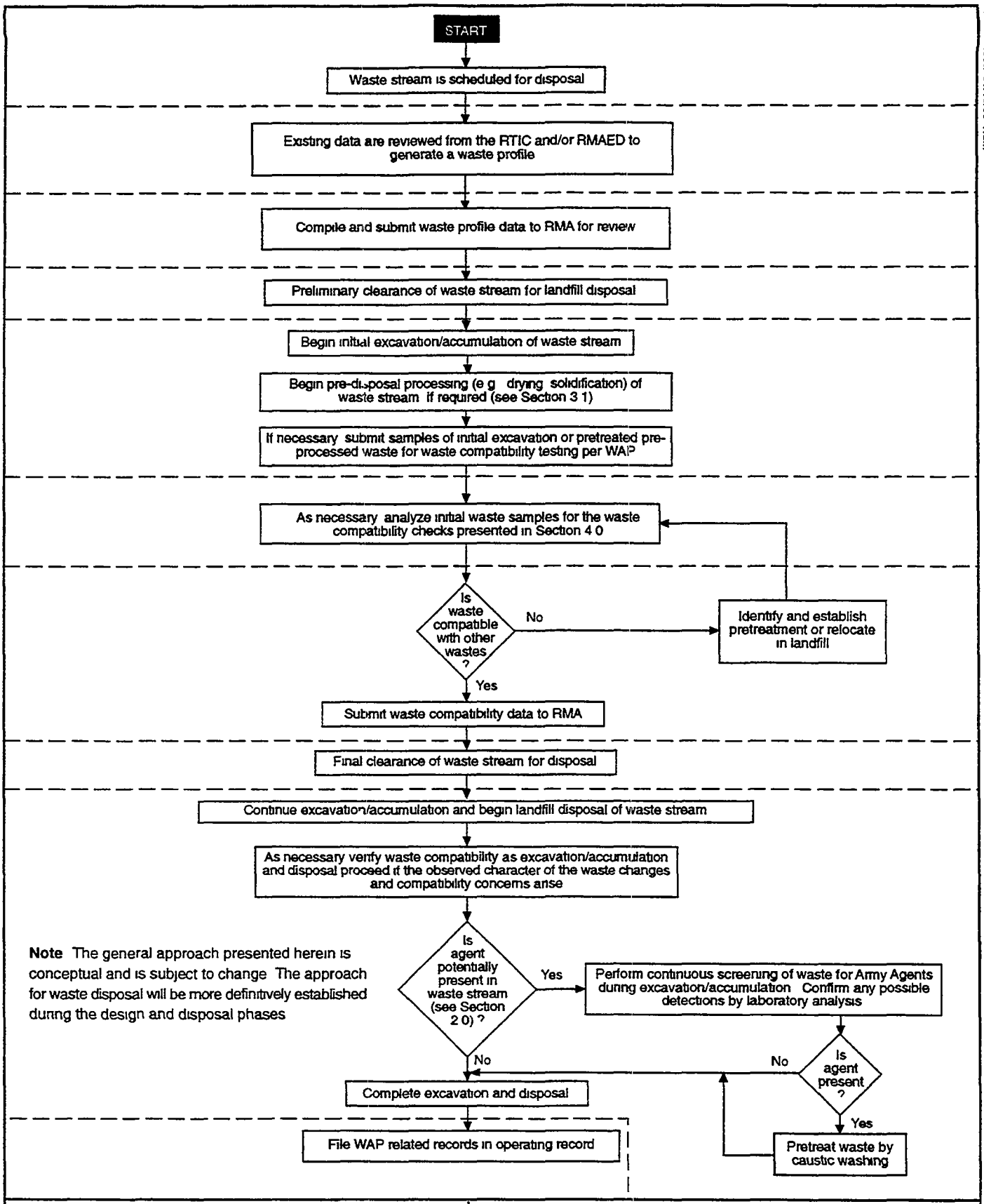
2 pH by EPA Method 9045A

3 Ignitability by EPA Method 1010

4 Free liquids by EPA Method 9095 (paint filter test)

5 Compatibility with commingled wastes by ASTM D-5058 90

ASTM American Society for Testing and Materials
EPA U S Environmental Protection Agency
GB Isopropylmethyl phosphonofluoridate (Sarin)
VX Ethyl S-2-diisopropylaminoethylmethyl phosphorothiolate



Note The general approach presented herein is conceptual and is subject to change The approach for waste disposal will be more definitively established during the design and disposal phases

RMA 1256a 01/10/98 NLM

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure D1

Conceptual Waste Characterization Approach for Wastes Disposed in the RMA CAMU Landfill

Harding Lawson Associates
WASTE SAMPLING DATA SHEET

Log Book. _____
Pages ____ to ____

Sample ID	Sample Media. ☐ Soil/Sediment ☐ Debris ☐ _____	Time	Date
		Sampling Crew Members	Organization/Title
Waste Stream ID	Sample Type ☐ Discrete Grab ☐ Composite Grab ☐ _____		
Waste Stream Description	Sampling Equipment: ☐ Shovel ☐ Trier ☐ Hand Auger ☐ Scoop ☐ _____	Site Conditions	

Description of Sample Collection Activities

Time	Location	Procedures	Visual Description	Bottles Collected

EXAMPLE

Analyses Requested	Sampling Site Health and Safety Measurements		
	☐ HNu ☐ OVM ☐ Microtip ☐ _____ Serial #	Site Readings	Sample Readings
Comments	Protective Level A B C D		
	HSO Signature _____		
	Sampler's Signature _____		

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by:
Harding Lawson Associates

Figure D2

Example Waste Sampling Data Sheet

RMA 12657 1/8/98 LAM

Harding Lawson Associates
Denver, CO 80202

707 Seventeenth Street, Suite 2400
303/292-5365

Sample Number:
Sample Type:
Depth.
Analysis
Preservative
Container
Remarks:
Sampler's Signature·

Tag Number:
Sample Technique:
Date/Time:

EXAMPLE

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by.
Harding Lawson Associates

Figure D3

Example Sample Label

RMA 11113 14698 LAM

Harding Lawson Associates
2400 ARCO Tower
707 Seventeenth Street
Denver, CO 80202
303/292-5365
Telecopy 303/292-5411

Lab I D.: _____

Work Authorization Number: _____

Sample Round/Episode _____

CHAIN-OF-CUSTODY RECORD

Project Name/Project No	Sample Date	Sample Technique	Site Identification
Sampler (Signature)	**Sample Depth (Ft)**	**File-Type/Matrix**	**Site Type**

TIME	TAG NO	ANALYSIS REQUIRED	CONTAINER	PRESERVATIVE/REMARKS

Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Airbill Number		

Laboratory Copy White — Project Office Copy Yellow — Field or Office Copy Pink

19108 H

EXAMPLE

RMA 1032 1/89 LAM

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by.
Harding Lawson Associates

Figure D4

Example Chain-of-Custody Form

Appendix E

SECURITY PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1.2 Organization

2 0 Access Control

- 2 1 Rocky Mountain Arsenal Access
- 2 2 CAMU Access
- 2 3 Active Waste Management Areas Access

3 0 Perimeter Controls

4 0 Warning Signs

5 0 Acronyms

6 0 References

Appendix F

PERSONNEL TRAINING PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 General

- 2 1 Instructor Qualifications
- 2 2 Training Schedule
  - 2 2 1 On-the-Job Training
  - 2 2 2 Classroom Training

3 0 Curriculum

- 3 1 Emergency Response
  - 3 1 1 Spill Response
  - 3 1 2 Fires and Explosions
  - 3 1 3 Natural Forces
  - 3 1 4 Other Emergencies
  - 3 1 5 Emergency Shutdown Procedures
- 3 2 Emergency Equipment
- 3 3 Alarm and Communication Systems
- 3 4 Waste Management

4 0 Recordkeeping

- 4 1 Job Descriptions
- 4 2 Training Descriptions
- 4 3 Training Records

5 0 Acronyms

6 0 References

Appendix G

INSPECTION PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix. During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 Inspection Requirements

- 2 1 Landfill Cells
- 2 2 Run-on/Runoff Control Systems
- 2 3 Decontamination Facilities
- 2 4 Basin F Waste Pile Drying Unit
- 2 5 Waste Staging/Consolidation Areas
- 2 6 Emergency Response Systems
- 2 7 Other Areas

3 0 Inspection Schedule

- 3 1 Daily Inspections
- 3 2 Weekly Inspections
- 3 3 Monthly Inspections
- 3 4 Quarterly Inspections
- 3 5 Annual Inspections

4 0 Deficiency Correction Requirements

5 0 Recordkeeping Requirements

- 5 1 Inspection Logs
- 5 2 Deficiency Correction Logs

6 0 Acronyms

7 0 References

Appendix H

CONSTRUCTION QUALITY ASSURANCE PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 General

- 2 1 Applicability
- 2 2 Construction Quality Assurance Personnel
  - 2 2 1 Organization
  - 2 2 2 Qualifications
  - 2 2 3 Responsibilities
- 2 3 Terminology
  - 2 3 1 Construction Parties
  - 2 3 2 Definitions
- 2 4 Reference Standards

3 0 Earthwork Construction Quality Assurance

- 3 1 Foundations
  - 3 1 1 Cell Subgrade
  - 3 1 2 Cover System Subgrade
- 3 2 Structural Fill
  - 3 2 1 Embankments
  - 3 2 2 Anchor Trenches
  - 3 2 3 Other Areas
- 3 3 General Fill
  - 3 3 1 Operations/Frost Protection Layers
  - 3 3 2 Other Areas

3 4 Clay Liners

3 4 1 Materials

3 4 2 Placement

3 4 3 Protection

3 5 Drainage Materials

3 6 Biota Barrier

4 0 Flexible Membrane Liner Construction Quality Assurance

4 1 Manufacture

4 2 Delivery and Storage

4 3 Installation

4 4 Conformance Testing

5 0 Geonet Construction Quality Assurance

5 1 Manufacture

5 2 Delivery and Storage

5 3 Installation

5 4 Conformance Testing

6 0 Geotextile Construction Quality Assurance

6 1 Manufacture

6 2 Delivery and Storage

6 3 Installation

6 4 Conformance Testing

7 0 Geocomposite Construction Quality Assurance

7 1 Manufacture

7 2 Delivery and Storage

7 3 Installation

7 4 Conformance Testing

8 0 Geosynthetic Clay Liner Construction Quality Assurance

8 1 Manufacture

8 2 Delivery and Storage

8 3 Installation

8 4 Conformance Testing

9 0 Pipe Construction Quality Assurance

9 1 Manufacture

9 2 Delivery and Storage

9 3 Installation

9 4 Conformance Testing

10 0 Miscellaneous Construction Quality Assurance

10 1 Pumps

10 2 Level Indicators

10 3 Access Ramp Surfacing

11 0 Surveying

12 0 Documentation

12 1 Field Logs

12 2 Design and Specification Changes

12 3 Certification Report

13 0 Acronyms

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Appendix I

CONCEPTUAL TEST FILL WORK PLAN

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I2 Test Fill 3 Plan View and Cross Sections
I3 Methodology for Selection of Test Fill 3 Placement Specifications

1.0 INTRODUCTION

This Conceptual Test Fill Work Plan (Work Plan) has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado This Work Plan will be used as a guide for development of the final procedures for the construction of Test Fill 3, and subsequently for specifications and Construction Quality Assurance Plans for landfill liner and capping systems The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act. The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

The CDD has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Background

Two compacted clay liner (CCL) tests fills (Test Fills 1 and 2) were constructed in the southeast portion of Section 25 during the summer of 1994 The primary objective of this program was to demonstrate that a hydraulic conductivity of 1×10^{7} centimeters per second (cm/s) or less can be achieved with the onsite clayey soils These soils were obtained from borrow areas located within 2 miles of Section 25 The field-scale hydraulic conductivity of each of these two test fills was evaluated using a sealed double-ring

infiltrometer (SDRI) and two-stage borehole permeameters (TSBP) The results of these field-scale tests indicated that a hydraulic conductivity of 1 x 10^{-7} cm/s or less was achieved The results of Test Fills 1 and 2 are presented in the Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program, (Landfill FS report) (HLA, 1995a) included as Appendix R of the CDD

While the Test Fill 1 and 2 results indicated that the minimum hydraulic conductivity can be achieved with onsite soils, the Colorado Department of Public Health and Environment (CDPHE) in an August 30, 1995, letter to Program Manager for Rocky Mountain Arsenal (PMRMA), raised general questions regarding clay liner moisture conditioning, placement, and compaction. In addition to the questions raised by CDPHE, the Army identified data needs relative to the development of CCL construction specifications that were not objectives in the initial test fill program Thus, Test Fill 3 will be constructed to

- Respond to the comments made by CDPHE
- Provide additional test fill data that will allow the landfill designer to prepare construction specifications and construction quality assurance procedures for CCLs

1.2 Purpose and Scope

The purposes of the test fill program described in this Work Plan are described below

1 To provide the Army with CCL construction specifications that provide the flexibility to construct full-scale CCLs using equipment and procedures for CCL moisture conditioning, placement, and compaction that will allow for more productive construction than the equipment and procedures used for Test Fills 1 and 2

2 To evaluate the clayey soil within the footprint of the CAMU landfill cell excavation for suitability of use as CCL material and possibly use this material to construct Test Fill 3

3 To evaluate the geotechnical property consistency of the five potential CCL material borrow areas at RMA Four of these areas are identified in the Final Feasibility Soil Support Program (Borrow Study Report) (HLA, 1995b) The fifth area is the clayey soil within the footprint of the landfill cell excavations

4 To select which of these five areas are sufficiently similar and which of these areas are significantly different.

5 To select the borrow area for Test Fill 3 based on the landfill and the borrow area design being performed by the U S Army Corps of Engineers, and the borrow area consistency evaluation described in Item 4 above

6 To define any additional test fill data needs for future landfill construction that exist after the construction and testing of Test Fill 3

The scope of this test fill program includes the following activities

- Preparing, submitting, and obtaining approval of this Conceptual Test Fill Work Plan
- Preparing, submitting, and obtaining approval of the Final Test Fill Work Plan At the request of CDPHE, the Final Work Plan may include detailed drawings and specifications for the construction of Test Fill 3, or further development and refinement of the procedures described in this Conceptual Plan.
- Tabulating and analyzing the geotechnical index properties (i e , proctor values, percent fines, Atterburg limits, hydraulic conductivity), submitting proposed borrow area consistency criteria along with the supporting documentation to CDPHE for approval, and selecting which of the five potential borrow areas (likely to be the landfill cell footprint area) will be used for Test Fill 3 construction (discussed in Section 3.0)
- Performing preconstruction testing and laboratory testing to obtain additional geotechnical index parameter data and to establish the relationship between moisture, density, and hydraulic conductivity of the Test Fill 3 borrow material (discussed in Section 4 0)
- Constructing the test fill using the most productive equipment, procedures, and specifications necessary to obtain a hydraulic conductivity of 1×10^{-7} cm/s or less (discussed in Section 5.0)
- Performing CQA monitoring and testing during construction of the test fill (discussed in Section 6 0)
- Performing post-test fill construction laboratory testing to verify that a hydraulic conductivity of 1×10^{-7} cm/s or less was achieved (discussed in Section 7 0), preparing CCL construction specifications using the procedures and equipment used to construct Test Fill 3, and preparing and submitting a summary report.
- Review data from all test fills and identify additional future data needs

A CQA effort will be incorporated into the construction of the test fill The test fill will be constructed by an earthwork contractor (Contractor) experienced in low-permeability soil (clay) liner construction. CQA will be performed by a CQA Engineer who will perform tests and observations to evaluate the effectiveness of the construction procedures and equipment in achieving the required hydraulic conductivity at a workable moisture content range and at an achievable dry density range

Test Fill 3 will be constructed on both a flat (5 percent or less) slope and a side (40 percent or less) slope The slopes used for the test fill will be similar to those selected during design of the landfill cell floor and sideslopes The test fill will be constructed near the location of Test Fills 1 and 2 using either soil from one of the borrow areas identified in the Final Feasibility Study Soils Support Program Report (Borrow Study Report) (HLA, 1995b) or onsite clayey soils excavated from within the expected footprint of the CAMU landfill cells (Sections 25 and 26) Figure I1 shows the locations of Test Fills 1 and 2 and the borrow areas used to construct them Figure I1 also shows the location of the borrow areas identified the Borrow Study Report (Areas 1 through 4) and the landfill area of the CAMU (Area 5) Figure I2 shows a typical plan view and cross sections of Test Fill 3

Large-scale hydraulic conductivity will be evaluated by obtaining large diameter (typically 12 inches) undisturbed soil liner samples and testing them in specially designed flexible wall permeameters in the same manner as small diameter (2 8 inches) sleeve (Shelby) samples and in accordance with American Society for Testing and Materials (ASTM) D5084 The large diameter undisturbed samples are commonly referred to as "block" samples in published literature Published comparisons between the hydraulic conductivity of large-scale block samples and the hydraulic conductivity of SDRIs have shown little variation in the test results (Benson, 1993) except in cases where little or no Construction Quality Assurance (CQA) was performed

1.3 Organization

The remainder of this appendix is divided into seven sections Section 2 0 provides a discussion of recent U S Environmental Protection Agency (EPA) guidance and other reference documents applicable to test fill construction Section 3 0 presents the scenario for comparing the geotechnical property data for the five potential Test Fill 3 borrow areas, selecting which of these areas are significantly different and which are sufficiently similar, and selecting which of these areas will be used for Test Fill 3 construction Section 3 0 also provides a discussion of the CCL volumes needed for the landfill construction, a discussion of the volume of potential CCL material available, and a discussion of how these volumes will effect Test Fill 3 and future test fill construction Section 4 0 describes the precon-

struction laboratory sampling and testing activities and data interpretation methodology Section 5 0 provides the procedures for construction of the test fill Section 6 0 provides the CQA procedures for construction of the test fill Section 7 0 provides the requirements of the post-construction testing and the report to be generated at the conclusion of the test fill construction and post-construction laboratory testing Section 7 0 also provides a discussion of the correlation between the measured hydraulic conductivity of large diameter undisturbed (block) samples and that of field-scale hydraulic conductivity measurements Section 8 0 provides a list of acronyms, and Section 9 0 is a bibliography

2.0 REFERENCED DOCUMENTS

EPA guidance documents entitled "Quality Assurance and Quality Control for Waste Containment Facilities" (EPA, 1993) and "Requirements for Hazardous Waste Landfill Design, Construction, and Closure" (EPA, 1989) discuss test fill design and construction and were used to prepare this work plan Other older EPA guidance documents discuss test fill construction and the contents of these were also considered in preparing this work plan. However, the two EPA documents referenced above, the published information these EPA documents referenced, and other recently published documents were used as the primary references in preparing this work plan References used to compile this work plan are given in the bibliography in Section 9 0 Copies of the referenced documents will be made available for review upon request

3.0 BORROW AREA EVALUATION AND SELECTION

In January 1995, the Army published the Borrow Study Report This report evaluated potential CCL material borrow areas at RMA and defined four areas that, based on geotechnical property data from each of the areas, contained potentially acceptable CCL material in substantial volumes The four areas identified in the Borrow Study Report are shown on Figure I1 and are described below

Area 1 Area 1 is divided into two subareas located immediately north of the landfill CAMU boundary in the southern portion of Section 24 Area 1 contains approximately 1 2 million cubic yards of potential CCL material

Area 2 Area 2 is divided into two triangle-shaped subareas One of the subareas is located in the extreme southeast corner of Section 25 and the other subarea is located in the extreme northeast corner of Section 36 Area 2 contains approximately 800,000 cubic yards of potential CCL material

Area 3. Area 3 is a larger area encompassing the central portion of Section 29 This area is located within the Bald Eagle Management Area (BEMA) Area 3 contains approximately 5 5 million cubic yards of potential CCL material

Area 4· Area 4 is located immediately north of Area 3 in Section 20 Area 4 is also located within BEMA Area 4 contains approximately 5 0 million cubic yards of potential CCL material

As part of this test fill program, a fifth area (Area 5) will be evaluated for inclusion as a potential CCL borrow area The limits of Area 5 have been initially set as the limits of the landfill CAMU boundary The subsurface soil located within the landfill CAMU boundary and within 30 feet below ground surface (bgs) contains roughly 3 5 million cubic yards or more of material meeting the same geotechnical target criteria as used for determination of Areas 1 through 4 The majority of this volume is located within the central and eastern portions of the landfill CAMU area

Once the final areal extent and depth of excavation of the individual landfill cells within the landfill area have been developed, Area 5 will be reduced to include the soil located within the general excavation footprint of the individual landfill cells that meets the target criteria given in Table I1 The Army does not anticipate excavating borrow soil from other areas within the landfill boundary Utilizing Area 5 borrow soil will potentially allow the Army the flexibility to use excavated material from the landfill cells to construct CCLs Utilizing clayey soil excavated from the landfill cells as

CCL material will help the Army meet U S Fish and Wildlife Service's (FWS's) goal of minimizing the area disturbed for borrow soil excavation.

The geotechnical property target criteria for low-permeability soil in Area 5 is the same as used in the Borrow Study Report The Area 5 target criteria is given in Table I1 Table I2 summarizes the geotechnical properties of borehole samples in Area 5 that meet the target criteria

Once Area 5 has been reduced to include only clayey soil that will be excavated as part of cell construction, an evaluation will be made of the volume of CCL material needed for construction and the volume of potential CCL material available from excavation. If the volume required for cell construction is greater than the volume available from cell excavation, Test Fill 3 will likely be constructed using material from either Area 1 or Area 2 If the volume required for construction is less than the volume available from excavation, Test Fill 3 will likely be constructed using material from Area 5

Areas 1 through 5 are all located within two miles of each other Due to their proximity, Areas 1 through 5 will be evaluated for consistency of geotechnical index properties as part of this test fill program Section 2 4 4 1 of Chapter 2, Compacted Soil Liners in the EPA Technical Guidance Document entitled, "Quality Assurance and Quality Control for Waste Containment Facilities (EPA, 1993), states that relatively homogeneous materials produce similar proctor value results and that

> "As an approximate guide, a relatively homogenous borrow soil would be considered a material in which W_{OPT} (optimum moisture) does not vary by more than ± 3 percentage points and $\gamma_{d,max}$ (maximum dry density) does not vary by more than $\pm 0\ 8$ KN/ft^3 (5 pcf) "

Using this guidance as a basis, the geotechnical property data (i e , proctor values, percent fines, Atterburg limits) for material meeting the geotechnical property target criteria in Areas 1 through 5 will be tabulated and analyzed Once this is completed, proposed criteria for selecting which borrow areas are significantly different and which borrow areas are sufficiently similar will be developed

This criteria will then be applied to Areas 1 through 5 and a preliminary selection made of the areas that are significantly different and the areas that are sufficiently similar The proposed criteria, proposed consistency determination of Areas 1 through 5, and the supporting data will be submitted to CDPHE for review

The required volume of CCL material needed to construct and close all of the landfill cell(s) is not known as of February, 1996 If the double-lined cells are assumed to cover 60 acres and use 6 feet of CCL in the base liners, if the triple-lined cells are assumed to cover 40 acres and use 9 feet of CCL in the base liners, and if all the cells use 2 feet of CCL in their covers, approximately 1 5 million cubic yards of CCL material will be required Of the five borrow areas, only Areas 3 and 4 contain the required volume The FWS has requested in working sessions that Areas 3 and 4 be avoided to the extent possible. Therefore, designation of one of the potential borrow areas as the sole source of all CCL material may not be feasible However, Areas 1, 2, and 5 may contain sufficient volume to construct the base liner CCLs or the cover CCL of individual cells If the consistency evaluation described above does not result in any of the areas being considered as sufficiently similar, the need to construct additional test fills will be further evaluated

4.0 PRECONSTRUCTION SAMPLING AND LABORATORY TESTING

A preconstruction sampling and laboratory testing program will be completed prior to the test fill construction and after selection of the Test Fill 3 borrow area If Area 5 is used for Test Fill 3, further sampling and testing of the clay soils in this area will be performed as part of the work described in the Work Plan for the Hydrogeologic and Geotechnical Program (Field Work Plan) (HLA, 1995c) Sampling will be performed over the area expected to be disturbed for Test Fill 3 borrow soil This area will be approximately 100 feet by 200 feet Approximately ten samples will be obtained from the near-surface of this area at evenly distributed locations

4.1 Preconstruction Testing

After the near-surface clay samples are obtained, laboratory testing will be performed following the general methodology set forth by Daniel (1990b) and Trast (1993) Index tests (Atterberg limits and particle size analysis) will be performed to evaluate the clay soils for suitability as CCL material A minimum of 10 index tests on the Test Fill 3 borrow soil will be initially performed Additional index tests will be performed on samples obtained during construction of Test Fill 3 (discussed in Section 6 0)

The average of the index test results must meet the requirements of Table I1 The minimum index properties for the Test Fill 3 borrow soil are as follows

Property	Test Method	Specification
USCS classification	ASTM D2487	SC, CL, or CH
Percent fines	ASTM D422	≥ 30 percent
Liquid Limit	ASTM D4318	≥ 30
Plasticity Index	ASTM D4318	≥ 11

In addition to the properties shown above, the final Work Plan may include "maximum particle size" as a criteria However, the evaluation for inclusion of "maximum particle size" as an index property will consider that

- Oversized materials are more critical for the top lift of a soil liner, which is the lower component of a composite liner
- Observation by CQA personnel is a very effective way to verify that oversized materials have been removed from the top lifts

The USCS classification specification is the same specification as used for Test Fills 1 and 2 The other specifications were not included in the Test Fills 1 and 2 specifications The Test Fill 1 and 2 specifications are included are included in Appendix R (Landfill FS Report)

When the index testing is complete, the relationship between moisture, density, and hydraulic conductivity of the clay will be established for soil meeting the minimum index properties The establishment between the moisture, density, and hydraulic conductivity of the borrow soil will follow the procedure set forth by Benson (1993) Standard Proctor (ASTM D698), modified Proctor (ASTM D1557), and reduced Proctor tests will be performed on a composite sample of the individual samples The reduced Proctor test procedure will follow the same procedure as for a standard Proctor test with the exception that 15 blows per lift will be used instead of the 25 blows per lift required by ASTM D698

The results of the three composite Proctor tests will be plotted on a moisture content versus dry density graph along with the zero air voids curve The optimum moisture content for each Proctor test will then be determined, and a "line of optimums" will be created by connecting the three optimum moisture contents Benson's research has shown that a hydraulic conductivity of 1×10^{7} cm/s or less will nearly always be achieved when samples are moisture conditioned and compacted such that a plot of moisture content and density will fall between the line of optimums and the zero air voids curve This area will define the Potential Acceptable Zone (PAZ) A typical moisture/density graph showing a plot of the three Proctor tests, the line of optimums, and the PAZ is shown in Figure I3(a)

The PAZ will be verified in the laboratory by remolding hydraulic conductivity samples (5 to 10 samples) to a range of moisture contents and dry densities within the PAZ The upper boundary of the PAZ will be initially set as a vertical line located at the modified Proctor optimum moisture content The lower boundary of the PAZ will be initially set as a horizontal line located at 100 percent of the reduced Proctor maximum dry density Figure I3(b) shows a typical PAZ and the approximate sample moisture contents and densities for remolded hydraulic conductivity testing

4.2 Data Interpretation

The results of the remolded hydraulic conductivity testing will then be plotted on similar moisture/density graph with an open circle symbol for those samples with a hydraulic conductivity of greater than 1×10^{7} cm/s and a closed circle symbol for those samples with a hydraulic conductivity of equal to or less than 1×10^{-7} cm/s The Acceptable Zone (AZ) will then be defined by reducing the PAZ to include only the range of moisture content/dry density that results in passing hydraulic conductivity The AZ will in no case extend to the left of the line of optimums This is shown in Figure I3(c)

After the AZ of moisture and density is established based on the laboratory hydraulic conductivity test results the limits of the AZ may be further modified depending on other factors required by the preliminary CAMU design One such factor would be that the lower boundary may be raised based on the minimum required shear strength requirements for slope stability and bearing capacity This may be necessary because a CCL compacted near the lower boundary of the AZ will have less shear strength (due to lower density and higher moisture content) than a CCL compacted near the upper boundary of the AZ

When the final AZ is defined based on the preconstruction laboratory testing program and the preliminary CAMU design, the AZ will become the "Placement Window" (PW) for test fill construction. The PW will then be divided into two approximately equal zones These zones will be identified as the Upper Placement Window (UPW) and the Lower Placement Window (LPW)

The UPW and LPW will be used as target zones during the test fill construction to establish the relationship between number of compactor passes, moisture, density, and hydraulic conductivity Figure I3(d) shows a typical PW and the UPW and LPW Section 5 0, Construction Quality Assurance Procedures, explains in detail the CQA monitoring, testing, and documentation requirements for each lane and each lift of the test fill

5.0 TEST FILL CONSTRUCTION PROCEDURES

The test fill will be constructed to the dimensions shown in Figure I2 CQA procedures to be implemented by the Engineer are given in Section 6 0 The construction procedures and specifications to be adhered to by the Contractor are given below The Engineer will be responsible for the Contractor's adherence to requirements given below The Test Fill 3 Contractor will be working under the direction of the Engineer

The intent of this test fill program is to furnish the data that will provide the technical basis to establish the detailed construction specifications for full-scale CCL construction. The specifications will be based on the equipment and procedures used to construct Test Fill 3, as opposed to writing detailed construction specifications for full-scale CCL construction and then constructing a test fill to verify the adequacy of the specifications The specifications given below detail the minimum requirements for the test fill construction, but yet allow some flexibility for some experimentation with different procedures and equipment in the construction of the lower two lifts

5.1 Site Preparation

The Test Fill 3 location is shown in Figure I1 The test fill subgrade will be constructed over an existing slope located approximately 100 feet east of Test Fills 1 and 2 The footprint of the test fill, processing area, and borrow area will be cleared and grubbed of all vegetation, debris, or other deleterious material, as directed by the Engineer, and disposed of at a location designated by the Army

5.2 Grading and Structural Fill Placement

Structural fill will be placed as necessary to construct a smooth, uniform surface for the test fill as shown in Figure I2 and to the grades selected during the CAMU design. The material for the structural fill will be obtained from the cleared and grubbed surface of the borrow area (Figure I1) Structural fill will consist of soil classified as SC, CL, or CH using the USCS. Structural fill will be free of vegetation and debris and will contain a maximum particle size of 4 inches The material will

be placed in maximum 10-inch loose lifts and compacted to 95 percent of the maximum standard Proctor density (ASTM D698) at a moisture content ±3 percent of optimum Monitoring, testing, and documentation of the structural fill placement will be performed by the Engineer After the subgrade is constructed to the dimensions shown in Figure I2, the subgrade will be proof rolled to achieve a smooth, uniform subgrade surface free of soft zones, irregularities, and loose earth The Engineer will observe the proof rolling, and any unacceptable areas of the subgrade will be repaired to the satisfaction of the Engineer

5.3 Soil Liner Conditioning

Soil to be used for the test fill construction will be obtained as directed by the Engineer from the borrow area and placed in the processing area The soil will contain no more than a negligible amount of organic or other deleterious materials and will contain no more than 5 percent gypsum or calcium carbonate Gypsum concretion, nodules, or other deleterious material will be less than 1 inch in largest diameter The soil will be processed and moisture conditioned to a maximum clod size of 2 inches and to the specified moisture contents given in Table I3 Whenever more than 3 percent moisture is added to the soil, a minimum hydration time of 24 hours will be required prior to compaction. Monitoring, testing, and documentation of the conditioning by the Engineer will be as outlined in Section 5 0 A water truck equipped with a spray bar for even distribution of water over a given area will be used for adding moisture to the soil The equipment listed below will be evaluated to raise the initial moisture conditioning up to approximately the optimum moisture content

- A Rome disc and tractor
- A Caterpillar SS250 soil stabilizer (pulvamixer) or equivalent

A Caterpillar SS250 soil stabilizer (pulvamixer) or equivalent will be used for final moisture conditioning (above optimum moisture content) A minimum two passes of the stabilizer will be made during final moisture conditioning

5.4 Soil Liner Placement and Compaction

The soil liner material will be placed and compacted using the following procedures

1 The processed soil liner will be removed from the processing area using scrapers or other hauling equipment approved by the Engineer

2 The processed soil liner will be placed directly on the base section of the test fill and initially spread to a nominal loose lift thickness of approximately 8 inches The first soil liner lift will be placed to a nominal loose lift thickness of 10 inches to minimize subgrade contamination A bulldozer, approved by the Engineer, will be used to spread the loose lift In no case will the loose lift thickness exceed the length of the penetrating foot of the compactor

3 The placed loose lift will be compacted by a Caterpillar 825c compactor The compactor will make the minimum number of passes on each lift and in each lane as directed by the Engineer and described in Section 6 6 Each compacted lift will be a nominal 6 inches or less The loose lift thickness may be adjusted by the Engineer after the placement of the second or third lift based on layer bonding observations.

4 Prior to placement of subsequent lifts, the preceding lift will be scarified using either a sheepsfoot compactor, the tracks of a bulldozer, or other method approved by the Engineer

5 A total of seven compacted lifts of the soil liner will be placed to achieve 6 compacted lifts After completion of Lift 7, the test fill surface will be graded to a minimum thickness of 3 feet

6 The finish grade surface of the test fill will be rolled smooth using a smooth-drum roller approved by the Engineer

Numerous testing and inspection activities will occur during and between lift placement These activities are described in detail in Section 6 0 The Contractor will spray water on the test fill surface and surrounding areas as directed by the Engineer to prevent fugitive dust emissions and soil liner desiccation cracking

5.5 Soil Liner Surface Protection

After the test fill construction and CQA sampling and testing activities are completed, the Contractor will immediately cover the test fill surface with a separator geomembrane or geotextile approved by the Engineer The Contractor will then cover the separator geomembrane or geotextile with a minimum soil thickness of 4 inches This surface protection will remain in place until the test fill results have been received and the test results approved by CDPHE

5.6 Drainage Control and Revegetation

The Contractor will regrade and revegetate all areas disturbed by the test fill construction as directed by the Engineer Areas to be regraded and revegetated include, but are not limited to, the borrow area, haul roads, and the processing area Regrading will consist of grading all areas to be relatively free-draining All regrading will be done as directed by the Engineer Revegetation will be done in accordance with the procedures given below

- The topsoil will require grading, raking, and rolling with a roller weighing not more than 100 pounds per linear foot and not less than 25 pounds per linear foot
- The seed will meet the requirements of the U S Fish and Wildlife Service
- Seeds will be sown by dividing the seed equally and sowing at 90 degree angles to produce a uniform broadcast.
- The seed will require raking into the ground and rolling with a roller, or other technique approved by the Engineer
- Seeding will not be allowed on rain compacted surfaces
- Seeding will not be allowed when the wind velocity exceeds 6 miles per hour
- No fertilizer will be applied
- Native grass hay mulch will be provided by the Army
- Mulch will be applied immediately after seeding
- Mulch will be applied at a rate of 2 tons/acre
- The mulch will be crimped immediately after application to prevent it from blowing away
- The mulch must be placed loosely enough to allow some sunlight to penetrate and air to circulate, but thick enough to shade the ground, conserve soil moisture, and minimize erosion

6.0 CONSTRUCTION QUALITY ASSURANCE PROCEDURES

CQA procedures to be implemented during construction of the test fill will be carried out by the Engineer The Engineer will be responsible for the surveying, testing, observation, and documentation requirements set forth below The Engineer will subcontract survey activities as necessary to properly lay out and document the test fill construction

This section presents the conceptual CQA requirements for the Test Fill 3 construction. After completion of the test fill program, detailed CQA requirements for full-scale CCL construction will be prepared based on the observations and test results obtained during completion of the test fill program

Testing frequency for index tests (Atterberg limits and particle-size analysis) for borrow material used to construct Test Fill 3 will be developed following completion of borrow area evaluation presented in Section 3 0 It is anticipated that the index testing frequency selected for the test fill will be representative of the frequency contemplated for full-scale CCL construction

6.1 Site Preparation

The Engineer will be responsible for layout of the borrow area, Test Fill 3, the processing area, and any associated haul roads The Engineer will monitor, direct, and document the Contractor's site preparation activities set forth in Section 5 1 to verify compliance with this Test Fill Work Plan.

6.2 Grading and Structural Fill Placement

The Engineer will direct the Contractor's removal of structural fill borrow soil The Engineer will observe, test, and document placing, compacting, proof rolling, and grading the structural fill to verify that the specifications given in Section 5 2 are met, that the test fill subgrade is shaped to the dimensions shown in Figure I2, and that the base and sideslope subgrade sections are graded to the slopes provided in the preliminary CAMU design The Engineer will survey the surface of the test fills subgrade to verify compliance with the requirements of this Test Fill Work Plan

6.3 Soil Liner Excavation and Testing

The Engineer will lay out and direct the Contractor's excavation of the borrow area and will perform index testing at a rate selected following the findings of the borrow area evaluation (see Section 3 0) The index test results must meet the minimum requirements given in Section 4 1 A minimum of two in situ moisture content tests (ASTM D4643 and/or D2216) per day will be performed on material excavated from the borrow area Index testing will consist of the following.

- Particle size analysis, including hydrometer testing (ASTM D422 and D1140)
- Atterberg limits (ASTM D4318)
- Soils classification (ASTM 2487)

In addition to the index testing, it is anticipated that the Proctor tests listed below will be performed at a rate that will be representative of the frequency contemplated for full-scale CCL construction.

- Modified Proctor (ASTM D1557)
- Standard Proctor (ASTM D698)
- Reduced Proctor (ASTM D698 with 15 blows per lift)

The Engineer will observe and document the borrow area excavation to verify that only clay soils are excavated The Engineer will observe and document that calcareous lenses and other deleterious materials within the clay zones are not excavated and placed in the processing areas. At the conclusion of excavation activities, the Engineer will verify that the Contractor regrades the borrow area to be relatively free draining and also that the Contractor revegetates the borrow area in accordance with the specifications given in Section 5 6

6.4 Soil Liner Conditioning

The Contractor will excavate the soil liner material from the borrow area and place it in the processing area for conditioning The Engineer will direct and document the Contractor's conditioning of soil liner material to verify that the equipment and procedures set forth in Section 5 3 are met The

Engineer will observe and document the processing and moisture conditioning of the soil liner material to evaluate the following

- The amount and distribution (evenness) of water applied by the water truck with spray bar The ability of the water truck to travel over the moistured clay will also be evaluated
- The workability of the clay within the process area at various moisture contents
- The number of passes, range of moisture contents, the distribution (evenness) of moisture content, and the ranges of clod sizes that the Rome disc can effectively condition prior to conditioning with the soil stabilizer The Engineer will observe, test, and document the initial and final moisture contents of the soil liner material and the amount of moisture that can be evenly and productively added to the soil liner material with the Rome disc
- The number of passes, range of moisture contents, the distribution (evenness) of moisture content, and the range of clod sizes that the Caterpillar SS250 soil stabilizer or equivalent can effectively condition Experimentation with the soil stabilizer may be performed to evaluate whether this apparatus can be productively and effectively used for initial moisture conditioning The Engineer will observe, test, and document the initial and final moisture contents of the soil liner material and the amount of moisture that can be evenly and productively added to the soil liner material with the soil stabilizer

6.5 Soil Liner Lift Placement

After conditioning, the Contractor will haul the soil liner material from the processing area and place it over the base section of the test fill Lift 1 will be placed in a 10 inch loose lift thickness This will be done to avoid subgrade mixing with the first lift during compaction All subsequent lifts will be placed in 8-inch maximum loose lifts The Engineer will observe and document the Contractor's placement of soil liner material to verify that the material is placed over the entire test fill area at the specified lift thickness

Due to the heavily textured nature of lifts compacted with a sheepsfoot compactor, it will be difficult to physically measure the loose and compacted lift thickness The Engineer will visually monitor the lift thicknesses and will take physical measurements where possible. Experimentation may be done on Lifts 2 and 3 with various thicknesses to ascertain the most effective loose lift thickness

6.6 Soil Liner Compaction and Testing

Soil liner compaction and testing activities will performed in accordance with Table I3 and in the test fill lanes shown in Figure I2 Table I3 gives the target number of compactor passes for each lane and each lift of the test fill Table I3 also gives the testing and sampling locations and frequencies for each lane and lift of the test fill Due to the heavily textured nature of sheepsfoot compacted lifts and the 8-inch nominal length of the compactor feet, it will be necessary to test each lift after placement and compaction of the overlying lift. The size of compactor and lift thickness were chosen so that the feet of the compactor will penetrate the underlying lift. Compaction in this manner will result in a kneading action of the overlying lift and compaction of the underlying lift. It also promotes layer bonding between lifts

6.6.1 Number of Compactor Passes

The Engineer will document the number of passes made over each lane of each lift (three lanes per lift) This will be done to establish a correlation between the number of passes and dry density at a specific moisture content range The number of passes shown for each lane of each lift in Table I3 is only a preliminary estimate of the number of passes that will be required The Engineer will test each lane of each lift after the minimum number of passes is made If the test results indicate that the target area of the placement window (UPW for Lifts 1 and 2, LPW for Lifts 3 and 4, or the entire PW for Lifts 5, 6, and 7) is met for that lift, no more passes will be made on that lift If the target density area of the PW is not met, additional passes will be made until the target area is met. If the target moisture content of the PW is not met, the area will be repaired or replaced as discussed in Section 6 6 4

When the minimum number of passes necessary to meet the target area of the PW is defined, additional passes, in increments of two to four, will be made in the next lanes to define the range of the target area that can be met. This will be done to allow the Engineer to evaluate whether soil liner material at various moisture contents can be compacted to within the PW This will also allow hydraulic conductivity samples to be obtained at a variety of locations within the PW

6.6.2 Moisture and Density Testing

The Engineer will perform nuclear moisture/density tests (ASTM D3017 and D2922) at a minimum frequency of six per lift The six test locations will be taken at a frequency of two tests per lane, one on the base section and one on the sideslope section. One sandcone (ASTM D1556) or rubber balloon (ASTM D2167) correlation test will be performed on each lift. The Engineer will perform both oven (ASTM D2216) and microwave (ASTM 4643) moisture content tests at the six test locations when testing both Lifts 1 and 2 This will be done to establish a correlation between nuclear, microwave, and oven-dried moisture contents The Engineer may increase the testing frequencies based on previous test results

6.6.3 Hydraulic Conductivity Sampling and Testing

Hydraulic conductivity sampling will be performed at the locations given in Table I3 Hydraulic conductivity sampling will consist of two types sample sleeves (2 8-inch diameter) and block (12-inch diameter) sampling

Sample sleeve sampling will be performed at nuclear test locations after completion of the nuclear test. The samples will be obtained by pressing the tube into the test location using a hydraulic jack and back pressure from a piece of heavy equipment (i e , the blade of a bulldozer or compactor) The samples will be extracted by digging the soil liner away from the sides of the tube using hand labor Upon removal, the samples will be immediately sealed to prevent moisture loss After sealing, the samples will be labeled and prepared for archiving or shipment to the laboratory for hydraulic conductivity testing

Section 2 5 1 of "Quality Assurance and Quality Control for Waste Containment Facilities" (EPA, 1993) states that one of the objectives of a test fill is, "To verify that the materials and methods of construction will produce a compacted soil liner that meets the hydraulic conductivity objectives defined for a project, hydraulic conductivity should be measured with techniques that will character-

ize the large-scale hydraulic conductivity and identify any construction defects that cannot be observed with small-scale laboratory hydraulic conductivity tests "

The SDRI and TSBP field-scale test methods were developed to measure the large-scale hydraulic conductivity of low-permeability soil liners Of these field-scale test methods, the SDRI has become the most widely used method primarily due to the large area tested (up to 25 square feet) compared to the TSBP method (approximately 10 inches) However, the calculated hydraulic conductivity obtained from an SDRI is only an approximation of the true hydraulic conductivity Errors can easily be introduced into SDRI calculations due to the effects of soil (matric) suction, soil swell, and inaccurate wetting front measurements (Benson, 1994)

The paragraph above lists one reason why the large-scale block samples were chosen to measure the final hydraulic conductivity of the test fill Another reason for using block testing instead of SDRI testing is that SDRIs (and TSBPs) cannot be practically performed on sideslopes when the soil liner is constructed in lifts parallel to the sideslope A significant amount of research has been performed on block-scale testing, particularly the minimum block size (diameter) necessary to accurately reflect field-scale hydraulic conductivity This research has indicated that a block sample diameter of approximately 12 inches can accurately reflect field-scale hydraulic conductivity (Benson, 1993).

Block test samples will be obtained by placing an approximately 12-inch-high by 14-inch-diameter sampling ring with a beveled cutting edge over the area to be sampled A trench around the outside of the sampling ring will then be excavated by hand to a depth of approximately 16 inches The excess soil between the trench and the inside of the sampling ring will then be trimmed off using trowels and knives until the sampling ring can slide easily downward around the test sample This process will continue until 2 or more inches of the test sample are above the top of the sampling ring

The portion of the block test sample protruding from the top of the sampling ring will then be trimmed flush with the sampling ring The top of the sample will then be sealed with plastic wrap (such as Visqueen) and duct tape to prevent moisture loss The base of the sample will be freed from the test fill using a wire saw or flat-headed shovels The sample will then be turned over carefully and the bottom trimmed and sealed in the same manner as the top The sample will then be labeled, sealed an additional time, and placed on a shipping palette for transportation to the testing laboratory After removal of the block sample, the Engineer observe the resultant hole in the test fill and document the layer bonding between lifts

Hydraulic conductivity testing for both the sampling tube and the block samples will be performed in accordance with ASTM D5084

6.6.4 Other CQA Requirements

The Engineer will perform and document other CQA activities during the test fill construction These activities will include repairing test holes, evaluating loose and compacted lift thickness, evaluating layer bonding between lifts, evaluating the effectiveness of repair or removal and replacement of soil liner areas failing to meet the placement specifications, evaluating the ability of the heavy equipment to travel over the process area and test fill and to place and compact soil liner on the sideslopes and documenting all aspects of the test fill construction.

Nuclear probe holes will be repaired by compacting granular bentonite into the bottom half of the probe hole using the driving pin used to create the probe holes and then hydrating the bentonite with water The upper half of the probe hole will be backfilled and hydrated in the same manner as the bottom half Sample sleeve and sandcone or rubber balloon test locations will be repaired by compacting processed clay and/or bentonite into the test locations using a sledge hammer or tamping rod Sand used in sandcone tests will be removed prior to backfilling Block samples will be obtained after the test fill construction is completed at the locations given in Table I3 These

locations will be filled with loose soil and compacted lightly using available equipment These observations will be documented by the Engineer

As stated previously, the evaluation of loose and compacted lifts will be difficult to physically measure The Engineer will visually monitor loose lift thickness and will obtain physical measurements where possible Compacted lift thickness will be measured by using a rod and level and taking numerous measurements over a cross-sectional area before a lift is placed and after that lift is compacted The nominal compacted lift thickness will then be calculated by using the average vertical difference between the measurements These observations will be documented by the Engineer

Layer bonding will be evaluated when excavating nuclear and block test locations A dozer or compactor blade will be used to trim a test pad for nuclear testing The depth the test pad is trimmed to be at or near the bottom of the sheepsfoot penetrations This depth is typically at the interface between lifts One indicator of less than desirable layer bonding is whether the top lift readily peels off when trimming the test locations Should this occur, the loose lift of the next lift placed will be lessened until no peeling of the overlying areas is observed Layer bonding will also be evaluated during or at the end of construction by trimming a vertical face along a portion or portions of the edge of the test fill The vertical face will then be inspected for stratification between lifts Effective layer bonding will be evident if no visual delineation can be observed between lifts These observations will be documented by the Engineer

The evaluation of repair or replacement of defective areas will be based on professional judgment If it is determined that the soil is excessively wet or dry during initial lift placements, attempts will be made to repair the soil liner in place If the soil is too wet, attempts will be made to dry it in place by mixing the soil using the disc and/or soil stabilizer and letting it stand If this is found to be time consuming or ineffective, the lift will be removed and replaced If the soil is too dry, attempts will

be made to add moisture by adding water and mixing the soil in place using the disc and/or soil stabilizer If this is found to be time consuming or too difficult, the lift will be removed and replaced The Engineer will document these activities

The Engineer will observe the ability of the heavy equipment used to construct the test fill to travel over the loose wet clay in the process and test fill areas Certain types of equipment may be more effective working within the process area than others The overall productivity of the equipment used in the process area will be evaluated and documented The Engineer will also evaluate and document the ability of equipment to work on the sideslope section of the test fill and the efficiency of placing and compacting soil liner material on the sideslopes

Comprehensive documentation will be performed on a daily basis by the Engineer The documentation will be both written and photographic Video tapes of various aspects of construction may also be made The daily written documentation will consist of documenting all testing and observation requirements given in this work plan including weather conditions, relevant observations, equipment in use, personnel onsite, and any pertinent conversations

7.0 POST-CONSTRUCTION TESTING AND SUMMARY REPORT

Post-construction testing will consist of completing the laboratory index and hydraulic conductivity testing on samples obtained during the test fill construction. When these data are complete, the hydraulic conductivity results (both sleeves and block) will be plotted on a moisture/density graph showing the PW derived during the pre-construction testing and preliminary CAMU design The PW will then be modified as necessary to reflect the actual PW Should conflicting or questionable results be obtained, additional laboratory testing will be performed as necessary to confirm the test fill results Although additional sampling is not anticipated, additional samples may be obtained by removing a portion of the protective soil and separator geomembrane or geotextile and obtaining samples as needed

The Engineer will prepare a summary report of the test fill construction and all laboratory testing When data are assimilated and evaluated, recommended specifications for full-scale construction of the CAMU soil liners will be given at the conclusion of the summary report The summary report will include the following

- The results of the borrow area evaluation and selection
- The ability of the selected borrow area and areas that have material with similar properties to meet the total landfill borrow needs
- A summary of the pre-construction testing program, including all test results
- A summary of the test fill construction, including the materials, equipment, and procedures used, the construction schedule, personnel involved, and pertinent weather data
- A summary of the test fill CQA testing and observations, including all test results and daily field reports
- An assessment of the equipment and procedures used to construct the test fill and recommendations for full-scale construction equipment and procedures
- A summary of the post-construction testing, including test results
- Recommendations for technical specifications for full-scale soil liner construction
- An identification of any test fill data needs that may have to be addressed

8.0 ACRONYMS

Army	U S Department of the Army
ASTM	American Society for Testing and Materials
AZ	Acceptable zone
BEMA	Bald Eagle Management Area
bgs	Below ground surface
Borrow Study Report	Final Feasibility Study Soils Support Program Report
CAMU	Corrective Action Management Unit
CDD	CAMU Design Document
CDPHE	Colorado Department of Public Health and Environment
CHWMA	Colorado Hazardous Waste Management Act
cm/s	Centimeter per second
Contractor	Earthwork contractor
CQA	Construction Quality Assurance
Engineer	CQA engineer
EPA	U S Environmental Protection Agency
Field Work Plan	Work Plan for the Hydrogeologic and Geotechnical Program
FS	Feasibility Study
FWS	U S Fish and Wildlife Service
HLA	Harding Lawson Associates
Landfill FS Report	Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program
LPW	Lower placement window
PAZ	Potential acceptable zone
PMRMA	Program Manager for Rocky Mountain Arsenal
PW	Placement window
RMA	Rocky Mountain Arsenal

SDRI	Sealed double-ring infiltrometer
State	State of Colorado
TSBP	Two-stage borehole permeameters
UPW	Upper placement window

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Table I1: Geotechnical Property Target Criteria

Test	Low Permeability Soil Target Criteria
Atterberg Limits	
Liquid limit (LL)	≥ 35 percent
Plasticity index (PI)	≥ 15 percent
Grain-size distribution	≥ 50 percent passing No 200 sieve
Remolded permeability	≤ 1 x 10^{-7} cm/s

cm/s	centimeters per second
≥	greater than or equal to
≤	less than or equal to

Table I2: Borrow Area 5, Geotechnical Data Summary for Soil Meeting the Geotechnical Target Criteria

Boring No	Sample Depth (feet)	USCS Soil Classification	Passing Sieve No 200 (percent)	In Situ Moisture Content (percent)	Liquid Limit (percent)	Plasicity Index (percent)	Permeability at 90 Percent (cm/s)	Permeability at 95 Percent (cm/s)	Optimum Moisture (percent)	Maximum Dry Density (pcf)
ASB11594	4	CL	69	11 3	40	22				
ASB11694	28	CH	52	16	54	36				
ASB11894	4	CL	83	10 4	44	23				
ASB11894	8	CL	61	9 4	43	24	6E-08	4E-08	14	112 4
ASB11894	12	CH	54	12 8	51	31				
ASB11894	16	CH	59	17 7	57	31				
ASB11894	20	CL	72	17 6	49	31				
ASB11894	24	CL	85	18	48	31				
ASB11994	4	CL	56	8 2	41	22				
ASB11994	8	CL	58	7 7	42	24	7E-08	1E-08	15 2	109 6
ASB12094	8	CL	57	13 7	47	27	3E-08	1E-07	15 1	111 3
ASB12094	12	CL	59	12 9	44	24				
ASB12494	4	CL	61	9 3	41	19	3E-08	2E-08	17 8	105 9
ASB12594	4	CL	78	9 5	39	20				
ASB12594	16	CL	54	7 5	38	21				
ASB12594	20	CL	70	11 1	42	24				
ASB12594	24	CH	72	16 7	60	41				
ASB12594	28	CH	77	17 7	76	56				
ASB12794	12	CL	63	12 1	43	22				
ASB12794	16	CH	88	20 6	71	46				
ASB12794	20	CL	56	9 4	35	18				
ASB12794	28	CL	81	9 2	36	18				
ASB13294	16	CL	56	7 1	38	23				
ASB13294	28	CL	80	15 3	45	29				
BRB12994	20	CL	62	9 2	37	22				
BRB13094	24	CL	53	11 2	42	27	2E-07	1E-07	16 4	113.2
BRB13094	28	CH	81	10 4	50	34				
BRB13594	12	CL	51	7 3	35	16	1E-07	1E-07	14 2	114 9
BRB13594	16	CL	51	7 4	37	20				
BRB13594	24	CL	54	9 4	48	31				
BRB13594	28	CL	60	8 3	39	20				
SAB11794	4	CH	56	10 3	57	37				
SAB12194	4	CL	74	10 4	39	19				
SAB12194	8	CL	56	7 8	39	24	8E-08	4E-08	15 3	111 8
SAB12194	20	CL	68	9 5	44	27				
SAB12194	24	CH	89	14	53	35				
SAB12194	28	CH	97	28 6	73	43				
SAB12294	4	CL	71	10	38	17				
SAB12294	8	CL	63	11 2	44	26				
SAB12294	12	CL	53	11 6	48	31				
SAB12294	16	CL	69	12 7	46	30				
SAB12394	4	CL	55	9 6	39	15				
SAB12394	12	CL	67	12 8	49	35				
SAB12394	24	CH	57	22 9	78	47				
SAB12394	28	CH	64	21 3	60	34				
SAB12694	12	CL	59	10 6	37	19				
SAB12694	20	CL	71	11 2	44	27				
SAB12694	24	CL	52	11.2	43	29				
SAB12694	28	CH	53	14 5	52	35				
SAB13194	16	CL	62	8 7	38	21				
SAB13194	20	CL	65	9 4	41	21				

Table I2 (continued)

Boring No	Sample Depth (feet)	USCS Soil Classification	Passing Sieve No. 200 (percent)	In Situ Moisture Content (percent)	Liquid Limit (percent)	Plasicity Index (percent)	Permeability at 90 Percent (cm/s)	Permeability at 95 Percent (cm/s)	Optimum Moisture (percent)	Maximum Dry Density (pcf)
SAB13194	24	CL	68	9 8	38	19				
SAB13194	28	CL	63	10 4	42	22				
SAB13194	30	CL	55	8 3	40	21				
WEB11494	8	CL	62	10 1	41	24				
WEB11494	16	CL	70	14 1	42	24				
WEB11494	20	CL	59	14 5	44	26				
AVERAGE	17	CL	65	12 1	46	27	8E-08	7E-08	15 4	111 3
STDEV	8	N/A	11	4 3	10	8	5E-08	5E-08	1 3	2 9
MAXIMUM	30	CH	97	28 6	78	56	2E-07	1E-07	17 8	114 9
MINIMUM	4	CL	51	7 1	35	15	3E-08	1E-08	14 0	105 9

CH	Inorganic clays of high plasticity
CL	Inorganic clays of low plasticity
cm/s	Centimeters per Second
pcf	Pounds per cubic foot
STDEV	Standard Deviation
USCS	Unified Soils Classification System

Screening Criteria	
USCS Classification	CL or CH
Passing Sieve No 200	> 50 percent
Liquid Limit	> 30 percent
Plasticity Index	> 15 percent
Depth below Surface	< 30 feet

Table I3: Compaction and Testing Criteria for Test Fill 3

Objectives	Lane 1	Lane 2	Lane 3
Place Lift 1 Target UPW 10" loose lift	5 passes Check for subgrade contamination 1 moisture grab sample	10 passes Check for subgrade contamination 1 moisture grab sample	15 passes Check for subgrade contamination 1 moisture grab sample
Place Lift 2 Target UPW Test Lift 1 8" loose lift	5 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	10 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	15 or more passes 2 nuclear moisture/density tests One location on base section and the other on sideslope section
Place Lift 3 Target LPW Test Lift 2 (UPW) 8" loose lift	5 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	10 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	15 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 4 Target LPW Test Lift 3 (LPW) 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 5 Target PW Test Lift 4 (LPW) 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 6 Target PW Test Lift 5 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 7 Target PW Test Lift 6 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Grade to 3 feet minimum Smooth roll surface	2 nuclear tests and 2 Shelby tube samples One test/sample set on base section and the other on sideslope section	2 nuclear tests and 2 Shelby tube samples One test/sample set on base section and the other on sideslope section	2 nuclear tests and 2 Shelby tube samples One test/sample set on base section and the other on sideslope section
Obtain block samples	3 samples with 2 taken from the upper foot and one taken from the middle foot of the test fill	3 samples with 2 taken from the upper foot and one taken from the lower foot of the test fill	3 samples with 2 taken from the upper foot and one taken from the middle foot of the test fill

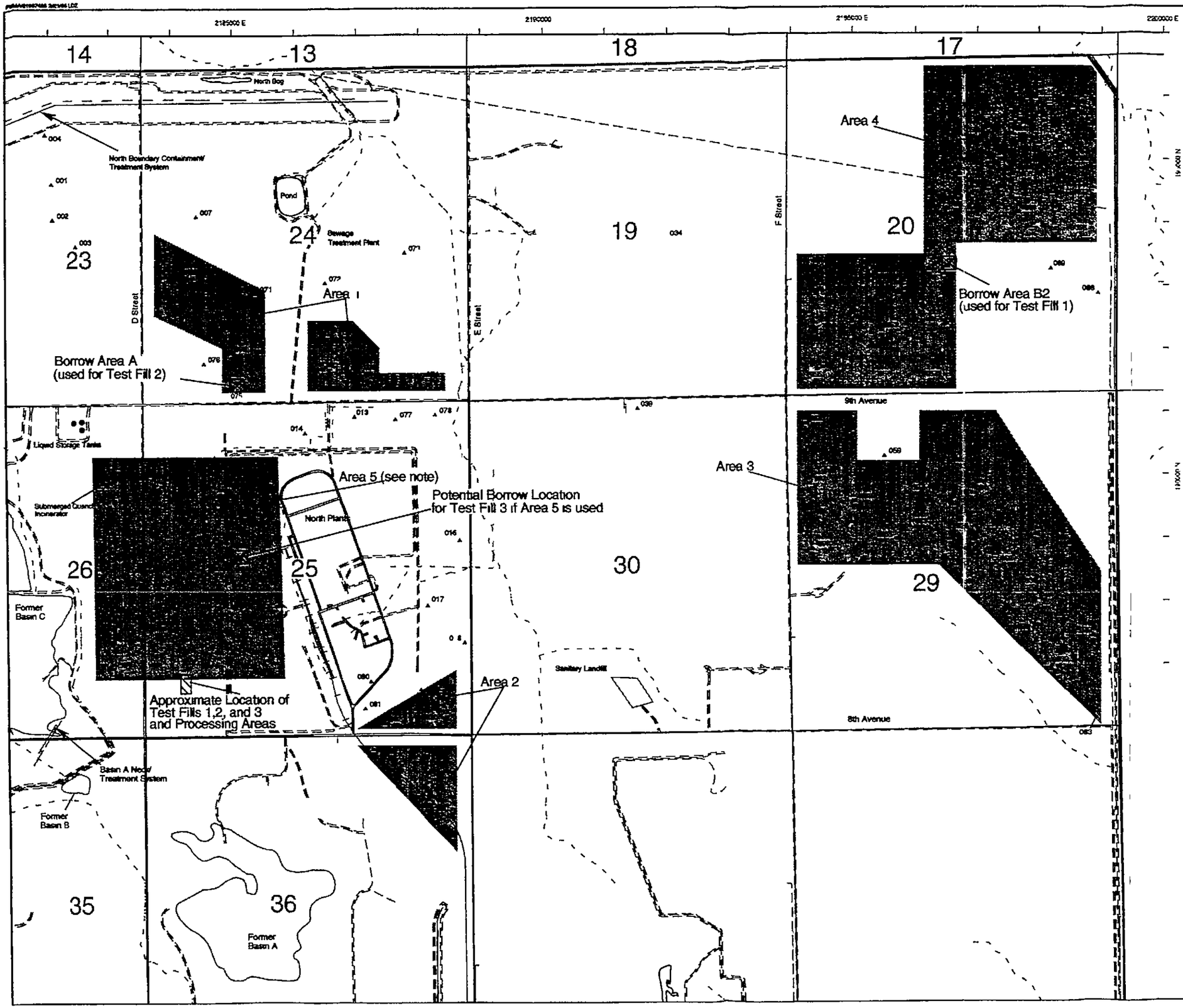
LPW Lower placement window
PW Placement window
UPW Upper placement window

1 Test and sample locations will be selected at random by Engineer in the areas specified
2 Shelby and block samples will be taken perpendicular to the lift placement direction

Table I3 (continued)

3 Not all Shelby tube samples will be tested The Engineer will select a minimum of five for initial testing The remainder will be archived Archived samples may be tested at a later date
4 Shelby tube samples will be taken beneath the nuclear test location (adjacent to probe hole)
5 Block samples will be taken after completion of construction. Block samples located below surface level will be obtained by excavating through the overlying lifts to the required sample depths
6 Microwave and oven moisture content tests will be performed on samples obtained at each nuclear test location when testing Lifts 1 and 2
7 One sandcone or rubber balloon correlation test will be performed on each lift at one of the nuclear test locations
8 Field Test Methods

Nuclear Moisture Content	ASTM D3017	Sandcone Density	ASTM D1556
Nuclear Density	ASTM D2922	Rubber Balloon Density	ASTM D2167
Microwave Moisture Content	ASTM D4643	Oven Moisture Content	ASTM D2216



Explanation

- Soil boring locations
- Borrow areas excavated for construction of test fills
- Low-permeability soil borrow areas
- Railroad
- Ditch or stream
- Paved road
- Unpaved road
- 16 — Section number
- CAMU — Corrective Action Management Unit

Note

Area 5 has been initially set with the same areal configuration as the Landfill CAMU areal configuration Area 5 will be further reduced in size to include only the areas that will be excavated as part of the individual landfill cell construction

N

0 1500

Scale in feet

Prepared for

Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

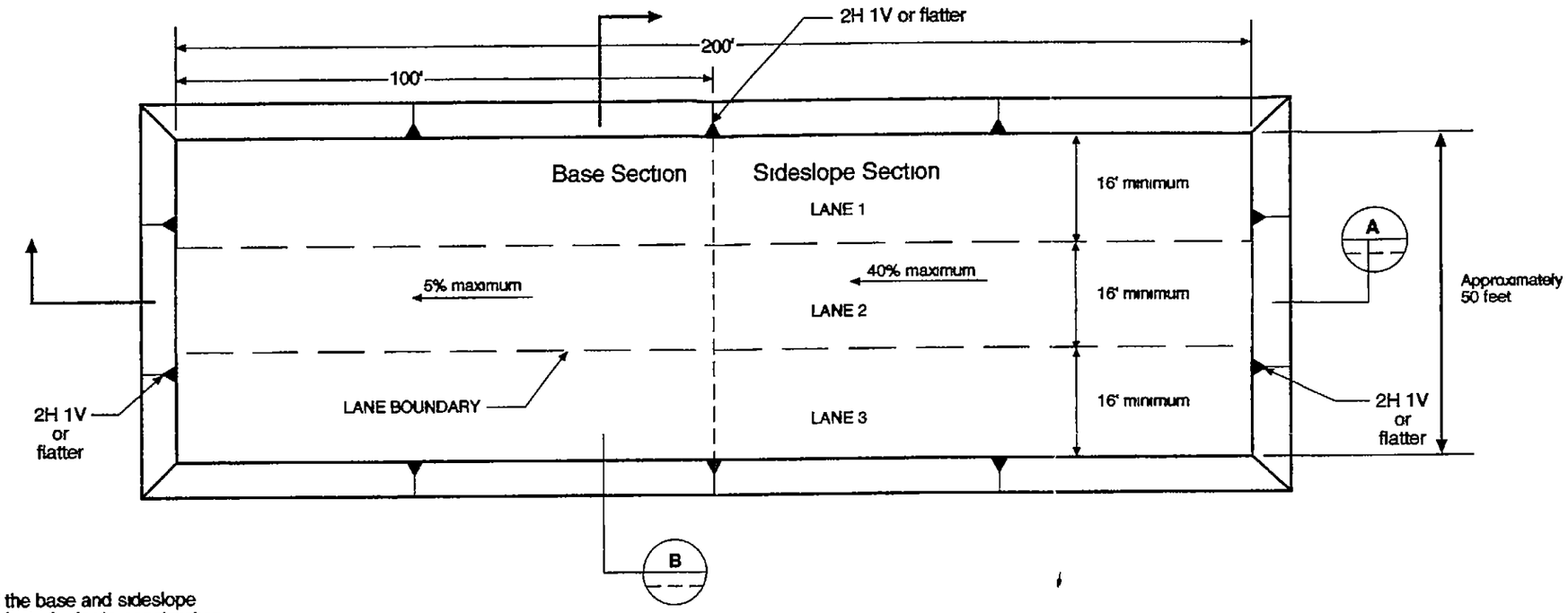
Prepared by

Harding Lawson Associates

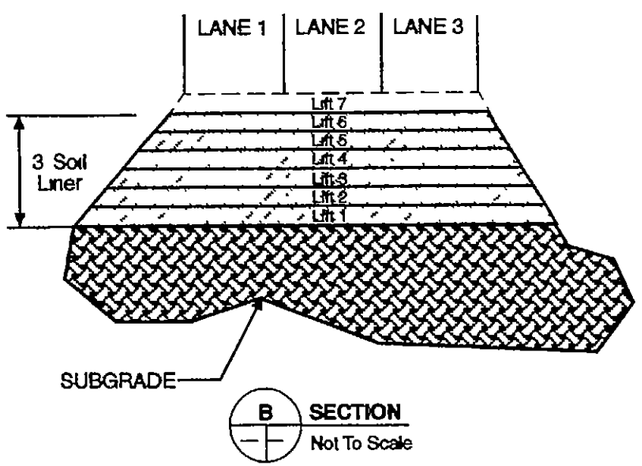
Figure I1

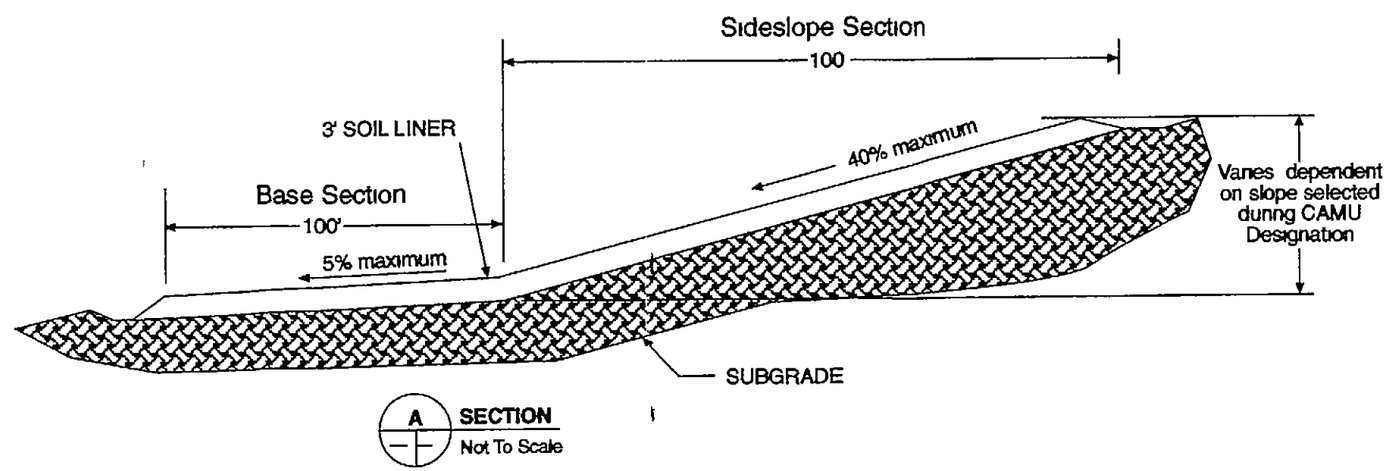
Borrow Area and
Test Fill Location Map

Test Fill 3 Plan View



Notes (1) The slopes of the base and sideslope sections will be selected prior to construction during the CAMU Designation Process.





HLA

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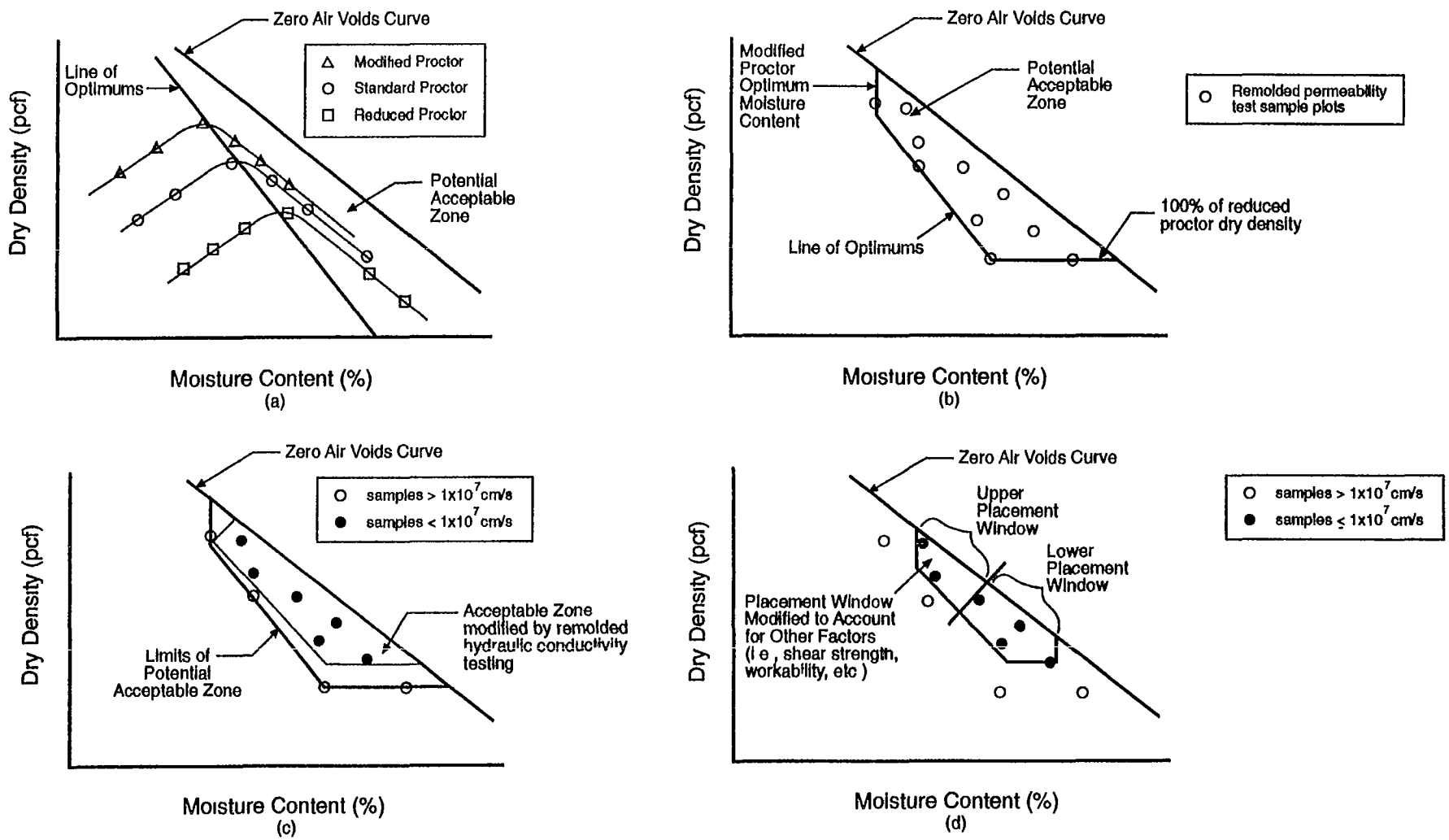
Engineering and Environmental Services

Test Fill 3 Plan View and Cross Sections
Rocky Mountain Arsenal
Commerce City CO

FIGURE 12

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
ECS	21907 705011 1		10/95	

RMA 1263.1 02/12/96 ECS



Harding Lawson Associates
Engineering and Environmental Services

Methodology for Selection of Test Fill 3 Placement Specifications
Rocky Mountain Arsenal
Commerce City, CO

FIGURE **13**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
ECS	21907, 705011 1		10/95	

RMA 1253 01/04/96 ECS

Appendix J

OPERATING RECORD SYSTEM PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 Waste Description, Quantities, and Disposition

3 0 Waste Analyses

4 0 Contingency Plan Implementations

5 0 Inspection Records

6 0 Monitoring, Testing, and Analytical Data

7 0 Records of Corrective Action

8 0 Annual Certification of Waste Minimization

9 0 Record Retention, Availability, and Disposition

10 0 Biennial Reporting Requirements

11 0 Additional Reporting Requirements

12 0 Acronyms

13 0 References