PROGRAM MANAGER
FOR ROCKY MOUNTAIN ARSENAL

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— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

Final Corrective Action Management Unit Designation Document Rocky Mountain Arsenal Commerce City, Colorado

Volume II of II

Harding Lawson Associates

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Volume II of II

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June 12, 1996

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1.0 INTRODUCTION

This guideline for the development of a groundwater monitoring program 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 It is contemplated that 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 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 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

This appendix provides guidance for the development of a detailed Groundwater Monitoring Plan for the CAMU at RMA The objective of this appendix is to provide information on the methods, approach, implementation, and procedures that may be incorporated into the CAMU Groundwater Monitoring Program The final Groundwater Monitoring Plan will be responsive to the applicable CAMU Groundwater Monitoring requirements The Groundwater Monitoring Plan will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0 of the CDD

1.1 Purpose, Scope, and Organization

The CDD, including this appendix, will be submitted to CDPHE to support the designation of the CAMU This document presents guidelines for the methodology the Army will employ to provide groundwater monitoring activities within the landfill CAMU areal configuration as required under 6 Code of Colorado Regulations (CCR) 1007-3, Section 264 552 (e)(3) This document will not address the specific data needs for the RMA sitewide Groundwater Monitoring Program often referred to as the RMA GMP The RMA sitewide GMP as required by the Onpost Record of Decision (ROD) will be specifically addressed by the ongoing RMA sitewide GMP

This document was developed to provide a framework for development of the groundwater monitoring program that will be implemented following designation of the CAMU After designation and prior to operation, the groundwater monitoring program will provide pre-operational data to better define the existing groundwater conditions in the landfill CAMU areal configuration These pre-operational data will be utilized to further develop detailed groundwater monitoring plans that will be implemented during the operational period of the landfill Data collected through the operational period of the landfill will also be used to develop groundwater monitoring plans that will apply during the closure and post-closure care period These plans will be provided to CDPHE for review and approval according to schedules for these activities

The framework for the CAMU Groundwater Monitoring Program described in this appendix

- Provides a long-term groundwater monitoring strategy that includes the constituents of concern, monitoring locations, frequency, and analytical methods
- Provides guidance on a method and frequency for collecting groundwater-level measurements for presentation on water-table surface maps to assess groundwater flow directions and gradients
- Defines quality assurance/quality control (QA/QC) procedures for sample collection, analysis, and well maintenance
- Provides a framework for effective data management and data evaluation
- Specifies record-keeping and reporting requirements

The appendix is organized as follows Section 1 0 provides an introduction to the overall monitoring program by presenting the regulatory requirements, CAMU Boundary description, and site-specific hydrogeology and current groundwater monitoring in the area Section 2 0 presents some methods and approaches to groundwater monitoring of the landfill CAMU areal configuration through the pre-operation, operational, closure, and post-closure periods Section 3 0 provides guidance on field procedures for well installation, and groundwater sampling Section 4 0 describes quality control samples and Section 5 0 decontamination procedures Section 6 0 includes sample documentation and shipping procedures Section 7 0 includes information on laboratory analyses and Section 8 0 on data evaluation and record keeping Attachment K1 presents the results of a groundwater monitoring well efficiency model that was used to assess the predicted efficiency of the proposed operational period monitoring well network.

1.2 Regulatory Requirements

The regulatory requirements for this groundwater monitoring program are defined in 6 CCR 1007-3, Section 264 552 (e)(3) This section requires that the groundwater monitoring program for a CAMU shall

- Continue to detect and to characterize the nature, extent, concentration, direction, and movement of existing releases of hazardous constituents in groundwater from sources located within the CAMU
- Detect and subsequently characterize releases of hazardous constituents to groundwater that may occur from areas of the CAMU in which remediation wastes will remain in place after closure of the CAMU

In conformance with these regulations, the groundwater monitoring program is outlined to first characterize the existing groundwater conditions within the landfill CAMU areal configuration and subsequently monitor for potential releases within the CAMU landfill footprints

As part of Section 264 552 (e)(4)(ii), a groundwater monitoring program will be implemented to assist in verifying that all waste from these CAMU waste management activities, that will not result in waste left in place, has been removed Specific monitoring methods and approaches is not specified in this document since the location of these activities has not yet been defined (e g , waste staging and

decontamination activities) The methods and approaches to monitoring specific to the regulatory requirements of Section 264 552 (e)(3) are defined below

1.3 Landfill Area Description

The CAMU boundary, components, waste types, and waste volumes were described in detail in Section 1 0 of this CAMU Designation Document The CAMU Groundwater Monitoring Program outlined here addresses the area within the landfill CAMU areal configuration This area is roughly outlined in Figure K1 based on the landfill concept developed for CAMU designation

1.4 Site-specific Hydrogeology and Current Groundwater Monitoring

This section describes the site-specific geology and hydrogeology in the landfill CAMU areal configuration The regional geology and hydrology for RMA have been discussed in detail in numerous reports including HLA (1995a), J May (1982), Morrison-Knudsen Engineers, Inc (MKE) (1988), and Ebasco Services, Inc (Ebasco) (1989) and are not repeated in the following discussion Further characterization of the site-specific geology is described in the Part 2 Siting Criteria Compliance Demonstration in Section 1 0 of Appendix A A brief overview of the geologic and hydrogeologic site conditions are described below to provide a framework for understanding the design of the CAMU Groundwater Monitoring Program

1.4.1 Geology

Immediately underlying the landfill CAMU areal configuration are Quaternary deposits that unconformably overlie the Denver Fm The Quaternary surficial deposits, commonly called the Quaternary alluvium, consist of unconsolidated alluvial and colluvial fill and eolian sand The alluvial and colluvial material is composed primarily of clay, silt, very fine- to fine-, to medium-grained sand with minor amounts of coarse-grained sands and gravel The alluvium ranges in thickness from approximately 5 to 58 feet below ground surface (bgs) as measured in 38 boreholes drilled in 1994 and 1995 within the area

Underlying the alluvial materials is the Cretaceous-Tertiary age Denver Formation (Denver Fm), which is composed primarily of claystone with interbedded siltstone, sandstone, and lignite The Denver Fm dips

slightly (2 to 3 degrees) to the southeast. The top of the Denver Fm is an erosional surface at RMA In the northern portion of Section 26 the Denver Fm is approximately 250 feet thick (Environmental Science and Engineering, Inc [ESE], 1988)

At RMA, the upper portion of the Denver Fm has undergone weathering and the thickness of this weathered zone ranges from a few feet to several tens of feet. Denver Fm bedrock at RMA is considered weathered if it is red, orange, yellow, tan, or brown, highly or moderately oxidized throughout or along fractures, closely to moderately fractured, or unconsolidated, crumbly or soft (HLA, 1995a)

Stratigraphic correlation of units within the Denver Fm is difficult because of the discontinuous nature of the sandstone lenses and the lateral variability in thickness and composition of other units A relatively thick, laterally continuous lignite layer, known as "Lignite A," occurs within the South Plants, Basin A, and North Plants area Lignite A has been used as a marker bed from which the other zones within the Denver Fm have been referenced (Ebasco, 1989) The stratigraphy of the landfill area illustrated in 12 cross sections is presented in Appendix A of the CDD

1.4.2 Hydrogeology

Groundwater at RMA occurs under both unconfined and confined conditions The Quaternary alluvium and weathered Denver Fm form a generally continuous groundwater system, and the groundwater system is typically unconfined This flow system is referred to as the unconfined flow system (UFS) Confining strata inhibit groundwater interaction between the UFS and deeper, more permeable zones in the Denver Fm, causing confined conditions to exist The confined groundwater underlying the UFS is referred to as the confined flow system (CFS)

In the UFS, groundwater flow occurs in saturated alluvium and the upper Denver Fm At RMA, groundwater flow in the UFS occurs primarily in the saturated alluvium, which generally has a higher hydraulic conductivity and transmissivity than the unconfined weathered Denver Fm In the landfill CAMU areal configuration, however, groundwater flow in the UFS occurs primarily within the weathered

Denver Fm due to the limited occurrence of saturated alluvium Therefore, groundwater flow is relatively slow in the landfill CAMU areal configuration, compared to other areas of RMA where the UFS flow is primarily within saturated alluvium

Figure K2 illustrates UFS (alluvium and unconfined portions of the Denver Fm) water-table map for the landfill area as presented in the most current version of the GMP Groundwater Monitoring Report (HLA, 1995b) The 1993 water-table map indicates that groundwater flow in the UFS is generally from the southeast to the northwest In general, the configuration of the water table in the landfill CAMU areal configuration resembles the configuration of the bedrock surface The water-table surface is highest where the bedrock surface is high. The depth to groundwater in the area ranges from 20 to 70 feet bgs

The CFS consists of flow through generally unweathered Denver Fm sandstones, siltstones, and lignites

1.4.3 Current Groundwater Monitoring Program in the Landfill Area

Figure K2 illustrates the existing groundwater monitoring wells in the landfill area As listed in Table K1, there are currently 48 wells from the sitewide RMA Groundwater Monitoring Program used to monitor the water levels in the landfill area As listed in Table K1, there are 4 UFS wells used to monitor groundwater quality in the eastern portion of Section 26 landfill area (U S Geological Survey [USGS], 1995) Currently, no UFS or CFS wells are used to monitor groundwater quality in Section 25 (USGS, 1995)

2.0 GENERAL GROUNDWATER MONITORING METHODS AND APPROACH

The CAMU Groundwater Monitoring Program outlined in this document has two primary objectives to monitor the existing pre-operational UFS groundwater conditions within the landfill CAMU areal configuration and to monitor potential releases to the UFS groundwater from the landfill footprint during the operational time period This section provides information on how the framework for the Groundwater Monitoring Program for the landfill CAMU areal configuration addresses both requirements Because the approach for monitoring will differ during the pre-operational, the operational, closure, and post-closure monitoring periods, each of these phases of the program is discussed separately below

2.1 Pre-Operational Characterization Within the Landfill CAMU Areal Configuration

As discussed in Section 1 4 3, the 1995 sitewide RMA Groundwater Monitoring Program does not include groundwater sampling of any wells in Section 25 (USGS, 1995) The characterization of the pre-operational water quality conditions within the landfill CAMU areal configuration is an integral part of the CAMU Groundwater Monitoring Program The detection of potential releases of hazardous constituents to the groundwater from within the landfill CAMU areal configuration will be based on the identification of a statistically significant increase in specific indicator constituents above the known pre-operational conditions Therefore, a proposed pre-operational monitoring well network, as well as proposed sampling frequencies and a proposed groundwater sample analyte list were developed to characterize existing/background groundwater quality within the landfill CAMU areal configuration It was important to develop specifics on this program prior to design so that implementation of the program could begin as soon as practicable

The wells included in the proposed pre-operational water quality network were selected by reviewing the site-specific hydrogeologic conditions including groundwater flow directions, hydraulic gradient, and geology For existing wells, the well construction information and sampling history of each well were also reviewed

The proposed pre-operational UFS monitoring well network includes a minimum of 18 wells to monitor the groundwater within the UFS in the landfill CAMU areal configuration The proposed UFS network includes 14 existing wells and a minimum of 4 proposed new wells The location of the 18 wells included in the proposed UFS pre-operational period monitoring well network is illustrated in Figure K3 and a list of the proposed networks included in Table K2

The sampling frequency for the pre-operational UFS monitoring period will be quarterly for two years If landfilling operations do not commence immediately after the final quarter of the 8-quarter pre-operational monitoring period, a minimum of one additional quarter of UFS monitoring will be performed prior to commencement of landfilling The pre-operational sample analyte list will be the RMA Target Analyte List currently utilized for the current sitewide Groundwater Monitoring Program The proposed analyte list is presented in Table K3

Water-level data collected during each UFS sampling event will be used to evaluate the groundwater flow patterns in the landfill CAMU areal configuration Water-level data will be plotted in conjunction with the annual RMA GMP results

A plan for developing a pre-operational water quality characterization of the CFS will be submitted for CDPHE review and approval This plan will evaluate the existing water quality data for the CFS and assess the need for any additional CFS pre-operational water quality data collection If additional data is required to adequately characterize the pre-operational CFS water quality, the plan will detail the requirements for obtaining such data

Groundwater analytical data collected as part of the pre-operational monitoring program will be reviewed initially to assess the existing background groundwater quality conditions within the landfill CAMU areal configuration Statistical methods will be used to evaluate the operational,

closure, and post-closure monitoring data using standard EPA guidance or other methods as appropriate to the data (U S Environmental Protection Agency [EPA], 1989 and 1992)

EPA guidance states that the appropriateness of a specific statistical method depends on the characteristics of the data set (EPA, 1989 and 1992) Important factors to be considered in selecting an appropriate statistical method include the apparent distribution of concentrations and the number of monitoring wells, nondetects, parameters, and sampling events For the CAMU Groundwater Monitoring Program, no one specific method will be selected for evaluation of the data until at least one full year of data has been collected The statistical method will be selected at that time to take into consideration the site-specific characteristics of the data set.

2.2 Operational Detection and Characterization of Potential Releases From the Landfill CAMU Areal Configuration

The proposed operational groundwater monitoring well network and sampling frequencies are outlined in this document so that potential releases of hazardous constituents to groundwater as a result of CAMU operations within the landfill CAMU areal configuration can be detected and characterized The proposed operational period monitoring well network outlined includes 15 wells to monitor groundwater within the UFS in the landfill CAMU areal configuration If a detection is confirmed, within the landfill CAMU areal configuration, that is a statistically significant exceedance above the pre-operational concentration, monitoring of the CFS will be implemented The location of the proposed 15 wells included in the operational period monitoring well network is illustrated in Figure K4 and a list of the proposed networks is included in Table K2 As design proceeds and the footprint of the landfill is better defined, more detailed monitoring plans will be submitted to CDPHE for approval

The wells included in the proposed operational period monitoring well network were selected by reviewing the site-specific hydrogeologic conditions including groundwater flow directions, hydraulic gradient, and geology as well as construction information and sampling history of each specific

existing well The proposed operational period well network has fewer wells than the pre-operational well network because as illustrated in Figure K1 2, the proposed locations of the landfill cells would most likely require abandonment of at least three well clusters If the landfill cell layout does not require abandonment of any of the three well clusters, they will be evaluated for inclusion in the proposed operational monitoring well network. Furthermore, if wells included in the proposed operational well network become damaged or otherwise unsuitable for sampling, a suitable replacement well will be installed, as necessary Installation of the replacement well will be subject to CDPHE approval

The proposed operational monitoring well network was evaluated using a Monitoring Efficiency Model (MEMO) developed by Wilson and others (1992) MEMO provides a computerized method for optimizing monitoring well locations at waste management areas MEMO quantifies the efficiency of a given well configuration by predicting areas where a chemical release would not be detected by the network. Monitoring efficiency is defined as the probability that a single source occurring in a random location within the extent of a site will be detected before resulting in detectable concentrations outside the boundary of the site

For this evaluation, because the objective was to evaluate the efficiency of the proposed operational monitoring well network, information on the site geometry, hydrogeologic characteristics, and existing monitoring well locations was input into the MEMO modeling program Figure K1 2 illustrates the site geometry and the proposed well network. Based on current understanding of the groundwater flow conditions in the area, the upgradient boundary for the site was defined as the southern boundary of the landfill CAMU areal configuration Likewise, the downgradient boundary of the site was defined as the north, east, and west boundaries of the landfill CAMU areal configuration

Based on the proposed well network, MEMO predicts a monitoring efficiency of 99 percent A 99 percent efficiency indicates that releases occurring over 99 percent of the source area would be detected by the well network The results of the modeling indicate that the proposed operational well network is an efficient system for monitoring the conditions within the landfill CAMU areal configuration. Further discussion of the modeling methods and results, and the results of a sensitivity analysis performed on the input parameters used in the model, is presented in Attachment K1

Sampling for the proposed operational monitoring period will be performed on a quarterly, semi-annual, or annual basis based on a review of the background monitoring period groundwater data and subject to CDPHE approval. The proposed operational sample analyte list will include a subset of the analytes identified in the target analyte list presented in Table K3 and will be based on the remedial waste types placed in the cells within the landfill as discussed in Section 1 0 of this CDD

2.3 Closure and Post-Closure Monitoring of the Landfill Area

After the landfill is constructed and groundwater monitoring data are available from the operational monitoring period, the Closure and Post-Closure Groundwater Monitoring Plan for the landfill area will be written and submitted by the Army to CDPHE for approval

3.0 FIELD ACTIVITIES

The field activities to be conducted during the CAMU Groundwater Monitoring Program will be performed in accordance with Program Manager for Rocky Mountain Arsenal (PMRMA) standard groundwater monitoring methods described in detail in previous documents (HLA, 1993a, 1993b, and 1995c) or consistent with procedures used in the current RMA GMP The groundwater monitoring field activities will include the following

- Drilling
- Lithologic logging
- Monitoring well installation
- Monitoring well development
- Monitoring well identification and surveying
- Water-level measurement
- Groundwater sampling

General guidelines for the field procedures are presented in this section

3.1 Monitoring Well Installation

The following sections describe the equipment and procedures to be used during monitoring well installation for the CAMU Groundwater Monitoring Program The field activities include drilling, lithologic logging, monitoring well installation, well development, well identification, and surveying Initially, a minimum of four additional alluvial or unconfined Denver Fm wells will be installed to initiate the pre-operational period groundwater monitoring well network. The proposed monitoring well locations for the four proposed additional wells are illustrated in Figure K3

3.1.1 Drilling Procedures

This section discusses drilling procedures for installing alluvial and weathered Denver Fm, monitoring wells Drilling methods that may be used during well installation activities include hollow-stem auger, and/or rotary-wash drilling methods

Techniques and procedures associated with the drilling program will be consistent with PMRMA geotechnical requirements Drilling equipment, including drilling rods, augers, samplers, tools, and water tanks, will be steam cleaned before arrival at RMA and washed with PMRMA-approved water before arrival at each boring or well site Well materials (casing, end plugs, and protector casing) will also be steam cleaned before installation Materials will be wrapped in plastic if they need to be stored before use at the well site Water used in drilling, grouting, or decontamination will be obtained from a PMRMA-approved source

Decontamination procedures are detailed in Section 4 0 Only PMRMA-approved lubricants, such as vegetable shortening, will be used on the threads of downhole drilling equipment Air usage, if any, will be fully documented with equipment descriptions and oil filter specifications Only PMRMA-approved air systems will be used

Hollow-stem Auger Drilling Procedures

Alluvial and weathered Denver Fm monitoring wells will be drilled using hollow-stem auger drilling methods During drilling, boreholes will be logged with a continuous coring device or split-spoon samplers at 4- to 5-foot intervals and at major changes in lithology

Specific drilling and sampling procedures for hollow-stem auger continuous sampling follow

1 Set up rig at staked and cleared borehole location

2 Record location, date, time, and other pertinent information on boring log form

3 Commence drilling and sampling

4 After each coring run, remove the core barrel or split-spoon sampler from the borehole and open the barrel

5 Measure each sample with an engineer's tape and lithologically log the sample as described in Section 3 1 2

6 The boring is considered complete when lithology indicates that the desired completion interval has been reached

7 The borehole will be reamed with 8-1/4-inch-inner diameter (ID) augers and installation inside the hollow-stem augers will be conducted as detailed in Section 3 1 4

8 Grout any boreholes that are not completed as wells with a cement-bentonite grout within 24 hours after drilling has been completed

9 Cuttings will be managed based on appropriate waste determination procedures established in the final groundwater monitoring plan

10 After completing each boring or well, decontaminate augers and other downhole equipment This decontamination will be accomplished after transporting the downhole equipment to the designated temporary mobile decontamination pad or at the drilling site using portable decontamination equipment

11 Have sufficient augers and core barrels available so that one set may be in use while a second set is being decontaminated

12 At the end of the each day, personnel and all equipment that are to leave the site will proceed to the temporary mobile decontamination pad where decontamination procedures will be initiated Drilling rigs will remain at the drilling location until all work has been completed Upon completion of activities at each location, the drilling rig and all associated equipment will be transported to an appropriate decontamination facility for thorough decontamination. Decontamination water and PPE will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation

3.1.2 Lithologic Logging

Boring lithology will be logged by a rig geologist. Data will be recorded on boring log forms and will include the boring number, location, date, drilling equipment, driller's name, method of sampling, sample depth, and lithologic descriptions Photocopies of boring logs will be submitted to PMRMA upon completion of the boring Soil and bedrock logging procedures are explained in detail in the following sections

Soil Logging

Soil logging will be performed on the basis of cuttings or split-spoon samples, depending on the drilling method This section describes the procedures that will be used to identify and describe soil samples that are collected, regardless of the method of collection.

The Unified Soil Classification System (USCS) is the standard that will be used to classify soil by visual and manual examination Soil will be described using standard terminology and nomenclature

associated with this system Each soil stratum will be identified by the following classifications in the following order (1) classification symbol, (2) classification name and content percentages, (3) Munsell color code, (4) color name, (5) consistency or relative density, (6) moisture, (7) structure (if any), and (8) modifying information, such as grain size, particle shape, cementation, plasticity, and stratification

The standard soil classification chart to be used to classify soil type is presented in Figure K5 Symbols will be sketched on the graphic portion of the boring log to assess stratigraphic relationships Color will be correctly described by comparing the soil sample with a Munsell color chart and applying appropriate designations and descriptions

An estimate of soil consistency, using standard penetration resistance as a guide, will accompany descriptions of all fine-grained soil (silts and clays) The following terminology will be used as a guide

Blows/foot[1]	Consistency	Identification Procedure
0 to 2	Very soft	Easily penetrated several inches by fist
2 to 4	Soft	Easily penetrated several inches by thumb
5 to 8	Medium stiff	Penetrated several inches by thumb with moderate effort
9 to 15	Stiff	Readily indented by thumb but penetrated only with great effort
16 to 30	Very stiff	Readily indented by thumbnail
> 30	Hard	Indented with difficulty by thumbnail

1 Blows/foot is defined as the total number of blows required to drive the second and third 6 inches of penetration (for the first 6 inches, blow count is also recorded) while driving an 18-inch sampler with a 140-pound hammer falling a free height of 30 inches

It is anticipated that samples will be collected using wire line sampling equipment rather than drive sampling equipment Therefore, estimates of soil consistency will be made on the basis of the "Identification Procedure" described above rather than on the basis of blows per foot

Descriptions of all coarse-grained soil (sand and gravel) will be accompanied by an estimate of the relative density The following terminology will be used as a guide

Blows per foot	Relative Density
less than 4	Very loose
4 to 10	Loose
10 to 30	Medium dense
30 to 50	Dense
over 50	Very dense

Evaluation of relative density in the field is assessed qualitatively

Moisture content will be estimated and described using the following terms dry, moist, wet, and saturated (below the water table) Other descriptors to be included on boring logs, if applicable, are approximate percentages of clay, silt, sand, and gravel, average grain size and maximum size of particles, shape/angularity of coarse grains, general composition or mineralogic description of grains (e g , granitic, micaceous), coatings on coarse grains, plasticity, organic content, cementation, and local or geologic name

Bedrock Logging

Bedrock logging will be performed on bedrock samples collected by split-barrel sampling or coring This section describes the procedures to be used to identify and describe bedrock samples that are collected

Written descriptions for bedrock samples will include the following information

- Lithology
- Color
- Texture, including grain size, roundness, and sorting
- Cementation and/or matrix materials
- Accessory minerals

- Hardness
- Strength
- Weathering
- Sedimentary/structural features

3.1.3 Monitoring Well Installation

This section describes well installation procedures for installing monitoring wells in the alluvium and the weathered Denver Fm Alluvial monitoring wells will be drilled by first completing a sampled borehole using the hollow-stem auger drilling procedures described in Section 3 1 1 The following procedures are for well installation

1. Each boring will then be reamed with an 8-1/4-inch-ID hollow-stem auger a using center bit
2. The 8-1/4-inch auger will be advanced 1 to 2 feet into competent bedrock and left in place until well installation begins
3. Well completion, which consists of placing the 4-inch Schedule 40 polyvinyl chloride (PVC) slotted screen (0 010 or 0 020-inch slot size depending on site conditions according to ASTM D 5092) and 4-inch Schedule 40 PVC well casing, adding the sandpack material, and placing the bentonite seal, shall be conducted inside the 8-1/4-inch-ID hollow-stem auger as the auger is progressively removed from the borehole as the installation process continues
4. The sand pack will be installed through a tremie pipe and its depth measured using a weighted tape or by measuring the length of tremie pipe A bentonite pellet seal will be slowly poured in the well and its depth measured using a weighted tape or by measuring the length of tremie pipe The dry bentonite pellets shall be hydrated with adequate time allowed for hydration The water used for hydration shall not contain constituents that could compromise the integrity of the well
5. Cement-bentonite grout will be emplaced using a side-discharge tremie pipe initial positioned approximately 3 to 5 feet above the bentonite seal and raised as grout is added to the borehole
6. A steel protector housing will then be centered over the well, and the grout will be allowed to cure for 24 hours After the grout has cured, a concrete well pad and a drainage port will be added and well development (Section 3 1 4) can begin

A proposed general construction diagram for an alluvial monitoring well is presented in Figure K6

3.1.4 Well Development

All monitoring wells will be developed after at least a 48-hour curing time has elapsed since installation The water generated during development will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation

Monitoring wells will be developed at least two weeks before sampling Well development will be conducted by either a submersible pump or a bottom discharge bailer, with or without a surge block. At least five times the volume of standing water in the well, sandpack, and annulus will be removed If any water is lost during drilling or completing the well, five times the volume of the lost water will be removed in addition to the previous requirement

Measurements obtained and recorded in the field will include static water levels before and after development. The pH, temperature, and conductivity of the water will also be measured before, during, and after development. The pH will be considered stabilized when three of the last five readings are within 0 1 pH units The temperature and conductivity measurements will be allowed to stabilize to within 10 percent of previous readings before the well is considered developed

3.1.5 Well Identification and Surveying

After well installation is complete, the well location, elevation of ground surface, and top of the well casing will be surveyed Well locations will be accurate to within 0 1 feet using State Planar coordinates Elevations will be surveyed to within 0 01 foot using the National Geodetic Vertical Datum of 1929

Well identification numbers, map coordinates, and elevations will be recorded in a field logbook and will be submitted to PMRMA and entered into the RMA environmental database A metal tag stamped with these data will be permanently attached to each protective casing

Monitoring well installation, groundwater sampling, and water-level measurement procedures described in this section are consistent with those developed for and used during previous investigations (HLA, 1993a and 1995b) Field personnel performing groundwater monitoring activities, depending on the level of activity required, may include a field supervisor, a safety officer, and one or more two-person field teams Equipment to be used and procedures to be followed during the sampling events are presented below

3.2 Groundwater Sampling and Water-level Measurement Procedures

The procedures for groundwater sampling and water-level measurement are described below The procedures are consistent with EPA guidance for these activities

3.2.1 Field Equipment

At the beginning of each monitoring event, the field teams will be issued field sampling kits containing field instruments (with operators' manuals), sampling equipment, and laboratory certified calibration standards Copies of the Health and Safety Program will be maintained in the field trailer Depending on the well to be sampled, the sampling equipment may include an electric submersible pump, an air-driven piston pump, a stainless-steel bailer system, an air compressor, and/or compressed air bottles

The components of each field kit will be contained within an all-weather storage locker Typical equipment that may be included in each locker is presented below

1. pH, conductivity, and dissolved oxygen meters, a complete set of spare probes, cables, and batteries for each instrument, and a flow-through cell in which to monitor groundwater parameters
2. Digital alkalinity titration kits
3. Calibration-standard solutions and detailed calibration procedure instructions for field instruments
4. Two 1-liter wash bottles and a set of two 500-milliliter (ml), two 250-ml, and two 100-ml beakers
5. A water-level measuring device

6 A 10-foot steel engineers tape

7 A roll of plastic sheeting

8 Gloves (nitrile and surgical)

9 Plastic bags

10 1/4-inch or appropriate sized nylon rope

11 A metals filtration kit (peristaltic pump, filter holder, replacement hoses, filters, 50 ml of dilute nitric acid [HNO_3] for metals preservation, and pH indicator paper)

12 A complete set of spare sample fraction containers including a set of 40-ml vials that have not been pre-preserved with hydrochloric acid (HCl)

13 A well casing volume calculation chart for 1-inch to 8-inch wells

14 Various equipment, such as marking pens, duct tape, clear tape, and tools for troubleshooting equipment

15 A 1 1 solution of sulfuric acid (H_2SO_4) for nitrate sample preservation

16 A 1 1 solution of sodium hydroxide (NaOH) for adjusting to pH greater than (>) 12 for cyanide sample preservation

17 A 1 1 solution of HCl for adjusting to pH less than (<) 2 for volatile fraction preservation

18 A detailed sampling procedure plan

Each field kit will be restocked as necessary Additional field equipment (e g , distilled water and decontamination wash basins) will be stocked as necessary by each field team It is recommended that a complete set of spare field instruments will be maintained at the onsite support facility

Data from samples collected in the field will be recorded on preprinted field data sheets and in bound field logbooks When not in use, field logbooks will be maintained in a secured area at the site support facility Logbooks will be checked in and out on a daily basis

3.2.2 Water-level Measurement Procedures

A water-level measurement program will be conducted before the initiation of each water sampling event A sufficient number of field personnel will be mobilized to ensure that water-level data are collected in a timely manner (i e , within three days) Water-level measurements and associated data

are recorded on the water-level measurement form shown in Figure K7 The general procedure for obtaining water-level measurements is summarized as follows

1 Record in a bound field book the manufacturer and model of the water-level indicator used

2 Record on the water-level measurement form the well number, date, time, and initials of field personnel obtaining measurements

3 Before uncapping the well, measure and record on the water-level measurement form the photoionization detector (PID) reading in the ambient air near the well (background) Uncap the well and record on the water-level measurement form the PID reading of the headspace at the top of casing (TOC) Measure the PID reading in the breathing zone near the well Record and label the breathing zone reading in the "Comment" section of the water-level measurement form and upgrade personal protective equipment (PPE) as appropriate before obtaining further well measurements

4 Measure the length of the riser stickup from ground surface to the measuring point marked at the TOC, and record the length of the riser stickup to the nearest 0 01 foot If no mark is present, all measurements will be performed on the north side of the stickup, and a measuring point will be marked on the stickup using a permanent marker

5 Insert the water-level indicator probe until it reaches water Measure depth to water from the same measuring point marked at the TOC and record the value to the nearest 0.01 foot

6 If there is a discrepancy between the previously accepted stickup measurement and the current stickup measurement, measure and record the total depth of the well for confirmation that measurements are being performed on the correct well Total depth of each well shall be measured yearly to verify well condition.

7 Retrieve the water-level indicator probe and thoroughly rinse the cable and probe with distilled water as they are withdrawn from the well Avoid allowing rinsewater to flow into the well

8 Compare total depth, water level, and stickup measurements to previous measurements If discrepancies are observed, a second measurement will be performed and documented as such

9 Record well conditions (e g , cracked casing, missing cap, prairie dog burrows) and any other pertinent observations

10 Ensure that labels and flagging clearly indicate well location and well number

11 Police the area to ensure that equipment and materials have been retrieved, litter has been collected, and the well cap is secure

3.2.3 Groundwater Sampling Procedures

A daily schedule of field activities and prepared sample cooler will be provided to each field team

Each cooler will contain sample containers, packing material, labels, chain-of-custody (COC) records,

and ice Each field team will also be provided with a well information file, which will include previous water-level data, expected casing volume, and any comments generated during previous sampling events The field team will be responsible for ensuring that sample and field sampling kits are complete and that instruments and sampling equipment are clean and fully operational

Groundwater monitoring wells, in general, will be sampled in order from low to high contaminant ranking to avoid possible cross contamination of groundwater samples or wells The sampling order will be decided on the basis of historical groundwater quality data

Water sampling data are recorded for each well on the groundwater sampling form shown in Figure K8 Upon arrival at the well site, the following procedures are typically implemented

1 Uncap the well and record background, breathing zone, and casing headspace readings from the PID, as described previously for water-level measurements

2 Record well number, date, pertinent observations (e g , weather, well condition), casing diameter, screened interval, and field instrument identification numbers

3 Place a sheet of plastic on the ground surface around the well stickup for wells that will be bailed

4 Measure and record well stickup, depth to water, and total well depth to the nearest 0 01 foot Measure from the measuring point marked at the TOC and compare measured values with previous measurements, investigate and document any discrepancies Equipment used downhole to obtain water-level and total depth measurements will be decontaminated with distilled water

5 Calculate and record casing volume, compare with previously recorded casing volumes to ensure relative comparability A sheet listing casing volumes on the basis of height of the water column and well diameter will be provided to field personnel The casing volume can also be calculated using the formula $V=(0\ 0408)(D^2)h$, where D is the diameter of the well in inches and h is the height of the water column in feet

6 Calibrate field instruments for monitoring pH, temperature, conductivity, alkalinity, and dissolved oxygen (for pumped wells only) against known standards Record instrument calibration responses, times, and calibration standards used

7 Whether to pump or bail a well will be decided on the basis of the well's hydraulic characteristics In general, wells containing less than 4 gallons per casing volume will be purged and sampled by bailing and other wells will be pumped Wells that dewater when monitoring the unconfined or confined flow system and have to be resampled will be bailed for sample collection.

8 Two methods are used for purging and sampling wells, depending on whether the well is to be pumped or bailed In both cases (bailing or pumping), it is preferred that a minimum of three casing volumes be purged from the well to allow water that may have been standing in the well casing and filter pack to be removed, allowing the sample to be representative of aquifer conditions The minimum requirements are to obtain three or more consecutive stabilized parameter measurements (and no less than three casing volumes) in which each parameter measurement (pH, electrical conductivity, temperature, and dissolved oxygen) differs by no more than 10 percent from the previous parameter measurement and turbidity is less than 5 NTU

If a well is to be bailed, purge the water column from the top of the column Lower the bailer into the water slowly to minimize agitation. Monitor well parameters carefully to ensure that water standing in the well casing and filter pack is removed from the well before sampling Some wells will dewater, other wells may appear to dewater if bailed too quickly It may, therefore, be necessary to carefully monitor the well's response when bailing low-production wells to ascertain how many casing volumes can be effectively purged before sampling

If a well is to be pumped, purge the standing water column in the well from the top to the bottom of the screened interval In many cases, the pump has a higher flow capacity than the well, and the well will appear to dewater Exercise care to reduce the pump flow rate so that it equals the well's recharge potential On occasion, it may be necessary to reposition the pump to progressively deeper locations in the well After purging three casing volumes from the well and after parameter measurements have stabilized, the optimal sampling depth should be at the middle of the well's screened interval Purge water from all pumped wells will pass through an in-line flow cell fitted with the required instrument probes The flow cell allows for real-time monitoring of sample parameters (pH, electrical conductivity, temperature, and dissolved oxygen) as well as the visual characteristics of the water passing through the cell

9 Collect a portion of the initial water purged from the well and record the following information sample parameter values (pH, temperature, electrical conductivity, dissolved oxygen, and turbidity), time, air monitoring instrument readings, pumping rate, and purged volume removed Similarly, document this information as each casing volume is removed Purge water will be appropriately managed onsite or offsite in accordance with applicable regulatory requirements at the time of generation.

a Following the manufacturer's instructions, calibrate the turbidimeter using the supplied standards and record the readings in the logbook. The ambient air temperature should be between 10°C and 40°C for calibration and measurement.

b Using a clean 500-milliliter (ml) beaker, obtain a sample (50 to 250 ml) of groundwater from the discharge hose of the development/purge pump after each ½ bore volume has been removed

c Set the sample aside for a few minutes to allow any rapidly settling coarse particulates to settle and to allow any entrained gases to escape However, the sample must not be set aside so long as to let any fines in the water settle out

d Decant some of the sample from the 500-ml beaker into a clean, scratch-free sample cuvette, and then pour the sample out to waste This is a rinse step before the actual measurement is made

e Refill the sample cuvette with groundwater from the beaker, being careful to pour the sample down the side to avoid creating bubbles

f Cap the cuvette and wipe off the sides with a clean, lint-free cloth until the cuvette is dry and smudge-free Handle the cuvette only by the cap, being careful not to touch the sides

g Insert the sample cuvette into the turbidimeter and select a standard with a value that is close to what you suspect the sample value to be

h. Be sure the sample and standard chamber lids are fully closed and the cuvettes are seated at the bottom of the chamber

i Adjust the standardization dial to the setting that is equal to the value of the standard

j Read the value of turbidity for the groundwater sample and record it in the field logbook.

k. Restandardize the turbidimeter before another sample is measured or between duplicate measurements Repeat steps 1 through 11 for each sample

10 Remove a minimum of three casing volumes from each well before sampling However, do not collect samples until sample parameters from three consecutive casing volumes have stabilized Wells that dewater before the removal of three casing volumes or stabilization are exempt from these requirements If the well dewaters, collect samples based on their previously determined priority (see item 14), within 24 hours following well dewatering

11 Perform an alkalinity titration on a portion of the well water collected after the fifth or final casing volume has been removed Record titration values required to reach colorimetric end points along with associated pH values (measured simultaneously), in accordance with the Quality Assurance Management Plan (QAMP)

12 Measure and record sample parameters immediately before sample collection Complete sample labels to include the following information well number, time, date, and sampler's signature

13 If the well is pumped, collect samples directly from a sampling spigot on the pump discharge line at low flow rates to avoid agitating samples and possibly degassing volatiles Obtain these samples from the spigot that is plumbed into the discharge line upstream from the in-line flow cell If the well is bailed, collect samples from bottom-decanting bailers

14 Use sample bottles supplied certified clean by the vendor and do not rinse them with well water before filling In general, add preservatives to the appropriate sample bottles before sampling Additional preservatives may be added after sample bottles are filled as described in item 15 The sample bottles listed in parenthesis may change depending on specific laboratory requirements Samples fractions will normally be filled in the following order

a Analyses not retained on the prior sampling round

b Volatile organic aromatics (VOAs) (two 40-ml amber glass bottles)
Volatile organohalogens (VOHs) (two 40-ml amber glass bottles)
Volatile hydrocarbons (VHCs) (two 40-ml amber glass bottles)
Note fill bottles completely to ensure that there are no air bubbles

c Dibromochloropropane (DBCP) (three 40-ml amber glass bottles)
Note fill bottles completely to ensure that there are no air bubbles

d Organochlorine pesticides (OCPs) (one 1-liter amber glass bottle)

e Organophosphorus pesticides (OPPs) (one 1-liter amber glass bottle)

f Organophosphorus compounds (OPCs) (one 1-liter amber glass bottle)

g Organosulfur compounds (OSCs) (one 1-liter amber glass bottle)

h Agent degradation products (isopropylmethyl phosphonic acid [IMPA] and thiodyglycol) (four 1-liter amber glass bottles)
Note for wells that dewater or have a low production capacity, collect one 1-liter bottle for each compound (IMPA and thiodyglycol) Fill the remaining two bottles after all other sample fractions have been collected

i Inductively coupled argon plasma (ICP) metals and cations (one 500-ml plastic container)
Arsenic (one 500-ml plastic container)
Mercury (one 500-ml plastic container)

j Cyanide (one 1-liter plastic container)
Anions (one 4-ounce plastic container)
Nitrate/nitrite (one 4-ounce plastic container)

k. Volatiles by gas chromatography gas/mass spectrometry (GC/MS) (two 40-ml amber glass bottles)
Note fill bottles completely to ensure that there are no air bubbles

l Semivolatiles by GC/MS (one 1-liter amber glass bottle)
Note fill bottle completely to ensure that there are no air bubbles

m N-nitrosodimethylamine (NDMA) by gas chromatography/chemiluminescence detection (GCCD) (one 1-liter amber glass bottle)

Fill the VOA, VOH, VHC, DBCP, and GC/MS sample fractions completely ensuring that there are no air bubbles Fill the remaining sample fractions to a minimum of 90 percent capacity

15 Before sample containers are filled, add preservatives to the following sample fraction bottles as required by the laboratory

- VOA, VOH, VHC, and GC/MS volatile fractions Analyses for the volatile fractions will require seven (or nine if GC/MS analyses are being performed) 40-ml bottles prepreserved with 250 to 500 microliters (μl) of concentrated HCl One of the 40-ml bottles will be used by the field team to check for effervescence and for proper preservation of pH <2 If effervescence is readily apparent as the first pre-preserved

40-ml sample bottle is being filled, then HCl will not be used as a preservative The laboratory will be informed that the volatile fractions were not preserved, and seven-day turn-around-time will be required for analyses If effervescence is not apparent, but the pH of the sacrificial sample is greater than 2, the field team will add 100 μl of HCl to the sacrificial sample bottle and recheck for a pH of <2 The process will be repeated until a pH of <2 has been achieved The same number of drops of HCl will be added to each of the six or eight remaining 40-ml sample bottles before they are filled

- Nitrate/nitrite fraction Analyses for the nitrate/nitrite fraction will require one 4-ounce plastic bottle pre-preserved with 0 5 ml of 1 1 H_2SO_4 Field samplers will pour a small amount of the groundwater sample onto pH paper to check for a pH of <2 If needed, 200 μl of H_2SO_4 will be added to the nitrate sample bottle The pH will be checked again by the same procedure until a pH of <2 is measured

- Cyanide fraction Analyses for the cyanide fractions will require one 1-liter amber glass bottle prepreserved with 4-ml of 1 1 NaOH The cyanide fraction will be checked by the field team to ensure that the sample has been preserved to a pH >12 If the pH needs to be adjusted, the field team will add 200 μl of 1 1 NaOH The pH will be checked again and the procedure will be repeated if necessary until a pH of >12 is achieved

- ICP metals and cations, arsenic, and mercury fractions Analyses for the dissolved metals fractions will require three 500-ml plastic bottles preserved with 2 ml 1 1 HNO_3 If the samples are collected by pumping, the pump will be stopped and a 0 45-micron nitrocellulose or cellulose acetate in-line filter will be attached to the discharge line The pump will be restarted and the first 50 to 100 ml of filtrate will be discarded to minimize possible contamination Samples of the filtered water will then be collected in designated containers prepreserved with HNO_3 to a pH of <2 If the samples are obtained by the bailing technique, field filtration equipment will be available The filtering device will contain a filter support of plastic or Teflon® with a disposable ungridded 0 45-micron nitrocellulose or cellulose acetate filter The unfiltered groundwater will be poured from the bailer into a clean container for ease of use The unfiltered water will be pumped from the clean container through the filtering device To minimize possible contamination, the first 50 to 100 ml of filtrate will be discarded Samples of the filtered water will then be collected in designated containers prepreserved with HNO_3 to a pH of <2 The pH of the samples will be checked by pouring a small amount of the sample onto the pH indicator paper If the pH needs to be adjusted, the field team will add 200 μl of 1 1 HNO_3 The pH will be checked again and the procedure will be repeated until a pH of <2 is achieved

16 Seal sample fractions inside plastic bags and place in the cooler under ice immediately upon filling Record sampling technique, sample depth, and fractions collected on field data sheets, COC records, and the sample tag

17 The field team will sign and date field data sheets after ensuring that they have been completed and that the information has also been recorded in the field logbook. The field team will complete the COC record when relinquishing custody of the samples

18 Thoroughly decontaminate sampling equipment at the well site or at a decontamination pad immediately after sampling Bailers and sample filtration equipment will be cleaned in a solution of PMRMA-approved water or tap water and detergent (Liquinox® or equivalent) and triple rinsed with distilled water

To decontaminate pumps used at wells identified as requiring low-level decontamination, clean the inside of the pump by running a volume of distilled water equal to three times the volume of the pump and hoses through the line Clean the outside of the pump and hose by triple rinsing with distilled water as the pump and hose are withdrawn from the well

After sampling wells identified as requiring high-level decontamination, decontaminate the outside of the sample pumps by scrubbing with a solution of PMRMA-approved water or tap water and detergent (Liquinox® or equivalent), steam cleaning using PMRMA-approved water or tap water, and triple rinsing using distilled water To decontaminate the interior surface of tubing and pumps, run a solution of PMRMA-approved water or tap water and detergent (Liquinox® or equivalent) through the pump This will be followed by running a volume of distilled water equal to six times the volume of the pump and tubing through the line

Wrap and store decontaminated equipment in clean plastic sheeting Decontamination water will be managed either onsite or offsite in accordance with applicable regulatory requirements at the time of generation.

19 The final activity at the well will be to remove all sampling equipment and debris from the area

In addition to these procedures, the following guidelines will be used to mitigate problems that could adversely affect sample integrity

1 Avoid agitation of VOC samples collected from either pumps or bailers that will reduce air stripping of volatiles and allow for the collection of more representative samples

2 Sampling equipment, including pumps, hoses, bailers, and rope, should contact only the well or a clean plastic surface Equipment should never contact the ground or any other surface that has the potential to transmit contaminants This equipment should always be encased or wrapped in clean plastic during transport

3 Change gloves frequently when handling downhole instruments Always change gloves after working with compressors or other equipment before sampling New gloves will be worn at the start of well purging and changed immediately before sample collection

4 When working with downhole equipment (e g , bailers, pumps) either decontaminate tools after use or decontaminate the equipment before re-entering the well

5 Avoid splashing waste or dirt on plastic sheeting If the sheeting becomes dirty, replace with clean plastic sheeting and dispose of the dirty sheeting in the proper manner

6 Vent gasoline engines downwind at least 30 feet from the well Gasoline tanks should never be filled in the field Keep all sampling equipment away from areas where gasoline spills or leaks may occur

7 Replace all dropped bottles, lids, or septa with counterparts from the kit Avoid contact with edges of lids or inside surfaces of sample bottles

8 Ensure that septa and Teflon® cap liners are in good condition Check that septa are oriented with Teflon® side down When full, septa bottles should be transported upside down.

9 Avoid sampling when precipitation or windblown dust may contaminate the sample

10 Do not dip pH indicator paper into acidified samples, check by pouring a small amount of sample on the paper Volatile fractions will be checked for proper preservation by collecting one additional sacrificial sample

11 To avoid unnecessary agitation of the water column, lower bailers slowly into the well A knot tied in the bailing rope approximately 2 feet above the static water level will serve as a marker below which the bailer will be lowered very slowly

12 Ensure that a stainless-steel protector is emplaced over the well head, on 2-inch-diameter wells, before bailing This protector will prevent the bailing rope from cutting into the top edge of the PVC casing

13 When using a disposable 0 45-micron filter, discard the entire assembly after filtering, disposable filters are not reused Also, discard the silicon rubber tubing used to connect the filter capsule to the spigot.

14 Fill sample bottles from a pump discharge line located upstream of the flow cell

15 When abrupt increases are observed in dissolved oxygen readings, a bailer will be used in place of the pump to sample the well When pumps malfunction, they may aerate samples and should be repaired immediately

16 Check documentation to ensure that corrections are properly recorded Also, check that all signatures and dates on forms are present and correct

17 In the field, field team members will check forms to ensure that they are legible and correct

4.0 QUALITY CONTROL SAMPLES

Investigative samples will be collected as detailed in Section 3 0 to provide data relevant to the objectives of this task. Concurrent with investigative sample collection, QC samples will be collected to evaluate the accuracy, precision, completeness, reproducibility, and representativeness of all data and observations relevant to field activities QC sample collection procedures are discussed below and detailed in the QAMP (HLA, 1993b) QC samples to be collected during field activities will include duplicate samples, rinse blanks, trip blanks, and field blanks QC samples will be collected according to procedures used for previous RMA programs, as described below

4.1 Duplicate Samples

Duplicate samples are groundwater samples collected in the identical fashion as the investigative sample Duplicate samples will be analyzed for the same analytical parameters as the related investigative samples To maximize the representativeness of duplicates, duplicates will be collected in parallel with the investigative samples For example, volatiles for the investigative and duplicate samples will be collected first as split samples, followed by those for the semivolatiles, and so forth Standard PMRMA Class 1-certified methods use a duplicate high spike in standard water to monitor method performance Native matrix spikes and matrix spike duplicates will be used if standard method protocols require modification to meet program data quality objectives (DQOs) Duplicate samples will generally be collected in an amount equal to 10 percent of the investigative samples

4.2 Rinse Blanks

Rinse blanks are samples obtained by running distilled water through nondedicated or nondisposal sample collection equipment after decontamination and collecting it in the appropriate sample containers for analysis Rinse blanks will be analyzed for the same analytical parameters as the related investigative samples. The rinse blank will be obtained by running distilled water through sample collection equipment (bailer or pump) after decontamination and placing the sample in the appropriate container Rinse blanks will be handled, transported, and analyzed in the same manner as investigative samples collected that day At a minimum, one rinse blank will be collected at the

beginning and the end of each sampling round for each pump used in sampling Generally, rinse blanks will be collected in an amount equal to 5 percent of the investigative samples If dedicated or disposal equipment is used for groundwater sampling, no rinse blanks will be required

Samples of the distilled water used for collection of the rinse blanks will also be collected This represents the same distilled water used for decontamination. These samples will be handled and analyzed similarly to rinse blanks Sample fractions will be filled in the field office Generally, distilled water blanks will be collected in an amount equal to 10 percent of the number of rinse blanks

4.3 Trip Blanks

Trip blanks are prepared by the laboratory before the sampling event by collecting analyte-free water in the actual sample bottles Trip blanks are kept with the investigative samples throughout the sampling event, then packaged for shipment to the laboratory for analysis with the investigative samples Trip blanks will be prepared by the laboratory to be analyzed for volatile organic aromatic compounds and volatile organic halogenated compounds At no time after its preparation will a trip blank container be opened before it is returned to the laboratory Generally, trip blanks will be prepared in an amount equal to 5 percent of the investigative samples

4.4 Field Blanks

Field blanks are samples prepared by collecting distilled water into the appropriate sample containers at the location where the investigative sample is being collected Field blanks will be prepared to be analyzed for the same analytical parameters as the related investigative samples

When filled, the field blank sample will remain uncapped during collection of the investigative sample Generally, field blanks will be prepared in an amount equal to 2 5 percent of the investigative samples

5.0 DECONTAMINATION PROCEDURES

Equipment that comes in contact with potentially contaminated groundwater, including equipment used for well installation, soil sampling, water sampling, measuring water levels, and sample preparation, will be decontaminated before and after each use Decontamination water used will generally be PMRMA-approved or distilled water Tap water may be used instead of PMRMA-approved water for use in steam cleaning and detergent solutions provided that deionized or distilled water is used afterward to rinse equipment PMRMA-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 PMRMA-approved water or tap water This section details decontamination procedures as well as types of equipment to be decontaminated

5.1 Drilling Equipment, Sampling Equipment, and Well Completion Materials

Equipment used for drilling, soil sampling, and well installation will be decontaminated before initiating drilling operations This initial decontamination will consist of steam cleaning with PMRMA-approved water In addition, well installation materials, including surface casings, well casings and screens, protector casings, and fittings, will also be decontaminated before use These materials will be steam cleaned, allowed to air dry, wrapped in clean polyethylene sheeting, and stored in a designated onpost area until they are needed If necessary, clean polybutyrate tubes for soil sampling will be provided by the manufacturer and will not require further decontamination before use

During drilling operations, downhole equipment will be thoroughly decontaminated after completing each boring or well Field decontamination will be accomplished using a trailer-mounted portable steam cleaner and a clean water tank filled with PMRMA-approved water Field decontamination will be performed in such a manner that all rinsewater is containerized Rinsewater will be pumped

into truck-mounted storage tanks and managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation.

Well installation materials will remain wrapped in clean polyethylene sheeting until immediately before use Care will be taken to ensure that materials do not contact the ground surface or potentially contaminated equipment Before placement, materials will be visually inspected for indications of contamination and, if necessary, steam cleaned in the field using the field decontamination procedures described above Clean gloves will be worn when handling unwrapped well installation materials

Upon completion of the drilling program, equipment will be given a final decontamination rinse before leaving RMA

5.2 Well Development Equipment

Equipment used for well development will be decontaminated before and after use at each well This procedure will include decontamination of pumps, purging bailers, and downhole tubing

5.3 Water-level Measurement Equipment

The electrical (sounding) tape or steel tape used to measure water levels will be decontaminated to avoid cross contamination between wells Decontamination will consist of rinsing the tape with distilled water as it is being removed from the well

5.4 Groundwater Sampling Equipment

Either dedicated or nondedicated sampling equipment will be used for purging and sample collection If nondedicated groundwater sampling equipment is used, it will be appropriately decontaminated after each well is sampled

Probes on the pH, conductivity, and dissolved oxygen meters used to measure field parameters will be cleaned by rinsing with distilled water After each round of sampling is completed, all non-dedicated sampling equipment will undergo decontamination.

6.0 SAMPLE DOCUMENTATION CUSTODY AND SHIPPING PROCEDURES

Sample and document custody procedures applicable to the CAMU Groundwater Monitoring Program are summarized in the following subsections Samples collected during field activities will be delivered on a daily basis 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 Laboratory Support Division or carried to PMRMA's onsite laboratory for analyses of Diisopropylmethyl phosphonate (DIMP) and NDMA

6.1 Field Documentation

Field logbooks (bound field survey books) will be used to record data collection activities performed onsite Field logbooks will be assigned to field personnel for each activity and will remain in the custody of field personnel during sampling activities Each logbook will be identified by a project-specific number The cover of each logbook will bear the following information

- Name of person or organization to whom the book is assigned
- Book number
- Project name
- Start date
- End date

At the beginning of each day, the date, start time, weather conditions, field personnel present, level of 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 field logbook. If appropriate, entries in the logbook 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
- Name(s) and title(s) of site visitors
- 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)
- Sample preservative, if applicable
- Sample distribution (e g , laboratory)
- References for all maps and photographs of the sampling site(s)
- Field observations and comments
- Field measurements recorded (e g , pH, electrical conductivity [EC], PID)
- Sample documentation, including dates and methods of sample shipment

Information included on field data sheets or COC records may not necessarily be repeated in the logbook. By the end of each day, samples should be brought back to the sample handling trailer for packaging The completed the COC records field logbooks and field data sheets will be reviewed for errors and omissions and submitted to PMRMA

6.2 Sample Classification, Handling, and Shipping

Sample classification is necessary to ensure the protection of personnel involved in the shipment of 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)

PMSD will be contacted no later than 9 00 a.m daily or as required for assignment of courier air bill numbers Sample shipments to each laboratory will receive a unique airbill number

Samples for volatile analyses will be collected and shipped with zero headspace Samples collected for other analyses will be shipped with approximately 10 percent air space so that the container is not full at 130 degrees Fahrenheit (°F) Glass containers used for all types of analyses will be wrapped in bubble wrap and placed inside a DOT-approved shipping container, such as a Coleman Sample Manager®, and packed to prevent breakage Sample shipments will be preserved by placing sealed plastic bags of wet ice and/or cooler packs around the sample containers Any remaining space will be filled with bubble wrap or vermiculite Samples will be delivered to the PMRMA Receiving Office, Building 618, until approximately 6 00 p m for shipping to the contract laboratory(ies) for analysis

The COC record for each sample shipment will be enclosed in a sealed, waterproof envelope attached to the inside of the cooler lid and delivered to the PMRMA Receiving Office The Quality Assurance Coordinator (QAC) (or designated representative) will contact the PMRMA Receiving Office daily 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 QAMP (HLA, 1993b) Containers will be obtained from the PMSD supply office, based on availability, and supplied to field personnel before sampling

6.3 Sample Identification and Labeling

Sample labels and COC records will be provided to sampling personnel by the 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 in the appropriate field logbook.

Each sample will be identified by a separate sample label and associated tag number The information generally recorded on the label may include, but not be 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 K9

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 assist the RMA sample shipping custodian with custody seals 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® or equivalent cooler will be sealed using wire and lead seals The seals will carry the following information

- PMRMA sample shipping custodian's initials
- Date and time of sealing

Locking shipping containers will not require the use of custody seals

6.4 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 Unused or excess samples returned to RMA will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of operation

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 PMRMA sample shipping custodian will arrange the shipping, prepare the courier airbill form, write the courier airbill number on the COC record, and sign a separate cooler COC record and the courier airbill form

The COC record generally contains the following information

- Sampling program identification including contract code and delivery order number
- 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
- Analytical laboratory identification
- Medium type and/or PMRMA-approved file 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 K10

Each COC record consists of three sheets of pressure-sensitive paper (white, yellow, and pink) After the PMRMA shipping custodian at Building 618 signs the COC, additional copies of the original will be made for the Logistic Branch of the Army and the Laboratory Support Division. 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 Army The yellow original will be retained in the sampling 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 when required, 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 the laboratory to send extracted or spent samples to RMA for storage

6.5 Corrections to Documentation

Unless otherwise prohibited, 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

7.0 LABORATORY ANALYSES

Laboratory analyses of samples for evaluating chemical properties and constituents will be performed according to the PMRMA certification program protocol for investigative samples The Army anticipates that certified and uncertified laboratory analytical methods will be used during the analyses of groundwater samples Approximately 18 investigative groundwater samples will be collected quarterly Additionally, QA/QC groundwater samples will be collected and analyzed for the landfill CAMU areal configuration pre-operational monitoring program Generally, samples for GC/MS conformational analyses will be collected in an amount equal to 10 percent of the investigative samples

During the pre-operational monitoring period, groundwater samples will be analyzed using PMRMA-certified methods for the list of 61 target analytes provided in Table K3 Also provided in the table are the methods of analysis applicable to each target analyte Noncertified analyses will be performed on groundwater samples by the field sampling team for temperature, conductivity, pH, alkalinity, dissolved oxygen, and turbidity

One or more analytical laboratories may be used to perform analyses for specific target compounds One certified reporting limit (CRL), described in the QAMP (HLA, 1993b), will be established for each target compound This will eliminate the possibility of more than one CRL being reported for any specific target compound

8.0 DATA EVALUATION AND RECORD KEEPING

8.1 Data Evaluation Including Statistical Analysis of Results

Water-level data collected during each sampling event and other available data, if applicable, will be used to evaluate the groundwater flow patterns in the landfill area Water-level data will be plotted in conjunction with the annual RMA GMP results

Groundwater analytical data collected as part of the pre-operational monitoring program will be reviewed initially to identify the background water quality conditions within the landfill CAMU areal configuration, including the CFS and the UFS Statistical methods will be used to evaluate the operational closure and postclosure monitoring data using standard EPA guidance on statistical analysis of groundwater monitoring data (EPA, 1989, 1992) as discussed in Section 2 1 After completion of the pre-operational monitoring period, a specific procedure for evaluation of the operation groundwater monitoring data will be developed by the Army and submitted for CDPHE approval as part of the Revised CAMU Groundwater Monitoring Program

8.2 Record Keeping and Reporting

The Army will keep records of the analyses and associated groundwater surface elevation throughout the closure and post-closure monitoring period Groundwater monitoring information will be reported to CDPHE on a frequency that will be established in the final groundwater monitoring plan

9.0 ACRONYMS

Army	U S Department of the Army
bgs	Below ground surface
C	Downgradient concentration of interest
C_o	Source concentration
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CFS	Confined flow system
COC	Chain of Custody
CRL	Certified Reporting Limit
CVAA	Cold vapor atomic adsorption
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
Denver Fm	Denver Formation
DIMP	Diisopropylmethyl phosphonate
DQO	Data quality objectives
DOT	U S Department of Transportation
Ebasco	Ebasco Services, Inc
EC	Electrical conductivity
EPA	U S Environmental Protection Agency
ESE	Environmental Science and Engineering, Inc
FFA	Federal Facilities Agreement
GCCD	Gas chromatography/chemiluminescencedetector
GC/CON	Gas chromatography/conductivitydetector
GC/ECD	Gas chromatography/electroncapture detector

GC/FID	Gas chromatography/flame ionization detector
GC/FPD	Gas chromatography/flame photometric detector
GC/MS	Gas chromatography/mass spectrometry
GC/PID	Gas chromatography/photoionization detector
GC/NPD	Gas chromatography/nitrogen phosphorous detector
GMP	Groundwater Monitoring Program
HCl	Hydrochloric acid
HLA	Harding Lawson Associates
HNO_3	Nitric acid
HPLC	High phase liquid chromatography
H_2SO_4	Sulfuric acid
ICP	Inductively coupled argon plasma screen
ID	Inner diameter
IMPA	Isopropylmethylphosphonic acid
IONCHROM	Ion chromatography
ISE	Ion selective electrode
MEMO	Monitoring Efficiency Model
MIBK	Methyl isobutyl ketone
MKE	Morrison-Knudsen Engineers, Inc
ml	Milliliter
NDMA	N-nitrosodimethylamine
NaOH	Sodium hydroxide
OCP	Organochlorine pesticides
OPP	Organophosphorus pesticides
OPC	Organophosphorus compounds
OSC	Organosulphur compounds
PID	Photoionization detector

PMRMA	Program Manager for Rocky Mountain Arsenal
PMSD	Program Manager Support Division
PPE	Personal protective equipment
PVC	Polyvinylchloride
QAC	Quality Assurance Coordinator
QAMP	Quality Assurance Management Plan
QA/QC	Quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RMA	Rocky Mountain Arsenal
ROD	Record of Decision
SPDA	South Plants Decontamination Area
State	State of Colorado
TOC	Top of casing
UFS	Unconfined flow system
USCS	Unified Soil Classification System
USGS	U S Geological Survey
UXO	Unexploded ordnance
VHC	Volatile hydrocarbons
VOA	Volatile organic aromatics
VOC	Volatile organic compounds
VOH	Volatile organic halogens
°F	Degrees Fahrenheit
µg/l	Micrograms per liter
µl	Microliters

10.0 REFERENCES

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Table K1: 1995 RMA Sitewide Groundwater Monitoring Program Monitoring Wells Located Near the Landfill Area

Water-Level Monitoring Wells

Section	Number of Wells	Well Designation–Unconfined Flow System
25	37	001, 003, 004, 008, 011, 012*, 015, 018, 022, 023, 025, 026, 028, 030, 031, 032, 033, 035, 038, 039*, 041, 042, 043, 044, 046, 047, 048, 049, 051, 052, 054, 055, 056, 057, 058, 059, 062,
Eastern 26	11	051, 037, 074, 123, 124, 143, 155, 158, 159, 164, 170

Section	Number of Wells	Well Designation–Confined Flow System
25	14	007, 009, 010, 013, 014, 016, 017, 019, 020, 021, 024, 029*, 034, 037
Eastern 26	5	055, 075, 144, 150, 156*

Water-Quality Monitoring Wells

Section	Number of Wells	Well Designation–Unconfined Flow System
25	0	none
Eastern 26	4	073, 155, 158, 170

Section	Number of Wells	Well Designation–Confined Flow System
25	0	none
Eastern 26	0	none

Source United States Geological Survey, 1995

* Flow system designation — unknown.

Table K2: Proposed CAMU Groundwater Monitoring Program Monitoring Well Networks

Well Number	Flow System Designation	Gradient Direction
Proposed Monitoring Well Network for the Background Monitoring Period		
25003	UFS	Downgradient
25008	UFS	Downgradient
25015	UFS	Downgradient
25022	UFS	Upgradient
25028	UFS	Downgradient
25031	UFS	Downgradient
25033	UFS	Downgradient
25035*	UFS	Downgradient
26073	UFS	Downgradient
26097	UFS	Downgradient
26123	UFS	Downgradient
26143	UFS	Downgradient
26155	UFS	Downgradient
26159	UFS	Upgradient
(plus 4 new wells)	UFS	1 upgradient and 3 downgradient
Proposed Monitoring Well Network for the Operational Monitoring Period		
25003	UFS	Downgradient
25015	UFS	Downgradient
25022	UFS	Upgradient
25028	UFS	Downgradient
25031	UFS	Downgradient
25033	UFS	Downgradient
25035*	UFS	Downgradient
26073	UFS	Downgradient
26123	UFS	Downgradient
26155	UFS	Downgradient
26159	UFS	Upgradient
(plus 4 new wells)	UFS	1 upgradient and 3 downgradient

The monitoring well network for the closure and post-closure monitoring period will be developed after groundwater data are available from the operational monitoring period

CAMU Corrective Action Management Unit
UFS Unconfined flow system

* Well number 25035 is dry periodically and will be sampled only when sufficient water is available

Table K3: Background Monitoring Period Analyte List

Agent Products by HPLC
Thiodiglycol

Agent Products by IONCHROM
Isopropylmethylphosphonic acid

Metals by ICP
Arsenic
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Zinc

Organophosphorus Compounds by GC/FPD
Diisopropylmethyl phosphonate (DIMP)

Semivolatile Organic Compounds by GC/MS*
1,4-Oxathiane
2,2′-bis(Para-chorophenyl)-
1,1-dichloroethane
2,2′-bis(Para-chlorophenyl)-
1,1,1-trichloroethane
Aldrin
Atrazine
Chlordane
Dibromochloropropane
Dicyclopentadiene
Dieldrin
Diisopropylmethyl phosphonate
Dimethylmethyl phosphonate
Dithiane
Endrin
Hexachlorocyclopentadiene
Isodrin
Malathion
p-Chlorophenylmethyl sulfide
p-Chlorophenylmethyl sulfone
p-Chlorophenylmethyl sulfoxide
Parathion
Supona
Vapona

Organochlorine Pesticides by GC/ECD
2,2′-bis(Para-chlorophenyl)-
1,1-dichloroethane
2,2′-bis(Para-chlorophenyl)-
1,1,1-trichloroethane
Aldrin
Chlordane
Dieldrin
Endrin
Hexachlorocyclopentadiene
Isodrin

Organophosphorus Pesticides by GC/NPD
Atrazine
Malathion
Parathion
Supona
Vapona

Organosulphur Compounds by GC/FPD
1,4-Oxathiane
Benzothiazole
p-Chlorophenylmethyl sulfide
p-Chlorophenylmethyl sulfone
p-Chlorophenylmethyl sulfoxide
Dimethyldisulfide
Dithiane

Volatile Aromatic Organic Compounds by GC/PID
Benzene
Ethylbenzene
Toluene
m-Xylene
o- and p-Xylene

Volatile Halogentated Organic Compounds by GC/CON
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
1,3-Dichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Carbon tetrachloride

Table K3 (continued)

Volatile Halogentated Organic Compounds by GC/CON (continued)
Chlorobenzene
Chloroform
Methylene chloride
Tetrachloroethylene
Trichloroethylene

Volatile Hydrocarbon Compounds by GC/FID
Bicycloheptadiene
Dicyclopentadiene (DCPD)
Methylisobutyl ketone (MIBK)

Mercury by CVAA

Cyanide by Colorimetric

Anions by IONCHROM
Chloride
Sulfate

Cations by ICP
Calcium
Magnesium
Sodium
Potassium

Fluoride by ISE

Other Organics by GC/ECD
Dibromochloropropane

N-nitrosodimethylamine by GCCD

Volatile Organic Compounds by GC/MS*
1,1-Dichloroethane
1,1-Dichloroethylene
1,2-Dichloroethane
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
1,3-Dichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Benzene
Bicycloheptadiene
Carbon tetrachloride
Chlorobenzene
Chloroform
Dibromochloropropane
Dicyclopentadiene
Dimethyldisulfide
Ethylbenzene
Methylene chloride
Methylisobutyl ketone
Tetrachloroethylene
Toluene
Trichloroethylene
m-Xylene
o- and p-Xylene

Total Organic Carbon

Dissolved Organic Carbon

Other Ions by Colorimetric
Nitrate/nitrite
Ammonium nitrogen
Total Kjeldahl nitrogen

Field Parameters
Alkalinity
Conductivity
Dissolved oxygen
pH
Temperature
Turbidity

Table K3 (continued)

Source RMA Groundwater Monitoring Program Target Analyte List USGS, 1995

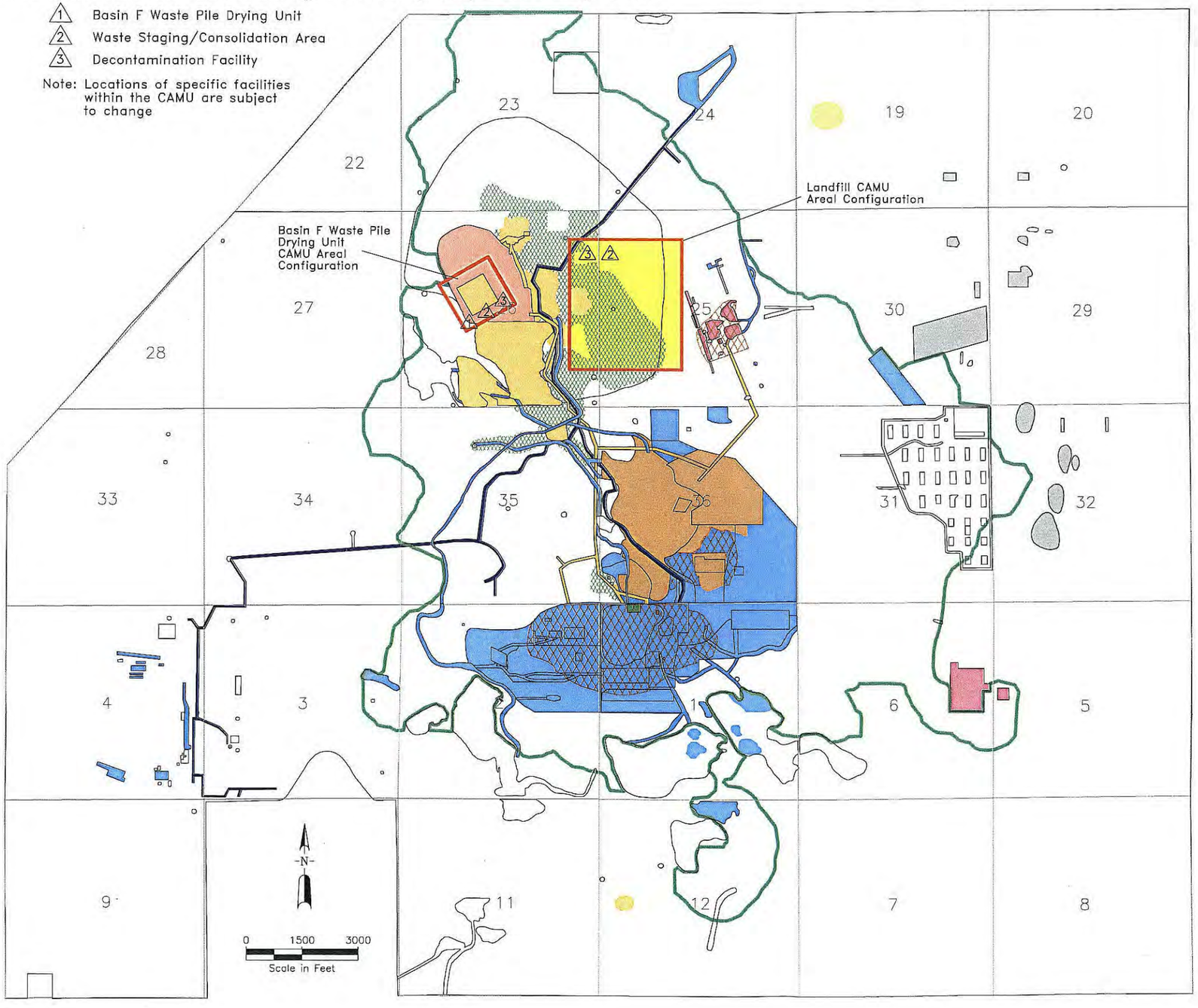
AA	Atomic absorption spectrometry
C	Colorimetric
CVAA	Cold vapor atomic absorption
GCCD	Gas chromatography/chemiluminescence detector
GC/CON	Gas chromatography/conductivity detector
GC/ECD	Gas chromatography/electron capture detector
GC/FID	Gas chromatography/flame ionization detector
GC/FPD	Gas chromatography/flame photometric detector
GC/MS	Gas chromatography/mass spectrometry
GC/NPD	Gas chromatography/nitrogen phosphorous detector
GC/PID	Gas chromatography/photoionization detector
HPLC	High performance liquid chromatography
ICP	Inductively coupled argon plasma screen
IONCHROM	Ion chromatography
ISE	Ion selective electrode
MIBK	Methylisobutyl ketone

* GC/MS analyses for confirmation purposes will be performed on 10 percent of samples only

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

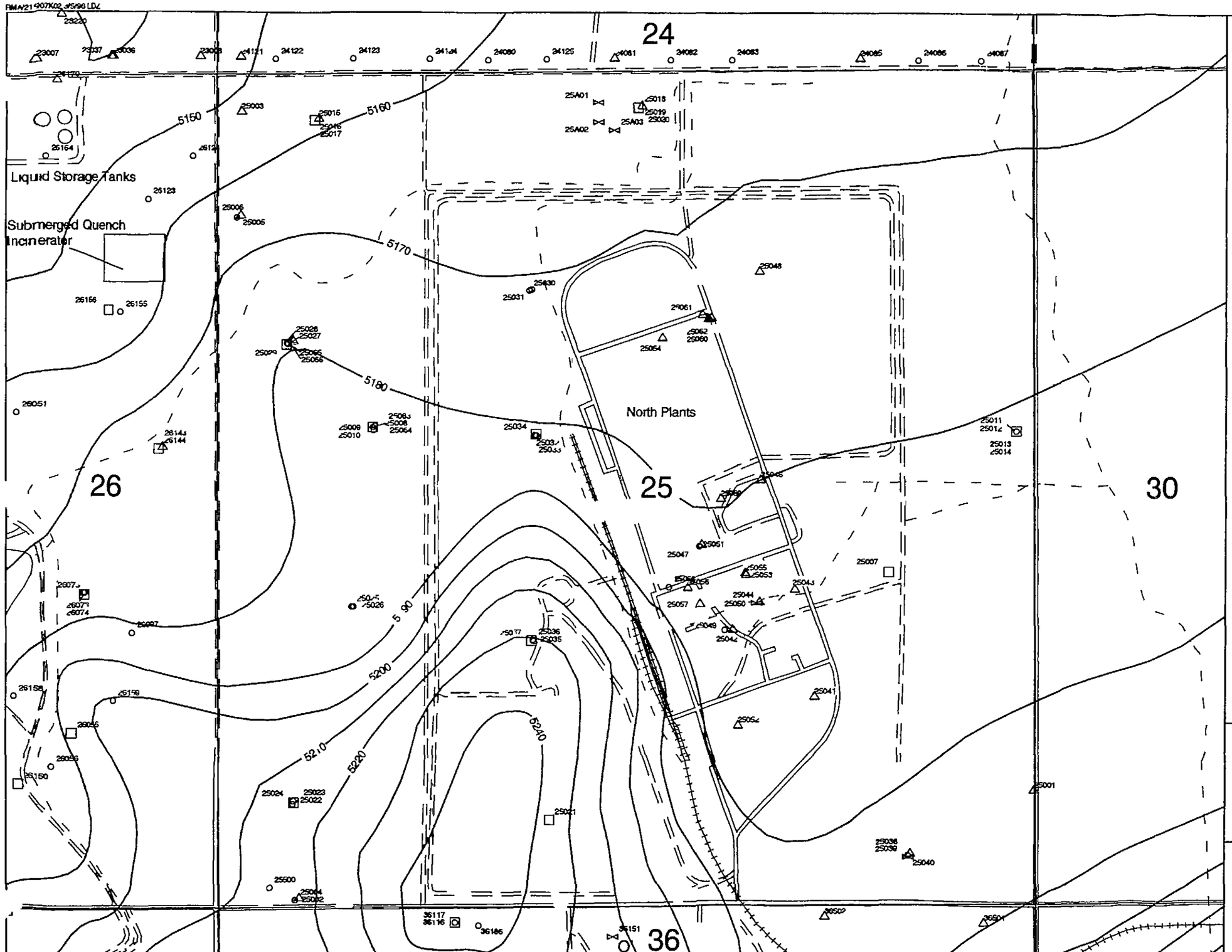
[2] Wastepile material will be dried prior to landfilling if paint filter test is failed

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

Prepared by: Tetra Tech EC, Inc.

Figure K1

Proposed Corrrective Action Management Unit Areal Configuration
Rocky Mountain Arsenal



Explanation

- Alluvial well with well number
- Unconfined Denver Formation well with well number
- Confined Denver Formation well with well number
- Unknown well classification
- Unpaved roadway
- Surface drainage
- 30 Section number
- Water table elevation (10 foot contour interval)

Source Groundwater Monitoring Program Groundwater Monitoring Report for 1993 (HLA 1995)

Note

Well number 25035 is periodically dry The water table measured in the well may represent perched groundwater conditions

0 600

Scale in feet

Prepared for:

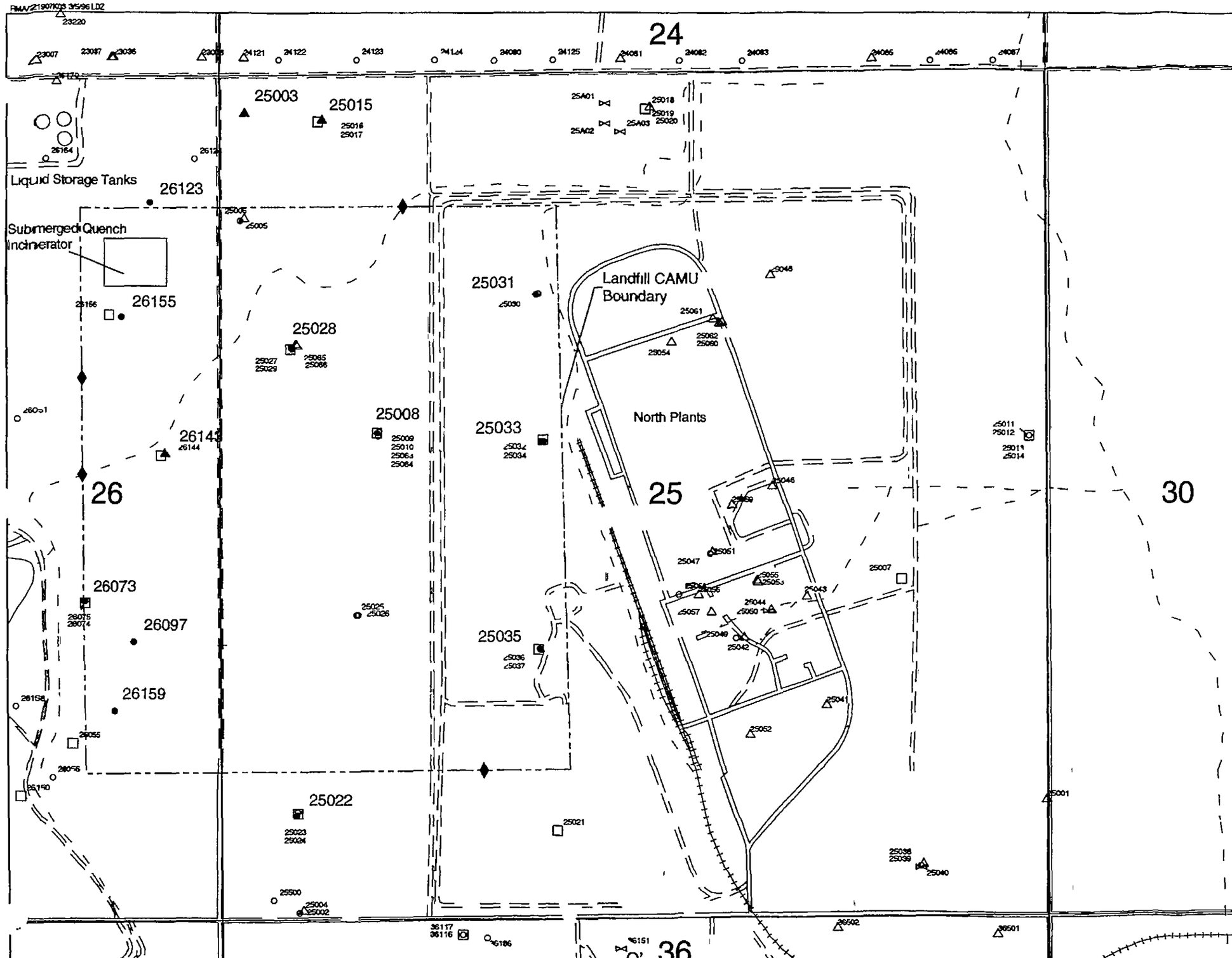
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by

Harding Lawson Associates

Figure K2

Water-Table Map of the Unconfined Flow System
Section 25



Explanation

- Alluvial well with well number
- Unconfined Denver Formation well with well number
- Confined Denver Formation well with well number
- Unknown well classification
- Unpaved roadway
- Surface drainage
- 30 Section number
- Corrective Action Management Unit Landfill Boundary
- Alluvial well included in monitoring well network
- Unconfined Denver Formation Well included in monitoring well network
- New well included in monitoring well network

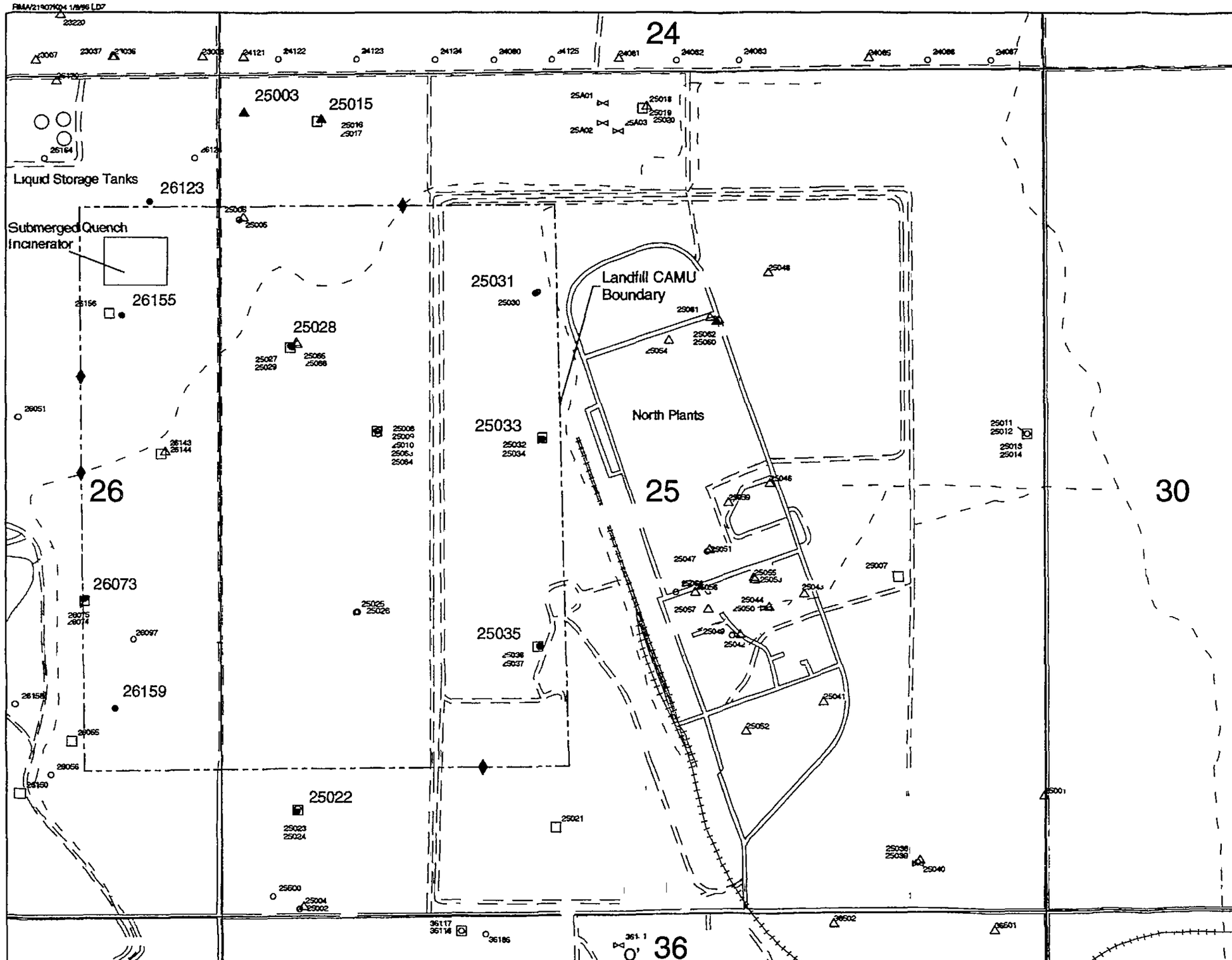
0 600
Scale in feet

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure K3

Location Map of the Proposed Pre-operational Period Monitoring Well Network



Explanation

- Alluvial well with well number
- Unconfined Denver Formation well with well number
- Confined Denver Formation well with well number
- Unknown well classification
- Unpaved roadway
- Surface drainage
- 30 Section number
- Corrective Action Management Unit Landfill Boundary
- Alluvial well included in monitoring well network
- Unconfined Denver Formation Well included in monitoring well network
- New well included in monitoring well network

0 600
Scale in feet

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure K4

Location Map of the Proposed Operational Period Monitoring Well Network

MAJOR DIVISIONS			SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS OVER 50%>No 200 SIEVE SIZE	GRAVELS MORE THAN 1/2 OF COARSE FRACTION> No 4 SIEVE SIZE	CLEAN GRAVELS WITH LESS THAN 5% FINES	GW	Well-graded gravels or gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH OVER 15% FINES	GM	Silty gravels, gravel-sand mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS MORE THAN 1/2 OF COARSE FRACTION< No 4 SIEVE SIZE	CLEAN SANDS WITH LESS THAN 5% FINES	SW	Well-graded sands or gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH OVER 15% FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS OVER 50%<No 200 SIEVE SIZE	SILTS & CLAYS LIQUID LIMIT 50% OR LESS		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS & CLAYS LIQUID LIMIT GREATER THAN 50%		MH	Inorganic silts micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils
DEBRIS ZONE*				Metal concrete plastic brick, wood, etc
CONSTRUCTION DEBRIS*				Concrete, wood, rebar, asphalt

SYMBOLS KEY

■	Bulk or classification sample
☒	No sample recovery
▯	Undisturbed sample
▽	First-encountered groundwater level
▼	Static groundwater level
(10YR 4/4)	Munsell soil color chart 1990 edition

GRAIN SIZE CHART

CLASSIFICATION	RANGE OF GRAIN SIZES	
	U S Standard Sieve Size	Grain Size in Millimeters
BOULDERS	Above 12"	Above 305
COBBLES	12" to 3"	305 to 76 2
GRAVEL	3" to No 4	76.2 to 4.75
coarse	3" to 3/4"	76.2 to 19 1
fine	3/4" to No 4	19 1 to 4 75
SAND	No 4 to No.200	4 75 to 0 075
coarse	No 4 to No 10	4 75 to 2 00
medium	No 10 to No 40	2 00 to 0 425
fine	No 40 to No.200	0 425 to 0 075
SILT & CLAY	Below No.200	Below 0.075

Source ASTM D 2488-90, based on Unified Soil Classification System
* Not part of ASTM Classification System

SOILCLS2

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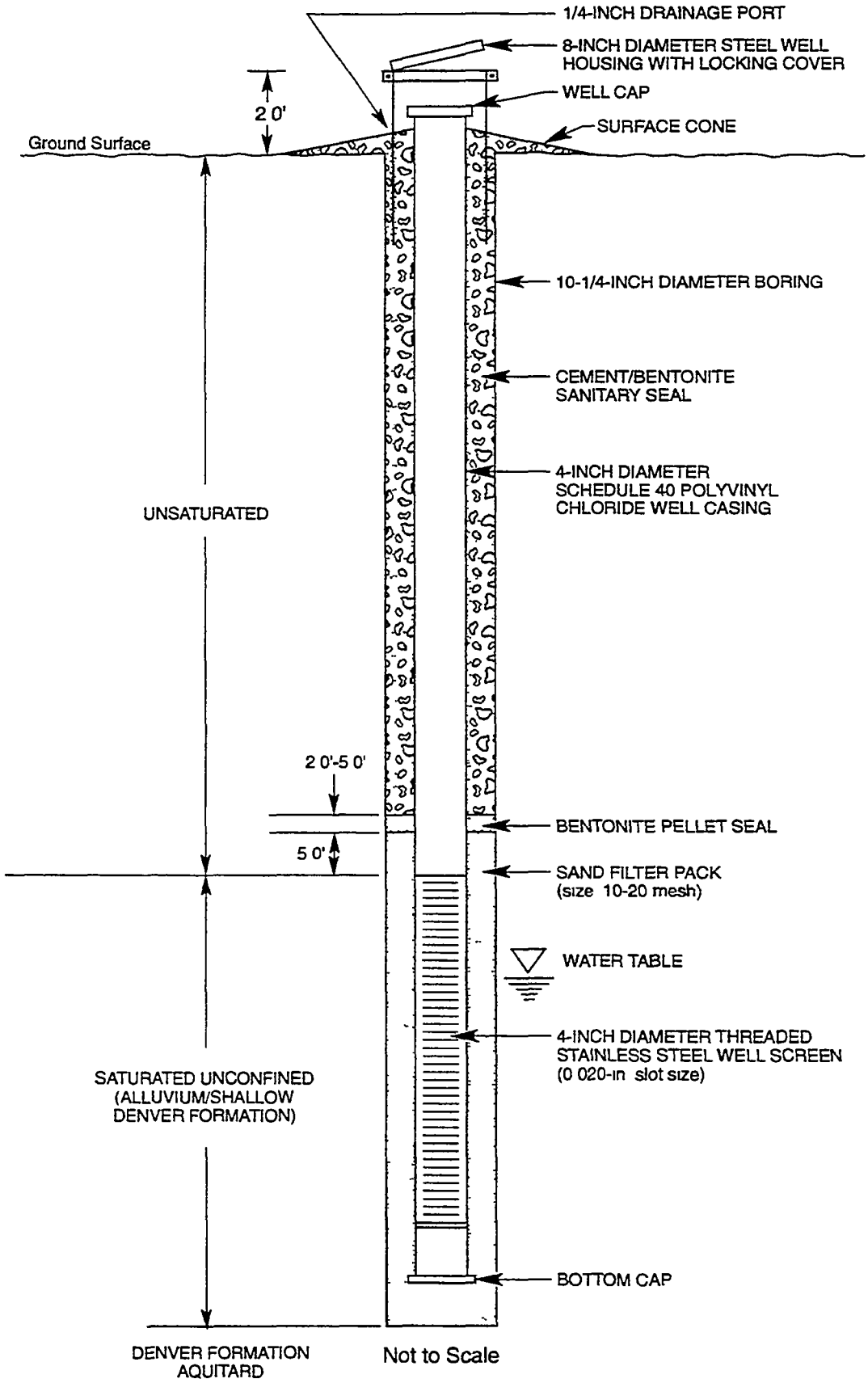
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K5

Unified Soil Classification Chart



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Harding Lawson Associates

Figure K6

Generalized Construction for Alluvial/Unconfined Denver Formation Monitoring Well

RMA 1254 1 1/8/96 LAM

Harding Lawson Associates
2400 ARCO Tower
707 Seventeenth Street
Denver CO 80202
303/292-5365
Telecopy 303/292-5411

RMA 1254 5a 1/9/96 LAM

Record of Activities at Well Sites Water Level Measurements

Project ______________________ Project Number ______________________

Location ______________________ Supervisor ______________________

Well No	Casing Dia (in)	Date	Time	PID Reading		Stick Up		Water Level		Total Depth (Feet)	Measuring Device	Sampler's Initials	Comments
				Bkgnd	TOC	(Feet)	(Tenths)	(Feet)	(Tenths)				

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Commerce City, Colorado

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Figure K7

Water-level Measurement Form

Harding Lawson Associates

GROUNDWATER SAMPLING FIELD DATA SHEET

Log Book # _____
Page _____ of _____

Well ID No

Casing Diameter _____ in

Casing Stickup _____ ft.

Total Well Depth _____ ft.

Static Water Level _____ ft.

Saturated Thickness _____ ft.

Casing Volume / Annulus Vol _____ gal

Screened Interval _____ ft.

Purge Equipment

- ☐ Dedicated Pump
  Settings:
  Charge _____
  Discharge _____
- ☐ Bennett Pump (Teflon Tubing)
- ☐ Meyers Pump (PVC Tubing)
- ☐ Grundfos Pump (Neoprene Tubing) ☐ 2 in. ☐ 3 in.
- ☐ Stainless Bailer

O D		LENGTH	
1.65"	☐	☐	2 ft.
1.85"	☐	☐	3 ft.
3.75"	☐	☐	4 ft.
___	☐	☐	___ ft.

SERIAL NO _____

Sample Equipment

- ☐ Dedicated Pump
  Settings:
  Charge _____
  Discharge _____
- ☐ Bennett Pump (Teflon Tubing)
- ☐ Meyers Pump (PVC Tubing)
- ☐ Grundfos Pump (Neoprene Tubing) ☐ 2 in. ☐ 3 in.
- ☐ Stainless Bailer

O D		LENGTH	
1.65	☐	☐	2 ft.
1.85	☐	☐	3 ft.
2.75	☐	☐	4 ft.
___	☐	☐	___ ft.

SERIAL NO _____

Purge Containerized ? ☐ Yes ☐ No

Bulk ☐ Tank # _____
Barrel ☐ # s _____

Analytical Equipment

pH Meter
- ☐ Beckman phi 21
- ☐ HACH
- ☐ Orion SA250
- ☐ Other _____

SERIAL NO _____

Conductivity Meter
- ☐ YSI Model 33
- ☐ Curtin Matheson
- ☐ Other _____

SERIAL NO _____

Dissolved Oxygen Meter
- ☐ YSI Model 51B

SERIAL NO _____

Temperature Meter
- ☐ Beckman phi 21
- ☐ HACH
- ☐ Orion SA250
- ☐ Other _____

SERIAL NO _____

Filtration Equipment
- ☐ Geotech Penstaltic Pump
- ☐ Geotech 0.45 micron filter
- ☐ Dispos. 0.45 micron filter

Water Level Meter
Solinst ___ HLA# ___

Samplers Initials	Time	Date

Meter Calibration

pH 7.00= _____ at _____ °C _____ Time

pH 10.00= _____ at _____ °C _____ Time

Conductance Standard _____ umhos/cm at 25°C

Measured Value _____ umhos/cm at _____ °C _____ Time

Calibrated Conductivity = Measured Conductance + (0.02) (measured conductance) (25°C - Actual Temp)

_____ umhos/cm at 25°C _____ Time

Dissolved Oxygen _____ mg/l at _____ °C _____ Time

Titration Results (Acid Concentration. 0.16 1.6)

pH	8.3	5.1	4.8	4.5
#Clicks				
Color				

Sample Depth. (ft.)

Time	Number of Casing Volumes	Gallons Removed	Water Level	°C	E.C umhos/cm	pH	Dissolved O_2 mg/Liter	Pump Rate GPM	Approx. Pump Depth ft.	Visual Description

Filter											
Analysis Requested											

- ☐ HNu
- ☐ OVm
- ☐ Microtip

Initial Readings	Sample Readings
TOC _____	TOC _____
BZ _____	BZ _____
Bkgnd _____	Bkgnd _____

Protective Level
A B C D

Serial # _____

HSO Signature

Condition of Well Remarks

Sampler Signature

RMA 1254.6a 1/30/96 LAM

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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K8

Groundwater Sampling Form

RMA 1254.3a 1/9/86 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

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K9

Sample Label

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

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

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Figure K10

Water Chain-of-custody Form

RMA 1254 4a 1/9/89 LAM

Attachment K1

ANALYSIS OF THE LANDFILL MONITORING WELL NETWORK EFFICIENCIES

The predicted performance of the proposed Corrective Action Management Unit (CAMU) landfill monitoring well network for monitoring the operational period of the landfill was evaluated using the Monitoring Efficiency Model (MEMO) MEMO provides a methodology for quantitatively comparing monitoring well system configurations based on site-specific geometries This attachment summarizes the MEMO methodology and describes how the method was applied to evaluate the landfill monitoring well network The MEMO methodology and model are described in greater detail in Wilson and others (1992) and Golder Associates (1992)

METHODOLOGY

To implement MEMO methodology, a potential source area is defined and divided into a uniform grid of potential source points A constituent plume is then mathematically simulated from each potential source point using an analytical contaminant transport solution MEMO uses the two-dimensional solution of Domenico and Robbins (1985) as modified by Domenico (1987), which characterizes the source as a horizontal line of constant concentration and finite width perpendicular to groundwater flow direction, and predicts downgradient concentrations as a function of location and time The analytical solution is used to assess whether mathematically generated plumes reach a specified boundary (in this simulation the CAMU Landfill Boundary) beyond the potential source area before being detected by a monitoring well

Figure K1 1 illustrates the three possible results for each potential source point (1) the predicted plume reaches a steady state condition without intersecting the site boundary or being detected by a monitoring well (i e the source is of such diminutive magnitude that the plume does not reach a well or the site boundary), (2) the predicted plume is detected by a monitoring well before intersecting the site boundary, or (3) the predicted plume intersects the boundary before being detected by a monitoring well The current version of MEMO does not differentiate between results 1 and 3 identified above Efficiency of the system is then evaluated as the percentage of potential source points for which a successful result, or result number 2, is obtained

INPUT PARAMETERS

MEMO requires the following input parameters to assess the efficiency of a monitoring well network

- Geometry of the simulation domain (potential source area, site boundary, and monitoring well locations)
- Velocity of the simulated constituent in groundwater
- Groundwater flow direction
- Longitudinal and transverse dispersivities
- Source width
- Dilution contour (defined as the ratio of source concentration to a downgradient concentration of interest, in this case the detectable concentration)

In addition, the model will accept inputs for molecular diffusion and first-order decay mechanisms These mechanisms, however, were not considered for this analysis Neglecting all nonreversible mass transfer mechanisms (e g , decay or volatilization) results in a conservative assumption in that system efficiency will be underestimated Likewise, neglecting molecular diffusion also results in underestimation of system efficiency and is therefore considered a conservative assumption

If molecular diffusion and decay mechanisms are neglected, as they have been for this analysis, the solution for the monitoring well system efficiency is independent of the constituent velocity in the groundwater because the shape of a plume (as predicted by the Domenico and Robbins analytical solution) of a given length is independent of elapsed time For example, in the absence of molecular diffusion and decay, a plume that takes 5 years to reach a length of 500 feet will be identical to a plume that takes 50 years to reach a length of 500 feet Therefore, a determination of constituent velocity, or parameters upon which it is dependent (i e , hydraulic conductivity, hydraulic gradient, porosity, and retardation), is not required for this analysis A discussion of the other input parameters is provided in the paragraphs below

Geometry of the Simulation Domain

Geometry of the simulation domain is shown in Figure K1 2 The potential source area is considered to be the seven landfill cell footprints as illustrated in Figure K1 2 and presented in this CAMU Designation Document as a potential landfill cell layout It should be noted that this cell layout will likely change during design of the landfill When the landfill design is complete, a new simulation should be run through the MEMO model to verify the well network. The site boundary is equal to the CAMU Landfill Boundary The buffer zone is an extension of this boundary by approximately 1,000 feet to the north and south and approximately 500 feet to the east and west

Groundwater Flow Direction

For the model, the groundwater flow direction in the landfill area was subdivided into four flow directions as shown in Figure K1 2 The four flow directions are based on the water-table map illustrated in Figure K2 of Appendix K. In the western portion of the landfill area, the groundwater flows north 50 degrees west (N 50° W) There is a bedrock and groundwater high in the southeast quarter of the area East of the bedrock high groundwater flow is primarily to the east (N 90° E) North of the bedrock high groundwater flow is primarily to the N 0° E and N 50° E An evaluation of the sensitivity of the solution to flow direction is discussed in the sensitivity section

Longitudinal and Transverse Dispersivity

Dispersivity is a characteristic property of a porous medium that describes its tendency to disperse a plume of dissolved constituents migrating through the subsurface Dispersivity is generally used to characterize plume dispersion that occurs due to small-scale spatial variation in soil properties and temporal variations in the groundwater flow As noted by Wilson and others (1992), site-specific dispersivity data are rarely available At Rocky Mountain Arsenal (RMA), however, the published value for alluvial longitudinal dispersivity is 30 5 feet (Anderson, 1979) U S Environmental Protection Agency (EPA) guidance (1985) suggests that transverse dispersivity may be approximated as 0 33 times the longitudinal dispersivity Based on the published dispersivity and EPA guidance, longitudinal dispersivity was estimated as 30 5 feet and transverse dispersivity was estimated at 10 feet (0 33 times

the longitudinal dispersivity) An evaluation of the sensitivity of the solution to transverse dispersivity is discussed in the sensitivity section

Source Width

For the purposes of this analysis, a source width of 20 feet was assumed The landfill area is approximately 2,000 feet in width at its widest point, and therefore a 20-foot source width represents a contaminant source point that is approximately 1 percent of the total width of the source area Larger source widths generate plumes that are more easily detectable by the monitoring well network Smaller source widths require relatively stronger source concentrations to generate a plume of sufficient magnitude to result in detectable concentrations at the site boundary An evaluation of the sensitivity of the solution to source width is discussed in the sensitivity section.

Dilution Contour

Generally, a plume contour delineates an area within which a specified concentration is exceeded Areas within the plume contour exhibit concentrations above the contour value, while areas beyond the plume contour exhibit concentrations below the contour value MEMO methodology, however, defines the plume boundary as the ratio between source concentration (C_0) and a downgradient value of interest (C), in this case the detectable concentration This is achieved by rearranging the Domenico and Robbins solution to solve for the C_0/C ratio Wilson and others (1992) refer to the line of equal ratio as the dilution contour In practice, this method generates contours that are representative of a variety of C_0/C ratios For example, a dilution contour of 100 is equally valid in describing the 1 microgram per liter ($\mu g/l$) contour resulting from a 100 $\mu g/l$ source, the 2 $\mu g/l$ contour resulting from a 200 $\mu g/l$ source, etc An evaluation of the sensitivity of the solution to dilution contour is discussed in the sensitivity section

RESULTS

MEMO was used to evaluate various well configurations on the northern, eastern, and western perimeters of the CAMU Landfill Boundary which, based on past water-level observations, are downgradient of the landfill cells Results of numerous MEMO simulations indicate that an optimal design of

12 downgradient wells are proposed to monitor the area The selected downgradient well configuration is illustrated in Figure K1 2, and is also described in the text of Appendix K.

A sample of model results for a single simulation is provided as Figure K1 2 The hatched portion of the landfill area indicates areas from which a source would be detected Figure K1 2 illustrates that for the selected downgradient well configuration the simulated efficiency of the system in detecting a single 20-foot-wide source is approximately 99 percent The input parameters used in the model run illustrated in Figure K1 2 are as follows

- The geometry of simulated domain as illustrated in Figure K1 2 with the seven-cell landfill footprints as the potential source areas of contamination and a network of 12 downgradient monitoring wells
- The velocity of the simulated constituent in groundwater is equal to the groundwater flow rate (no retardation or attenuation of the constituents)
- The longitudinal dispersivity is 30 5 feet and the transverse dispersivity is 10 0 feet
- The source width is 20 feet
- The dilution contour is $1\ 0 \times 10^{-3}$

The input parameters were selected after performing a sensitivity analysis discussed in the following section The input parameters represent the selected values based on the results of the sensitivity analysis

Two points are worth noting about the model results, as expected, the further upgradient the potential source is from the monitoring wells and the closer it lies to a stream line that runs through a well, the easier it is to detect a release from that point. Furthermore, the definition of efficiency is the probability that a single source occurring in a random location within the source area extent will be detected before resulting in a detectable concentration at the site boundary Probability of detection greatly increases in the event of multiple sources The probability that multiple, randomly distributed sources would be detected can be calculated as $1-(1-\alpha)^n$, where α is the probability of detection for one source and n is the

number of sources For example, the optimal 12-well efficiency increases from 99 percent to 100 percent if two sources exist rather than just one

SENSITIVITY OF RESULTS TO INPUT PARAMETERS

Sensitivity of the model results to the input parameters including source width, flow direction, transverse dispersivity, longitudinal dispersivity, and dilution was examined by perturbing one of the parameter inputs while keeping all other inputs fixed Results of the sensitivity tests are summarized in Table K1 1

Table K1 1 illustrates that 20 feet is a conservative source width for this analysis, as using source widths that are either an order of magnitude higher or lower both resulted in system efficiencies of greater than 90 percent As described in the results section, larger source widths result in plumes that are more easily detected by the monitoring well system, and smaller source widths result in plumes that do not increase concentrations to detectable levels at the site boundary, except at very high source concentrations Table K1 1 also illustrates that this analysis is not highly sensitive to variations in flow direction, or 50 percent changes in transverse or longitudinal dispersivity The maximum change observed in the predicted system efficiency during analysis of sensitivity was a decrease to 82 percent (from 98 percent), which resulted from a change in the groundwater flow direction from the four estimated flow directions calculated from the map in Figure K1 2 to a simplified estimate of two flow directions

REFERENCES

Anderson, M P 1979 Using models to simulate the movement of contaminants through groundwater flow systems, *Critical Reviews in Environmental Control* 9(2) 97-156

Domenico, P A 1987 An analytical model for multidimensional transport of a decaying contaminant species *Journal of Hydrology* (91) 49-85

Domenico, P A and G A. Robbins 1985 A new method of contaminant plume analysis *Ground Water* 23(4) 476-485

Golder Associates 1992 *User's manual, monitoring analysis package including MEMO, PLUME, and COPRO* (version 1 1)

U S Environmental Protection Agency 1985 *Water quality assessment, a screening procedure for toxic and conventional pollutants in surface and ground water-part II* Environmental Research Laboratory, Office of Research and Development, Athens, GA., EPA/600/6-85/002b, September

Wilson, C R , C M Einberger, R L Jackson, and R B Mercer 1992 Design of ground-water monitoring networks using the monitoring efficiency model (MEMO) *Ground Water* 30(6) 965-970

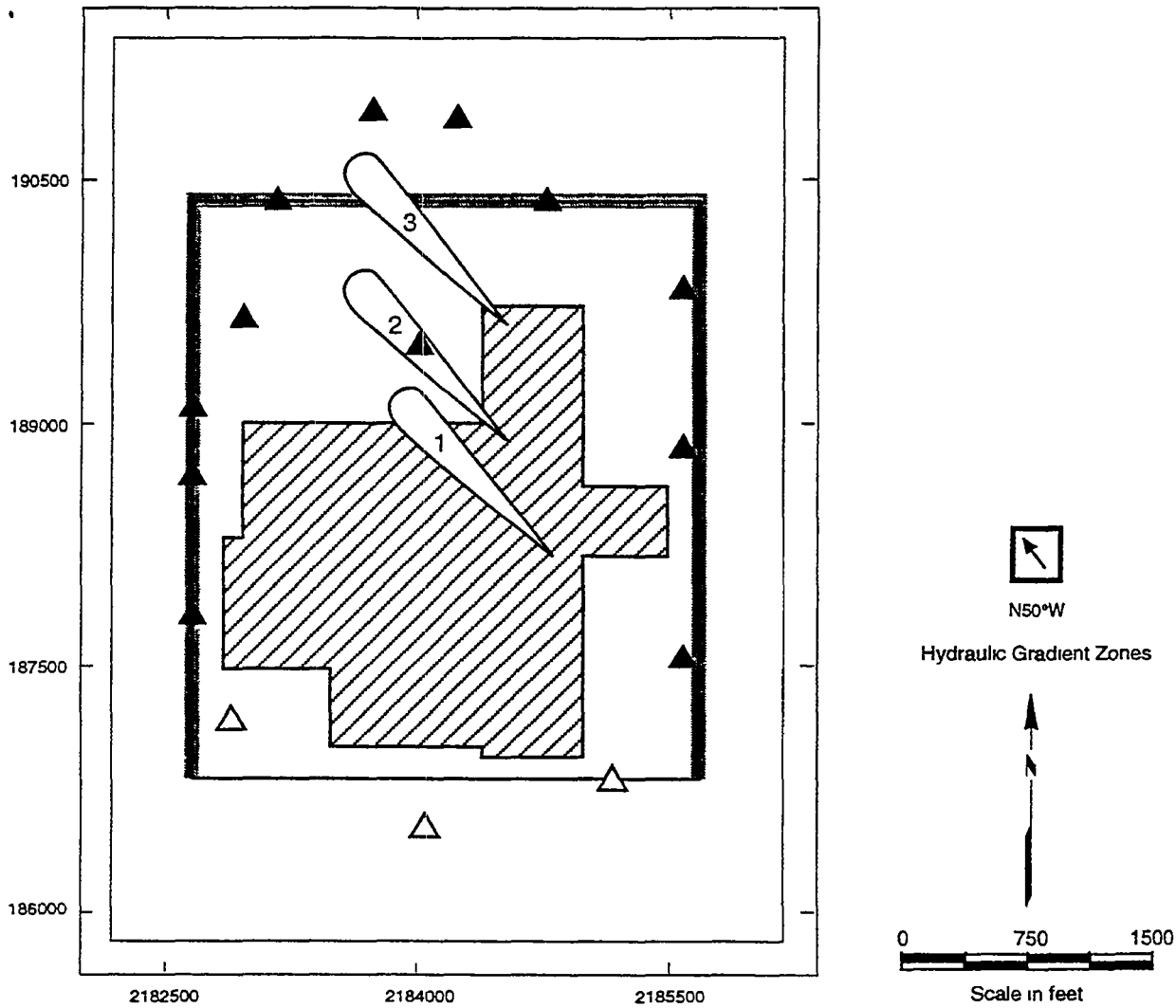
Table K1.1: Summary of Analysis of MEMO Sensitivity to Input Values Selected

Parameter	Sensitivity to Higher Value		Selected Value Result		Sensitivity to Lower Value	
	Model Input	Efficiency	Model Input	Efficiency	Model Input	Efficiency
Source width	200 feet	100 percent	20 feet	99 percent	2 feet	95 percent
Groundwater flow direction	N 50° W	99 percent	N 90° E N 40° E N 0° W N 50° W	99 percent	N 95° E N 45° E N 5° E N 45° W	99 percent
Transverse dispersivity	15 feet	99 percent	10 feet	99 percent	5 feet	97 percent
Longitudinal dispersivity	45 feet	99 percent	30 5 feet	99 percent	15 feet	99 percent
Dilution	10×10^4	99 percent	$1\ 0 \times 10^3$	99 percent	$1\ 0 \times 10^2$	95 percent

MEMO Monitoring Efficiency Model
N North
E East
W West
° Degrees

21907 705013
1213010696 CP

RMA 1249 03/07/86 ECS



Explanation

▨	Conceptual Landfill Footprints (Potential Source Areas)	N	North
▲	Downgradient monitoring well locations	°	Degrees
△	Upgradient monitoring well locations	W	West
	Three possible results for simulated constituent plumes	E	East
		2182500,186000	X and Y state planar coordinates
▬	Line of compliance		
─	CAMU Landfill Boundary		

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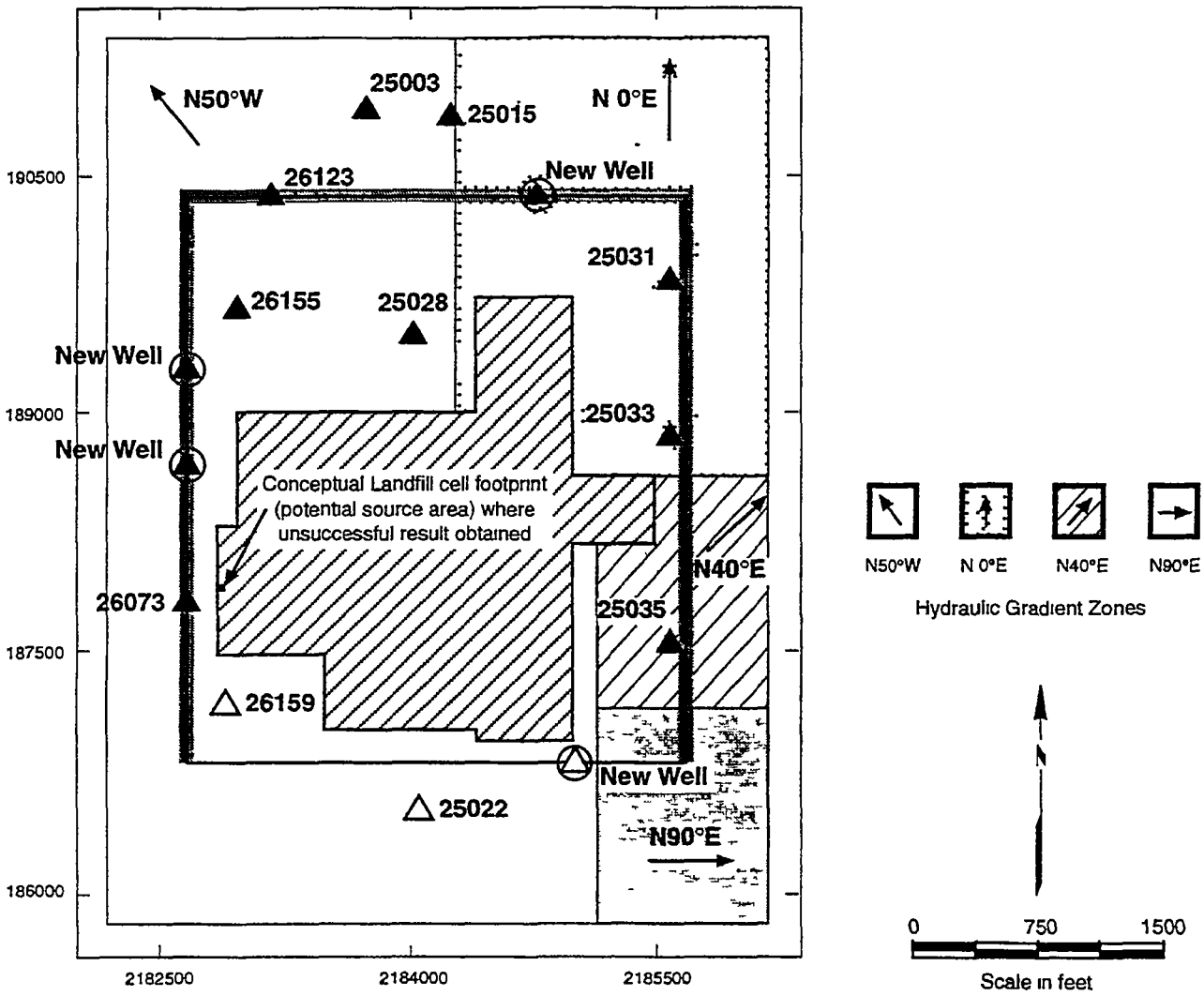
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K1 1

Simulation Domain and Three Possible Results for Simulated Constitutent Plumes



Explanation

- Conceptual Landfill cell footprints (potential source areas) where successful result is obtained using the selected input values
- ▲ Downgradient monitoring well locations
- △ Upgradient monitoring well locations
- Line of compliance
- CAMU Landfill Boundary

N	North
°	Degrees
W	West
E	East
2182500,186000	X and Y state planar coordinates

Note Well numbers not available for proposed new wells

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Commerce City, Colorado

Prepared by
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Figure K1 2

Sample Simulation Result

RMA 1249 1a 3/5/96 NLM

Appendix L

GUIDELINES FOR THE DEVELOPMENT OF A CLOSURE AND POST-CLOSURE PLAN

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1.0 INTRODUCTION

This guideline for the development of the CAMU Closure and Post-Closure 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 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

The CDD, including this appendix, will be submitted to Colorado Department of Public Health and Environment (CDPHE) in support of the designation of the CAMU This document presents guidance for the development of a final Closure and Post-Closure Plans for the CAMU at RMA. A general location map for RMA is presented in Figure L1 and the CAMU areal configuration is presented in Figure L2 The final Closure and Post-Closure Plan will be prepared in accordance with the Colorado Hazardous Waste Regulations found at 6 Code of Colorado Regulations (CCR) 1007-3, Section 264 552 Although not specifically required by 6 CCR 1007-3, Section 264 552, this Closure Plan will also use as guidance

many of the elements for closure and post-closure care specified in 6 CCR 1007-3, Part 265, Subpart G (Closure and Post Closure)

The final Closure Plan will specifically addresses the following areas or facilities within the CAMU that will require closure (1) landfill, (2) Basin F Waste Pile drying unit, (3) various waste staging/consolidation areas, and (4) decontamination facilities The Closure Plan will include post-closure care activities associated with the landfill 6 CCR 1007-3 Section 264 552 requires that areas within the CAMU where remediation wastes remain in-place after closure of the CAMU be managed and contained to control, minimize, or eliminate future releases to the extent necessary to protect human health and the environment The landfill is the only area identified within the CAMU boundary where remediation wastes will be placed into the CAMU as part of CAMU operations and will remain in place after closure Other facilities within the CAMU will not require post-closure care because waste will either be removed from these facilities or these facilities will be decontaminated during closure Closure performance standards will be established in the final closure plans developed for each facility Closure performance standards will be developed in consideration of existing contamination at RMA and will not be based on practical quantitation limits or other analytical detection limits

Section 2 0 of this document presents a general description of the RMA facility and the facilities within the CAMU undergoing closure Section 3 0 presents a general discussion of the closure procedures and the associated waste management activities that will be incorporated into the Closure Plan Section 4 0 describes the anticipated schedule for closure activities, and Section 5 0 provides guidance for the Post-Closure Plan Section 6 0 provides a list of acronyms, and Section 7 0 provides the reader with a list of references used in the document.

This document provides a framework for the final closure and post-closure of facilities within the CAMU The final Closure and Post-Closure Plan for each facility will be developed in the future as the design of

the CAMU progresses The Closure and Post-closure Plan will be submitted to CDPHE for approval in accordance with the schedule discussed in Section 5 0 and of the CDD

2.0 FACILITY DESCRIPTION

This section describes the RMA facility Specifically, the following subsections describe (1) the RMA site location and history, (2) the physical setting of the CAMU, (3) hydrogeologic conditions in the CAMU area, (4) current air monitoring activities, (5) remediation wastes associated with the CAMU, and (6) a description of the areas within the CAMU that require closure

2.1 General Description

RMA occupies more than 17,000 acres in Adams County, Colorado, northeast of the metropolitan Denver area (Figure L1) The RMA property was primarily used for agricultural purposes prior to 1942 In 1942, RMA was purchased by the federal government and used during World War II to manufacture and assemble chemical warfare materials and incendiary munitions A significant amount of chemical warfare materials destruction took place during the 1950s, 1960s, and 1970s The last demilitarization operations ended in the 1980s, and in November 1988, RMA was reduced to inactive military status with the only remaining mission at RMA being contamination cleanup In addition to military activities, major portions of the RMA facilities were leased to private industries, including Shell Oil Company, for the manufacture of various pesticides, insecticides, and herbicides

2.2 Physical Setting

RMA is accessible only to authorized personnel The CAMU boundary is within the property boundaries of RMA, as shown in Figure L2 The ground surface elevation within the CAMU generally ranges between 5,200 and 5,300 feet above mean sea level (msl) No 100-year floodplains have been identified within the CAMU The CAMU area includes the Basin F Waste Pile drying unit area and the landfill area The Basin F Waste Pile drying unit area occupies approximately 50 acres in the vicinity of the waste pile The landfill area occupies approximately 245 acres in the western half of Section 25 and the eastern half of Section 26

2.3 Hydrogeologic Information

This section describes the general geology and hydrogeology characterizing the area in which the CAMU is located The regional geology and hydrogeology have been discussed in detail in numerous reports including reports prepared by J May (1982), Morrison Knudsen Engineers, Inc (MKE) (1988), and Ebasco Services, Inc (Ebasco) (1989) and are not discussed in detail in this Closure Plan

2.3.1 Geology

Immediately underlying the western half of Section 25 and eastern portion of Section 26 (CAMU landfill area), are alluvial Quaternary deposits that overlie the Denver Formation. The alluvium is composed primarily of clay, silt, very fine- to fine-, to medium-grained sand with minor amounts of coarse-grained sands and gravels The alluvium ranges in thickness from approximately 5 to 58 feet thick in the landfill area. The Cretaceous-Tertiary Age Denver Formation is composed of primarily claystone with interbedded siltstone, sandstone, and lignite In the northern portion of Section 26, the Denver Formation is approximately 250 feet thick (Environmental Science and Engineering, Inc [ESE], 1988)

2.3.2 Hydrogeology

Groundwater at RMA occurs under both confined and unconfined conditions The Quaternary alluvium and weathered portion of the Denver Formation form a generally continuous groundwater system where the groundwater is typically unconfined This flow system is called the unconfined flow system Confining strata inhibit groundwater interaction between the unconfined flow system and the deeper, more permeable zones in the Denver Formation, called the confined flow system Within the landfill area, the groundwater flow in the unconfined flow system is generally from the southeast to the northwest There is a water-table high associated with a bedrock high in the south central portion of Section 25 The depth to groundwater in the landfill area ranges from 20 to 70 feet below ground surface

2.4 Current Groundwater Monitoring Program

Currently, as part of the site-wide Groundwater Monitoring Program, there are 48 wells used to monitor the water levels in the landfill area (U S Geological Survey [USGS], 1995). The water quality monitoring network is less extensive and includes only 4 unconfined flow system wells used to monitor the groundwater quality in the eastern portion of Section 26. Currently no wells are used to monitor the groundwater quality in the western portion of Section 25.

2.5 Remediation Wastes Associated with the CAMU

The On-post Operable Unit Detailed Analysis of Alternatives (DAA) Dispute Resolution Agreement dated October 16, 1995, states "A CAMU incorporating the future hazardous waste landfill, Basin F Waste Pile drying units(s), and the appropriate waste staging and/or management area(s) will be designated." The DAA was prepared under various authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The CAMU boundary shown in Figure L2 includes the landfill, Basin F Waste Pile drying unit, waste staging/consolidation areas, and decontamination facilities. Remediation wastes that will be placed into the landfill include (1) Basin F Waste Pile soils and (2) principal threat and human health exceedance soil or debris that will be landfilled from various areas of RMA, as defined in the Final DAA (Foster Wheeler, 1995). **Basin F Waste Pile soils and waste from Former Basin F, 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 will be placed in the triple-lined cells**. Basin F Waste Pile soils are listed hazardous wastes. Soil and debris from the balance of areas at RMA will be placed in the double-lined cells may be hazardous. Remediation waste placed into the CAMU does not constitute land disposal of hazardous waste for purposes of Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (LDRs) applicability

Leachate generated from the landfill will be managed appropriately either offsite or onsite in accordance with applicable regulatory requirements at the time of generation.

2.6 Description of Areas and Facilities Undergoing Closure

The following sections provide a physical description of the areas within the CAMU that will undergo closure, including the landfill, Basin F Waste Pile drying unit, waste staging/consolidation areas, and decontamination facilities. Although the Waste Pile and portions of the Former Basin F are included in the CAMU, closure of the Waste Pile and Former Basin F are addressed in a separate closure plan (BLA, 1995) and will not be addressed in the CAMU Closure Plan.

2.6.1 Landfill

A new onpost landfill will be constructed within the CAMU boundary as shown in Figure L2. The landfill will receive remediation waste from various areas at RMA and Basin F solids (currently stored in the Waste Pile). Approximately 1.8 million cubic yards of material win be placed into the landfill. The landfill CAMU area is approximately 245 acres. One or more cells (approximately 750,000 bank cubic yards [BCYI) will have an enhanced design with an additional liner and leak detection system and will contain contaminated soil from the Basin F Waste Pile, **Former Basin F, 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.**

2.6.2 Basin F Waste Pile Drying Unit

The Basin F Waste Pile drying unit will be constructed to dry waste pile solids that do not pass the paint filter test before placing the waste pile solids into enhanced cell(s) of the landfill. The drying system, as defined in the DAA, may consist of a direct or indirect-fired heating system to increase the soil temperature to reduce the soil moisture content. The off-gas from the drying unit will be collected and treated. A preliminary process flow diagram for the drying unit is illustrated in Figure L3. This process flow diagram and the unit processes shown are conceptual and will be finalized during the design process.

There are approximately 600,000 BCY of Basin F Waste Pile solids that will be placed into the landfill. It is currently estimated that up to 100,000 BCY (FosterWheeler,1995) of the waste pile solids will not pass the paint filter test and will require drying before being landfilled. However, this

estimate is preliminary and may be revised based on additional information that may be collected before and during the design process The proposed location for the Basin F Waste Pile drying unit is illustrated in Figure L2, and is included within the CAMU boundary The proposed location is preliminary and may be revised during the design process

2.6.3 Waste Staging/Consolidation Areas

Waste staging/consolidation areas will be used for temporary staging, processing, size reduction, and/or storage of remediation waste before it is transported to a treatment facility or to the landfill Figure L2 identifies preliminary staging areas that may be used during construction The proposed locations are preliminary and may be revised during the design process

2.6.4 Decontamination Facilities

Decontamination facilities will be used to decontaminate equipment or personnel that have been in contact with remediation waste Figure L2 identifies preliminary decontamination facilities that may be used during remedial action at the site The proposed locations are preliminary and may be revised during the design process

3.0 CLOSURE PROCEDURES

Closure activities will be performed to meet the closure standards specified in 6 CCR 1007-3, Section 264 552 The components of the contemplated closure procedures presented in this section use as guidance many of the elements for closure specified in 6 CCR 1007-3, Part 265, Subpart G In accordance with 6 CCR Section 264 552, the components of closure procedures described in this plan are designed to (1) minimize the need for further maintenance and (2) control, minimize, or eliminate, to the extent necessary to protect human health and the environment, for areas where remediation wastes remain in place, post-closure escape of remediation waste, hazardous constituents, leachate, contaminated runoff, or remediation waste decomposition products to the ground, groundwater, surface waters, or the atmosphere

The detailed components of closure which will be developed during design will be designed to provide long-term protection of human health and the environment Closure of the CAMU will include the following

- Containment of remediation waste in the landfill
- Requirements for capping the landfill, where remediation waste is placed into the CAMU and will remain in place
- Requirements for removal and decontamination of equipment, devices, and structures used in remediation waste management activities within the CAMU Equipment, devices, and structures within the CAMU that will require closure may include the thermal drying unit, construction staging areas, and decontamination facilities

Specific procedures for closure of these facilities will be developed during design and will include confirmation sampling and verification of decontamination

The following sections provide a general description of contemplated closure components, procedures for handling remediation waste during closure, site security, safety and health plan, decontamination, spill prevention and response, and a survey plat Guidance for post closure care for the landfill is addressed in Section 5 0

3.1 Closure Process

The closure process will consist of three phases of work construction, certification, and post-closure care As shown in Figure L4, each phase is comprised of one or more tasks A brief summary of the anticipated closure process and a description of each task are provided below

3.1.1 Construction Phase

This section describes the contemplated tasks associated with the construction phase including final cover installation, removal and/or decontamination of equipment, devices, and structures, and restoration

Task 1 - Final Cover Installation

A final cover will be installed over each cell upon completion of waste placement in each cell The final cover will be designed to

- Provide long-term minimization of migration of liquid through the closed landfill cell
- Function with minimum maintenance
- Promote drainage and minimize erosion or abrasion of the cover
- Accommodate settling and subsidence so that the cover's integrity is maintained
- Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil present

The proposed engineered cover will be a multi-layered system comprised of earthen and synthetic materials The conceptual design incorporates erosion control, water balance, and biotic barriers as primary factors Each component of the cover system performs a unique function and in some cases one component may serve multiple functions

A conceptual cross section of the anticipated cover is illustrated in Figure L5 Each of the cover components along with their intended functions is described in the CDD (Appendix B) The components selected for the final cover may change during design with CDPHE approval

The final cover will reduce the migration of remediation wastes into the surrounding environment by minimizing infiltration through the contaminated soil by isolating the contaminated media and reducing the possibility of human and biota exposure by direct contact. The cover will be designed to function with minimum maintenance The cover design will include self-sustaining vegetation and a biota barrier layer that will inhibit cover damage from burrowing animals The cover design will include a sloped surface and a vegetation layer that promotes drainage and minimizes erosion. The final cover will have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil present The cover will also accommodate settling and subsidence so that the cover's integrity is maintained The details of the final cover will be developed during the design phase and submitted for CDPHE approval

Task 2 - Removal and/or Decontamination of Equipment, Devices, and Structures

Decontamination procedures for equipment, containment system components, and structures that are part of the CAMU will be developed during preparation of the final closure plan for the landfill Contaminated soil resulting from equipment, devices, or structures decontamination will be placed in the onsite landfill Decontaminated equipment, devices, and structures will be disposed or reused Specific procedures for decontamination and disposal or reuse of equipment, devices, and structures that are part of the CAMU will be developed during design

Task 3 - Restoration

After the final cover has been installed over the landfill, the cover will be revegetated The vegetation types that will be used will be selected on the basis of low maintenance requirements, ability to minimize erosion, depth of root structure, drought resistance, and factors related to wildlife use The details of restoration will be developed during the design phase

Upon completion of the Construction Phase, any wells needed for ongoing monitoring that are damaged or otherwise rendered unsuitable for groundwater monitoring will be replaced The replacement wells will be constructed according the State of Colorado requirements for monitoring

well installation The damaged wells will be abandoned in accordance with state well closure requirements

3.1.2 Certification Phase

Task 4 - Closure Certification

Certification that the CAMU has been closed in accordance with the procedures outlined in the final Closure Plan will be submitted to CDPHE within 60 days of completion of final closure of the CAMU The closure certifications will be submitted to CDPHE and will be signed by the Army and by an independent Colorado registered professional engineer The professional engineer will not have participated, or belong to a firm that has participated either as a contractor or subcontractor, in the planning, construction, oversight, operation, or closure of any portion of the CAMU Documentation supporting the certifications of the independent registered professional engineer will be maintained on file by the Army

3.1.3 Post-Closure Phase

Task 5 - Post-Closure Maintenance and Monitoring

After the landfill is closed, the post-closure monitoring period will begin. Post-closure maintenance and monitoring is required for the landfill because this is the only area within the CAMU where remediation waste placed into the CAMU will remain in place after closure Procedures for the post-closure monitoring and maintenance for the landfill is described in Section 5 0 of this Closure Plan

3.2 Procedures for Handling Remediation Wastes Generated During Closure

The following sections describe the storage, transportation, and disposal of solid and liquid remediation wastes that are anticipated to be generated during closure of facilities

3.2.1 Disposal

Solid remediation waste generated during decontamination or other closure-related activities while the onsite landfill is operational may be placed in the onsite landfill Solid remediation wastes generated during decontamination or other closure-related activities after the landfill is no longer

operational will be disposed at an appropriately permitted offsite disposal facility Waste that will be disposed at an offsite facility will be characterized, stored, and transported in accordance with all applicable regulations Liquid remediation waste will either be transported to an appropriately permitted offsite disposal facility or treated at an onsite treatment facility Liquid remediation waste that will be disposed at an offsite facility will be characterized, stored, and transported in accordance with all applicable regulations

3.2.2 Transportation

Any waste being transported offsite for treatment or disposal will be characterized in accordance with all applicable regulations The transportation of hazardous remediation wastes to offsite treatment or disposal facilities will follow the U S Department of Transportation (DOT) regulations for hazardous materials transport (49 Code of Federal Regulations [CFR] Parts 171 to 178) and the manifest requirements of 6 CCR 1007-3, Part 262

3.3 Groundwater Monitoring Program

The proposed groundwater monitoring program for this background period of the CAMU will be described in the Groundwater Monitoring Program (Appendix K to the CDD) Groundwater monitoring for the operational period and closure of the CAMU will be developed based on the results of the background and operational monitoring program

3.4 Site Security

The following security measures, at a minimum, are planned to be in effect during closure

- Twenty-four hour surveillance by facility personnel will control and monitor entry to the CAMU and all areas associated with closure of the CAMU
- A chain-link perimeter fence will prevent unknowing or unauthorized entry into the landfill portion of the CAMU The fence will also be maintained to minimize entry of wildlife into the landfill area
- Temporary fencing will be installed, as required to limit access to the Basin F Waste Pile drying unit, decontamination facilities, and temporary staging areas

- Signs at each entrance and at other locations on the perimeter fence, with the words "Danger - Unauthorized Personnel Keep Out" in English and Spanish, will be posted during closure activities
- Access to the CAMU during decontamination and demolition will be controlled at all times by facility personnel

3.5 Safety and Health Plan

A safety and health plan for work being performed during closure and post-closure activities will be prepared before work commences The purpose of the safety and health plan is to assign responsibilities, establish protection standards, specify safe operating procedures, and provide for contingencies that may arise during proposed site activities The Safety and Health Plan will be distributed to and followed by all personnel participating in field activities The Safety and Health Plan will be evaluated throughout the course of the field activities to incorporate any changes generated as a result of site activities The Safety and Health Plan will be submitted to CDPHE for review and approval

3.6 Decontamination

Equipment and materials used in decommissioning and closure activities will be decontaminated or disposed of as remediation waste in the landfill, or at an approved offsite disposal facility Detailed procedures for equipment and personnel decontamination for closure-related activities will be established during design Personal decontamination and support facilities will be provided and located in accordance with the appropriate Safety and Health Plans Personal protective equipment (PPE) will be decontaminated or managed as a remediation waste Washwater and sludge generated from the decontamination will be collected and disposed of as described in Section 3 2

3.7 Spill Prevention and Response

During transfer of remediation waste materials into or within the CAMU and to trucks or railcars for onsite or offsite transportation, care will be taken to minimize spills Trucks used in the transfer process will be loaded in an area designed to contain spills Liquid spills will be immediately

vacuumed into tanks or trucks and/or contained with soil or a nonreacting sorbent Confirmation sampling will be performed for spills to verify spill cleanup

Soil or solid spills will be removed and disposed at an appropriately permitted offsite facility or in the onsite landfill Confirmation sampling, if necessary, will be performed to verify containment of soil or solid spills

A Spill Prevention and Response Plan will be incorporated in the above-referenced Safety and Health Plans for CDPHE review and approval

3.8 Survey Plat

A survey plat indicating the location and dimensions of landfill cells will be submitted to CDPHE and the local zoning authority or the authority with jurisdiction over local land use This survey plat will be provided at the completion of closure activities

4.0 CLOSURE SCHEDULE

4.1 Expected Year of Closure and Total Time to Close

Closure of the CAMU includes the construction phase, certification phase, and post-closure care phase Based on Foster Wheeler's current schedule for remediation, final closure of the CAMU is anticipated to occur at the end of fiscal year 2008 The schedule for remediation is preliminary and subject to change due to uncertainties associated with the funding and implementation of the remedy

The certification phase will follow the closure construction phase A record of the type, location, and quantity of remediation wastes disposed in the landfill will be submitted to CDPHE

The post-closure care phase begins after closure of the landfill is complete and includes monitoring and maintenance programs for the landfill Post-closure care will be conducted for 30 years following closure of the landfill

A detailed sequence schedule for the closure activities of the CAMU will be developed during design. However, the precise schedule of closure activities will be dependent on the overall remediation schedule

5.0 POST-CLOSURE CARE PLAN

The Army will perform post-closure care of the landfill for 30 years after certification of final closure, subject to the requirements of 6 CCR 1007-3, Section 264 552 If appropriate, the Army may request that the post-closure care period be reduced The requirements of 6 CCR 1007-3, Section 264 552 specify that post-closure care be conducted to protect human health and the environment for areas where remediation wastes will remain in-place CDPHE may extend the post-closure care period if it is found that the extended period is necessary to protect human health and the environment (Section 265 117(a)(2)(ii)) Post-closure activities include monitoring and maintenance activities to protect the integrity of the closed landfill

5.1 Post-Closure Monitoring and Maintenance Plan

Throughout the post-closure care period, ongoing monitoring and maintenance programs will be implemented The primary objectives of these programs are to assess the overall integrity of the closed landfill by performing regularly scheduled inspections, monitoring the groundwater conditions beneath the landfill, and performing regularly scheduled and periodic maintenance as required associated with the final cover, run-on/runoff controls, leachate collection and leak detection systems, groundwater monitoring wells, and surveyed benchmarks

5.1.1 Monitoring Plan

Inspections of the following items at the landfill will be performed throughout the post-closure period in accordance with the schedule established in the final closure plan

- Condition of the cover including cracks, uneven settlement, erosion features, presence of trees or deep-rooted vegetation, holes or burrows caused by wildlife, lack of vegetation, or any other condition that could hinder the effectiveness/integrity of the cover
- Run-on/runoff controls
- Condition of benchmarks
- Condition of the groundwater monitoring wells

The frequency of benchmark and groundwater monitoring well inspections will be in accordance with the schedule established in the final closure/post closure plan. It is not anticipated that there will be significant activity in the vicinity of these structures that would result in damage

Unsatisfactory items discovered during inspections will be noted and reported to CDPHE, and recommended corrective actions will be developed and implemented

The proposed groundwater monitoring program for the background period of the CAMU will be described in the Groundwater Monitoring Program (Appendix K to the CDD) Groundwater monitoring for operational post-closure care periods of the CAMU will be developed based on the results of the background and operational monitoring period

5.1.2 Maintenance Plan

Post-closure maintenance activities will be performed for the final cover, run-on/runoff controls, leachate collection and leak detection systems, groundwater monitoring wells, and surveyed bench-marks A general description of routine maintenance activities that are anticipated during the post-closure period is presented below Conditions that may warrant interim maintenance will be attended to as needed, based on the findings of routine inspections

5.1.2.1 Final Cover

Maintenance of the final cover will be performed and will, at a minimum, include repairing any desiccation cracks, erosion, gullying, holes, or burrows caused by wildlife, areas of uneven settlement, or other disruption that may effect the integrity of the cover A self-sustaining vegetative cover will be maintained

5.1.2.2 Run-on/Runoff Controls

Run-on/runoff control devices and storm-water conveyance structures will be maintained in good functional condition and prevent erosion or other damage of the final cover Maintenance of the

run-on/runoff controls will be performed in accordance with the schedule established in the final closure plan The run-on/runoff control devices will be kept free of any obstructions, and any damage will be repaired as necessary for continued adequate operation

5.1.2.3 Leachate Collection and Leak Detection Systems

The leachate collection and leak detection systems will be maintained in good functional condition Pumpable leachate will be removed from the leachate collection and leak detection sumps on a regular basis to minimize the head on the bottom liner The amount of liquid removed from the leachate collection and leak detection systems will be recorded at regular intervals during the post-closure care period

Leachate collected from the landfill will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation The details regarding leachate treatment will be addressed during design

5.1.2.4 Groundwater Monitoring Wells

Groundwater monitoring wells will be maintained for measurement of water levels, collection of water samples, and analysis of the collected water samples for contaminant concentrations in accordance with the schedule established in the final monitoring plan. Well heads will be properly protected to prevent damage and equipped with locking caps to prevent tampering Necessary repairs to maintain the integrity of the wells will be performed, and, if necessary, abandonment and/or replacement of the wells will be performed

5.1.2.5 Surveyed Benchmarks

Benchmarks utilized for surveying the landfill during closure and grading of the final cover will be maintained in good condition throughout the post-closure period This will include making sure the benchmarks remain adequately located and easily accessible The benchmarks will be inspected and resurveyed periodically to check that consistent elevation and location control are maintained in accordance with the schedule established in the final closure plan

5.2 Certification of Post-Closure Care

After post-closure care of the landfill has been completed, post-closure monitoring results will be reviewed by the Army and an independent Professional Engineer, registered by the State of Colorado The professional engineer will not have participated, or belong to a firm that has participated either as a contractor or subcontractor, in the planning, construction, oversight, operation, or closure of any portion of the CAMU Within 60 days of completion of the post-closure care period, a certification report will be submitted by registered mail to CDPHE with certifications signed by the Army and the independent registered Professional Engineer that the post-closure care activities were conducted in accordance with the approved Post-Closure Plan.

5.3 Notation in the Deed

The post-closure certification report will include a copy of a survey plat pertaining to deed recordation in accordance with 6 CCR 1007-3, Section 264 552 that requires a notation to the deed to the facility property that will in perpetuity notify any potential purchaser of the property that the land has been used to manage remediation wastes, unless an alternative deed notation is approved by CDPHE the final closure plan will specify a deed notation for CDPHE review and approval A certification signed by the Army that the deed recordation described above has been performed will be submitted with the post-closure care certification report

6.0 ACRONYMS

Army	U S Department of the Army
BCY	Bank cubic yard
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CFR	Code of Federal Regulations
DAA	Detailed Analysis of Alternatives
DOT	U S Department of Transportation
Ebasco	Ebasco Services, Inc
ESE	Environmental Science and Engineering, Inc
FFA	Federal Facilities Agreement
HLA	Harding Lawson Associates
LDRs	Land disposal restrictions
MKE	Morrison-Knudsen Engineers, Inc
msl	Mean sea level
PPE	Personal protective equipment
RCRA	Resource Conservation and Recovery Act
RMA	Rocky Mountain Arsenal
State	State of Colorado
USGS	U S Geological Survey

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1215031296 CDD

7.0 REFERENCES

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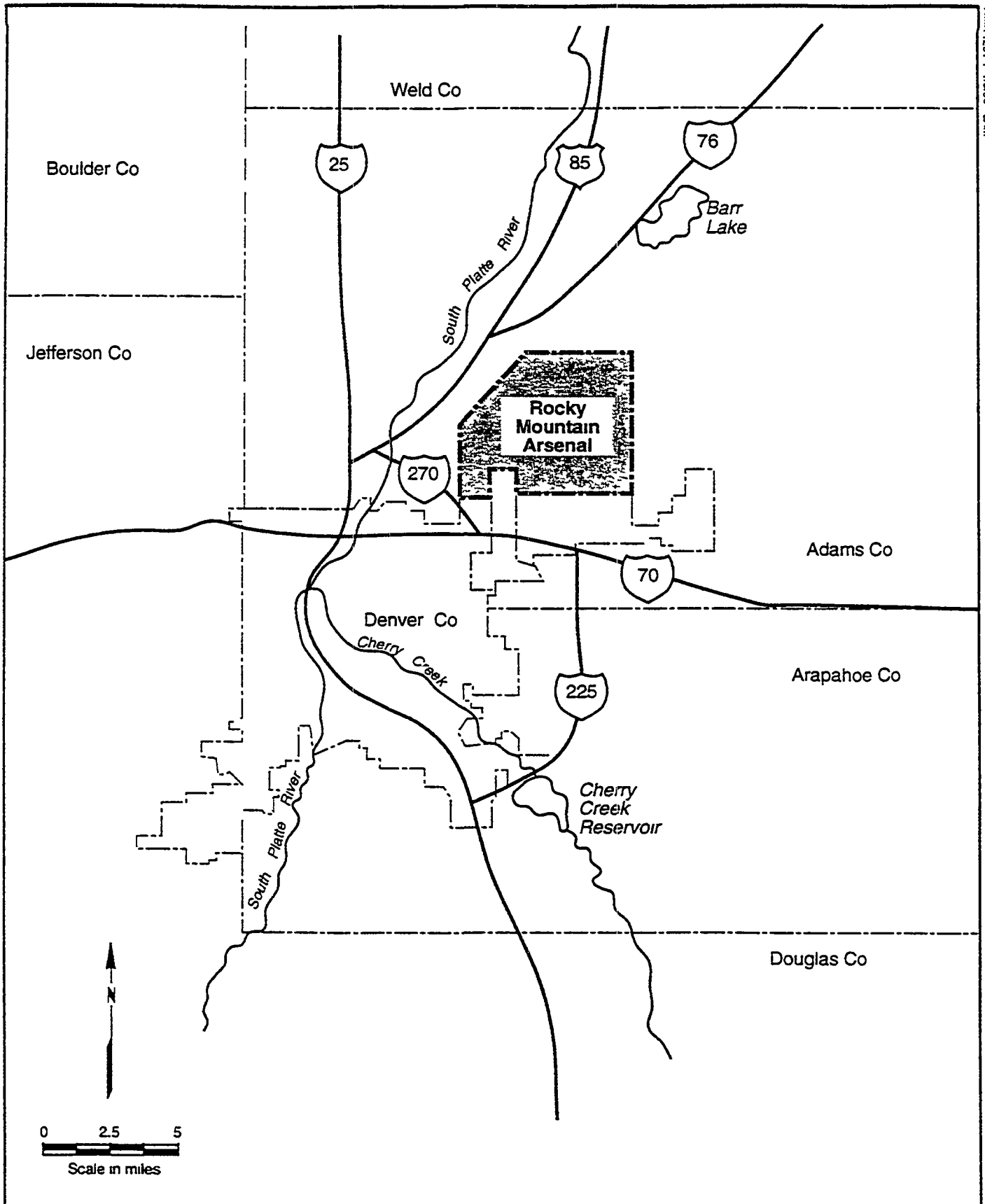
United States Geological Survey 1995 *Final groundwater monitoring program task plan 1995* Rocky Mountain Arsenal September



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Harding Lawson Associates

Figure L1

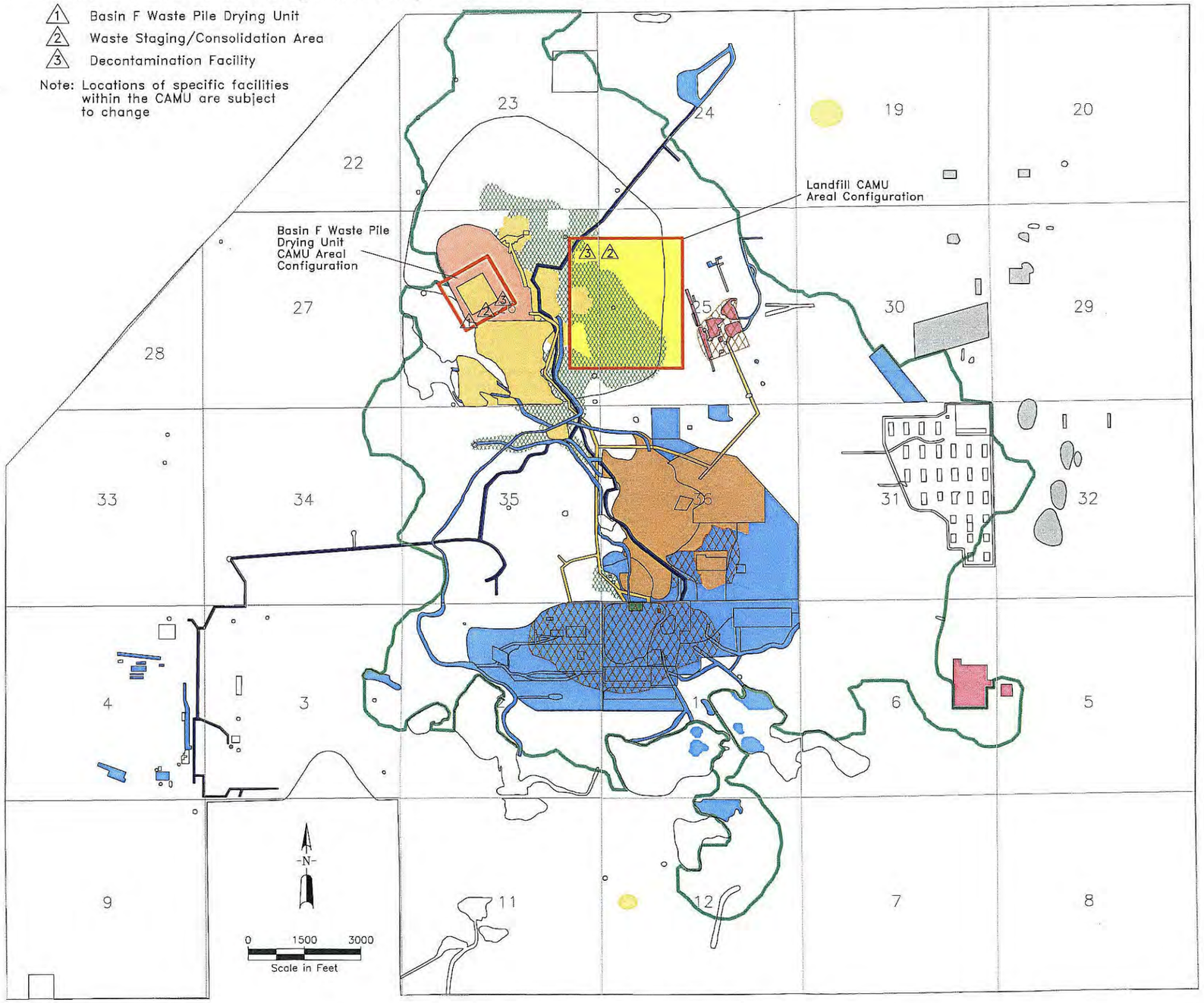
Site Location Map

RMA 12511 1/26/96 LAM

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

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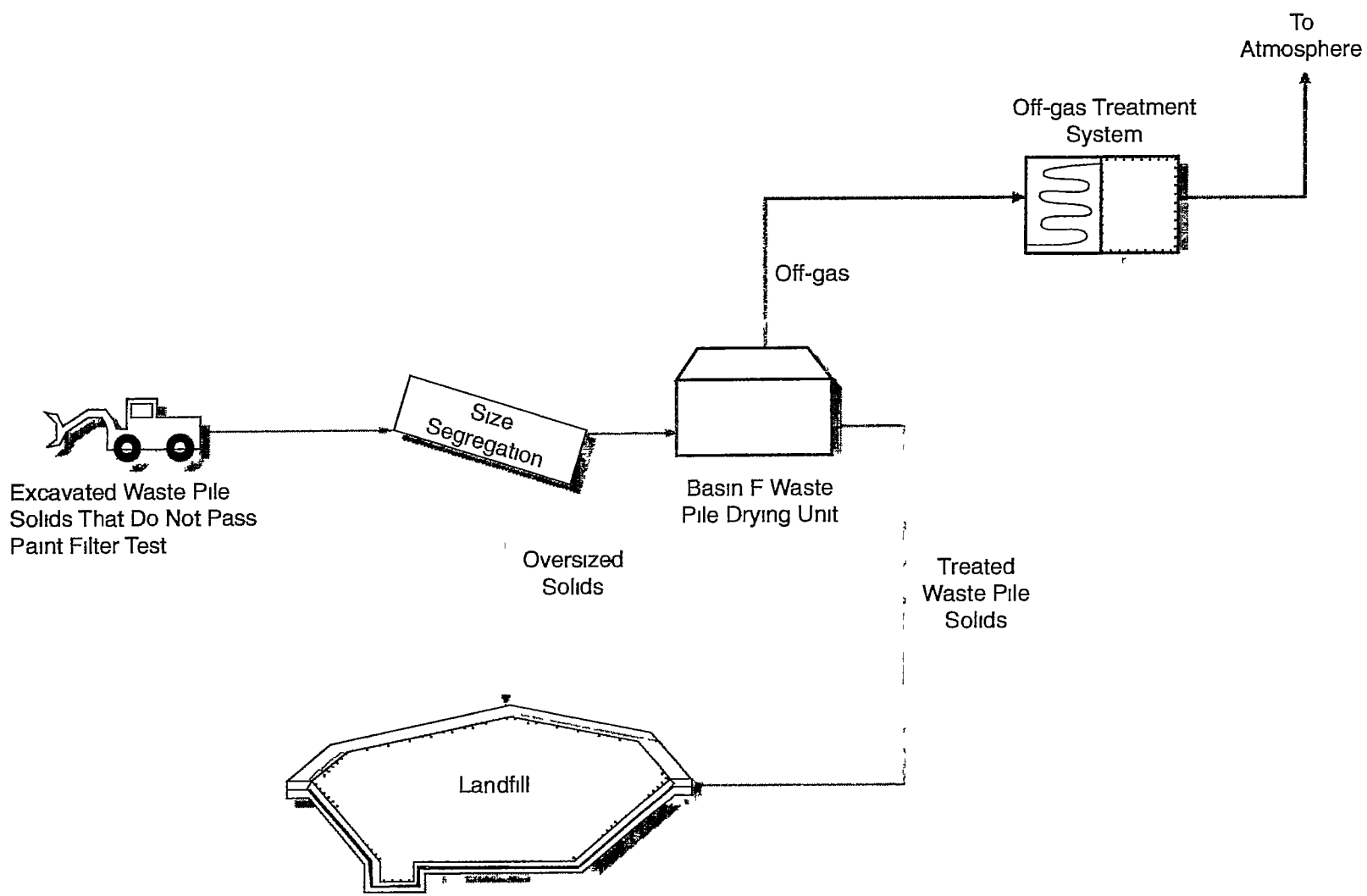
Commerce City, Colorado

Prepared by: Tetra Tech EC Inc.

Figure L2

Proposed Corrrective Action Management Unit Areal Configuration
Rocky Mountain Arsenal



Explanation

Off-gas

Process residuals

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Figure L3

Conceptual Process Flow Diagram for Basin F Waste Pile Drying Unit

RMA 1257.2a 1/5/98 LAM

RMA 1251.dfb 1/8/96 LAM

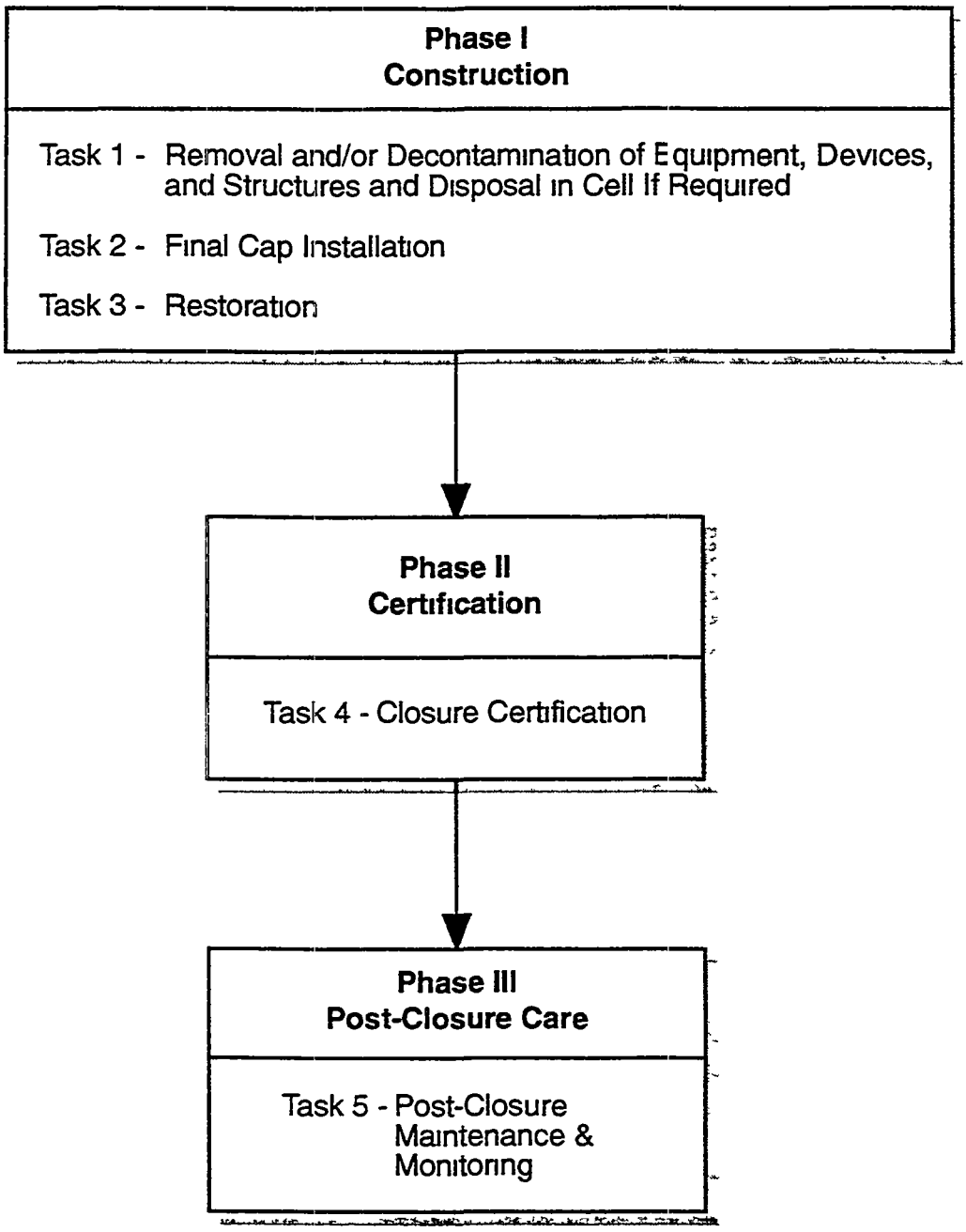

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Figure L4

Closure Process

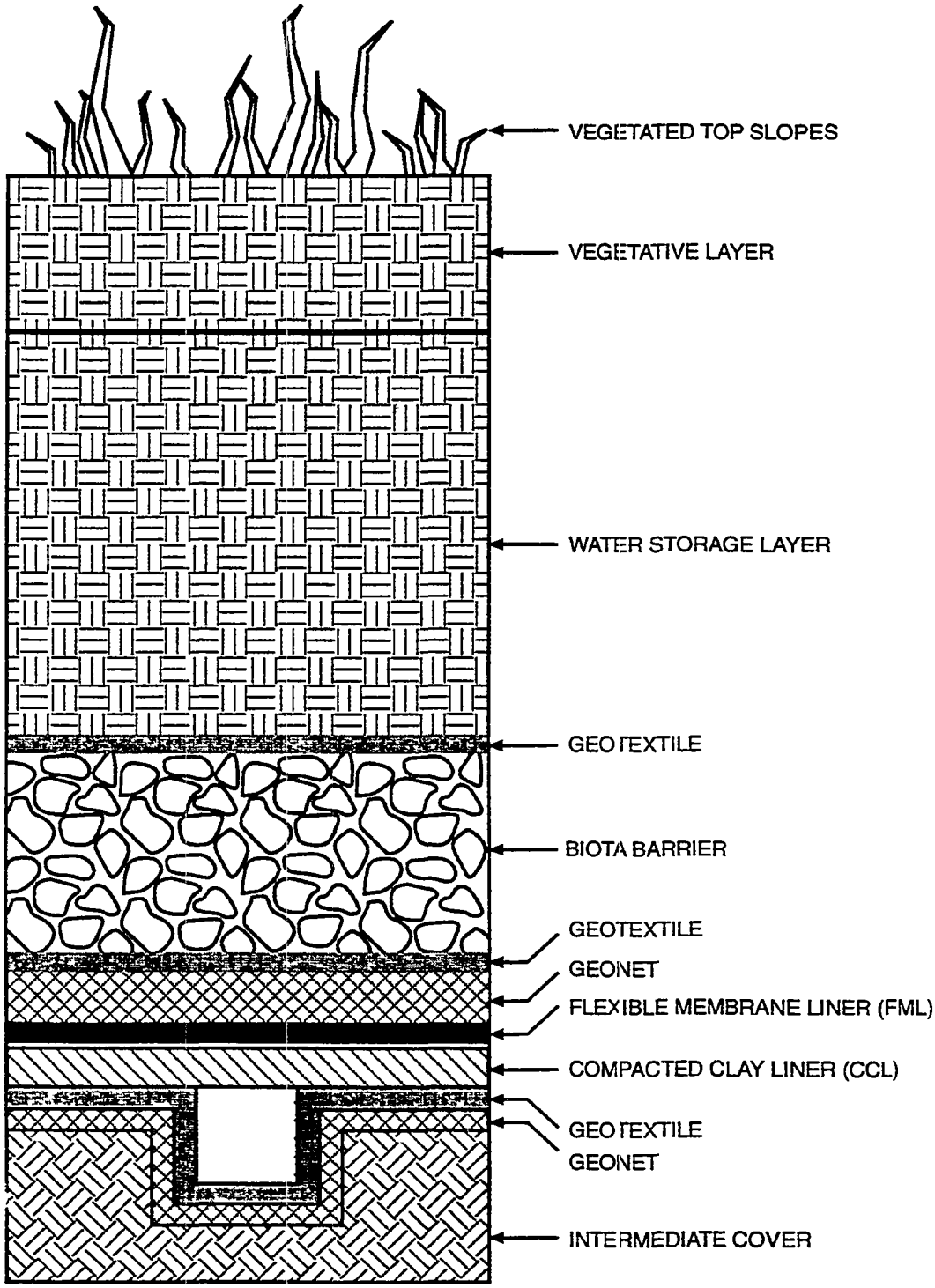

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Figure L5

Conceptual Cover Design

RMA 1258 1/9/95 LAM

Appendix M

POST-CLOSURE PLAN

The Post-Closure Plan has been combined with the Closure Plan and included in Appendix L

Appendix N

ACTION LEAKAGE RATE AND RESPONSE ACTION 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 Action Leakage Rate

- 2 1 Background
  - 2 1 1 Liner Systems
  - 2 1 2 Leachate Collection Systems
  - 2 1 3 Leak Detection Systems
  - 2 1 4 Potential Sources of Liquids in Leak Detection Systems
- 2 2 Action Leakage Rate Calculation
- 2 3 Operational Leakage Rate Calculation
- 2 4 Action Leakage Rate Exceedance

3 0 Response Action Plan

- 3 1 Initial Notification
- 3 2 Source Assessment
- 3 3 Response Actions
- 3 4 Status Notifications

4 0 Acronyms

5 0 References

Appendix O

HEALTH AND SAFETY 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

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PRELIMINARY SPECIFICATIONS

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INTRODUCTION

This appendix 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 U S Army's Rocky Mountain Arsenal (RMA) located in Adams County, Colorado This Appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03 Feasibility Study Soils Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This appendix 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. These Specifications are not intended to be used for construction of the RMA landfill, their sole purpose is to assist in the CAMU designation

Appendix P presents conceptual Specifications to assist in the overall demonstration of compliance with the requirements of 6 Code of Colorado Regulations (CCR) 1007-2, Part 2, Section 2 4 9, and additional guidance provided in 6 CCR 1007-3, Part 264 These Specifications are intended to demonstrate that the materials and methods are available for potential use in construction of the RMA landfill liner system, cover system, leachate collection system, leak detection system, and groundwater monitoring system that can meet regulatory requirements and satisfy the design criteria presented in Appendix B General product standards and execution procedures including material properties, testing requirements, and quality assurance/quality control procedures have been included for the primary components of the systems listed above

References to personnel (e g , Contractor, Owner's Representative) in these Specifications are general terms and are not intended to define personnel requirements during construction. Contractor refers to any company, organization, and personnel retained to assemble, fabricate, and erect the systems, facilities, and related appurtenances of the RMA landfill Owner's Representative refers to any company,

organization, and personnel responsible for performing construction oversight and engineering during construction-related Work.

These Specifications typify the level of detail to be included in the final construction Specification package They will be appended and modified during design based on engineering evaluations, collection of additional site data, and other technical considerations as the design process proceeds In addition, portions of these Specifications may not be applicable to the final design and will be appropriately modified during the design process The Specifications have been prepared in Constructions Specifications Institute (CSI) format. The design Specifications may be prepared in a different format

SECTION 02200 EARTHWORK

PART 1 GENERAL

1 01 SUMMARY

A Section Includes

1 The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and other services necessary to perform general site grading, excavation, construction of roads, berms and other earthen structures, placement of the earthen components of the cover and liner systems (with the exception of compacted clay components addressed in Section 02721), disposal of unsuitable earthen materials, and all subsidiary Work required to complete such earth Work. The Work shall be carried out in accordance with these Specifications, the Construction Quality Assurance (CQA) Plan, the Drawings and other Contract Documents

1 02 REFERENCES

A American Society for Testing and Materials (ASTM) D422 - Method for Particle Size Analysis of Soils

B ASTM D698 - Test Methods for Moisture-Density Relations of Soil and Soil Aggregates Mixtures using a 5 5 lb Rammer and 12 in. Drop

C ASTM D1556 - Test Method for Density of Soil in Place by the Sand-Cone Method

D ASTM D2167 - Test Method for Density and Unit Weight of Soils in Place by Rubber Balloon Method

E ASTM D2216 or D4643 - Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

F ASTM D2487 - Test Method for Classification of Soil for Engineering Purposes

G ASTM D2922 - Test Method for Density of Soil and Soil Aggregate In Place by Nuclear Methods

H ASTM D3017 - Test Method for Moisture Content of Soil and Soil Aggregate In Place by Nuclear Methods

I ASTM D4318 - Test Method for Liquid Limit, Plastic Limit, and Plasticity Index for Soil

J ASTM C131 - Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

K ASTM C136 - Test Method of Sieve Analysis of Fine and Coarse Aggregate

L ASTM C88 - Test Method for Soundness of Aggregate

M FB85 703 06 U S Department of Transportation Federal Highways Administration - Aggregate for subbase, base or surface courses, cold asphaltic concrete pavement and road mixed asphaltic concrete pavement.

1 03 QUALITY ASSURANCE

A Field Measurements

1 Verify that survey benchmark and intended elevations for the Work are as indicated on Drawings

B Regulatory Requirements

1 Perform all excavation Work in accordance with Occupational Safety and Health Administration (OSHA) requirements, "Excavating and Trenching Operations "

2 Comply with applicable county and state codes and ordinances

1 04 SUBMITTALS

A Submit laboratory test data and Manufacturer's product data and certification

B Samples Submit samples of each type of fill to a testing laboratory in airtight containers in accordance with the requirements of the design.

1 05 PROJECT/SITE CONDITIONS

A Environmental Requirements

1 Noise

a Noise levels are to be maintained as required by applicable local and state laws and ordinances

2 Pollution

a Equipment emissions and dust levels are to be maintained as required by applicable local and state laws and ordinances

B Existing Conditions

1 Information shown on Drawings regarding existing site conditions is believed to be correct, but is not guaranteed Contractor shall visit the site for necessary information and data regarding present ground levels, groundwater level, conditions of property, location, size of obstructions, and access

2 Existing utilities may be encountered that are not shown on Drawings or evident from site inspection. Owner's Representative shall be notified immediately if such utilities are discovered

3 Provide and maintain all barricades, shoring, and bracings as required by federal and state codes

4 Construct and maintain temporary drainage routes during construction so that rainfall or snowmelt will drain from site and not accumulate or pond

5 Contractor shall assume all responsibility for damage to utilities, survey monuments, streets, monitoring wells, and structures that may be caused by this Work.

6 Contractor shall not interfere with other facility operations or operating roadways without prior consent from the Owner's Representative

C Excavation Safety

1 Provide appropriate measures to retain excavation sideslopes and prevent slope failures or rock falls to ensure that persons working in or near the excavation are protected

2 Contractor shall become familiar with and comply with all applicable codes, ordinances, and statutes and bear sole responsibility for the penalties imposed for noncompliance

1 06 DEFINITIONS

A Percent compaction The in-place dry density of the material expressed as a percentage of the maximum dry density of the same material as determined by the ASTM D698 test method

B Optimum moisture content The moisture content (expressed as a percentage of the dry weight of the material) corresponding to the maximum dry density of the same material as determined by the ASTM D698 test method

C Structural fill areas Where used in these Specifications, structural fill areas shall mean (1) within building or access road areas and for a distance of at least 5 ft beyond the outside edges of perimeter footings, (2) within exterior concrete slab areas and for a distance of 3 ft beyond slab edges, and (3) to establish berms, dikes, and other miscellaneous earthen structures as shown on the Drawings

D Soil subgrade Where used in these Specifications soil subgrade shall mean (1) within concrete slab-on-grade floor areas, the surface on which slab rock is placed, (2) within exterior concrete slab areas, the surface on which concrete is placed, (3) within asphalt paved and access road areas, the surface on which aggregate base is placed, and (4) within the extent of subgrade construction, as shown on the Drawings, including the surface on which the landfill cell liners or covers are placed

E Completed Course

1 A course or layer that is ready for the next layer or next phase of Work.

F Imported Material

1. Material obtained by the Contractor from sources offsite

1 07 DELIVERY, STORAGE, AND HANDLING

A Acceptance at Site

1 Imported Materials

a No imported materials shall be delivered to the site until the proposed source and materials tests have been accepted by Owner's Representative

b Final acceptance shall be based on tests made on samples of materials taken from the completed and compacted course

B Storage and Protection

1 During the interval between the delivery of material and installation, material shall be stored in a manner affording protection and favorable conditions to prevent material loss or deterioration.

PART 2 PRODUCTS

2 01 MATERIALS

A Structural fill Structural fill material shall be free of perishable material and rocks or lumps larger than 4 in in greatest dimension All fill material shall be approved by the Owner's Representative

B Fine-grained soil fill Fine-grained soil shall be acceptable soil excavated from the project site and stockpiled, excavated from an approved borrow area, or provided from an accepted offsite source The fine-grained soil shall meet the following requirements

1 Be free of plants, roots, rubble, litter, insect infestation, and other deleterious matter

2 Be in accordance with the gradation set forth in the design, as determined by ASTM D422

C Topsoil/Gravel Admix If required by the design, the Contractor shall provide a topsoil/gravel admixture proportioned to meet the requirements set forth during design

The topsoil portion of the topsoil/gravel admixture shall meet the following requirements

1 Be capable of sustaining healthy plant life and shall be free of noxious weeds, sticks, brush, litter, insect infestation, and other deleterious matter

2 Have a pH and soluble salt level capable of supporting vegetation

3 Meet the nutrient requirements determined during design either by natural occurrence or by means of additives as determined by American Society of Agronomy, Inc (ASA) Methods of Soil Analysis

4 Follow the gradation set forth in design, as determined by ASTM D422

The gravel portion of the topsoil/gravel admixture shall meet the following requirements

1 Be washed rock.

2 Consist of angular fragments with a percentage of wear set forth during design, as determined by ASTM C131

D Gravel Armoring If required by the design, the Contractor shall provide gravel armoring for the engineered cover in those areas designated on the design Drawings The gravel shall be washed screened rock with the gradation set forth during design. The rock shall

be angular crushed rock with a percent fracture determined during design, as determined by FP-85 703 06

E Biotic Barrier Rock The Contractor shall supply material for the biotic barrier of the engineered cover The rock shall meet gradation and material requirements set forth in the design

F Sand Drainage/Vent Material If required in the design, the Contractor shall provide sand fill or other suitable media for drainage/vent layers of the cover and liner systems The material shall meet the following criteria

1 Be in accordance with the gradation provided during design, as determined by ASTM C136

G Pipe Bedding Material The Contractor shall furnish pipe bedding material for backfill around pipes in pipe trenches The bedding material shall meet the following criteria

1 The bedding material shall be in accordance with the gradation provided during design, as determined by ASTM C136

H Gravel Road Base The Contractor shall provide gravel road base material for those areas designated on the design Drawings The gravel road base shall meet the following requirements

1 The gravel road base shall be in accordance with the gradation provided during design, as determined by ASTM C136

I Imported Materials Imported material required for earthwork shall be tested by the Contractor and approved by the Owner's Representative before use The Contractor shall provide at least two weeks notice before using the imported material to enable the Owner's Representative to sample and test the material, if necessary

PART 3 EXECUTION

3 01 UTILITIES

A Utilities The Contractor shall be responsible for location and protection of all new and existing utility lines during execution of Work onsite in accordance with 1 05 B 2 of this Section Damage to any utility resulting from the Contractor's activities onsite shall be repaired or replaced by the Contractor as required by the utility Owner

3 02 DISPOSAL OF EXCAVATED MATERIAL

A. Disposal of excavated material Excavated material generated during the execution of Work specified herein, that is not used as backfill, shall be stored and disposed as directed by the Owner's Representative

3 03 OVEREXCAVATION

Excavation shall be held to those limits shown on the design Drawings unless otherwise directed by the Owner's Representative Where unsuitable sub-base is encountered, the Contractor shall notify the Owner's Representative immediately Overexcavation that is

executed without prior approval of the Owner's Representative shall be at the expense of the Contractor

3 04 EXCAVATION

A Preparation

1 Identify required lines, levels, contours, and datum

2 Identify known underground, aboveground, and aerial utilities Stake and flag locations

3 Protect or replace at no cost to Owner above and below grade utilities that are to remain

4 Protect benchmarks, fences, paving, and curbs from excavation equipment and vehicular traffic

5 Removal of water during construction operations

a Provide and operate equipment adequate to keep all excavations and trenches free of water

b Avoid settlement or damage to adjacent property

c Disposition of water within Owner's property to be designated by Owner's Representative

d Dewatering open excavations shall be from outside the structural limits and from a point below the bottom of the excavation when possible

e Design dewatering systems to prevent removal of fines from existing soil

B Erection, Installation, and Application

1 General

a Perform all excavation of every description, regardless of the type, nature, or condition of material encountered as specified, shown on Drawings, or required to accomplish the construction.

b Method of excavation is optional, however, no equipment shall be operated within 5 ft. of existing structures or newly completed construction.

c Excavation that cannot be accomplished without endangering present or new structures shall be done with hand tools

2 Limits of Excavation

a Excavate to the depths and widths as shown on Drawings

b Allow for forms and working space, as required by OSHA regulatory requirements

c Excavation carried below the grade lines shown on Drawings shall be replaced with the same fill material as specified for the overlying fill or backfill and compacted in accordance with this Section

d For overexcavation where the overlying area is not to receive fill, replace the overexcavated material and compact to a density not less than that of the underlying ground

e Cuts below grade shall be corrected by similarly cutting adjoining areas and creating a smooth transition

f Underpin adjacent structures that may be damaged by excavation Work including utilities and pipe chases

g Excavate subsoil required to accommodate building foundations, slabs-on-grade, paving and site structures, and construction operations

h Machine slope banks to angle of repose or less, until shored

i Excavation cut not to interfere with normal 45 degree bearing splay of foundation

j Grade top perimeter of excavation to prevent surface water from draining into excavation

k. Hand trim excavation and remove loose matter

l Notify Owner's Representative of unexpected subsurface conditions and discontinue affected Work in area until notified to resume Work.

m Stockpile excavated material in area designated onsite and remove excess material not being reused from site or place in area onsite as directed by Owner's Representative

3 05 INSTALLATION AND APPLICATION OF FILL MATERIALS

A Backfilling

1 Backfill areas with unfrozen materials to contours and elevations shown on Drawings

2 Systematically backfill to allow maximum time for natural settlement. Do not backfill over porous, wet, frozen, or spongy subgrade surfaces, unless approved by Owner's Representative

3 Place and compact fill materials in continuous layers not exceeding 8-in. compacted depth

4 Employ a placement that does not disturb or damage foundation perimeter drainage and yard piping in trenches

5 Backfill against supported foundation walls Do not backfill against unsupported foundation walls

6 Backfill simultaneously on each side of unsupported foundation walls until supports are in place

7 Remove surplus fill materials from site or place in areas designated by the Owner's Representative

8 Backfill around concrete structures only after the concrete has attained the specified compressive strength indicated in Division 3, Concrete, and concrete Work is accepted by Owner's Representative

9 Do not operate earth-moving equipment within 5 ft. of walls of concrete structures for the purpose of depositing or compacting backfill material Compact backfill adjacent to concrete walls with hand-operated tampers or similar equipment that will not damage the structure

B Fill

1 Place fill to the lines and grade as shown on Drawings

2 Make allowance for granular base material or topsoil when required

3 Remove all form materials and trash from the sub-base before placing any fill materials

C Compaction

1 Compact all materials by mechanical means Flooding or jetting shall not be permitted

2 If in-place density tests indicate that compaction or moisture content is not as specified, material placement shall be terminated and corrective action shall be taken by the Contractor before continued placement

D Moisture Control

1 Moisture condition material before placement.

2 Maintain moisture content required for compaction purposes in each lift of fill

3 Maintain moisture content uniform throughout the lift

4 At the time of compaction, the moisture content of the material shall be as specified during design.

5 Supplement, if required, by sprinkling the fill

6 Do not attempt to compact fill material that contains excessive moisture Aerate material by blading, discing, harrowing, or other methods to hasten the drying process

E Field Density and Moisture Tests

1 Owner's Representative will determine in-place density and moisture content by any one or combination of the following methods

a ASTM D1556

b ASTM D2167

c ASTM D2216

d ASTM D2922

e ASTM D3017

f ASTM D4643

2 Frequency and location of testing shall be determined solely by Owner's Representative

3 CQA firm will test any lift of fill at anytime, location, or elevation

F Disposal of Excess Excavation

1 Dispose all excess excavation not required or suitable for backfill or filling within Owner's property at an area to be designated by the Owner's Representative

G Tolerances

1 Acceptable dimensional tolerances shall be followed as set forth during design

3 06 QUALITY CONTROL

A The Contractor shall be responsible for documenting all test results and the number of compaction passes completed per lift.

B Placed materials not in accordance with the requirements of this Specification shall be repaired and/or replaced by the Contractor The Contractor shall submit a description of repair and/or replacement methods to the Owner's Representative for written approval before implementation

C Acceptance criteria for repaired and/or replaced materials shall be in accordance with the requirements of this Specification

D Areas that do not conform with the Specifications will first be investigated by the Contractor for the extent of nonconformance Areas that are of a different material type or that have failed the Specifications, after efforts to recompact the soil shall undergo additional testing regardless of the testing frequency guidelines The Owner's Representative will determine when additional testing is required Results of additional testing shall be submitted to the Owner's Representative for review and final acceptance

E Final acceptance shall be explicitly detailed by survey location, layer description, material type, and lift number

- END OF SECTION -

SECTION 02712 GEOSYNTHETIC CLAY LINERS

PART 1 GENERAL

1 01 SCOPE OF WORK

A If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geosynthetic clay liner (GCL) components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A The Contractor shall abide by all qualification and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A. All Work will be monitored and tested in accordance with requirements of the CQA Plan.

B Any GCL rolls that do not meet the requirements of these Specifications will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

C If testing indicates Work does not meet the requirements of the Specifications, the Owner's Representative will establish the extent of the nonconforming area The nonconforming area shall be repaired by the Contractor at no cost to the Owner until acceptable test results are obtained

PART 2 PRODUCTS

2 01 GCL PROPERTIES

A The Contractor shall require that the GCL Manufacturer furnish material with minimum average roll values, as defined by the Federal Highway Administration (FHWA), meeting or exceeding the criteria that will be developed during design. The Contractor shall require that the GCL Manufacturer provide results for tests performed using the test procedures identified during design, as well as a certification that the material properties for the material delivered to the site will meet or exceed the specified values

B In addition, the GCL shall

1. Retain its structure during handling, placement, and long-term service

2 Meet any additional requirements of the Drawings

2 02 MANUFACTURING QUALITY CONTROL

A The Contractor shall require that the GCL Manufacturer sample and test the GCL to demonstrate that the material conforms to the requirements of these Specifications All Quality Control testing required by the Specifications and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor Test results shall be provided to the Owner's Representative Sampling shall, in general, be performed on sacrificial portions of the GCL material such that repair is not required The Contractor shall require that the GCL Manufacturer sample and perform the manufacturing quality control tests as specified

B Any GCL sample that does not comply with these Specifications shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

C If a GCL sample fails to meet the quality control requirements of these Specifications, the Contractor shall require that the GCL Manufacturer sample and test each roll manufactured, in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results is established as specified within the CQA Plan

D Additional sample testing may be performed, at the GCL Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

2 03 LABELING

A GCL rolls shall be labeled with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

2 04 TRANSPORTATION

A. Transportation of GCL shall be the responsibility of the Contractor The Contractor shall be liable for damage to the GCL incurred prior to and during transportation to the site The Contractor shall repair or replace damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A. GCL shall be protected from moisture during shipping and storage

B Handling, storage, and care of the GCL prior to and following incorporation into the Work is the responsibility of the Contractor The Contractor shall be liable for damage to the

material incurred prior to final acceptance by the Owner The Contractor shall repair damage in accordance with Part 3.03 of this Section and at no additional cost to the Owner

C The Contractor shall be responsible for storage of the GCL at the site The GCL shall be stored off the ground and shall be protected from excessive heat or cold, moisture, dirt, dust, or any other damaging or deleterious condition. The GCL shall be stored in accordance with any additional requirements of the GCL Manufacturer

PART 3 EXECUTION

3.01 HANDLING AND PLACEMENT

A. If required by the design, GCL shall be installed at all locations shown on the Drawings

B The Contractor shall handle the GCL in such a manner as to ensure the GCL is not damaged in any way

C The area over which the GCL will lie should be smooth and free of standing water and protruding rocks, roots, vegetation, debris, and large voids

D Just prior to GCL placement, any geosynthetics that may underlie the GCL shall be clean and free of dust, dirt, stones, rocks, or other obstructions that could potentially damage the GCL These geosynthetics shall be swept or blown clean prior to GCL placement

E. The Contractor shall take all necessary precautions to prevent damage to underlying materials during placement of the GCL.

F In the presence of excessive wind, the GCL shall be weighted by the Contractor with sandbags or equivalent weight approved by the Owner's Representative

G If necessary, the Contractor shall position the GCL by hand and after it is unrolled to minimize wrinkles

H Only as much GCL shall be deployed as can be covered at the end of the day, or that can be covered in a reasonably short time in the event of precipitation

1 When GCL is being installed under a geomembrane liner, the leading edge of the GCL should be folded back under the membrane at the end of the construction day The leading edge of the membrane should be secured by sandbags or suitable ballast to prevent uplift and the infiltration of runoff water

I GCL panels shall be deployed in the direction of greatest slope (i e , longest dimension is parallel to slope direction)

J GCL panel deployment shall generally proceed from the highest elevation to the lowest elevation.

3 02 OVERLAPS AND SEAMS

A. Adjacent GCL panels are to be overlapped according to the match line on the bottom panel Overlaps shall be and in accordance with Manufacturer's instructions and requirements of the design

B Transverse overlaps at the ends of each roll shall be as required in the design.

C Overlaps shall be shingled in a downslope direction so that water would flow from the top sheet to the bottom sheet.

D Care shall be taken to ensure that no native soil or debris is present between overlaps

E Granular bentonite shall be placed between seam overlaps in accordance with the Manufacturer's recommendations

F The joints on adjacent GCL panels shall be staggered as required in the design

G No horizontal seams shall be allowed on slopes steeper than 4 1 (horizontal vertical), unless approved by the Owner's Representative.

3 03 REPAIR

A Any holes or tears in the GCL shall be repaired by placing a patch over the hole or tear extending beyond the edges of the hole or tear The patch shall be secured to the original GCL by applying granular bentonite between the overlap If the hole or tear width across the roll is more than 50 percent of the width of the roll, the damaged area shall be cut out and the two portions of the GCL shall be joined in accordance with Part 3 02 of this Section

B On slopes steeper than 4 1, repairs shall be performed by removing and replacing the damaged panel

C Any GCL exposed to standing water or to any hydrocarbon fuels, chemicals, pesticides, leachates, or other such liquids during installation, shall be removed and replaced

3 04 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B The Owner's Representative will identify any areas requiring repair The Contractor shall make repairs and replacements as necessary, to the approval of the CQA firm at no additional cost to the Owner

C The Owner's Representative will issue an approval of the GCL installation to the Owner prior to placement of material over the GCL in accordance with the CQA Plan

- END OF SECTION -

SECTION 02713 GEOMEMBRANE LINERS

PART 1 GENERAL

1 01 SCOPE OF WORK

A The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geomembrane liners components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 SUBMITTALS

A In accordance with the CQA Plan and the Specifications

B Materials Submit laboratory test data and Manufacturer's product data and certification in accordance with the CQA Plan and the Products Subsection of this Section

C Layout Drawings Contractor shall submit Layout Drawings for the geomembrane liners to the Owner's Representative describing in detail where and how the liners will be installed Work covered in this Section shall not commence until Layout Drawings are reviewed and approved by the Owner's Representative

D The Contractor shall furnish the following submittals for the geomembrane liner

1 Raw Materials

a Certification that all raw materials used in the manufacture of geomembrane for this job meet the Specifications

b Copy of quality control certificates issued by the geomembrane supplier

2 Geomembrane Roll Production

a Copy of quality control certificates

1 03 QUALITY ASSURANCE

A. The Manufacturer of the geomembrane shall be listed by National Sanitation Foundation as having met Standard 54 for Flexible Membrane Liners and shall have at least five (5) years of continuous experience in the manufacture of geomembranes

PART 2 PRODUCTS

2 01 GEOMEMBRANE PROPERTIES

A The geomembrane Manufacturer shall be a Manufacturer making geomembrane meeting the requirements of this Section. The Owner's Representative (based on concurrence with regulatory authorities) may approve an alternate material if sufficient evidence is submitted to verify that the alternate material meets the requirements of this Specification.

B Smooth or textured geomembrane shall be used based on the requirements of the Drawings

C The Contractor shall furnish geomembranes having properties that comply with the required property values specified during design and that meet the manufacturing quality control requirements in Section 2 02 below

2 02 MANUFACTURING QUALITY CONTROL

A Geomembrane Materials

1 The Contractor shall require that the geomembrane Manufacturer sample and test the geomembrane to demonstrate that the resin complies with this Specification. The Contractor shall require that the geomembrane Manufacturer certify in writing that the material meets this Specification, and the geomembrane Manufacturer be held liable for any noncompliance Any geomembrane manufactured from noncomplying materials shall be rejected

2 The Contractor shall require that the geomembrane Manufacturer comply with the submittal requirements of these Specifications

B Rolls

1 The Contractor shall require that the geomembrane Manufacturer continuously monitor the geomembranes during the manufacturing process for inclusions, bubbles, or other defects No geomembrane that exhibits any defects will be accepted

2 The Contractor shall require that the geomembrane Manufacturer continuously monitor the geomembrane thickness during the manufacturing process No geomembrane that fails to meet the specified minimum thickness will be accepted

3 The Contractor shall require that the geomembrane Manufacturer sample and test the geomembrane to demonstrate that its properties conform to the values specified

a Samples shall be taken across the entire width of the roll and shall not include the first wrapping or outer layer of the roll

4 Geomembrane rolls that do not have acceptable manufacturing quality control test results shall be rejected by the Contractor

5 In the case of the rejection of a roll of geomembrane, the Contractor shall require that the geomembrane Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results is established

6 Additional testing may be performed at the geomembrane Manufacturer's discretion and expense, to more closely identify the noncomplying rolls and/or to qualify individual rolls

2 03 LABELING

A. The geomembrane shall be labeled with the following information

1 Thickness of the material

2 Length and width of the roll or factory panel

3 Name of Manufacturer

4 Product identification

5 Lot number

6 Roll or factory panel number

2 04 TRANSPORTATION

A Transportation of the geomembrane is the responsibility of the Contractor The Contractor shall be liable for all damage to the materials incurred prior to and during transportation to the site The Contractor shall repair or replace any damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Handling, storage, and care of the geomembrane prior to and following installation at the site, is the responsibility of the Contractor The Contractor shall be liable for all damage to the material incurred prior to final acceptance of the installation by the Owner's Representative The Contractor shall repair all damage in accordance with Part 3 03 K.4 of this Specification at no additional cost to the Owner

B The Contractor shall be responsible for storage of the geomembrane at the site The Owner will provide storage space in a location (or several locations) such that onsite transportation and handling are optimized, if possible During storage, the geomembrane shall be protected from theft, vandalism, dirt, excessive heat or cold, puncture, cutting, or other damaging or deleterious conditions The geomembrane shall also be stored in accordance with any additional requirements of the geomembrane Manufacturer

PART 3 EXECUTION

3 01 EARTHWORK

A. Surface Preparation

1 Geomembrane liner shall be installed at all locations shown on the Drawings

2. The geomembrane liner shall be installed as soon as practical after the completion and acceptance by the Owner's Representative of the placement area

3 Areas to receive geomembrane liner shall be smooth and even, and free of ruts, voids, obstruction, etc The final surface to receive the geomembrane shall be prepared in accordance with requirements developed during design No rubber-tired vehicles shall be allowed on the final dressed surface without the approval of the Owner's Representative

4 The Contractor shall provide certification that the surface on which the geomembrane will be installed is acceptable The certification of acceptance for each area under consideration shall be given to the Owner's Representative prior to commencement of geomembrane installation in that area.

B Anchor Trenches

1 The anchor trench shall be excavated prior to geomembrane placement to the elevations, grades, and widths shown on the Drawings

2 No loose soil shall be allowed beneath the geomembrane in the anchor trench

3 The anchor trench shall be backfilled after the geosynthetic layers have been installed (as applicable) Care shall be taken when backfilling the anchor trench to prevent any damage to the geomembrane or other geosynthetics

4 Slightly rounded corners shall be provided in the anchor trench where the geomembrane adjoins the trench to avoid sharp bends in the geomembrane

3 02 GEOMEMBRANE DEPLOYMENT

A. Field Panel Identification

1 A geomembrane field panel is defined as a roll or a portion of a roll cut in the field

2 Each field panel must be given an identification code (number or letter-number)

B Field Panel Placement

1 Field panels shall be placed one at a time, and each field panel shall be seamed immediately after its placement

2 Geomembranes shall not be placed when the ambient temperature is below 40°F unless the Contractor has previously submitted a geomembrane cold-weather placement and seaming plan and such plan has been approved by the Owner's Representative

3 Geomembranes shall not be placed during any precipitation, in the presence of excessive moisture (e g , fog, dew), in an area of ponded water, or in the presence of excessive winds

4 The Contractor shall employ placement methods which ensure that

a No vehicular traffic shall be allowed on the geomembrane

b Equipment used shall not damage the geomembrane by handling, trafficking, excessive heat, leakage of hydrocarbons, or other means

c. Personnel working on the geomembrane shall not smoke, wear damaging shoes, have glass containers or tools not required for liner placement on the geomembrane, or engage in other activities that could damage the geomembrane

d The method used to unroll the panels shall not scratch or crimp the geomembrane and shall not damage the underlying materials

e The method used to place the panels shall minimize wrinkles (especially differential wrinkles between adjacent panels)

f Temporary loads and/or anchors (e g , sandbags), not likely to damage the geomembrane, shall be placed on the geomembrane to prevent uplift by wind (in high winds, continuous loading is recommended along panel edges to minimize the risk of damage due to uplift cause by wind flow under the panels)

g The geomembrane shall be especially protected from damage in heavily trafficked areas

5 On slopes, geomembranes shall be installed in a controlled manner from the top of the slope to the bottom The geomembrane shall be temporarily anchored at the top of the slope prior to deployment Unrestrained release of the geomembrane from the top of the slope is not acceptable

6 Any field panel or portion thereof that becomes seriously damaged (torn, twisted, or crimped) shall be replaced with new material at no expense to the Owner Less serious damage may be repaired with the approval of the Owner's Representative Damaged panels or portions of damaged panels that have been rejected shall be removed from the Work area at no expense to the Owner

7 Adjacent geomembrane panels shall be overlapped as described in Part 3 03 D below Larger overlaps shall be used if thermal contraction of the geomembrane is anticipated prior to seaming Adjacent panels shall be placed under similar temperature conditions, preferably early in the day when temperatures are cooler, to minimize the potential for differential contraction

3 03 FIELD SEAMING

A Seam Layout

1 In general, seams shall be oriented parallel to the line of maximum slope (i e , oriented down, not across, the slope) In corners and at odd-shaped geometric locations, the number of field seams shall be minimized No seams shall be located in an area of potential stress concentration (i e , seams shall be along, not across, the slopes), except as part of a patch, unless approved by the Owner's Representative

B Personnel

1 All personnel performing seaming operations shall be qualified as required by this Specification

C Weather Conditions for Seaming

1 Seaming shall not be attempted at ambient temperatures below those identified during design and as specified by the Manufacturer recommendations In all cases, the geomembrane shall be dry and protected from excessive wind

2 If the Contractor wishes to perform seaming at ambient temperatures below those specified, the Contractor shall demonstrate that the seam so produced is equivalent to those produced under normally approved conditions and that the overall quality of the geomembrane is not adversely affected The Contractor shall submit a geomembrane cold-weather placement and seaming plan that details all aspects of the cold-weather seaming operation. The plan must certify that the cold-weather seaming procedure does not cause any physical or chemical modification to the geomembrane

that the seam so produced does not result in any short- or long-term damage to the geomembrane

3 To minimize geomembrane contraction stresses, seaming should ideally be carried out in the morning and later evening when the geomembrane is relatively contracted, and during the middle of the day if overcast conditions prevail If the geomembrane must be seamed in the middle of a sunny day, the Contractor shall ensure that the panels to be seamed are at the same temperature and that there is sufficient slack in the geomembrane to prevent the generation of excessive stresses or trampolining when the geomembrane contracts as cooler temperatures prevail The required amount of slack shall be determined by the Contractor and it should not be so much so as to cause significant wrinkling of the geomembrane If trampolining or excessive wrinkling of the geomembrane is observed, the Contractor will be required to make repairs so that the problem is eliminated

D Overlapping and Temporary Bonding

1 Geomembrane panels shall have sufficient overlap provided to meet requirements developed during design and allow specified tests to be performed on the seam

2 The procedure used to temporarily bond adjacent panels together shall not damage the geomembrane

E Seam Preparation

1 Prior to seaming, the seam area shall be cleaned so that it is free of moisture, dust, dirt, debris of any kind, and foreign material

2 If seam overlap grinding or other preparation procedure is required, the process shall be completed within 30 minutes of the seaming operation in a manner that does not damage the geomembrane

3 Seams shall be aligned with the fewest possible number of wrinkles and "fishmouths "

F General Seaming Requirements

1 All geomembrane overlaps shall be continuously seamed using approved procedures The sequence for seaming geomembranes will be determined jointly by the Contractor and Owner's Representative during preconstruction meetings

2 Seaming shall extend to the outside edge of panels to be placed in the anchor trench.

3 If required, a firm substrate shall be provided by using a flat board, a conveyor belt, or similar hard surface, directly under the seam overlap to achieve proper support

4 If seaming operations are carried out at night, adequate illumination shall be provided

5 Fishmouths or wrinkles at the seam overlaps shall be cut along the ridge of the wrinkle to achieve a flat overlap The cut fishmouths or wrinkles shall be seamed, and any portion where the overlap is inadequate shall then be patched with an oval or round patch of the same geomembrane that extends beyond the cut in all directions in accordance with requirements specified in the design

6 At the end of each day or installation segment, all exposed geomembrane edges shall be anchored by sandbags or other approved means If high winds are expected, boards with weighted sandbags on top may be used to keep wind from getting under the exposed edge of the geomembrane

G Seaming Process

1 Approved processes for field seaming will be identified during design. Alternate processes shall not be used unless a plan for their use has been submitted by the Contractor and approved by the Owner's Representative Seaming equipment and methods shall not damage the geomembrane

H Trial Seams

1 Trial seams shall be made on fragment pieces of geomembrane to verify that seaming conditions are adequate Such trial seams shall be made at the frequencies specified in the design Trial seams shall be made under the same conditions as actual seams

2 Specimens shall be cut from the trial seam sample by the Contractor for testing The test specimens shall not fail in the seam If a specimen fails, the entire operation shall be repeated If the additional trial seam fails, the seaming apparatus or seamer shall not be accepted and shall not be used for seaming until the deficiencies are corrected and two consecutive successful trial seams are achieved

3 The Owner's Representative will observe all trial seam procedures Successful trial seam samples will be assigned a number and marked accordingly by the Owner's Representative, who will also log the date, hour, ambient temperature, name of seamer, and pass or fail description The sample itself will be retained in the Owner's Representative's archives

I Nondestructive Seam Continuity Testing

1 Contractor shall nondestructively test all field seams over their full length, except as indicated using a test method identified during design

J Destructive Testing

1 Destructive seam tests shall be performed on samples collected from selected locations to evaluate seam strength and integrity Samples shall be collected at a minimum frequency of one sample per 500 feet of seam Destructive tests shall be carried out as the seaming Work progresses, not at the completion of all field seaming

2 Sampling

a Test locations shall not be determined prior to seaming and may be prompted by suspicion of excess crystallinity, contamination, offset seams, or any other potential cause of imperfect seaming The Owner's Representative will be responsible for choosing the locations of destructive seam samples The Contractor shall not be informed in advance of the locations where the seam samples will be taken. The Owner's Representative reserves the right to increase the sampling frequency

b Samples shall be cut by the Contractor at the locations designated by the Owner's Representative as the seaming progresses in order to obtain laboratory test results before the geomembrane is covered by another material Each sample shall be numbered and the sample number and location identified on the panel layout drawing All holes in the geomembrane resulting from the destructive seam sampling shall be repaired immediately in accordance with the repair procedures described in Part 3 03 K. of this Section. The continuity of the new seams in the repaired areas shall be tested according to Part 3 03 I of this Section

K. Defects and Repairs

1. The geomembrane will be inspected before and after seaming for evidence of defects, holes, blisters, undispersed raw materials, and any contamination by foreign matter The surface of the geomembrane shall be clean at the time of inspection The geomembrane surface shall be swept or washed by the Contractor if surface contamination inhibits inspection

2 Each suspect location, both in seam and nonseam areas shall, at the discretion of the Owner's Representative, be either repaired or tested Each location that fails testing shall be marked by the Owner's Representative and repaired by the Contractor

3 When seaming of a geomembrane is completed (or when seaming of a large area of a geomembrane is completed) and prior to placing overlying materials, the Owner's Representative shall identify all excessive geomembrane wrinkles The Contractor shall cut and reseam all wrinkles so identified The seams thus produced shall be tested like any other seams

4 Repair Procedures

a Any portion of the geomembrane exhibiting a flaw or failing a destructive or nondestructive test, shall be repaired by the Contractor The final decision as to the appropriate repair procedure shall be agreed upon between the Owner's Representative and the Contractor

b In addition, the following shall be satisfied

(1) Surfaces of the geomembrane that are to be repaired shall be prepared no more than 30 minutes prior to the repair

(2) All surfaces must be clean and dry at the time of repair

(3) All seaming equipment and materials used in repair procedures must be approved by the Owner's Representative

(4) The repair procedures, materials, and techniques shall be approved in advance, for the specific repair, by the Owner's Representative and Contractor

(5) The geomembrane below large repairs shall be appropriately cut to avoid water or gas collection between the two sheets

5 Repair Verification

a Each repair shall be located, numbered, and logged and shall be nondestructively tested, as appropriate Repairs that pass the nondestructive test shall be taken as an indication of an adequate repair Failed tests will require the repair to be redone and retested until a passing test results

3 04 MATERIALS IN CONTACT WITH THE LINER

A The Contractor shall not leave any tools or equipment on the geomembrane

B The Contractor shall take all necessary precautions to ensure that the geomembrane is not damaged during its installation or during the installation of other components of the liner system or by other construction activities Installation on rough surfaces shall be performed carefully

C Equipment shall not be driven directly on the geomembrane Unless otherwise specified by the Owner's Representative, all equipment operating on materials overlying the geomembrane shall comply with maximum allowable ground pressure criteria developed during design

- END OF SECTION -

SECTION 02714 GEOCOMPOSITE

PART 1 GENERAL

1 01 SCOPE OF WORK

A If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geocomposite components of the landfill cells The Work shall be carried out in accordance with the Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A. The Contractor shall abide by all qualification and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A. Work will be monitored and tested in accordance with the requirements of the CQA Plan

B Any geocomposite rolls that do not meet the requirements of these Specifications will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

C If the Owner's Representative's testing indicates that Work does not meet the requirements of the Specifications, the Owner's Representative will establish the extent of the nonconforming area. The nonconforming area shall be reworked by the Contractor at no cost to the Owner until acceptable test results are obtained

PART 2 PRODUCTS

2 01 GEOCOMPOSITE PROPERTIES

A The Contractor shall require that the geocomposite Manufacturer furnish material with minimum average roll values, as defined by the FHWA, meeting or exceeding the criteria specified during design. The Contractor shall require that the Manufacturer provide results for tests performed, as well as a certification that the material delivered to the site meets or exceeds the specified values

B In addition to the required property values identified during design, the geocomposite shall

1 Retain its structure during handling, placement, and long-term service

2 Be capable of withstanding outdoor (i e , ultraviolet [UV] light) exposure for a minimum of 30 days with no measurable degradation in the specified physical properties

3 Meet any additional requirements of the Drawings

4 Be manufactured with a geonet that does not contain any reclaimed polymer, nor any foaming or blowing agents

2 02 MANUFACTURING QUALITY CONTROL

A The Contractor shall require that the geocomposite Manufacturer sample and test the geocomposite to demonstrate that the material conforms to the requirements of the Specifications All Quality Control testing required by the Specifications and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor Test results shall be provided to the Owner's Representative Sampling shall, in general, be performed on sacrificial portions of the geocomposite material such that repair is not required The Contractor shall require that the geocomposite Manufacturer sample and test the geocomposite at the minimum frequency specified and perform the manufacturing quality control tests defined during design.

B Any geocomposite sample that does not comply with the Specifications shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

C If a geocomposite sample fails to meet the quality control requirements of this Specification, the Contractor shall require that the geocomposite Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results as determined by the Owner's Representative is established

D Additional sample testing may be performed, at the geocomposite Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

2 03 LABELING

A Geocomposite rolls shall be labeled with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

B If any special handling is required, it shall be so marked on the geocomposite itself (e g , "This Side Up" or "This Side Against Soil To Be Retained")

2 04 TRANSPORTATION

A Transportation of the geocomposite shall be the responsibility of the Contractor The Contractor shall be liable for damage to the geocomposite incurred prior to and during transportation to the site The Contractor shall replace damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Geocomposite shall be shipped and stored in watertight and opaque protective covers

B Handling, storage, and care of the geocomposite prior to and following incorporation into the Work is the responsibility of the Contractor The Contractor shall be liable for damage to the material incurred prior to final acceptance by the Owner's Representative The Contractor shall repair damage in accordance with Part 3 03 of this Section at no additional cost to the Owner

C The Contractor shall be responsible for storage of the geocomposite at the site The geocomposite shall be stored off the ground and out of direct sunlight and shall be protected from puncture, cutting, and excessive heat, cold, moisture, mud, dirt, dust, or any other damaging or deleterious conditions The geocomposite shall be stored in accordance with any additional requirements of the geocomposite Manufacturer

PART 3 EXECUTION

3 01 HANDLING AND PLACEMENT

A If required by the design, geocomposite shall be installed at all locations shown on the Drawings

B The Contractor shall handle the geocomposite in such a manner as to ensure that the geocomposite is not damaged in any way

C Just prior to geocomposite placement, the geomembrane that may underlie the geocomposite shall be clean and free of excessive dust and dirt, stones, rocks, or other obstructions that could potentially damage the geomembrane The geomembrane shall be swept clean prior to geocomposite placement. At the direction of the Owner's Representative, the Contractor may be required to clean the geomembrane with water

D The Contractor shall take all necessary precautions to prevent damage to underlaying layers during placement of the geocomposite

E In the presence of excessive wind, the Contractor shall weight the geocomposite with sandbags or equivalent method approved by the Owner's Representative

F On sideslopes, the geocomposite shall be secured, by the Contractor, at the top of the slope and then rolled down the slope

G If necessary, the Contractor shall position the geocomposite by hand after it is unrolled to minimize wrinkles

H Geocomposite shall be clean when installed During installation, care shall be taken by the Contractor not to entrap stones, excessive dirt, or moisture that could damage the underlying geomembrane, clog drains or filters, or hamper subsequent seaming

I Geocomposite shall not be welded to the geomembrane liners Geocomposite shall only be cut using a cutter approved by the geocomposite Manufacturer and the Owner's Representative

J Tools shall not be left on or in the geocomposite

K. After placing the geocomposite, the geocomposite shall not be left exposed for a period in excess of 30 days unless a longer exposure period is approved by the Owner's Representative based on a formal demonstration from the Contractor (e.g., a certification from the geocomposite Manufacturer) that the geotextile component of the geocomposite is stabilized against UV light degradation for a period in excess of 30 days

L. If white geotextile is used in the geocomposite, precautions shall be taken against "snow blindness" of personnel

3.02 SEAMS AND OVERLAPS

A. The components of the geocomposite (e g , geotextile-geonet-geotextile) shall not be bonded together at the ends and edges of the rolls Each component shall be secured or seamed to the like component at overlaps

B No horizontal seams shall be allowed on slopes steeper than those specified in the design unless approved by the Owner's Representative

C Geonet Components

1 The geonet components shall be overlapped by the distance specified in the design and in accordance with Manufacturer's recommendations These overlaps shall be secured by tying

2 Tying shall be achieved by nylon strings, plastic fasteners, or polymer braid Metallic devices shall not be used Tying devices shall be provided in a color different than the geonet to allow easy inspection.

3 The spacing shall be as specified in the design.

4 When more than one layer of geocomposite is installed, joints shall be staggered as specified in the design.

5 The joints on adjacent geocomposite panels shall be staggered as specified in the design.

D Geotextile Components

1 The top layers of geotextiles shall be sewn in accordance with the requirements of the design. Geotextiles shall be overlapped prior to sewing in accordance with the design.

3 03 REPAIR

A Any holes or tears in the geocomposite shall be repaired by placing a patch extending beyond the edges of the hole or tear as required by the design The patch shall be secured over the hole or tear by tying fasteners through the geocomposite patch, and through the top geotextile and geonet beneath the patch The patch shall be secured with approved tying devices A larger geotextile patch shall be placed over the geocomposite patch and shall be heat sealed to the top geotextile of the geocomposite needing repair If the hole or tear width across the roll is more than 50 percent of the width of the roll, the damaged area shall be cut out and the two portions of the geocomposite shall be joined in accordance with Part 3 02 of this Section.

3 04 PLACEMENT OF OVERLYING MATERIALS

A Earth fill, geosynthetic clay liner, compacted clay liner, or vegetative soil layer as required by the Drawings, shall be placed as soon as possible after placement and approval of the geocomposite Placement of each overlying material shall be in accordance with the appropriate Sections of the Specifications

B The Contractor shall place overlying soil materials in such a manner as to ensure that

1 The geocomposite and underlying geosnythetic materials are not damaged

2 Minimal slippage occurs between the geocomposite and underlying layers

3 Excessive stresses are not produced in the geocomposite

C Unless otherwise specified by the Owner's Representative, the equipment operating on soil material overlying a geocomposite shall comply with the maximum permissible ground pressure requirement specified in the design. The acceptability of equipment operating at ground pressures greater than the maximum specified will be evaluated by the Owner's Representative at the Contractor's expense

D The CQA firm will provide monitoring of the spreading of soils over the geocomposite in accordance with the CQA Plan.

3 05 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B The CQA firm will identify any areas requiring repair The Contractor shall immediately make repairs and replacements necessary, to the approval of the Owner's Representative at no additional cost to the Owner

C The CQA firm will issue an approval of the geocomposite installation to the Owner's Representative prior to placement of material over the geocomposite in accordance with the CQA Plan

- END OF SECTION -

SECTION 02715 GEONET

PART 1 GENERAL

1 01 SCOPE OF WORK

A If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geonet components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 SUBMITTALS

A In accordance with the CQA Plan and the Specifications

B Materials Submit laboratory test data and Manufacturer's product data and certification in accordance with the Products Subsection of this Section.

C Layout Drawings Contractor shall submit Layout Drawings for the geonet to the Owner's Representative describing in detail where and how the geonet will be installed Work covered in this Section shall not commence until Layout Drawings are reviewed and approved by the Owner's Representative

PART 2 PRODUCTS

2 01 GEONET PROPERTIES

A Unless otherwise noted on the Drawings, the Contractor shall require that the geonet Manufacturer furnish material having properties that comply with the required values established during design. The Contractor shall require that the geonet Manufacturer provide results for tests performed using the procedures identified in the final design, as well as a certification that the material properties meet or exceed the specified values

B In addition to the property values identified in the final design, the geonet shall

1 Retain its structure during handling, placement, and long-term service

2 Be chemically inert when immersed in a leachate representative of that from the landfill

3 Meet any additional requirements of the Drawings

4 Not be manufactured from any reclaimed polymer

2 02 MANUFACTURING QUALITY CONTROL

A The geonet shall be manufactured with quality control procedures that meet or exceed generally accepted industry standards

B The Contractor shall require that the geonet Manufacturer sample and test the geonet to demonstrate that the material conforms to the requirements set forth in design.

C Any geonet sample that does not comply with the Specifications shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

D If a geonet sample fails to meet the quality control requirements of the Specifications, the Contractor shall require that the geonet Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results as determined by the Owner's Representative is established

E Additional sample testing may be performed, at the geonet Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

F The Contractor shall require that the geonet Manufacturer comply with the certification and submittal requirements of this project manual

2 03 LABELING

A Geonet rolls shall be labeled with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

2 04 TRANSPORTATION

A Transportation of the geonet shall be the responsibility of the Contractor The Contractor shall be liable for damage to the geonet incurred prior to and during transportation to the site The Contractor shall replace damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Geonet shall be protected from damage during shipping and storage

B Handling, storage, and care of the geonet prior to and following incorporation into the Work is the responsibility of the Contractor The Contractor shall be liable for damage to the material incurred prior to final acceptance by the Owner The Contractor shall repair damage in accordance with Part 3 03 of this Section at no additional cost to the Owner

C The Contractor shall be responsible for storage of the geonet at the site The geonet shall be stored off the ground and out of direct sunlight and shall be protected from puncture,

cutting, and excessive heat, cold, moisture, mud, dirt, dust, or any other damaging or deleterious condition The geonet shall be stored in accordance with any additional requirements of the geonet Manufacturer

PART 3 EXECUTION

3 01 HANDLING AND PLACEMENT

A If required by the design, geonet shall be installed at all locations shown on the Drawings

B The Contractor shall handle the geonet in such a manner as to ensure that the geonet is not damaged in any way

C Just prior to geonet placement, the geomembrane liner that may underlie the geonet shall be clean and free of excessive dust and dirt, stones, rocks, or other obstructions that could potentially damage the geomembrane The geomembrane shall be swept clean prior to geonet placement At the direction of the Owner's Representative, the Contractor shall clean the geomembrane with water

D The Contractor shall take all necessary precautions to prevent damage to underlaying layers during placement of the geonet.

E In the presence of excessive wind, the geonet shall be weighted with sandbags or equivalent weight approved by the Owner's Representative Such sandbags shall be installed during placement and shall remain until replaced with an overlying layer

F On sideslopes, the geonet shall be secured in the anchor trench and then rolled down the slope

G If necessary, the geonet shall be positioned by hand after being unrolled to minimize wrinkles

H Geonet shall be clean when installed During installation, care shall be taken not to entrap stones, excessive dirt, or moisture that could damage the underlying geomembrane or generate clogging drains or filters

I Geonet shall not be welded to geomembrane liners Geonet shall only be cut using a cutter approved by the geonet Manufacturer and the Owner's Representative

J Tools shall not be left on or in the geonet.

K. Geonet shall not be placed in direct contact with textured geomembrane liner unless specifically called for on the Drawings

3 02 STACKING AND JOINING

A. When two or more layers of geonets are stacked, care shall be taken to prevent the strands of one layer of geonet from penetrating the channels of an overlying or underlying layer

B A layer of Geonet shall not be installed in a direction perpendicular to an underlying layer of geonet

C In the corners of the sideslopes, where overlaps between perpendicular geonet strips are required, an extra layer of geonet shall be unrolled along the slope, on top of the previously installed geonets, from top to bottom of the slope, as shown on the Drawings

D Adjacent rolls of geonet shall be overlapped as required in the final design These overlaps shall be secured by tying

E Tying shall be achieved by nylon strings, plastic fasteners, or polymer braid Metallic devices shall not be used Tying devices shall be provided in a color to allow for easy inspection.

F Tie spacing shall be as required in the final design

G When more than one layer of geonet is installed, joints shall be staggered as required in the final design.

H The joints on adjacent geonet panels shall be staggered as required in the final design

3 03 REPAIR

A Any holes or tears in the geonet shall be repaired by placing a patch over the hole or tear extending beyond the edges of the hole or tear as set forth in the final design. The patch shall be secured to the original geonet by tying with approved tying devices If the hole or tear width across the roll is more than 50 percent of the width of the roll, the damaged area shall be cut out and the two portions of the geonet shall be jointed in accordance with Part 3 02 above

3 04 PLACEMENT OF OVERLYING MATERIALS

A An installed layer of geonet shall be covered with the overlying layer (geotextile or geomembrane), as required by the Drawings, as soon as possible after installation and approval The purpose of this action is to minimize the accumulation of dirt or dust in the geonet and the potential for damage to the geonet or the underlying geomembrane If dust or dirt accumulates in the geonet layer prior to placement of the overlying layer, the Owner's Representative will direct the Contractor to clean the geonet by sweeping or washing with water

B Soil shall never be placed in direct contact with geonets Geonets shall be separated from soil materials by a geotextile or other material, as indicated on the Drawings The only exception to this shall be at those locations shown on the Drawings (e g , pipe bedding gravel directly overlies one or more layers of geonet.)

C When soil is placed above the overlying layer the Contractor shall place the soil in such a manner as to ensure that

1 The geonet and underlying geomembrane are not damaged

2 Minimal slippage occurs between the geonet and the underlying geomembrane

3 Excess stresses are not produced in the geonet

D The CQA firm will provide continuous monitoring of the spreading of any soil materials over the geonet with earth moving equipment.

E Unless otherwise specified by the Owner's Representative, all equipment operating on soil material overlying a geonet shall comply with the maximum permissible ground pressure requirements specified in the design.

- END OF SECTION -

SECTION 02716. GEOTEXTILE FABRIC

PART 1 GENERAL

1 01 SCOPE OF WORK

A. If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of geotextile fabric components of the landfill cells The Work shall be carried out in accordance with this Specification, the CQA Plan, the Drawings, and other Contract Documents

1 02 SUBMITTALS

A In accordance with the CQA Plan and the Specifications

B Materials Submit laboratory test data and Manufacturer's product data and certification in accordance with the Products Subsection of this Section.

C Layout Drawings Contractor shall submit Layout Drawings for the geotextile fabric to the Owner's Representative describing in detail where and how the geotextile fabric will be installed Work covered in this Section shall not commence until shop Drawings are reviewed and approved by the Owner's Representative

1 03 CONSTRUCTION QUALITY ASSURANCE

A Work will be monitored and tested in accordance with the requirements of the CQA Plan.

B Any geotextile rolls that do not meet the requirements of the Specification will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

PART 2 PRODUCTS

2 01 GEOTEXTILE PROPERTIES

A The Contractor shall require that the geotextile Manufacturer furnish geotextile with minimum average roll values, as defined by the FHWA, meeting or exceeding the criteria set forth in design The Contractor shall require that the geotextile Manufacturer provide results for tests performed as well as a certification that the material properties meet or exceed all property values specified for that type of geotextile

B In addition to the required property values identified during design, the geotextile fabric shall

1. Retain its structure during handling, placement, and long-term service

2. Be capable of withstanding outdoor (i e , UV) light for a minimum of 30 days with no measurable deterioration.

3 Be chemically inert when immersed in a leachate representative of that from the landfill

4 Meet any additional requirements of the Drawings

2 02 MANUFACTURING QUALITY CONTROL

A. The geotextile shall be manufactured with quality control procedures that meet or exceed generally accepted industry standards

B The Contractor shall require that the geotextile Manufacturer sample and test the geotextile to demonstrate that the material conforms to the requirements of the Specifications

C Any geotextile sample that does not comply with this Specification shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

D If a geotextile sample fails to meet the quality control requirements of this Specification, the Contractor shall require that the geotextile Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results as determined by the Owner's Representative is established

E Additional sample testing may be performed, at the geotextile Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

F Sampling shall, in general, be performed on sacrificial portions of the geotextile material such that repair is not required

G The Contractor shall require that the geotextile Manufacturer comply with all applicable certification and submittal requirements

2 03 LABELING

A Geotextile rolls shall be marked or tagged with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

B If any special handling is required, it shall be so marked on the geotextile itself, (e g , "This Side Up" or "This Side Against Soil to be Retained")

2 04 TRANSPORTATION

A Transportation of the geotextile shall be the responsibility of the Contractor The Contractor shall be liable for all damage to the geotextile incurred prior to and during transportation to the site The Contractor shall repair or replace any damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Geotextile shall be shipped and stored in watertight and opaque protective covers

B Handling, storage, and care of the geotextile prior to and following installation at the site is the responsibility of the Contractor The Contractor shall be liable for all damages to the geotextile incurred prior to final acceptance by the Owner's Representative The Contractor shall repair all damage in accordance with Part 3.03 of this Specification and at no additional cost to the Owner

C The Contractor shall be responsible for storage of the geotextile at the site The geotextile shall be stored off the ground and out of direct sunlight and precipitation and shall be protected from excessive heat or cold, mud, dirt, dust, puncture, cutting, or any other damaging or deleterious conditions The geotextile shall also be stored in accordance with any additional requirements of the geotextile Manufacturer

PART 3 EXECUTION

3 01 HANDLING AND PLACEMENT

A. If required by the design, geotextile fabric of the type(s) specified in the design shall be installed at all locations shown on the Drawings

B The Contractor shall handle the geotextile in such a manner as to ensure that the geotextile is not damaged in any way

C The Contractor shall take all necessary precautions to prevent damage to underlying layers during placement of the geotextile

D Just prior to geotextile placement, the layer that will underlie the geotextile, if it is geosynthetic, shall be clean and free of dust, dirt, stones, rocks, or other obstructions that could potentially damage the liner system

E. After placing the geotextile, the geotextile shall not be left exposed for a period in excess of 30 days unless a longer exposure period is approved by the Owner's Representative, based on a demonstration from the Manufacturer (e g , a certification from the geotextile Manufacturer) that the geotextile is stabilized against UV light degradation for a period in excess of 30 days This requirement does not apply to material used as sacrificial geotextile

F If white geotextile is used, precautions shall be taken against "snow blindness" of personnel

G In the presence of wind, the geotextile shall be weighted with sandbags or equivalent weight approved by the Owner's Representative Such sandbags shall be installed during placement and shall remain until replaced with an overlying layer

H On sideslopes, the geotextile shall be secured in the anchor trench and then rolled down the slope in such a manner as to continually keep it in tension

I If necessary, the geotextile shall be positioned by hand after being unrolled to minimize wrinkles

J Geotextile shall be clean when installed During installation, care shall be taken not to entrap stones, excessive dirt, or moisture that could damage the underlying layers, clog drains or filters, or hamper subsequent seaming

K Tools shall not be left on or in the geotextile

L The Contractor and Owner's Representative shall examine the entire geotextile surface after installation to ensure that no potentially harmful foreign objects (including broken sewing needles) are present The Contractor shall remove any such foreign objects and shall replace any damaged geotextile

3 02 SEAMS AND OVERLAPS

A All geotextile overlaps shall be continuously sewn (i e , spot sewing and thermal bonding are not allowed) Geotextiles shall be overlapped in accordance with design requirements prior to sewing No horizontal seams shall be allowed on slopes steeper than those specified in the design (i e , seams shall be along, not across, the slopes), except as part of a patch, unless approved by the Owner's Representative

3 03 REPAIR

A Any holes or tears in the geotextile shall be repaired as follows

1 A patch made from the same type of geotextile Should any tear exceed 10 percent of the width of the roll, that roll shall be removed from the slope and replaced with new material, at no additional cost to the Owner

2 A patch made from the same type of geotextile shall be overlapped and stitched into place in accordance with requirements set forth in the design

B Care shall be taken to remove any soil or other material that may have penetrated the torn geotextile

3 04 PLACEMENT OF OVERLYING MATERIALS

A The Contractor shall place all overlying soil materials in such manner as to ensure that

1 The geotextile and underlying geosynthetic materials are not damaged

2 Minimum slippage occurs between the geotextile and underlying layers

3 Excess stress is not produced in the geotextile

B The Owner's Representative will provide continuous monitoring of the spreading of any soil materials over the geotextile with earth moving equipment

C Unless otherwise specified by the Owner's Representative, all equipment operating on soil material overlying the geotextile shall comply with the maximum permissible ground pressure requirements specified in the design

3 04 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B The CQA firm will identify any areas requiring repair The Contractor shall immediately make repairs and replacements necessary, to the approval of the Owner's Representative and at no additional cost to the Owner

C The CQA firm will issue an approval of the geocomposite installation to the Owner's Representative prior to placement of material over the geocomposite in accordance with the CQA Plan.

- END OF SECTION -

SECTION 02721 COMPACTED CLAY LINER

PART 1 GENERAL

This Section will be modified based on the results of the test fill program (see Appendix I) and future design

1 01 SCOPE OF WORK

A The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the construction of the compacted clay liner components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A The Contractor shall abide by all qualifications and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A All Work shall be monitored and tested in accordance with the requirements of the CQA Plan.

B The Contractor shall be aware of all testing activities outlined in the CQA Plan and shall account for these activities in the construction schedule No additional costs to the Owner shall be allowed by the Contractor as a result of the performance of the CQA activities

C Soil testing (both field and laboratory testing) required by the CQA Plan will be the responsibility of the CQA firm All Quality Control testing required by these Specifications, the CQA Plan, and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor The Contractor shall cooperate with the CQA firm during all testing activities The Contractor shall provide equipment and labor to assist the CQA firm in sampling The Contractor shall provide access to all areas requiring testing The Contractor shall repair any damage to finished Work caused by the CQA firm's sampling or testing activities

D If the CQA firm's tests indicate Work does not meet the requirements of the Specifications, the CQA firm will establish the extent of the nonconforming area The nonconforming area shall be reworked by the Contractor at no cost to the Owner until acceptable test results are obtained

PART 2 PRODUCTS

2.01 MATERIALS

Clay liner material may only be used for construction if it has been shown to be suitable in the test fill program (see Appendix I) The test fill program will have been performed prior to construction of

the landfill cells and is not part of the Work included in this Specification Depending on the results of future test fills, onsite clay may be used on the base and/or the sideslopes of the landfill cell The Specifications may be modified per the results of the test fill program

A Clay liner material shall be obtained from borrow areas or stockpiles identified by the Owner's Representative

B Clay liner material for landfill cell construction shall meet the characteristics and requirements defined during design which may include but not be limited to

1 Classification according to the Unified Soil Classification System (USCS) (ASTM D 2487) and exhibit specified minimum liquid limit and a minimum plasticity index

2 Have a percentage of gravel (i e , dry weight retained on a U S No 4 sieve) of less than that specified

3 Have a hydraulic conductivity of not more than 1×10^{7} centimeters per second (cm/s) when compacted in accordance with the Specifications and tested in the laboratory

C The water used to increase the moisture content of the clay liner shall be provided by the Owner The Contractor shall maintain an accurate record of water usage

PART 3 EXECUTION

3 01 CLAY LINER COMPACTION CRITERIA

A The compaction moisture content and the minimum dry unit weight of onsite clay shall be as defined in the design

3 02 CLAY LINER PLACEMENT

A The clay liner shall be constructed to the elevations, grades, and thicknesses shown on the Drawings The thickness of the clay liner at any location shall be measured perpendicular to the plane of the slope at the location The compacted clay liner shall be a minimum of three (3) feet thick over the bottom and perpendicular to sideslopes of the landfill cell

B Clay liner placement shall begin only after completion of all, or an approved portion of, excavation and structural fill placement in the landfill cell Placement shall not begin until the Contractor has verified that subgrade elevations and grades conform to the Drawings and CQA firm has completed testing and surveying of the subgrade as required by the CQA Plan

C The Contractor shall not place clay liner material on a surface or subgrade that contains debris, branches, vegetation, mud, ice, or frozen material If frozen subgrade material is encountered, it shall be removed and replaced in accordance with these Specifications Immediately prior to clay liner placement, the subgrade shall be proof-rolled as directed by the Owner's Representative Any excessively wet or soft areas shall be excavated and replaced with properly compacted structural fill

D The Contractor shall construct the clay liner in lifts Each lift of the clay liner shall meet the minimum requirements as defined in the design

E The loose lift thickness and the average lift thickness after compaction shall be no more than the allowable maximum lift thickness in accordance with the test fill results and design requirements

F Lift placement procedures for sideslopes and flat areas shall be performed in accordance with the requirements of the design

G Prior to placement of a lift clay liner material, Contractor shall allow the CQA firm to complete field testing in accordance with the CQA Plan The Contractor shall not place a new lift of clay liner material over a preceding lift until approval is given by the CQA firm If the Contractor fails to comply with this requirement, the Contractor will be required by the Owner to remove and replace all unauthorized Work at no additional cost to the Owner

H Prior to placement of a lift of clay liner material, the previous lift shall be thoroughly scarified in accordance with design requirements to provide good bonding between lifts

I The trafficking of prepared lift surfaces by trucks or other equipment shall not be permitted during the period between preparation and placement of the following lift

J If normal handling does not reduce the maximum clod size in onsite clay to an acceptable size, the Contractor shall use an approved equipment to break up the clods The onsite clay material shall be pulverized until the maximum soil clod size is reduced to meet size requirements The use of specific equipment shall be approved by the Owner's Representative prior to use

K. Moisture conditioning of the clay liner material shall be accomplished in the processing area prior to clay liner construction The processing area location shall be approved by the Owner's Representative Clay liner material shall be moisture conditioned using approved equipment and procedures If the clay liner material is wetter then required, it shall be repeatedly mixed to achieve drying

L No more than the percent moisture defined during design shall be added to the clay liner material at the time of compaction Clay liner material more than the defined percent moisture shall be removed, returned to the processing area, and conditioned until the proper moisture content is achieved If the in-place moisture content is too high, the clay may be dozed, windrowed, disced, and/or otherwise mixed to facilitate drying

M Clay liner material shall not be placed or compacted during a sustained period of temperature below 32 degrees Fahrenheit Clay liner material may be placed and compacted during periods of early morning freezing temperatures if above freezing temperatures are anticipated during the day

N The Contractor shall not place frozen clay nor shall the Contractor place clay on frozen ground

O If clay liner material freezes after compaction, the Contractor shall remove the frozen material, scarify the remaining unfrozen clay, and then place and compact new clay in

accordance with these Specifications Frozen clay shall not be reused until it has thawed and been reworked to an acceptable moisture content. The Contractor shall be responsible for protecting compacted lifts of clay liner material from freezing If extended freezing conditions are anticipated, the Contractor shall prepare a plan for approval by the Owner's Representative, which outlines the measure that will be taken to protect finished Work.

P Clay liner material shall be placed during periods of unfavorable weather conditions, as determined by the Owner's Representative

3 03 CLAY LINER COMPACTION

A. The sequence of compaction of the clay liner for a landfill cell shall be as described in the design Specifications or as shown on the Drawings

B Compaction of clay liner on the base of the cell and on the sideslopes shall be performed using approved equipment.

C The daily Work area shall extend a sufficient distance so as to maintain soil moisture conditions within an acceptable range to allow continuous operations Desiccation and crusting of the lift surface shall be avoided as much as possible

D. The CQA firm will identify any areas of significant desiccation and crusting of a lift surface The Contractor shall scarify the surface of such areas to the nominal depth specified during design or to the depth of desiccation identified by the CQA firm and then water condition, disc, or mix as necessary and recompact the area

E. The transition from an existing full-depth Section of clay liner to the beginning of an adjacent Section that is to be constructed subsequently shall be accomplished by sloping (cutting back) the end of the full-depth Section, scarifying the slope of the exiting full-depth liner at the transition, and then immediately pacing the adjacent lifts of clay liner

F Corners and other areas inaccessible to driven compaction equipment shall be compacted using hand-operated equipment (such as a walk-behind roller) approved by the Owner's Representative

3 04 SURVEY CONTROL

A The Surveyor shall survey the final location and elevation of the top of the clay layer Surveying shall be performed in accordance with these Specifications The survey will ensure that

1 The specified thickness of compacted clay liner has been achieved

2 The top of the clay liner slopes across the landfill cell at the grade shown on the Drawings toward the collection sump

3 The top of the clay liner is at the grades and elevations specified on the contract Drawings

B The Surveyor shall provide a Record Drawing to the Owner's Representative of the final location and elevation of the top of the clay liner, including the location and elevation of the leak detection system sump, in accordance with the requirements of these Specifications. The Surveyor shall submit this Drawing prior to geomembrane liner construction unless otherwise approved by the Owner's Representative and the CQA firm The Contractor may submit a partial record to obtain approval for a portion of the Work. The Owner's Representative will define the minimum requirements for a partial submittal

3 05 FIELD QUALITY CONTROL

A. All quality control testing required by these Specifications and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor

B If the CQA firm's tests indicate that Work does not meet the requirements of the Specifications, the CQA firm will establish the extent of the nonconforming area The nonconforming area shall be reworked by the Contractor at the Contractor's own expense until acceptable test results are obtained

3 06 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B In the event of damage, the CQA firm will identify areas requiring repair, and the Contractor will make repairs and replacements necessary to the approval of the Owner's Representative at no additional cost to the Owner

C The Contractor shall minimize, to the maximum extent feasible, desiccation cracking of clay liner material The Contractor shall sprinkle the clay with water if cracking is observed or if directed by the Owner's Representative The Contractor may seal roll the surface of the clay to reduce drying and desiccation The Contractor may protect exposed surfaces using light-colored or translucent membranes, such as Visqueen, to inhibit drying of the clay The CQA firm will identify areas of significant cracking of the surface of the clay liner and the Contractor shall repair the identified area to the satisfaction of the Owner s Representative at no additional cost to the Owner

D The clay liner surface shall be seal rolled and made smooth and free from ruts or indentations at the end of every working day when precipitation is forecast and/or at the completion of compaction operations in an area

E. The Contractor shall maintain the clay liner surface in a condition suitable for geomembrane installation as specified in the CQA Plan and these Specifications until the surface is covered Desiccation cracks shall be repaired in accordance with the requirements of the design

F The layer of over-built material shall be removed as applicable prior to placement of geomembrane liner The over-built materials may be removed in sections to coordinate with geomembrane placement Where the over-built material is removed, the finished surface shall be protected and maintained as required by the Specifications The surface

of the clay liner on the sideslope shall be trimmed to meet the requirements of these Specifications prior to the installation of the geomembrane liner

G No synthetic sealants or other chemical treatments may be applied to the clay liner material

H The CQA firm will issue an approval of the installation of the clay liner to the Owner's Representative prior to placement of material over the clay liner in accordance with the requirements of the CQA Plan

3 07 PERFORATIONS

A Perforations in the secondary clay liner resulting form construction and CQA activities shall be filled Such perforations may include, but are not limited to, the following

1 Nuclear density test probe locations

2 Shelby tube sample locations

3 Sand-cone or rubber balloon test locations

4 Survey stake locations

- END OF SECTION -

SECTION 02800 MONITORING WELLS

PART 1 GENERAL

1 01 SCOPE OF WORK

A The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation, development and testing of the monitoring wells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A The Contractor shall abide by all qualification and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A All Work will be monitored and tested in accordance with requirements of the CQA Plan.

B Any materials that do not meet the requirements of these Specifications will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

C Regulatory Requirements

1 The Contractor shall comply with all applicable state, county, and local codes and ordinances

D Contractor shall coordinate installation with all utilities to obtain approval of locations

1 04 SUBMITTALS

A Submittals shall include the following

1 Utility field location tickets and forms as applicable

2 Tabulated survey coordinates of staked boring locations

3 Drill rig equipment Specifications

4 Drilling Method The Contractor shall submit the proposed plan for drilling the wells The proposed plan shall take into account all information furnished and all restrictions imposed by the Drawings and Specifications Loss of a hole or well because of lack of material, inadequate or faulty equipment, or careless operating procedures will be considered cause for abandonment of the well at no cost to Owner

5 Specifications for well materials including blank riser pipe, well screen, sandpack, bentonite pellet seal, and concrete grout as applicable and in accordance with the design.

6 Specifications for development pump, bailer, and other testing equipment

7 Product Submittals Contractor shall submit Manufacturers' Specifications for each of the products listed in Section 2 0, Products

8 Tabulated survey coordinates of installed well locations Include horizontal coordinates and elevation of permanent reference point in accordance with the requirements of the design

9 Daily reports, field logs, field well completion forms, and well development data sheets as required in the design.

10 Sandpack Sieve Analysis and Sample The Contractor shall submit for approval the results of a sieve analysis of the proposed sandpack material a minimum of 7 days prior to commencement of well drilling activities

PART 2 PRODUCTS

2 01 MATERIALS

A Well screen, riser pipe, sandpack, bentonite seal, cement-bentonite grout, well casing, and all other materials shall be as specified in the design

B Water for construction shall be clean and free of contaminants The Owner will provide water and specify the source The Contractor shall be responsible for transport of the water from the source to the construction site

PART 3 EXECUTION

3 01 PREPARATION

A Location of borings

1 Stake boring locations at the locations shown on the Drawings in the presence of the Owner's Representative Following Owner's Representative approval of staked locations, survey stakes using survey methods under the direction of a surveyor registered to practice surveying the in State of Colorado Coordinate boring locations with all utilities and obtain utility approval of staked locations Submit utility field location tickets and forms

2. Tabulate horizontal and vertical survey coordinates of staked locations Coordinates shall be consistent with control points established per the design Submit tabulated survey coordinates

3 02 INSTALLATION

A. Drilling

1 Drilling Method Wells shall be drilled and installed in accordance with the methods and procedures set forth in the design. The diameter of the hole shall permit the placement of the minimum thickness of sandpack as specified in the design.

B Riser Pipe, Casing, and Screen

1 Assembly All riser pipe, casing pipe, and screen shall be new and in good condition before installation, and all joints and other accessory parts shall be securely fastened in place Particular care shall be exercised to avoid damaging the screen, centralizers, and riser pipe during installation and throughout all subsequent operations The screen, and riser pipe shall be centered in the well hole and held securely in place during placement of the sandpack using centralizers

2 Joints Sections of the riser pipe shall be joined in accordance with the methods specified in the design.

3 Installation The assembled screen and riser pipe shall be placed in the borehole in such a manner as to avoid jarring impacts and to ensure that the assembly is not damaged or misplaced Immediately after the installation of the well screen and riser pipe, the depth of the well shall be measured The top of the riser pipe shall stick up above ground level as indicated on the Drawings and be sealed after development by installing a protective cap on the top

4 Alignment and Plumbness Each completed well shall be straight and plumb Immediately before placing the sandpack and with top of riser fastened securely in a vertical and horizontal position, alignment and plumbness surveys shall be conducted by the Contractor The Contractor shall furnish all labor, tools, and equipment to perform the tests required in the design

C Sandpack Placement

1 After the screen and riser pipe have been placed and plumbness and alignment surveys are conducted, the sandpack shall be placed around the screen in such a manner as to ensure uniform placement around the screen. The sandpack material shall be placed in one continuous run. Sandpack shall be installed over the depths and at the thickness required by the design Material that may have entered the well screen and riser pipe shall be removed before development of the well is commenced

D Cement-Bentonite Grout Placement

1 Upon completion of sandpack placement, the Contractor shall determine that the sandpack extends to the correct elevation Then the Contractor shall seal the annular space between the casing and the drill hole wall with a bentonite pellet seal and a cement-bentonite seal as set forth in the design.

E Well Development

1 Development of wells shall consist of pumping to create flow from the well and bailing to remove silts Development of the well shall be continued until water entering the well during pumping is visually clear Well development procedures shall be performed as set forth in the design

F Decontamination and Materials Disposal

1. Drill cuttings, groundwater, and other wastes generated during well installation development, and testing shall be handled in accordance with the requirements of the design.

2. All downhole drilling, sampling, and hydraulic testing equipment shall be decontaminated before use at the site and following use at the site

G Survey Locations

1 Following installation, provide horizontal and vertical survey control for all wells in accordance with the requirements of the design.

3 03 CONSTRUCTION QUALITY CONTROL

A. The Contractor shall establish and maintain quality control for all well construction and development to assure compliance with contract requirements The Contractor shall maintain records of quality control for all operations

- END OF SECTION -

Division 3

CONCRETE

To Be Completed During Design

Division 4

MASONRY

To Be Completed During Design

Division 5

METALS

To Be Completed During Design

Division 6

WOOD AND PLASTICS

To Be Completed During Design

Division 7

THERMAL AND MOISTURE PROTECTION

To Be Completed During Design

Division 8

DOORS AND WINDOWS

To Be Completed During Design

Division 9

PROTECTIVE COATINGS

To Be Completed During Design

Division 10

SPECIALTIES

To Be Completed During Design

Division 11

EQUIPMENT

To Be Completed During Design

Division 12

FURNISHINGS

To Be Completed During Design

Division 13

SPECIAL CONSTRUCTION

To Be Completed During Design

Division 14

CONVEYANCE SYSTEMS

To Be Completed During Design

Division 15

MECHANICAL

SECTION 15050 PIPING SYSTEMS - GENERAL

PART 1 GENERAL

1 01 SUMMARY

A. Section Includes

1 Piping system general requirements

2. Piping identification

3 Testing piping systems

4 The Contractor shall furnish all labor, materials tools, equipment, supervision, transportation, and other services necessary to complete the construction of all facilities and systems incorporating piping and related appurtenances and all subsidiary Work required to complete such Work. The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 REFERENCES

A. Standards Referenced in This Section

1	ANSI A13 1-81	Scheme for the Identification of Piping Systems
2	MIL-STD-810C (1975)	Environmental Test Methods
3	UPC (1985)	Uniform Plumbing Code

1 03 DEFINITIONS

A Pressure terms used in this Section and elsewhere in Division 15, Mechanical, are defined as follows

1 Maximum pressure The greatest continuous pressure at which the piping system will operate

2 Test pressure The hydrostatic pressure used to determine whether piping system meets specified requirements

1 04 SUBMITTALS

A Submittals required for piping systems may include the following information (submittal requirements will be developed during design)

1 Layout Drawings showing the location and size of all pipe, fittings, valves, and thrust restraints

2 Details of connections or interfaces between pipes of different materials

3 Details of connections to new and existing structures

4 Details of flexible connections

5 Details of fittings and angles

6 Details of joints and gaskets

B Quality Control Submittals

1. Submit Manufacturers' design data, test reports, certificates, and instructions for installation and operation of pipe, fittings, and valves

2 Record of piping system tests including date of test, signature of Owner's Representative witnessing the test, and statement of test performance

C Project Record Documents

1 Record Drawings

1 05 QUALITY ASSURANCE

A Piping system identification shall conform to ANSI A13 1

PART 2 PRODUCTS

2 01 GENERAL REQUIREMENTS

A Piping Systems

1 Unless otherwise specified, piping systems and materials including pipe, gaskets, fittings, joint assemblies, linings, and coatings shall conform to Specifications for each type of pipe and piping appurtenance specified in other related Sections

2 Flanged Connections Use proper length bolts for each size flange Bolts with excessive length of exposed threads will not be permitted and will be replaced or cut to correct length at the Contractor's expense

3 Unions shall be installed in all piping connections to equipment, regulating valves, and wherever necessary for dismantling of piping or removal of valves and other items requiring maintenance Flanges on equipment may be considered as unions, unless otherwise indicated on Drawings Provide dielectric unions at connections of dissimilar metals

4 Copper tubing shall be cut so that ends are square Thoroughly clean sockets and ends of tubing before soldering Heat joints uniformly to proper temperature so that

solder will flow to all parts Where solder joint valves are provided with composition discs, remove discs before soldering

5 Pump Strainers Furnish and install temporary pump strainers for initial unit start-up where permanent strainers are not provided Temporary strainers shall be removed by the start-up crew after cleaning and flushing systems and run-in of equipment, and before general tightness test.

6 Cleaning and Protecting Exercise reasonable care to prevent entry of foreign matter during handling, assembling, and erecting Use compressed air, wire brush, solvent, and other acceptable means to remove residual scale, dirt and other foreign matter from interior of piping before final connections are made Protect open ends of pipe by capping, plugging or other acceptable means

B UNDERGROUND PIPING SYSTEMS

1 General

a The underground installation of any piping system, using any piping material (steel, concrete, cast iron, plastics, clay, etc) shall satisfy the Codes and Regulations of the authorities having jurisdiction at the site If no such Codes or Regulations exist, the ANSI Standards or recommendations of the Manufacturers, Manufacturers' associations, or other technical organizations involved in the manufacturing, fabrication, installation or utilization of the specific piping material, as indicated in the applicable Specification, shall govern.

b If tunneling or jacking is required, the subcontractor shall submit to the Owner's Representative the details of the construction method that he prefers and secure approval from the Owner's Representative prior to beginning the Work.

2 Excavating and Trenching

a Safeguards. Provide, erect, maintain, and later remove temporary safeguards such as barricades, bridges, guard rails, signs, lights, and flares for protection of personnel, the public, equipment, and materials as Owner's Representative directs and as required by federal, state, and local codes and ordinances

b Retaining Excavations Provide shoring, sheeting, and bracing necessary to retain excavations, maintain banks securely, withstand water pressure, prevent cave-ins, and protect life and property As backfilling proceeds, remove shoring, sheeting, and bracing in a manner to prevent damage or disturbance to the construction and surrounding areas

c Dimensions Run trenches straight at required elevations and dimensions Keep width of trench at pipe level to a minimum, allowing adequate space for laying pipe, constructing underground structures, and inspection. Where materials are removed below required elevations, place and compact fill as specified to correct elevations

d Portions of the site contain potentially contaminated materials In areas where contaminants are present, special procedures as described in the Contractor Health and Safety Plan shall be followed to protect personnel and avoid further contamination of the site or equipment The Contractor will be advised of the location of potentially contaminated areas by the Owner's Representative.

e Excavation, removal, disposal, or stockpiling of contaminated materials shall conform to the requirements of the Health and Safety Plan Contaminated soil will be designated by the Owner's Representative Owner's Representative will be responsible for arranging for characterization, storage, and final disposal as required

f Suitable Bearing Where unsuitable material is exposed at completion of planned excavation, perform further excavation as directed by the Owner's Representative until suitable bearing is reached Place and compact fill as specified herein to correct elevations It is assumed that materials at the job site can be excavated by hand labor or with normal equipment such as a trencher, backhoe, or power shovel

g. Water Removal Maintain grades to promote water drainage Provide and operate equipment to keep excavations and construction areas free of subsurface, surface and storm water Provide necessary diversion ditches for dewatering systems Dispose of water as required so construction and storage areas, streets, roads, and other surfaces are not flooded Water removal shall be performed as described in the Health and Safety Plan if the area is designated potentially contaminated by the Owner's Representative

h. Excavating Under Foundations Obtain the Engineer's approval before excavating under footings or other foundations, or within a 45 degree slope from horizontal plane at bottom of same Stability of such foundations must be ensured by means directed by the Owner's Representative

i Material Storage and Disposal Selected excavated materials that are to be reused shall be classified and stockpiled separately Dispose of unsuitable and excess material and debris as directed by the Owner's Representative

3 Pipe Laying

a General

(1) Pipe laying in trenches shall follow excavation as closely as possible Pipe to be located underground shall be laid in dry trenches maintained free of accumulated water

(2) Carefully inspect pipe and fittings before installation. Items that are cracked or otherwise defective shall be rejected, broken, and removed from the site immediately

(3) Lay pipe in such a manner that bottom of pipe is uniformly supported in firm pipe bedding material as shown in the Drawings Fill areas excavated to lower than planned elevations with bedding material

(4) Where the frost line has penetrated the soil prior to backfilling, the soil shall be thawed out prior to backfilling Backfill must be free of frozen material

(5) Sleeves/Encasement for Piping Where required by Drawings, to accommodate passage of piping services under roads or elsewhere, furnish and install pipe sleeves of size and material noted Place a steel plate cut to closely fit pipe at each end of sleeve before backfilling Concrete cradles, arches or full encasements shall be provided as detailed on Drawings

(6) Cleaning and Protecting Clean piping interior of dirt and other foreign matter For bell and spigot pipe, keep a swab in the line and pull it past each joint after its completion Protect open ends of pipe with temporary stoppers or covers

(7) Owner's Representative must sign off on installation of all underground piping systems prior to backfilling

4 Filling, Backfilling, and Compacting

a. Fill and Backfill Materials Use approved materials as outlined Provide fill suitable for required compaction and free of debris, organic material, large rocks, frozen matter, and excessive moisture or dryness

2 02 PIPE AND VALVE IDENTIFICATION

A. Piping Identification

1. Pipe Markers

a Pipe markers shall be as manufactured by Seton Name Plate Corporation or Owner's Representative approved equal.

b Pipe identification shall include individual vinyl letters and numbers that adhere to blank pipe markers Blank pipe markers shall adhere directly to pipe

c Pipe markers style numbers PMLN1, PMLN2

d Blank pipe marker style numbers. DDBLNK, AABLNK, OPT12B.

e. Pipe markers shall include uni- and bidirectional arrows in the same sizes as the legend.

f Arrow style numbers will be identified during design.

2 Underground Warning Tape—Plastic

a Tape shall be 6-in. wide, 4 mil, acid- and alkali-resistant polyethylene

b. Tape shall be suitable for direct burial.

c A message shall be printed on the tape and read _____- BURIED BELOW" with bold letters approximately 2-in. high. The message shall be printed at maximum intervals of 2 ft.

d The blank space in the message shall include identification of the buried utility line or pipeline

3 Underground Warning Tape—Metallic

a. Printed polyethylene tape with a metallic core for detection of nonmetal pipes and cables

b Polyethylene material, tape, and message shall be as specified in subparagraph 2 02, A.2 of this Section.

B Valve Identification

1 Identify valves by letter and valve number Identification shall be peel-off vinyl letters or as required in the design

PART 3 EXECUTION

3.01 PREPARATION

A Protection and surface preparation of piping identification materials and adhered surfaces shall be in accordance with Manufacturer's instructions

3 02 INSTALLATION

A. Piping Systems

1 Unions shall be installed where required for piping or equipment installation, even though they may not be shown on Drawings Install unions in piping systems wherever they will expedite removal of equipment and valves.

2 Changes in location of equipment or piping, advisable in the opinion of Contractor, shall be submitted to Owner's Representative for acceptance before proceeding with Work. All measurements and dimensions shall be verified at the site

3 Where schematic diagrams are used to show piping connections, Contractor is cautioned that these diagrams shall not be used for obtaining quantities

4 All pipe flanges shall be set level, plumb, and aligned Fittings shall be true and perpendicular to the axis of the pipe Bolt holes in flanges shall straddle vertical centerline of pipes

5 Where invert elevations are shown on Drawings, Contractor shall lay the pipe in a straight grade between these points

6 Locate piping and pipe supports so that they do not interfere with open accesses, walkways, platforms, or with maintenance or disassembly of equipment.

7 Piping shall be provided as shown on Drawings and as specified except for adjustments to avoid architectural and structural features and shall be coordinated with electrical construction

B Piping Identification

1 Pipe Markers

a After application of the specified coating and insulation systems, exposed piping, interior and exterior, and piping in ceiling spaces, pipe chases, pipe galleries, well vaults, and valve boxes shall be identified with pipe markers and directional arrows Pipe marking schedule will be developed during design

b Legend markers and directional arrows shall be located at each side of walls, floors, and ceilings, at one side of each piece of equipment, at piping intersections, and at approximately 20-ft centers

2 Underground Warning Tape—Plastic

a. A single line of tape as specified in this Section shall be provided 2 5 ft above the centerline of all buried ferrous pipe For ferrous pipelines buried 8 ft or greater below finished grade, Contractor shall provide a second line of tape 12 in. below finished grade, above and parallel to each buried pipe Tape shall be spread flat with message side up before backfilling

3 Underground Warning Tape—Metallic

a Tape shall be buried 12 to 18 in. below grade and shall be above and parallel to buried nonferrous and plastic-pipe pipelines For pipelines buried 8 ft or greater below final grade, Contractor shall provide a second line of tape 2 5 ft above and parallel to the buried pipe

3 03 FIELD QUALITY CONTROL

A. Tests/Inspection

1 General

a The Contractor shall perform all cleaning, flushing, and testing including conveyance of test water from Owner's Representative designated source to point

of use, and including all disposal thereof, complete and acceptable, for hydraulic structures and appurtenant piping as specified herein and in accordance with the requirements of the Contract Documents

b The Contractor shall submit minimum 48-hour advance written notice of its proposed testing schedule for review and concurrence of the Owner's Representative The Contractor's proposed plans for water conveyance, control, and disposal shall also be submitted in writing The Contractor shall submit a description of all proposed test procedures to the Owner's Representative for approval No testing shall be conducted until Owner's Representative's approval of the test procedures is obtained

c Water for testing will be furnished by the Owner, however, the Contractor shall make all necessary provisions for conveying the water from the Owner-designated source to the points of use

d Piping shall be tested after installation but before backfilling of underground lines, and before insulation of aboveground piping

e Upon completion of piping installation, but before application of insulation when required on exposed piping, Contractor shall test the piping systems Pressures, media, and test durations shall be as specified Equipment that may be damaged by the specified test conditions shall be isolated Testing shall be performed using calibrated test gauges and calibrated volumetric measuring equipment to determine leakage rates Each test gauge shall be selected so that the specified test pressure falls within the upper half of the range of the gauge

f Unless otherwise specified, testing, as specified herein, shall include existing piping systems that connect with new pipe systems Existing pipe shall be tested to the nearest existing valve Any piping that fails the test shall be repaired or replaced Repair and replacement of new piping shall be furnished and paid for by Contractor at no expense to Owner

g Pipe system test record shall be submitted to Owner's Representative Test records shall include for each test

(1) Identification of piping system

(2) Testing medium

(3) Testing pressure and other appropriate test data

(4) Time of test

(5) Date of test approval

(6) Signature of test supervisor

2. Liquid Systems

a Leakage shall be zero at the specified test pressure throughout the specified duration for the systems tested Testing procedure and requirements will be developed during design.

3.04 ADJUSTING/CLEANING

A. General

1 Piping systems shall be cleaned following completion of testing and before connection to operating, control, regulating, or instrumentation equipment. Contractor may, at its option, clean and test sections of buried or exposed piping systems Use of this procedure, however, shall not waive the requirement for a full-pressure test of the completed system Unless specified otherwise, piping 12 in. in diameter and smaller shall first be cleaned by pulling a tightly fitting cleaning ball or swab through the system

B Temporary Screens

1 Upon completion of the cleaning, Contractor shall connect the piping systems to related equipment Temporary screens of sizes to be determined during design shall be inserted in pipelines at the suction of pumps and compressors

2. Temporary screens shall be provided with locator tabs that remain visible from the outside when the screens are in place

3 Contractor shall maintain the screens during testing, start-up, and initial operating phases Screens may be removed as required for performance tests Contractor shall remove the temporary screens and make the final piping connections after the screens have remained clean for at least 24 consecutive hours of operation Systems handling solids are exempted

C Gas and Air Systems

1 Gas and air system piping 6 in. in diameter and smaller shall be blown out, using air or the testing medium specified Piping larger than 6 in shall be cleaned by having a swab or "pig" drawn through the separate reaches of pipe After connection to the equipment, it shall then be blown out using the equipment.

2 Upon completion of cleaning, the piping shall be drained and dried with an air-stream

D Liquid Systems

1 After completion of cleaning, liquid systems shall be flushed with service water With temporary screens in place, the liquid shall be circulated through the piping system using connected equipment for a minimum period to be determined during design and until no debris is collected on the screens

- END OF SECTION -

Division 16

ELECTRICAL

To Be Completed During Design

LIST OF ACRONYMS

ANSI	American National Standards Institute
Army	U S Department of the Army
ASA	American Society of Agronomy, Inc
ASTM	American Society for Testing of Materials
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
cm/s	Centimeter per second
CQA	Construction Quality Assurance
CSI	Construction Specifications Institute
FFA	Federal Facilities Agreement
FHWA	U S Department of Transportation Federal Highways Administration
HLA	Harding Lawson Associates
GCL	Geosynthetic clay liner
MIL-STD	Military standard
OSHA	Occupational Safety and Health Administration
PMLN#	Pipe marker style number
RMA	Rocky Mountain Arsenal
State	State of Colorado
UPC	Uniform Plumbing Code
USCS	Unified Soil Classification System
UV	Ultraviolet
°F	Degrees Fahrenheit

Appendix Q

CONTINGENCY 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 Emergency Coordinators

3 0 Implementation of the Contingency Plan

- 3 1 Landfill Cells
  - 3 1 1 Containment Failure or Failure Due to External Forces
  - 3 1.2 Human Exposure
  - 3 1 3 Reportable Quantities
- 3 2 Decontamination Facilities
  - 3 2 1 Containment Failure or Failure Due to External Forces
  - 3 2 2 Human Exposure
  - 3 2 3 Reportable Quantities
- 3 3 Basin F Waste Pile Drying Unit
  - 3 3 1 Containment Failure or Failure Due to External Forces
  - 3 3 2 Human Exposure
  - 3 3 3 Reportable Quantities
- 3 4 Waste Staging/Consolidation Areas
  - 3 4 1 Containment Failure or Failure Due to External Forces
  - 3 4 2 Human Exposure
  - 3 4 3 Reportable Quantities

4 0 Emergency Response Procedures

- 4 1 Preincident Phase (Preparedness)
- 4 2 Incident Phase
  - 4 2 1 Notification

4 2 2 Identification and Compatibility of Hazardous Wastes

4 2 3 Wind Rose

4 2 4 Assessment

4 2 5 Control Procedures

4 2 5 1 Fire and/or Explosion

4 2 5 2 Spills or Material Releases

4 3 Post-Incident Phase

4 3 1 Recording Procedures

4 3 2 Field Investigation

4 3 3 Clean-up and/or Reconstruction/Modification

4 3 4 Resumption of Normal Operations

5 0 Responsibilities of Incident Response Personnel

5 1 Emergency Coordinator

5 2 Field Incident Commander

5 3 Incident Safety Officer

5 4 Response Teams

6 0 Emergency Equipment

6 1 Fire Fighting Equipment

6 2 Spill Control Equipment

7 0 Evacuation Plans

8 0 Administration of the Contingency Plan

9 0 Acronyms

10 0 References

Attachment 1 Emergency Contacts

Appendix R

FINAL LANDFILL SITE FEASIBILITY REPORT

Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program

Prepared for

Program Manager for Rocky Mountain Arsenal
Building 111, Rocky Mountain Arsenal
Commerce City, Colorado 80022-2180

HLA Project No 21907 703040
Contract No DAAA05-92-D-0003
Delivery Order No 0007 (Task 93-03)

THIS DOCUMENT IS INTENDED TO COMPLY WITH THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT

July 7, 1995

Harding Lawson Associates
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EXECUTIVE SUMMARY

This Site Feasibility report presents the results of the Material, Area, and Site Feasibility Studies (FSs) performed by Harding Lawson Associates (HLA) in support of Task 93-03 FS Soils Support Program at Rocky Mountain Arsenal (RMA) under contract with the U S Department of the Army (Army) Task 93-03 supports the evaluation of specific remedial alternatives presented in the Proposed Final Detailed Analysis of Alternatives (DAA) (Ebasco, 1994)

The primary objective of Task 93-03 was to collect soil data in support of the DAA portion of the Onpost Operable Unit at RMA and the Record of Decision (ROD) Task 93-03 was subdivided into three separate subtasks Material, Area, and Site FSs The objectives of the three-fold FSs presented in this report are to address issues concerning the implementability of constructing a hazardous waste landfill at RMA. The objectives of each FS are described below

Material Feasibility Study

As stated above, the primary objective of the Material FS was to evaluate the suitability of onpost soil for use as landfill liner and capping material To meet this objective, soil was collected from two borrow areas identified in the Final FS Soils Support Program Report (HLA, 1995) Testfills 1 and 2 were constructed from soil excavated from the central portion of Section 20 and the southeast quarter of Section 24, respectively The two testfills were constructed to evaluate the construction methods necessary to achieve a permeability of less than 1×10^{-7} centimeters per second (cm/s) as required by both state and federal regulations In situ permeability tests were performed on the testfills using two testing techniques sealed double-ring infiltrometers (SDRIs) and two-stage borehole permeameters (TSB) Laboratory permeability tests were conducted on soil samples collected from the constructed testfills to further evaluate the permeability of the soil

One SDRI and five TSBs were installed and tested on each testfill The hydraulic conductivity computed for each SDRI was $1\ 18 \times 10^{-6}$ cm/s from Testfill 1 and $8\ 30 \times 10^{-6}$ cm/s from Testfill 2

The average vertical hydraulic conductivity measured by the TSBs on the testfills was 4 28 x 10^{-8} cm/s from Testfill 1 and 5 94 x 10^{-8} cm/s for Testfill 2 Laboratory permeability tests and geotechnical tests were performed on "undisturbed" Shelby tube soil samples collected from the testfills after the SDRI and TSB monitoring was complete The average hydraulic conductivity measured from the testfill soil samples was 5 6 x 10^{-8} cm/s from Testfill 1 and 3 04 x 10^{-8} cm/s from Testfill 2

Based on the results presented in this report, the objectives of the Material FS were met The field and laboratory test results indicate that onpost soil can be used to construct caps and liners that meet the required hydraulic conductivity of less than 1 x 10^{-7} cm/s

Area Feasibility Study

The primary objective of the Area FS was to identify areas within RMA that are suitable for siting a hazardous waste landfill based on current regulatory and institutional criteria. The following activities were performed as part of the Area FS to identify areas suitable for a hazardous waste landfill

- Reviewing previous landfill siting studies at RMA
- Reviewing current state and federal landfill siting regulations and combining them with institutional landfill siting policies established by the Program Manager for Rocky Mountain Arsenal (PMRMA) and the U S Fish and Wildlife Service (USFWS)
- Performing a Geographic Information System (GIS) analysis to identify areas at RMA that meet the regulatory and institutional suitability criteria

Based on the GIS analysis, an area of approximately 300 acres in the western half of Section 25 was selected as the preferred landfill location at RMA. The selection was based on achieving the following suitability criteria

- Greater than 1000 feet from a Holocene fault
- Outside the 100-year floodplain
- Not within salt formations

- No waste placed below or into surface water or groundwater
- Notification if the landfill is placed within 5 miles of a runway
- Not within a wetland
- Not located in seismic impact zone without demonstration
- Not within unstable area
- Maximized protection from wind with precipitation catchment area
- Isolation of waste from the public and environment
- Reasonable assurance that the waste is isolated for 1000 years
- Located within distance controlled by the Army to prevent adverse effects to public health
- Noise levels within limits
- Avoidance of sensitive habitats

Upon identification of the preferred area, the secondary objective of the Area FS was to obtain adequate data regarding the geologic and geotechnical characteristics of the area After the area within the western half of Section 25 was identified as suitable based on the regulatory and institutional criteria, a geologic and geotechnical investigation was performed in the identified area to

- Lithologically log the core and geophysically log three deep (approximately 150-foot) boreholes
- Drill 30 shallow (approximately 50-foot) boreholes and lithologically log and collect soil samples
- Perform geotechnical tests on the soil samples including particle size analysis, Atterberg limits, natural moisture content, standard Proctor tests, remolded permeability, shear strength, shrink and swell, and organic content.

Geologic and geotechnical results indicate the identified area is conducive to construction of a hazardous waste landfill with primarily alluvial clay and Denver Formation claystone underlying the site Bedrock sandstone units were mapped in the identified area, however, depending on the size of the landfill required, areas where the sandstone units subcrop into the alluvium may be avoided

Based on the geotechnical testing program, approximately 65 percent of the soil tested was classified as clay, which indicates it may be suitable for use in the construction of the landfill liner and cap

Site Feasibility Study

The primary objective of the Site FS was to evaluate whether a hazardous waste landfill of sufficient capacity could be constructed in the area identified in the Area FS and meet pertinent federal, state, and local regulatory requirements The Site FS also provided information regarding the conceptual landfill models, design elements, construction costs, and schedules The Site FS included the following evaluations

- Waste types, volumes, and generation rates
- Site-specific considerations and limitations
- Conceptual landfill design alternatives
- Evaluation and screening of alternatives
- Facility layout
- Material quantities and availability
- Construction and operation and maintenance (O&M) cost estimates and schedules
- O&M plans

The results of each of these evaluations are discussed briefly below

Three conceptual landfill models were evaluated to account for potential variation of waste volumes that may be generated on the basis of selected remedial action alternatives defined in the Proposed Final DAA (Ebasco, 1994) The three conceptual models were based on 1 million, 2 3 million, and 6 million cubic yards (cy) of waste Waste volumes were increased by 20 percent to account for intermittent waste cover for conceptual design purposes Waste generation rates were estimated to be in the range of 98,000 cy to 1,100,000 cy of material per year without a funding limit, and 37,000 to 280,000 cy of material per year assuming a $100 million annual funding limit.

Site-specific considerations such as climate, topography, geology, hydrogeology, and surface hydrology should not significantly impact landfill construction Based on the geologic investigation, no geologic hazard or environmentally sensitive areas were identified within the preferred siting area Additional geologic and/or geotechnical studies will be required prior to final landfill siting and design Denver Formation sandstone units are in contact with the alluvium in the vicinity of the landfill siting area and should be avoided if possible To maximize the depth to groundwater beneath the proposed landfill site, the landfill should be sited within the central portion of western Section 25 Furthermore, to facilitate long-term monitorability, areas of groundwater mounding such as in the southwest central portion of Section 25 should also be avoided

Conceptual design alternatives were developed for liner systems, leachate collection and removal systems, gas management systems, and final cover systems Six conceptual liner system alternatives and four final cover system alternatives were developed A leachate collection and removal system consisting of 12 inches of sand with a 200-foot drainage length and 2 percent slope was proposed Gas generation from landfilling of RMA waste is expected to be minimal and may be managed using a passive venting system

Conceptual liner and final cover alternatives were evaluated for effectiveness using the Hydrologic Evaluation of Landfill Performance (HELP) Model Version 3 and evaluated for cost by estimating the unit cost on a square foot basis In the HELP model simulations system, the six liner alternatives performed similarly Conceptual liner designs that included geosynthetic clay as the base layer performed only slightly better than those with compacted clay or tertiary geomembrane liner as the base As a result, the final screening of the conceptual liner designs should consider cost and constructibility because performance results for conceptual liner designs are so similar Similarly, the performance results for cover alternatives indicate that final screening of the cover systems should also consider cost and constructibility since the four cover systems evaluated performed equally well Based on a unit cost comparison of the six liner systems and four cover systems

evaluated, the liner and cover systems that use geosynthetic clay liners were found to be more cost-effective

The overall landfill performance was also evaluated using the HELP model to assess the potential effectiveness of the cover and liner systems The most cost-effective cover and liner systems were used to estimate the long-term leachate production from the landfill using worst-case conditions At predicted leachate product rates, it would take from 1000 to 1200 years for soil water in the vadose zone to move downward from the base of the landfill 1 foot.

The landfill facility layouts were evaluated for the three conceptual models The landfill footprint areas for each conceptual model are as follows 19 acres (Conceptual Model 1), 35 acres (Conceptual Model 2), and 87 acres (Conceptual Model 3) The excavation depth for each landfill scenario was assumed to be average of 30 feet below the existing ground surface, with a maximum liner thickness of 5 feet. The excavation sideslopes were assumed to be 3 horizontal 1 vertical (3H.1V), and above grade sideslopes were assumed to be 6H 1V A final geotechnical investigation should be performed to refine and expand upon the testing and analyses presented in this report, and consider in its analysis any changes from these conceptual models

Material quantities for low-permeability soil and structural fill soil used in landfill liner and cover system components were estimated and compared to the estimated available volumes of onpost materials Conceptual Models 1, 2, and 3 required 270,000 cy, 510,000 cy, and 1,235,000 cy of clay soil, respectively, and 296,000 cy, 640,000 cy, and 1,635,000 cy of structural fill soil, respectively Based on the estimated volumes of onpost soil from borrow areas and the landfill excavation, it appears that sufficient onpost soil exists to meet construction requirements for even the largest landfill (Conceptual Model 3)

Construction and annual (O&M) cost estimates for three conceptual landfill models were prepared to be accurate within plus 50 percent to minus 30 percent The estimated construction cost for Conceptual Models 1, 2, and 3 are $12,500,000 ($12 50 per cy), $22,500,000 ($10 00 per cy), and $52,500,000 ($9.00 per cy), respectively Estimates of annual O&M costs were made for each conceptual model using both restricted and unrestricted funding scenarios The O&M costs range from a high of approximately $1,487,000 per year for 12 years or $18 per cy of waste for Conceptual Model 1 in the restricted funding scenario The lowest O&M costs correspond with Conceptual Model 3 at approximately $4,460,000 per year for 9 years or $7 per cy of waste with unrestricted funding Construction for cell development of an approximate 200,000-cy module that could be applied to any of the three conceptual landfill models would take approximately 34 weeks to prepare

Based on the results of the Site FS presented in this report, it is feasible to construct a hazardous waste landfill of sufficient capacity within the preferred site at RMA that would meet the applicable federal, state, and local regulatory requirements Information provided in this report can be used for rapid implementation of the preferred remedial alternative once the ROD is completed for RMA.

1.0 INTRODUCTION

This report fulfills Data Requirement A004, a contract deliverable under Delivery Order 0007 (Modification to Task 93-03 Feasibility Study [FS] Soils Support Program) of Contract DAAA05-92-D-0003 between Harding Lawson Associates (HLA) and the U S Department of the Army (Army) This report was prepared by HLA at the direction of the Army for the sole use of the Army and the signatories of the Federal Facilities Agreement (FFA) of Rocky Mountain Arsenal (RMA), the only intended beneficiaries of this work.

1.1 Site Description, Task Objectives, and Report Organization

This report presents the results of the Task 93-03 Material, Area, and Site FS Based on evaluations of the results provided, conclusions and recommendations are presented regarding the materials, area, and site for construction of an onsite hazardous waste landfill facility The site description, task objectives, and report organization are discussed in the following subsections

1.2 Site Description

RMA is located in Commerce City, Colorado (see Figure 1.1) RMA was established in 1942 by the Army as a manufacturing facility for the production of chemical and incendiary munitions Military, industrial, and agricultural chemicals, primarily pesticides and herbicides, were also manufactured at RMA by several lessees from 1947 to 1982 The industrial waste liquid produced from operations performed by the Army and its lessees was initially discharged to Basin A, an unlined basin in Section 36 Subsequently, liquid wastes were discharged to other unlined basins and, after 1956, to Basin F, which was asphalt-lined Although solid wastes were disposed of primarily in Section 36, other onpost disposal sites were also used. Some of the basins, pits, burn sites, sewers, and structures (buildings, pipes, and tanks) became sources of soil and groundwater contamination as a result of spills, leaks, or other releases

1.2.1 Task Objectives

The primary objective of Task 93-03 was to collect soil data in support of the Detailed Analysis of Alternatives (DAA) portion of the Onpost Operable Unit at RMA and the Record of Decision (ROD) The Proposed Final DAA completed by Ebasco in December 1994 presents the results of a multiyear, multidiscipline evaluation of specific remedial alternatives and their applicability to the known areas and types of contamination at RMA Based on the proposed final version of the DAA, the preferred alternative for remediation of the soils and structures at RMA includes construction of an onpost hazardous waste landfill for containment of a portion of the contaminated material and capping other areas of contamination in place The preferred alternative includes landfilling approximately 2,300,000 cubic yards of material.

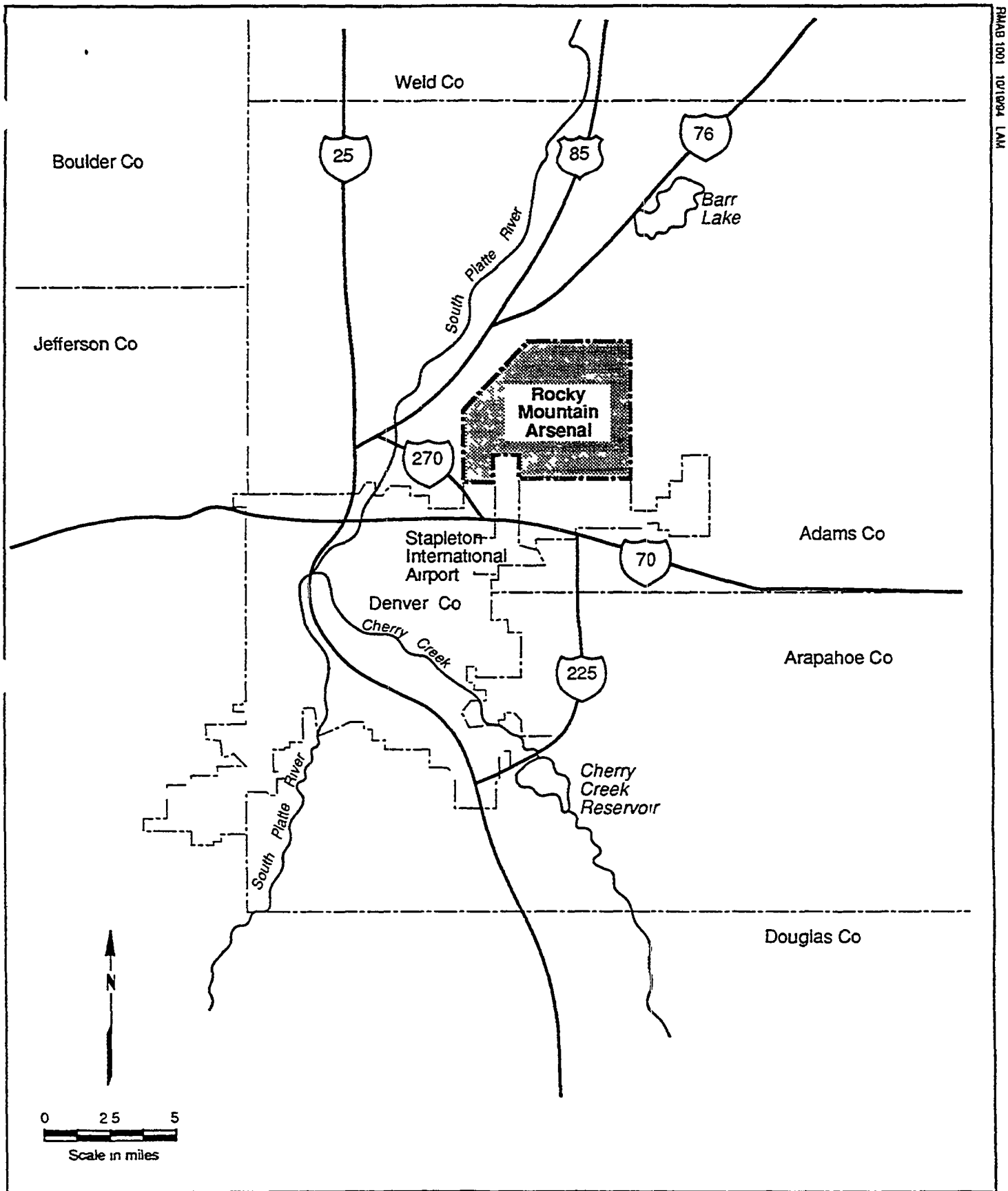
The three-fold FSs presented in this report address many of the issues raised about the implementability of the preferred remedial alternative As described above, this portion of Task 93-03 was subdivided into three separate subtasks Material, Area, and Site FS The objectives of each subtask are described below

The primary objective of the Material FS was to evaluate whether onsite soil is suitable for use as landfill liners and capping material based on field and laboratory tests The primary objective of the Area FS was to identify areas within RMA suitable for siting a landfill based on current regulatory and institutional criteria. Upon identification of the optimal site, the secondary objective of the Area FS was to obtain adequate data regarding the geologic and geotechnical characteristics of the site to evaluate the feasibility of constructing a landfill in the existing foundation materials The primary objective of the Site FS was to identify an appropriate landfill site within the area identified in the Area FS and provide information on conceptual landfill models, design elements, construction costs, and schedules

1.2.2 Report Organization

The remainder of this report is divided into seven sections Section 2 0 describes the technical approach for the three-fold feasibility studies for Task 93-03 Section 3 0 (Material FS) presents the results and conclusions of the test fill construction, and field and laboratory testing program Section 4 0 presents the results of the Area FS, which identifies the most suitable location for an onpost hazardous waste landfill at RMA based on previous studies, current regulatory criteria, and institutional criteria. Results of an extensive geologic and geotechnical testing program performed within the preferred area are also presented within Section 4 0 Section 5 0 presents the results of the Site FS, which evaluates the feasibility of constructing a hazardous waste landfill at RMA using onpost materials Also included in Section 5 0 are discussions regarding landfill construction cost estimates, construction schedules, and operation and maintenance (O&M) plans. Section 6 0 presents a summary, conclusions, and recommendations based on the results presented in this report. Section 7 0 is a list of acronyms, and Section 8 0 is the bibliography

In addition to the main body of this report, several items related to the Task 93-03 FS have been appended Appendix A presents testfill construction specifications, and Appendix B presents testfill construction photographs Testfill construction equipment is described in Appendix C Appendix D presents the sealed double-ring infiltrometer and two stage borehole (TSB) test data. Lithologic boring logs are presented in Appendix E, and the boring locations and elevations are provided in Appendix F Appendix G presents the geophysical logging data, and Appendix H presents the cost estimates for the various conceptual models described in this report. The Final Work Plan for material and Feasibility Studies Soil Support Program is provided as Appendix I



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

Prepared by
Harding Lawson Associates

Figure 1.1

Site Location Map

RMAB 1001 10/18/94 LAM

2.0 TECHNICAL APPROACH

This report presents the results of a study completed to evaluate the feasibility of siting and constructing a hazardous waste landfill at RMA As stated previously, the evaluation was subdivided into three feasibility studies (1) Material, (2) Area, and (3) Site This section describes the technical approach used to accomplish the objectives established for each of the FSs Figure 2 1 presents a report overview

2.1 Material Feasibility Study

The Material FS had two main objectives (1) to evaluate the feasibility of using soil from onpost borrow areas for use in the construction of landfill liners and caps, and (2) to evaluate the construction specifications such as optimum lift thickness, soil moisture content, density, and compactive effort necessary to achieve the required permeability of 1×10^{-7} centimeters per second (cm/s) for the construction of landfill liners and caps To accomplish the stated objectives the following work elements were completed

- Geotechnical tests were performed on soil collected from two borrow areas identified in the Final FS Soils Support Program Report (HLA, 1995a) as containing soils thought to be suitable for construction of low-permeability soil liners and caps
- Two testfills were constructed with soil excavated from the borrow areas to evaluate the construction methods necessary to achieve the required permeability
- In situ permeability tests were performed on the constructed testfills using two testing techniques, sealed double-ring infiltrometers (SDRI) and two-stage borehole (TSB) permeameters
- Laboratory permeability tests were conducted on soil samples collected from the constructed testfills to further evaluate permeability

2.2 Area Feasibility Study

The Area FS was conducted to (1) identify areas at RMA that meet the current regulatory and institutional landfill siting criteria, and (2) further evaluate the suitability of a preferred area through geologic and geotechnical evaluations To identify areas suitable for the hazardous waste landfill at RMA the following work elements were completed

- Previous landfill siting studies conducted at RMA were reviewed with regard to current Colorado landfill siting regulations
- Regulatory and institutional landfill siting suitability criteria, such as locating the landfill outside floodplains and avoiding sensitive habitats, were established based on current regulatory and institutional requirements
- Using the established siting suitability criteria, a Geographic Information System (GIS) analysis was performed to identify areas at RMA that meet the suitability criteria

Limitations to this study included the following

- A fourth deep borehole was not drilled as originally scoped due to limited funding
- No hydrogeologic field work was scoped for this program
- No soil or groundwater chemical analyses were scoped for this program Geochemical interpretations used for this report were based on previous studies performed at RMA

Once a preferred area was identified based on the GIS analysis, a geologic and geotechnical investigation was performed at the preferred area The investigation was performed in the western half of Section 25 and included drilling 33 boreholes, downhole geophysical logging, and geotechnical property testing

2.3 Site Feasibility Study

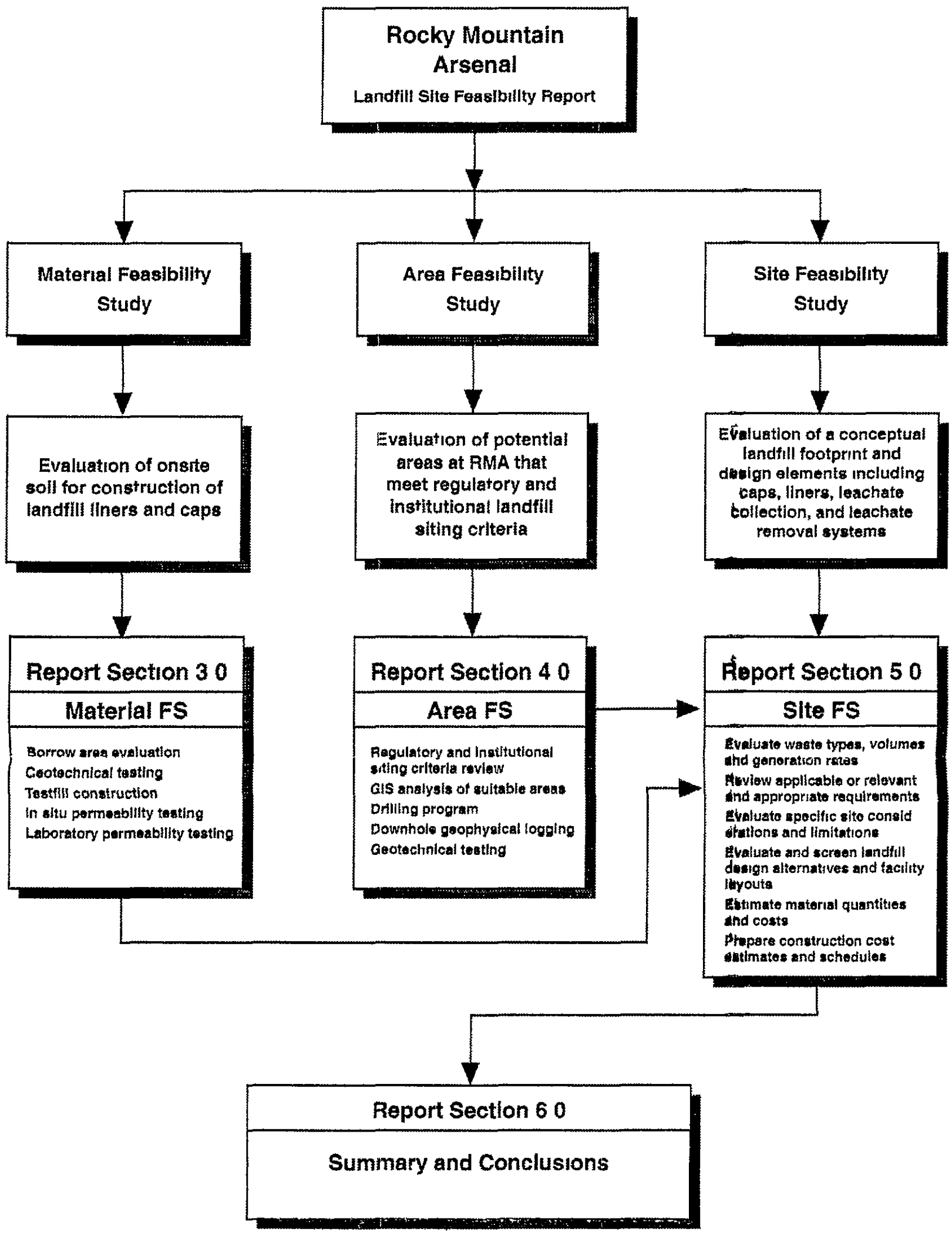
The primary objective of the Site Feasibility Study was to determine whether a hazardous waste landfill of sufficient capacity could be constructed at this site that would meet all applicable federal, state, and local regulatory requirements

The study included a review and evaluation of the following

- Evaluate waste types, volumes, and generation rates
- Review regulatory criteria
- Evaluate specific site considerations and limitations
- Evaluate and screen landfill design alternatives and facility layouts

- Estimate material quantities and costs
- Prepare construction cost estimates and schedules

Three conceptual landfill models were evaluated to account for various waste volumes depending on the remedial action alternative selected for the RMA The waste volumes were considered to represent minimum, maximum, and most probable



Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure 2 1

Technical Report Overview

3.0 MATERIAL FEASIBILITY STUDY

This section presents the results of the Material FS, which included a testfill construction and a permeability testing program The purpose of the Material FS program was to simulate construction of a low-permeability soil cap or liner by constructing two testfills then testing the constructed testfills to assess whether they meet the desired permeability of 1×10^{-7} cm/s

In summary, the Material Feasibility portion of the FS Soils Support Program had two main objectives (1) to verify that onpost soil from two distinct borrow areas are capable of meeting a permeability of less than or equal to 1×10^{7} cm/s (the required permeability of soils used as clay caps or liners [6 Code of Colorado Regulations (CCR) 1007-2 2 5.3]) and (2) to evaluate the optimum lift thickness, moisture content, density, and compactive effort necessary to achieve the required permeability Permeability of the constructed testfills was measured both in the field and in the laboratory to evaluate the suitability of the materials and methodology used to construct the testfills

The testfills were constructed in July and August 1994 generally following the procedures presented in the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) (see Appendix I) and included in Appendix A. The testfills were constructed in the southwest quarter of Section 25 (Figure 3 1) Following completion of the testfills, one sealed double-ring infiltrometer (SDRI) and five two-stage borehole permeameters (TSBs) were installed on each testfill following installation procedures provided by the manufacturer and included in the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) An HLA geotechnical engineer and a engineering technician provided construction observation and geotechnical testing required during installation. Data collection and data reduction of the SDRI and TSB testing equipment were performed by HLA in August, September, and October 1994 The following sections describe in detail the work elements performed in the Material FS

3.1 Borrow Material Excavation and Geotechnical Testing

This section describes the excavation and geotechnical testing of borrow material used in the construction of the testfills Figure 3 1 illustrates the two borrow areas used to supply the required volume of clay soil The borrow areas were identified in the Final FS Soils Support Program Report (HLA, 1995a) to contain suitable borrow material The borrow areas were approved by the United States Fish and Wildlife Service (USFWS) for excavation provided the areas were reseeded following excavation This section presents the borrow material excavation procedures along with the geotechnical test results of analyses performed on the borrow material

3.1.1 Borrow Material Excavation and Borrow Pit Closure

Topsoil was stripped from the borrow areas prior to excavation of the testfill material The topsoil was stockpiled adjacent to the respective borrow pits Borrow material was visually inspected prior to transport. Scrapers, a front-end loader, and 20-cubic-yard dump trucks were used to excavate and transport the borrow material to the testfill construction stockpile areas Upon completion of the excavations, borrow pit closure was accomplished by grading the borrow pit area, covering the affected area with the stockpiled topsoil, and reseeding

Excavation and reseeding specifications are provided in Appendix A, Testfill Construction Specifications Photographs A and B in Appendix B illustrate the excavation and reseeding operations performed

3.1.2 Geotechnical Testing of Borrow Material

Geotechnical laboratory tests were performed on samples collected from borings near the borrow pits and from samples collected from the excavation pits Results from the tests are presented in Table 3 1 The laboratory testing program included grain size analysis (American Society for Testing and Materials [ASTM] D422), Atterberg limits (ASTM D4318), and standard Proctor compaction tests (ASTM D698) The compaction test results were used to identify the optimum moisture content and

maximum dry density of the soil used for construction of the two testfills Further discussion of the testfill construction specifications is presented in Section 3.2

Soil excavated from Borrow Area A was used in the construction of Testfill 2 Soil from Borrow Area A was classified as inorganic clays with low to high plasticity (Table 3 1) The Atterberg tests indicate liquid limits ranging from 46 to 55 and plasticity indices (PI) ranging from 25 to 33 The percent passing the No 200 sieve ranged from 70 9 to 81 6 The average maximum dry density and optimum moisture content, as determined by the standard Proctor compaction test, were 102 8 pounds per cubic foot (pcf) and 19 0 percent, respectively

Borrow Area B was subdivided into two subareas, B1 and B2 Following visual inspection of the borrow pit, the soil in Borrow Area B1 was not used in the construction of the testfill because of observed calcium carbonate content of the soil Calcium carbonate content greater than approximately 5 percent in soil is not recommended for use as low-permeability liner or cap material because of the potential for dissolution and subsequent increased permeability Soil used in the construction of Testfill 1 was excavated from Borrow Area B2

The soils from Borrow Area B2 are classified as inorganic clay with low to high plasticity (Table 3 1) The Atterberg tests indicate liquid limits ranging from 44 to 55 and PI ranging from 23 to 31 The percent passing the No 200 sieve ranged from 59 8 to 65 3 The average maximum dry density and optimum moisture content as determined by the standard Proctor density test, were 102 3 pcf and 19 3 percent, respectively

As indicated by the sieve analysis results, the difference between the material excavated from the two borrow areas was that the material from Borrow Area B had a higher sand content than the samples from Borrow Area A. On average, the material from Borrow Area B had approximately 10 percent more very fine-grained sand This increased sand content helped facilitate the moisture conditioning

process The sandier soil from Borrow Area B2 was able to uptake the added moisture more rapidly than the material from Borrow Area A This resulted in more rapid soil processing and therefore increased construction rates

3.2 Testfill Construction

This section describes the equipment and procedures used to complete the construction of the two testfills Each testfill is approximately 100 feet long by 40 feet wide at the top (Figure 3 2) and consist of a 3-foot-thick clay test layer, underlain by a 6-inch working layer constructed over a prepared subgrade Each testfill slopes uniformly to one side at approximately 2 percent

3.2.1 Processing and Testfill Area Preparation

The soil processing areas were used to stockpile soil, break up the soil to reduce clod size, and moisture condition the soil before placement on the testfills The processing and testfill areas were prepared following the specifications included in Appendix A In summary, the following procedures were followed

The processing and testfill construction areas were stripped of topsoil The topsoil was stockpiled adjacent to the processing areas The surface of the processing areas was smoothed (proof-rolled) with the pneumatic tires of the front-end loader The testfill subgrades were graded to slope approximately 2 percent in a northerly direction, compacted with the wedge-foot roller, scarified, and proof-rolled Photographs C and D (Appendix B) illustrate the preparation procedures

Four grain size analyses were performed on the testfill area subgrade material to evaluate potential for hydraulic head build-up at the interface between the first lift of the testfill and the subgrade Head build-up at the base of the testfill could adversely affect the in situ permeability test results (SDRI) by creating an infiltration barrier The grain size analyses indicate the material is a silty sand (SM according to the Unified Soil Classification System [USCS]) Head build-up at the base of the testfill at the subgrade interface was considered unlikely because of the higher permeability of the

silty sand To avoid further surface tension and capillary effects on the downward infiltration through the testfills, the subgrade was thoroughly wetted to a depth of 1 foot prior to placement of the first testfill layer (working layer)

3.2.2 Soil Processing

Soil processing, including clod size reduction, moisture conditioning, blending, and curing, was completed prior to testfill lift compaction generally following the specifications in Appendix A The soil processing was performed both in the processing area and on the test pad In general, optimum construction performance was achieved when the bulk of the moisture conditioning was performed in the processing area and final moisture conditioning was performed on the test pad

Initially, soil processing activities were performed with a bulldozer, tiller, and a water truck It was observed that this process was time consuming and only marginally effective Photograph E in Appendix B illustrates the initial processing procedures Because moisture conditioning using the tiller was not adequate to achieve the uniform moisture content required prior to lift compaction, a Caterpillar SS-250 was used for soil processing Photograph F illustrates soil processing using the pulvamixer The testfill construction equipment specifications are presented in Appendix C

3.2.3 Final Subgrade Preparation and Working Layer Placement

The testfills were constructed on a foundation of in situ sandy soils as described in Section 3 2 1 A 6-inch-thick clay working layer was placed above the prepared subgrade The working layer had a 6-inch compacted lift thickness The working layer surface was scarified using the track of the dozer to facilitate lift bonding to the first lift of the testfill

Compaction and moisture content of the working layer was measured in the field using a nuclear density gauge (ASTM Methods D2922 and D3017) The relative compaction of the working layers ranged from 96 1 to 99 8 percent in Testfill 1 and from 95 9 to 99 5 in Testfill 2 The moisture

content of the completed working layers ranged from 19 96 to 21 45 percent in Testfill 1 and 20 7 to 21 3 percent in Testfill 2 A summary of the density test data is presented in Tables 3 2 and 3 3

3.2.4 Testfill Lift Placement

Upon completion of the working layer, placement of the testfill lifts was initiated The following procedures were used during construction of the testfills (Listed photographs can be found in Appendix B)

1 Prior to placement of each successive lift, the surface of the previous lift was scarified using the track of the dozer to a depth of approximately 2- to 3-inches to achieve proper bonding between lifts The surface was moisture conditioned as necessary to prevent desiccation of the soils Also, the elevation of the surface was measured using a surveyors' level and rod (Photograph G)

2 Lifts were placed on the testfills in 9-inch loose lifts using the front-end loader and a dozer (Photograph H)

3 The soils were blended, moisture conditioned, and clod size was reduced using the pulva-mixer (Photographs I)

4 Prior to compaction, the moisture content of the loose lift was measured using the nuclear gauge

5 The lifts were compacted using a Caterpillar 815C compactor The lifts were compacted in adjacent longitudinal passes One roller pass was defined as a trip up and a trip back the length of the testfill Each consecutive pass was offset the width of the roller The entire surface of the lift was compacted with a total of two passes per lift (Photograph J)

6 Compaction and moisture content of each lift were measured using the nuclear density gauge For confirmation soil samples were collected at each location and tested using ASTM D2216, an oven-drying methodology

7 If the test results indicated that the lift did not achieve the construction specifications (95 percent relative compaction and 1 to 4 percent wet of the optimum moisture content) the lift was reblended and moisture conditioned using the pulvamixer and recompacted using the compactor as described above

8 Following compaction of the final lift, the surface was bladed smooth to approximately 2 percent of grade to provide for proper surface drainage The surface was then completed with steel-wheel roller passes across the entire surface (Photograph K)

9 Throughout the construction, and upon completion of the testfill, plastic tarps were placed over the testfills to reduce the potential for desiccation of the clay soil (Photograph L)

3.2.5 Testfill Completion

The testfills were completed using a smooth-drum roller to provide a smooth, uniform surface as described above Furthermore, to prevent desiccation of the testfill, topsoil was placed across the entire surface of the test pad except for the 12-foot by 12-foot area sealed with a tarp where the SDRI test was to be installed (Photograph M)

3.3 Field and Laboratory Permeability Testing Programs

The following section presents an overview of the field and laboratory permeability testing program used to evaluate the in situ hydraulic conductivity of the clay testfills One SDRI and five TSB permeameter tests were performed at each testfill Figure 3.3 illustrates the SDRI, TSB, and laboratory permeability testing sample locations

3.3.1 Sealed Double-Ring Infiltrometer Test Method Description

The SDRI test measures the vertical infiltration rate of water through the constructed testfills The SDRIs are specifically designed to measure low infiltration rates in the range of 1×10^{-5} to 1×10^{-6} cm/s Based on previous laboratory results (HLA, 1995a), the remolded permeability of the soil at 95 percent of maximum dry density and at approximately 4 percent above optimum moisture content (ASTM D698) at the proposed borrow areas ranges from $4\ 80 \times 10^{-6}$ to $1\ 98 \times 10^{-8}$ cm/s

A detailed summary of the SDRI test method was provided in Appendix A of the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) (Appendix I) along with the manufacturer's installation and operating instructions A synopsis of the test method from the installation follows

- The SDRI consists of 12-foot by 12-foot outer ring and a 5-foot by 5-foot sealed inner ring (Figure 3 4)
- The rings are grouted within the trench excavated into the top of the testfill.
- The outer ring is installed at 14 to 18 inches below the ground surface (bgs).
- The inner ring is installed at 4 to 6 inches bgs
- The areas between both rings are filled with water (the outer ring to a depth of 12 inches, which completely submerges the inner ring)

The flow of water in the SDRI is monitored by filling a flexible bag with a known weight of water and connecting the bag to a port on the inner ring As the water infiltrates the ground and leaves the sealed inner ring, it is replaced with an equal amount of water drawn in from the flexible bag After a specified time interval, the flexible bag is removed and weighed The weight loss is then converted into milliliters of water that have infiltrated into the testfill Infiltration rate is calculated using an equation with the following parameters the volume of water loss, the area of the inner ring, and the interval of time that the bag was connected onto the inner ring The tests are monitored until the infiltration rate reaches a steady state Upon completion, a plot of the infiltration rate over time is prepared For the purposes of this test, the specified permeability value to be achieved is less than 1×10^{7} cm/s

3.3.2 Sealed Double-Ring Infiltrometer Installation and Monitoring

The SDRIs were installed immediately following completion of the testfills between August 5 and August 9, 1994 The SDRIs were installed under the direction of the installation subcontractor, Mr Steve Trautwein of Trautwein Soil Testing Equipment (manufacturer of the SDRIs) Photographs (N through P) of the SDRI installation are included in Appendix B

SDRI monitoring was conducted between August 10, 1994, to November 11, 1994 SDRI monitoring procedures included flow measurements, water temperature readings, water-level measurements, swell measurements, and tensiometer readings In general, the readings were taken on a daily basis until the infiltration rate slowed sufficiently to allow measurements to be collected once every several days The readings were taken by field personnel trained and experienced in taking SDRI measurements The readings were recorded in field logbooks and then transferred onto the SDRI data forms (Appendix D) Plots of the infiltration rate and hydraulic conductivity were evaluated concurrently with the testing to identify when the test could be terminated

3.3.3 Sealed Double-Ring Infiltrometer Data Reduction and Evaluation

Data were reduced and evaluated by transferring the field measurements recorded on the data forms to computer spreadsheets for ease of computation The infiltration rate was calculated using the following equation

$$I = Q/(At)$$

where

I = infiltration in cm/s

Q = volume of flow in cubic cm

A = area of flow in square cm

t = time interval in seconds

The hydraulic conductivity within the SDRI is calculated using the following equation

$$k = Q/(iAt)$$

where

k = hydraulic conductivity in cm/s

Q = volume of flow in cubic cm

t = time interval in which Q was determined in seconds

i = $\Delta h/\Delta s$ (gradient) dimensionless

Δh = head loss

Δs = length of flow path for which Δh is measured

A = area of flow in square cm

since,

I = $Q/(At)$

then,

k = I/i

The calculation of k depends on calculating a value for the gradient (i). Unlike the calculations for I and k, the calculation of i is not straightforward The parameters used to calculate the gradient are as follows

$$i = (H + D + Hs) / D$$

where

H = depth of water ponded in rings

D = depth to the wetting front

Hs = suction at the wetting front

There are differing opinions on what value should be used for Hs One view is that Hs should be equal to the ambient suction in the soil below the wetting front. The ambient suction can be measured with tensiometers Values of Hs can be as high as 275 inches of water Another view is that Hs should be equal to zero, i e , the suction in the soil at the wetting front has no influence on the infiltration rate Hence, if the position to the wetting front is known, the gradient is simply (H + D) / D

At the SDRI manufacturer's suggestion, the second view (Hs = 0) was used in this study Assuming Hs = 0, yields a close approximation to the actual gradient Measurements made at several sites have shown that the drop in infiltration rate versus time can be accounted for by the increase in D as the wetting front moves through the soil If suction had an influence, a much larger decrease in the infiltration rate would have occurred

If suction near the wetting front has an influence on the infiltration rate, then the hydraulic conductivity calculated assuming Hs equals zero is a conservative estimate, i e , the actual hydraulic conductivity will be less

3.3.3.1 Factors that Affect Flow Measurements

Two factors that can have a significant effect on the measured amount of flow are temperature changes and swelling of the soil The total flow (Q) measured is the sum of the following

$$Q = Q_i + Q_s + Q_t$$

where

Q_i = flow due to infiltration

Q_s = flow due to swell

Q_t = flow due to temperature changes

When calculating hydraulic conductivity, the infiltration rate used should correspond to Q_i The infiltration rate corrected for swell and temperature changes is calculated as follows

$$I = Q_i / At$$

where

$$Q_i = Q - Q_s - Q_t$$

If either Q_s or Q_t are significant, greater than 10 percent of Q, then Q_i should be used to determine I Procedures for measuring Q_s and Q_t are discussed below

3.3.3.2 Temperature Effects

Flow corresponding to Q_t results from temperature changes that cause the inner ring and the water contained within it to undergo a volume change Measurements have shown that for an inner ring of the type used in this project, a 1 degree Fahrenheit (°F) change can amount to 15 milliliter (ml) to 30 ml of flow in or out of the ring If the temperature rises, the net effect of inner ring and water expansion is to expel water from the inner ring Similarly, water is drawn into the inner ring if the temperature decreases

For this project, temperature effects were minimized by following the manufacturer's monitoring procedures Measurements were taken at approximately the same time each day to minimize

temperature effects When temperature changes were unavoidable due to changing weather patterns, measurements were collected for several days at a new baseline water temperature

3.3.3.3 Swell Effects

The remaining portion of flow to consider is Q_s, the flow due to soil swell The process of water infiltrating an unsaturated swelling soil is complex and difficult to analyze Presently, there is no accepted procedure to account for the effect of soil swell on the infiltration rate The SDRI manufacturer believes, however, that a close estimate of Q_s can be obtained as follows First, it is assumed that any volume change that occurs is vertical Second, it is assumed that the additional volume generated by the swelling soil is filled with water that infiltrated the soil Based on these two assumptions

$$Q_s = \Delta h \times A$$

where

Δh = vertical swell of soil beneath inner ring

A = area of inner ring

Once the wetting front passes below the bottom of the inner ring, swelling of the soil will cause the ring to rise The rise of the inner ring, Δh, was measured as discussed in the instruction manual included in Appendix A of the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c)

3.3.4 Two-Stage Borehole Permeameter Test Method Description

The TSB permeameter test measures the infiltration rate of water into the test medium through a cased borehole The TSB test has been successful in evaluating both compacted and natural materials with permeabilities as low as 1×10^{-9} cm/s (Boutwell, 1992) At RMA, the permeability of compacted soil from the two borrow areas ranges from 3.02×10^{-9} to 8.24×10^{-8} cm/s (HLA, 1995a), which corresponds to the TSB methodology in the measurement capabilities

Five TSB permeameters were installed and monitored on each of the constructed testfills Multiple installations of the TSBs allow for statistical confidence and further verification of the hydraulic conductivities measured by the SDRIs

A detailed summary of the TSB test method was provided in Appendix B of the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) (Appendix I) A synopsis of the test method follows

- The TSB procedure is a falling-head infiltration test conducted in a cased borehole that is typically 4-inches in diameter (Figure 3 5)
- The first stage of the test is performed with the bottom of the borehole flush with the bottom of the casing
- The first stage of the test provides data to calculate vertical permeability (K_v)
- The second stage of the text provides data to calculate horizontal permeability (K_h)

Stage 1 of the test provides a measurement of the maximum possible value for K_v Stage 2 provides a measurement of the minimum possible value for K_h

The infiltration rate at the TSB is calculated by monitoring the flow of water into the soil from the TSB The TSB is filled with water and as water flows out of the uncased bottom of the TSB, the height of the water in a standpipe is measured (Figure 3 5) The infiltration rates are calculated over the measurement period and plotted to illustrate infiltration rates over time Further calculations are used to estimate the apparent hydraulic conductivity of the material based on the infiltration rate measurements

Temperature changes can affect the infiltration rate of water in the TSB Field measurements on previous TSBs indicate that rising temperatures cause the water column to rise and the standpipe to expand, thereby causing a lower apparent flow rate The net effect is a lower apparent permeability. If the temperatures decrease, the converse is true One temperature effect gauge (TEG) was installed

and monitored on each test pad to measure the volume changes due to temperature changes over the testing period

3.3.5 Two-Stage Borehole Installation and Monitoring

Five TSB permeameters were installed at each testfill (Figure 3 3) immediately following installation of the SDRIs on August 10 and 11, 1994 The TSBs were installed following the manufacturer's installation procedures under the direction of Mr Steve Trautwein. The boreholes were excavated using a hand auger to the desired depth The bottoms of the holes were scarified as directed Polyvinyl chloride (PVC) casings were grouted in place, and the boreholes were completed with the measurement standpipe and fill tube, as illustrated in Figure 3 5

TEGs were set up and installed similarly to the typical TSB with one exception, the bottom of the casing was sealed with a cap Because there is no flow of water from the TEG, any changes in the readings must be the result of changes in the ambient air temperature and/or barometric pressure Any changes noted in the TEGs are then used as correction factors to calculate the infiltration rate using the equations described in Section 3 3 6

TSBs were monitored between August 17 and September 16, 1994 Monitoring included flow measurements, water temperature readings, and TEG readings The readings were taken by field personnel trained and experienced in TSB monitoring The readings were recorded in field logbooks and then transferred onto the TSB data forms (Appendix D)

3.3.6 Two-Stage Borehole Data Reduction

For ease of computation, data were reduced and evaluated by transferring the field measurements recorded on the data forms onto computer spreadsheets Apparent permeability for both Stage 1 and Stage 2 of the TSB tests was calculated using the following falling-head test equations as specified in the test method calculations

Stage 1 calculations (nomenclature for the various terms of the Stage 1 calculations is illustrated in Figure 3 6)

$K1 = R_T G1 \, Ln(H_1/H_2)/(t_2-t_1)$

and

$G1 = (\pi d^2/11D_1)[1+a(D_1/4b_1)]$

where

- d = inner diameter (ID) of standpipe
- D_1 = effective diameter of Stage 1 casing ID
- b_1 = depth of tested medium below bottom of casing
- a = +1 for impervious boundary
- a = 0 for infinite depth of tested medium (b_1 = infinity)
- a = -1 for pervious lower boundary
- k = permeability in cm/s
- H_1 = initial head at $t = t_1$
- H_2 = initial head at $t = t_2$
- t_1 = initial time
- t_2 = final time
- Ln = natural logarithm
- R_T = kinematic viscosity correction to water at 68°F as defined in ASTM D5084

Stage 2 calculations (nomenclature for the various terms of the Stage 2 calculations is illustrated in Figure 3 6)

$K2 = R_T G2 \, Ln(H_1/H_2)/(t_2-t_1)$

and

$G2 = (d^2/16Lf) \{Ln[u(1, r_0, o)] + a \, Ln[u(1, r_0, 2b_2)]\}$

where

$f =$ 1-0 5623 Exp(-1 566 L/D)

$L =$ Length of Stage 2 cylinder below casing

$$u(1, r_0, o) = \{L/D_2 + \sqrt{1 + (L/D_2)^2}\}^2$$

$$u(1, r_0, 2b_2) = \frac{4b_2/D_2 + L/D_2 + \sqrt{1 + (4b_2/D_2 + L/D_2)^2}}{4b_2/D_2 - L/D_2 + \sqrt{1 + (4b_2/D_2 - L/D_2)^2}}$$

$D_2 =$ ID of Stage 2 extension

$b_2 =$ distance from center of Stage 2 extension to underlying boundary

Using the equations above, the apparent permeabilities calculated during Stage 1 and Stage 2 were plotted against time The tests were terminated when either steady-state conditions or a close approximation of steady-state conditions were achieved. Test termination criteria outlined in Boutwell (1992) are as follows

- The time-weighted averages do not show an upwards or downwards trend with time
- Test results do not fluctuate more than 10 to 20 percent among themselves
- The time-weighted averages do not fluctuate more than 10 to 20 percent for 12 to 72 hours
- Arithmetic time-weighted averages were calculated using the following equation

$K' = (T_iK_i)/(T_i)$

where

$K' =$ arithmetic time-weighted average permeability

$T_i =$ time duration of test increment (i)

$K_i =$ Permeability measured during test increment (i)

Throughout each stage of the tests, variations in apparent permeability were evaluated, and the test was terminated when steady-state conditions were achieved

3.3.7 Laboratory Permeability Testing

Eighteen soil samples were collected from the completed testfills for laboratory geotechnical property testing The samples were collected in 3-inch diameter Shelby tubes pushed into the testfills using a drilling rig The samples were collected adjacent to TSB locations illustrated in Figure 3 3 Flexible wall, falling head permeability tests (ASTM D5084) were performed on 6 samples Atterberg limits (ASTM D4318) and grain size analyses (ASTM D422) were performed on 12 samples The permeability tests were performed for comparison with the in situ permeability tests (SDRI and TSB) Atterberg limits and grain size tests were performed to verify the homogeneity of the individual testfills Six samples were further analyzed for unconsolidated, undrained, and consolidated undrained shear strength analyses (ASTM D4767 and D2850).

3.4 Permeability Test Data Results

The following section presents the results of the field and laboratory permeability and geotechnical test results performed on the testfills

3.4.1 Sealed Double-Ring Infiltrometer Test Results

SDRI 1 and SDRI 2 were filled with water on August 10, 1994, and monitored for 81 days Original data sheets and spreadsheet tables used for calculations are included in Appendix D The following discussion summarizes the test results

3.4.1.1 Infiltration

The infiltration rate was calculated according to procedures outlined in Section 3 3 3

Figures 3 7 and 3 8 illustrate the infiltration rate for the 81-day test period The initial infiltration rates and the final infiltration rates are summarized below:

		Infiltration Rate in centimeters per second	
SDRI Number	Test Fill	Initial	Final
SDRI 1	1	4.24×10^{-7}	1.03×10^{-8}
SDRI 2	2	3.60×10^{-7}	$1\ 15 \times 10^{-8}$

3.4.1.2 Hydraulic Conductivity

Hydraulic conductivity (k) was calculated using the equations described in Section 3 3 3 The parameters required to calculate k include the infiltration rate divided by the hydraulic gradient The hydraulic gradient (1) was calculated by using the equation outlined in Section 3.3 3, which uses the parameters of water depth and wetting front depth The depth to the wetting front was calculated using the tensiometer data as described below

To calculate the wetting front within the testfills, the average values at each group of the tensiometers is plotted over time as shown in Figures 3.9 and 3 10 The plots were used to evaluate when the wetting front reached the depths of 6, 12, and 18 inches by noting when the pressure on the tip of the tensiometers dropped to below 10 The tensiometer gauge is at a higher elevation than the tip, therefore, a positive gauge reading (less than 10) will be noted when the pressure at the tip is actually zero A summary of the wetting front advancement with time through each testfill is as follows

		Wetting Front Depth in Days		
SDRI Number	Testfill	6 inches	12 inches	18 inches
SDRI 1	1	9	55	Not attained
SDRI 2	2	10	40	Not attained

As noted in Figures 3 9 and 3 10, the wetting front did not reach a depth of 18 inches within the 81-day monitoring period Wetting front depths greater than 12 inches and less than 18 were calculated by linear extrapolation of the wetting front data It was assumed that the rate of advancement of the wetting front depth beyond 12 inches was the same as the rate between 6 and 12 inches

The values of hydraulic conductivity computed for SDRI 1 and 2 are illustrated in Figures 3 7 and 3 8 As illustrated in the figures, the hydraulic conductivity decreased over the testing period and reached a relatively steady-state condition approximately 18 days before the tests were terminated

As a conservative measure, the average hydraulic conductivity values were calculated for each test pad over the last 33 days of the test and are as follows

SDRI Number	Testfill	Hydraulic Conductivity in centimeters per second
SDRI 1	1	1.18×10^{-8}
SDRI 2	2	8.30×10^{-8}

3.4.1.3 Temperature and Swell Factors

Temperature and swell were monitored at the SDRIs to evaluate whether either may have affected the flow measurements. The total flow measured includes flow due to temperature changes (Q_t), soil swell (Q_s), and flow due to infiltration (Q_i). As described in Section 3.3.3, calculations of flow due to temperature changes and soil swell were made throughout the test to evaluate the significance of Q_t and Q_s at each of the SDRIs.

The measured values of water temperature in the four outer rings are recorded in Appendix D and plotted in Figure 3.11. In general, the maximum temperature difference noted during any given measurement period resulted in a flow amounting to less than or equal to 10 percent of the total flow measured. The only exception to this is the second to the last reading where a 9 degree temperature difference over the measurement period was noted. Overall, the effect due to temperature change was considered to be insignificant because the estimated total percent of flow attributed to temperature change was 5 percent for SDRI 1 and 3.6 percent for SDRI 2.

The average vertical movement of the inner ring was measured throughout the testing period. The results of the measurements are included in Appendix D. Less than one centimeter of swell was measured in each of the two inner rings. Overall, the effect due to soil swell was considered to be insignificant because the estimated total percent of flow attributed to soil swell was 10 percent or less.

3.4.2 Two-stage Borehole Test Results

On August 17, 1994 TSB permeameter testing was initiated Each stage of the test was run until the test termination criteria were met For Stage 1 the test ran between August 17 and August 31, 1994, and Stage 2 of the test ran between September 1 and September 16, 1994 Field data sheets and spreadsheet tables used for calculations are included in Appendix D The following discussion summarizes the results

3.4.2.1 Stage 1 Hydraulic Conductivity

The apparent hydraulic conductivity for Stage 1 of the TSBs (K1) was calculated for each of the TSBs according to the equations outlined in Section 3 3 6 As stated earlier, the value for hydraulic conductivity is calculated from measurements of infiltration during Stage 1, and provides an estimate of the maximum possible value for the vertical permeability of the medium being tested

The hydraulic conductivity values for Testfills 1 and 2 are plotted against time in Figures 3 12 and 3 13, respectfully Additionally, the arithmetic time-weighted average value of the Stage 1 hydraulic conductivity (K1') for each TSB is presented below

TSB Number	Stage 1 Time-weighted Average Hydraulic Conductivity K1' in centimeters per second	Testfill Number
B1A	$8\ 06 \times 10^{-8}$	1
B1B	$2\ 29 \times 10^{-8}$	1
B1C	$4\ 47 \times 10^{-8}$	1
B1D	$2\ 45 \times 10^{-8}$	1
B1E	$4\ 13 \times 10^{-8}$	1
B2A	$8\ 20 \times 10^{-8}$	2
B2B	$8\ 00 \times 10^{-8}$	2
B2C	$3\ 80 \times 10^{-8}$	2
B2D	$4\ 52 \times 10^{-8}$	2
B2E	$5\ 16 \times 10^{-8}$	2

3.4.2.2 Stage 2 Hydraulic Conductivity

The apparent hydraulic conductivity for Stage 2 of the TSBs (K2) was calculated for each of the TSBs according to the equations outlined in Section 3 3 6 As stated earlier, the value for hydraulic conductivity is based on measurements of infiltration during Stage 2, and provides an estimate of minimum possible value for the horizontal permeability of the medium being tested

The hydraulic conductivity values for Testfills 1 and 2 are plotted against time in Figures 3 14 and 3 15, respectfully Additionally, the arithmetic time-weighted average value of the Stage 2 hydraulic conductivity (K2') for each TSB is presented below

TSB Number	Stage 2 Time-weighted Average Hydraulic Conductivity K2' in centimeters per second	Testfill Number
B1A	$1\ 27 \times 10^{-8}$	1
B1B	$1\ 34 \times 10^{-8}$	1
B1C	$1\ 04 \times 10^{-8}$	1
B1D	$8\ 27 \times 10^{-9}$	1
B1E	$9\ 42 \times 10^{9}$	1
B2A	$8\ 00 \times 10^{9}$	2
B2B	$6\ 34 \times 10^{-9}$	2
B2C	$1\ 20 \times 10^{-8}$	2
B2D	$8\ 14 \times 10^{9}$	2
B2E	$8\ 15 \times 10^{9}$	2

3.4.3 Laboratory Permeability Test Results

Table 3 4 presents the permeability, grain size, Atterberg limits, and the shear strength test results performed on samples collected from the testfills The six samples tested for falling head permeability indicate hydraulic conductivities below the required 1×10^{7} cm/s The average hydraulic conductivity value measured on samples from Testfill 1 was $5\ 80 \times 10^{-8}$ cm/s For Testfill 2, the average hydraulic conductivity measured was $3\ 40 \times 10^{-8}$ The Atterberg limits test results indicated liquid limits ranging from 40 to 50 percent and plasticity limits ranging from 22 to 32 percent The percent passing the No 200 sieve ranged from 63 to 82 percent

3.5 Testfill Construction and Testing Program Summary and Conclusions

The testfill construction and testing program included the construction of two clay soil testfills using soil excavated from two onpost borrow areas Subsequent to construction, field and laboratory tests were performed on the testfills to evaluate the permeability of the testfill's compacted clay soil This section provides a summary and conclusions about the testfill construction and testing program

3.5.1 Summary

Two onpost borrow areas were used to supply the required volume of clay soil to construct two testfills The clay soil used to construct Testfill 1 was excavated from the central portion of Section 20 in the northeast corner of RMA The clay soil used to construct Testfill 2 was excavated from the southwest quarter of Section 24, approximately 1/2 mile north of the proposed landfill location site Both soil types are classified as inorganic clay with low to high plasticity However, the soil from Section 20 contains approximately 10 percent more sand by weight than the soil from Section 24

The two testfills were constructed in the southwest quarter of Section 25 in July and August of 1994 The following summarizes the construction procedures

1 Clay used in the construction of the testfills had the following properties

	Liquid Limit (%)	Plasticity Index (%)	Percent Passing No. 200 Sieve (%)
Testfill 1	44 to 49	23 to 29	62 to 65
Testfill 2	46 to 55	25 to 33	71 to 82

2 Lifts were placed on the testfills in 9-inch loose lifts

3 The material was blended, moisture conditioned and clod size was reduced using a Caterpillar SS-250

4 The lifts were compacted with a minimum of two passes using a Caterpillar 815B compactor

5 The lifts were compacted to a minimum of 95 percent of the standard Proctor maximum dry density (102 pcf) The moisture content of the compacted lifts was 2 to 4 percent above the

optimum moisture content (19 percent) Density and moisture content were measured with a nuclear density gauge

6 Portions of the clay testfill that did not achieve the required compaction or moisture content specification were scarified to the previous lift and recompacted as described above

7 Prior to placement of the subsequent lift, each lift was scarified and moisture conditioned to achieve proper lift bonding

8 The lifts were protected from desiccation by sprinkling the surface of the testfills with water and covering the entire surface of the testfills with plastic tarps

Following testfill construction, one SDRI and five TSBs were installed for in situ permeability testing on each testfill Field permeability tests were conducted following the SDRI and TSB manufacturer's installation and monitoring procedures The SDRIs were monitored for three months from August 10 to November 11, 1994 Each stage of the TSBs was monitored for approximately two weeks beginning August 17, 1994

The field permeability tests confirmed that the procedures employed to construct the testfills were sufficient to achieve the design requirement that vertical hydraulic conductivity of the testfill be less than 1×10^{7} cm/s The average hydraulic conductivity measured by the SDRI on Testfill 1 was $1\ 18 \times 10^{-8}$ cm/s and $8\ 30 \times 10^{-8}$ cm/s for Testfill 2 The average vertical hydraulic conductivity measured by the TSBs on Testfill 1 was $4\ 28 \times 10^{-8}$ cm/s and $5\ 94 \times 10^{-8}$ cm/s for Testfill 2

Laboratory permeability and geotechnical tests were performed on samples collected from the testfills after the SDRI and TSB monitoring was complete The laboratory permeability tests reconfirm that the construction procedures specified in this testfill construction program were adequate to achieve the required hydraulic conductivity value The average conductivity value measured on samples from Testfill 1 was $5\ 60 \times 10^{-8}$ cm/s and $3\ 04 \times 10^{-8}$ cm/s from Testfill 2

3.5.2 Conclusions

The Material FS portion of the FS Soils Support Program had two main objectives (1) to verify that onpost soils are capable of meeting a permeability of less than or equal to 1×10^{7} cm/s (as required

in the construction of clay caps or liners [6 CCR 1007-2 2 5 3]), and (2) to evaluate the optimum lift thickness, moisture content, density, and compactive effort necessary to achieve the required permeability

Based on the results presented in this report, both objectives of the Material FS were met First, the field and laboratory test results confirm that onpost soils can be used to construct caps and liners that meet the regulatory required hydraulic conductivity Second, the construction methods employed to construct the two testfills identified the lift thickness, moisture content, density and compactive effort used to achieve the required permeability Soils within the proposed borrow areas may vary and thus, require additional testing to finalize specifications for future cap and liner construction

It should be noted that the specifications included in this report as Appendix A were written specifically for testfill construction The specifications may require modification for full-scale construction

Table 3.1: Summary of Geotechnical Laboratory Test Data on Borrow Material

Borrow Area	Sample Depth (ft)	Percent Passing No 200 Sieve (%)	USCS Soil Classification	Liquid Limit (%)	Plastic Index (%)	Natural Moisture Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
A	2 0	70 9	CH	55	33	10 0	19 7	101 9
A	2 5	81 6	CH	51	30	10 2	20 5	102 5
A	3 5	70 9	CL	46	25	8 4	17 4	104 4
B2	4 0	61 7	CL	44	23	9 8	18 8	101 7
B2	4 0	65 3	CL	49	29	10 1	19 3	103 1

% Percent
CH Inorganic clays of high plasticity
CL Inorganic clays of low to medium plasticity
ft Feet
pcf Pounds per cubic foot
USCS Unified Soil Classification System

Table 3.2: Summary of Field Density Test Data, TestFill 1

Test Number	Lift Number	Test Location East/West*	Test Location North/South*	Date	Moisture Content (Nuclear Method) ASTM D3017 88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction# (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216-90 (%)	Comments
1	1 (WL)	20	C	7/29/94	20 23	103 2	100 4	NT	Failed moisture, Retest No 4
2	1 (WL)	50	E	7/29/94	19 49	100 1	97 4	NT	Failed moisture, Retest No 5
3	1 (WL)	75	D	7/29/94	17 71	102 8	100 0	NT	Failed moisture, Retest No 6
4	1 (WL)	20	C	7/30/94	17 44	102 2	99 4	NT	Failed moisture, Retest No 7
5	1 (WL)	50	E	7/30/94	18 1	105 6	102 7	NT	Failed moisture, Retest No 9
6	1 (WL)	75	D	7/30/94	19 5	103 4	100 0	NT	Failed moisture, Retest No 8
7	1 (WL)	20	C	7/30/94	21 15	96 8	94 2	NT	
8	1 (WL)	75	D	7/30/94	19 96	98 8	96 1	NT	
9	1 (WL)	50	E	7/30/94	21 45	102 6	99 8	NT	
10	2	80	E	7/30/94	19 7	101 0	102 0	NT	
11	2	55	E	7/30/94	23 26	99 6	96 9	NT	
12	2	55	E	7/30/94	24 96	96 7	94 1	NT	
13	2	20	C	7/30/94	18 86	106 8	103 6	NT	
14	2	75	C	7/30/94	21 13	104 1	102 0	21 3	
15	2	56	E	7/30/94	22 09	93 7	91 1	NT	Failed compaction, Retest No 17
16	2	22	B	7/30/94	21 00	102 5	99 7	18 8	
17	2	56	E	7/30/94	19 94	105 0	102 2	NT	Failed moisture, Retest No 17A
17A	2	56	E	7/30/94	20 77	104 2	101 4	18 95	Retest of No 15 and No 17 after compaction and moisture added
18	3	25	D	7/31/94	18 98	106 3	103 4	NT	Test failed, Retest No 21
19	3	53	C	7/31/94	23 53	100 0	98 0	NT	
20	3	78	E	7/31/94	21 3	103 0	100 2	21 5	
21	3	25	D	7/31/94	20 17	103 9	101 0	21 9	Retest of No 18, added moisture
22	4	18	C	7/31/94	20 68	105 1	102 2	21 7	
23	4	56	D	7/31/94	22 62	101 1	98 3	22 0	
24	4	80	E	7/31/94	22.52	102 4	99 6	21 3	
25	5	26	E	8/2/94	21 2	103 4	100 0	20 2	
26	5	55	G	8/2/94	23 77	96 6	95 9	22 6	
27	5	82	E	8/2/94	21 78	102 0	99 7	20 2	
28	6	20	C	8/3/94	15 68	106 6	103 1	NT	Failed moisture, Retest No 31
29	6	53	E	8/3/94	23 54	99 0	96 3	NT	Retest of No 32
30	6	88	G	8/3/94	19.87	104 4	101 6	NT	Failed moisture, Retest No 33

Table 3.2 (continued)

Test Number	Lift Number	Test Location Fast/West*	Test Location North/South*	Date	Moisture Content (Nuclear Method) ASTM D3017-88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction# (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216-90 (%)	Comments
31	6	20	C	8/3/94	20 24	106 1	103 2	22 5	Retest of No 28, added moisture
32	6	53	E	8/3/94	22 97	100 9	98 1	18 7	Retest of No 29
33	6	88	G	8/3/94	21 78	101 8	99 0	20 4	Retest of No 30, added moisture
34	7	25	D	8/4/94	17 79	108 4	105 4	NT	Failed moisture, Retest No 37
35	7	56	B	8/4/94	14 19	106 6	103 2	NT	Failed moisture, Retest No 38
36	7	97	F	8/4/94	19 27	106 9	104 0	NT	Failed moisture, Retest No 39
37	7	25	D	8/4/94	19 56	105 1	102 2	NT	Failed moisture, Retest No 40
38	7	56	B	8/4/94	20 71	104 1	101 3	20 6	
39	7	97	E	8/4/94	22 94	98 7	96 0	22 0	
40	7	25	D	8/4/94	22 73	100 0	97 9	20 3	
41	7	23	G	8/4/94	22 81	99 2	96 5	20 6	
42	8	24	G	8/4/94	21 88	100 0	97 2	22 2	
43	8	50	D	8/4/94	22 07	100 3	97 6	22 9	
44	8	94	F	8/4/94	20 81	104 3	101 4	20 2	
45	9	22	F	8/5/94	18 91	107 1	104 2	NT	
46	9	50	D	8/5/94	21 82	99 5	96 8	NT	
47	9	22	F	8/5/94	20 94	103 7	100 9	21 2	
48	9	50	D	8/5/94	22 84	100 0	98 0	22 5	
49	9	95	E	8/5/94	23 0	98 0	95 3	21 7	
50	10	11	F	8/5/94	20 86	103 4	100 5	21 2	
51	11	9	G	8/5/94	23 23	98 4	96 2	23 3	
52	12	7	D	8/5/94	21 91	101 7	98 9	20 4	
53	10	16	G	8/5/94	20 87	103 2	100 4	NT	
54	10	58	E	8/5/94	22 00	102 2	99 4	NT	
55	10	91	F	8/5/94	21 07	102 1	99 3	NT	

Table 3.2 (continued)

For the material tested, optimum moisture content equals 19 3 percent and maximum dry density equals 102 3 percent

ASTM	American Society for Testing and Materials
NT	Not tested
pcf	Pounds per cubic foot
WL	Working layer
%	Percent

* See Figure 3 3 for grid system used to identify the test location

\# Relative compaction refers to the in-place dry density of soil expressed as a percentage of the maximum dry density of the same material, as determined by the ASTM D 698 test procedure

Table 3.3: Summary of Field Density Test Data, TestFill 2

Test Number	Lift Number	Test Location East/West	Test Location North/South	Date	Moisture Content (Nuclear Method) ASTM D3017 00 (%)	Dry Density (Nuclear Method) ASTM D2922 01 (pcf)	Relative Compaction* (Nuclear Method) ASTM D2922 01 (%)	Moisture Content (Oven Dry Method) ASTM D2216 00 (%)	Comments
1	1	6	Q	7/14/04	19.08	104.7	101.9	21.4	
2	1	50	N	7/14/04	19.98	104.6	101.8	21.3	
3	1	85	N	7/14/04	20.47	104.4	101.5	24.0	
4	2	25	L	7/15/04	19.27	105.2	102.3	20.6	Test failed, Retest No. 7
5	2	65	M	7/15/04	17.19	104.3	101.5	20.1	Test failed, Retest No. 8
6	2	84	P	7/15/04	17.79	106.1	103.2	17.0	Test failed, Retest No. 9
7	2	24	K	7/16/04	21.21	103.3	100.5	21.7	Retest of No. 4, added moisture
8	2	50	N	7/16/04	22.37	99.4	96.7	22.5	Retest of No. 5, added moisture
9	2	84	O	7/16/04	23.03	98.8	96.1	25.1	Retest of No. 6, added moisture
10	3	15	M	7/19/04	18.30	99.8	97.1	NT	
11	3	85	P	7/19/04	21.00	103.5	100.7	NT	
12	WL	5	Q	7/22/04	20.75	102.3	99.5	NT	Began using Pulvamixer
13	WL	53	N	7/22/04	21.34	98.6	95.9	20.9	
14	WL	90	K	7/22/04	20.66	107.3	99.5	20.9	
15	1	35	M	7/22/04	20.03	104.0	101.1	21.4	
16	1	65	O	7/22/04	21.18	107.5	99.7	20.5	
17	1	90	P	7/22/04	20.12	102.9	100.1	20.9	
18	2	25	R	7/22/04	22.15	101.3	98.5	22.6	
19	2	50	N	7/22/04	21.31	101.7	98.9	21.4	
20	2	80	M	7/22/04	22.00	99.9	97.2	20.9	
21	3	30	K	7/25/04	22.62	95.7	93.1	NT	Test failed, Retest No. 21A
22	3	60	N	7/25/04	21.39	100.4	97.7	19.8	
23	3	85	P	7/25/04	20.87	100.5	97.8	20.1	
21A	3	30	K	7/25/04	21.33	101.4	98.6	20.0	Retest of No. 21, after further compaction
24	4	25	P	7/25/04	22.02	98.7	96.1	21.1	
25	4	50	N	7/25/04	20.23	101.6	99.1	19.6	
26	4	90	L	7/25/04	20.23	103.6	100.7	19.8	
27	5	25	L	7/25/04	21.00	102.2	99.4	20.06	
28	5	50	N	7/25/04	19.54	103.7	100.9	19.4	Failed moisture, Retest No. 31
29	5	80	P	7/25/04	21.14	102.3	99.5	21.9	
30	5	80	N	7/26/04	21.44	101.9	99.1	23.2	

Table 3.3 (continued)

Test Number	Lift Number	Test Location: East/West	Test Location: North/South	Date	Moisture Content (Nuclear Method) ASTM D3017-88 (%)	Dry Density (Nuclear Method) ASTM D2922-91 (pcf)	Relative Compaction* (Nuclear Method) ASTM D2922-91 (%)	Moisture Content (Oven Dry Method) ASTM D2216-90 (%)	Comments
31	5	50	L	7/26/94	23.09	100.1	97.4	22.7	Retest of No. 28, added moisture
32	5	10	M	7/26/94	24.34	96.6	93.9	NT	Test failed, Retest No. 33
33	5	15	M	7/26/94	20.07	104.8	101.9	19.8	Retest of No. 32, added dry soil and recompacted
34	6	15	L	7/26/94	25.13	98.1	95.5	NT	Test failed, Retest No. 37
35	6	45	M	7/26/94	18.64	96.7	94.1	NT	Test failed, Retest No. 38
36	6	75	M	7/26/94	20.41	102.6	99.8	NT	
37	6	20	N	7/26/94	20.27	102.2	99.4	19.2	Retest of No. 34, after wetting dry areas, pulverizing, and compacting
38	6	45	M	7/26/94	19.73	101.3	98.6	NT	Retest of No. 35 after wetting dry areas, pulverizing, and recompacting, failed, Retest No. 39
39	6	45	M	7/26/94	20.54	NR	98.0	NT	Retest of No. 38
40	6	45	M	7/26/94	21.44	100.5	97.8	21.0	Retest of No. 38
41	7	20	P	7/27/94	17.75	103.2	100.4	NT	Test failed, Retest No. 43
42	7	45	L	7/27/94	18.76	98.0	95.4	NT	Test failed, Retest No. 44
43	7	20	O	7/27/94	20.36	104.3	101.4	19.02	Retest of No. 41, wetted, pulverized, and recompacted
44	7	60	O	7/27/94	21.09	101.0	98.3	19.7	Retest of No. 42, wetted, pulverized, and recompacted
45	7	95	N	7/27/94	20.74	103.9	101.1	19.9	
46	R1	15	L	7/29/94	21.56	102.6	99.8	21.7	
47	R1	70	L	7/29/94	20.43	105.5	102.6	21.9	
48	R2	65	L	7/29/94	20.59	102.0	99.2	20.7	
49	R2	15	K	7/29/94	20.22	104.6	107.7	22.0	
50	R3	25	L	7/29/94	19.76	105.6	102.7	NT	Test failed, Retest No. 50A
51	R3	75	L	7/29/94	21.80	101.8	99.0	19.2	
50A	R3	25	K	7/29/94	20.64	104.1	101.3	19.9	Retest of No. 50 after adding moisture and recompacting
51	10	19	N	7/31/94	18.65	99.5	96.8	NT	Test failed, Retest No. 54
52	10	50	L	7/31/94	22.13	99.3	96.6	NT	Retest No. 55
53	10	78	Q	7/31/94	18.93	98.1	95.4	NT	Test failed, Retest No. 56 and No. 57
54	10	19	N	8/2/94	23.64	99.3	96.6	24.2	Retest of No. 54, added moisture

Table 3.3 (continued)

Test Number	Lift Number	Test Location East/West	Test Location North/South	Date	Moisture Content (Nuclear Method) ASTM D3017 88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction# (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216 90 (%)	Comments
55	10	50	L	8/2/94	24 68	96 9	94 3	22 9	Retest of No 52
56	10	76	O	8/2/94	23 04	99 1	96 5	NT	Retest of No 53, added moisture
57	10	78	O	8/2/94	23 70	98 8	96 2	21 7	Retest of No 53, added moisture
58	11	23	O	8/3/94	21 62	100 7	98 0	23 4	
59	11	58	M	8/3/94	22 92	99 9	97 2	23 6	
60	11	86	Q	8/3/94	22 62	100 6	97 9	23 2	
61	12	15	M	8/3/94	21 93	100 7	98 0	20 3	
62	12	46	K	8/3/94	22 44	99 8	97 0	23 1	
63	12	92	M	8/3/94	21 20	101 6	99 0	21 8	
64		8	K	8/4/94	22 23	100 4	97 7	21 9	
65		5	K	8/4/94	22 05	100 4	97 6	22 6	
66		10	K	8/4/94	21 27	102 7	99 9	22 3	
67		12	L	8/4/94	22 09	101 6	98 8	21 8	
68	13	85	L	8/4/94	20 41	103 2	101 1	NT	
69	13	27	N	8/4/94	22 19	100 7	97 9	NT	
70	13	55	P	8/4/94	21 67	102 6	99 8	NT	

For the material tested, optimum moisture content = 10 percent and maximum dry density = 102 8 pcf

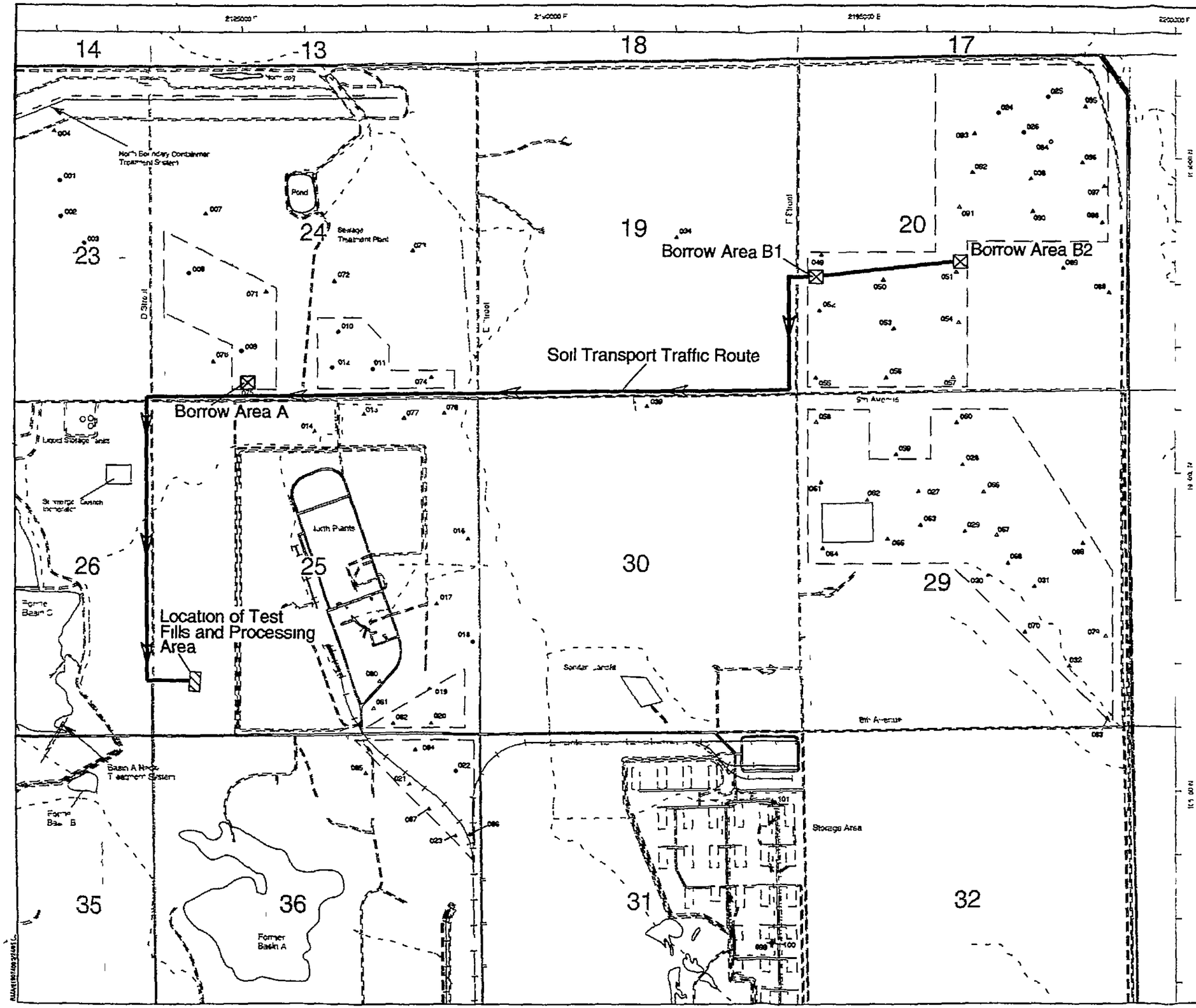
ASTM American Society for Testing and Materials
WL Working layer
% Percent
NT Not tested
pcf Pounds per cubic foot

* See Figure 3 3 for grid system used to identify test location
\# Relative compaction refers to the in place dry density of soil expressed as a percentage of the maximum dry density of the same material, as determined by the ASTM D 698 test procedure

Table 3.4: Testfill Laboratory Test Results

Testfill Number	Percent Passing No 200 Sieve (%)	Moisture Content (%)	Liquid Limit (%)	Plasticity Index (%)	Permeability (cm/s)	USCS Classification	USCS Description
1	62 7	14 1	40	22	$1\ 3 \times 10^{8}$	CL	Brown Sandy Lean Clay
1	71 1	10 6	42	23	$5\ 2 \times 10^{8}$	CL	Brown Lean Clay With Sand
1	56 5	20 4	43	25	$1\ 0 \times 10^{7}$	CL	Brown Sandy Lean Clay
2	80 9	21 5	50	32	$7\ 9 \times 10^{8}$	CH	Brown Fat Clay With Sand
2	82 2	20 9	47	30	$2\ 6 \times 10^{9}$	CL	Brown Lean Clay With Sand
2	81 7	20 9	47	30	$9\ 5 \times 10^{9}$	CL	Brown Lean Clay With Sand

% Percent
cm/s Centimeters per second
psf Pounds per square foot
USCS Unified Soil Classification System



Explanation

- Soil boring locations for 1993 drilling program reported in Final Feasibility Study Soils Report (HLA, 1995)
- Borrow areas excavated for construction of test fills
- Low permeability soil borrow areas
- Railroad
- Ditch or stream
- Paved road
- Unpaved road
- 16 — Section number

Note:
The boring identification numbers shown have been abbreviated. The full boring identification number contains the soil unit before the number and 93 for 1993 at the end. For example the complete boring identification number for Boring 012 is WEB01293.

0 1500
Scale in feet

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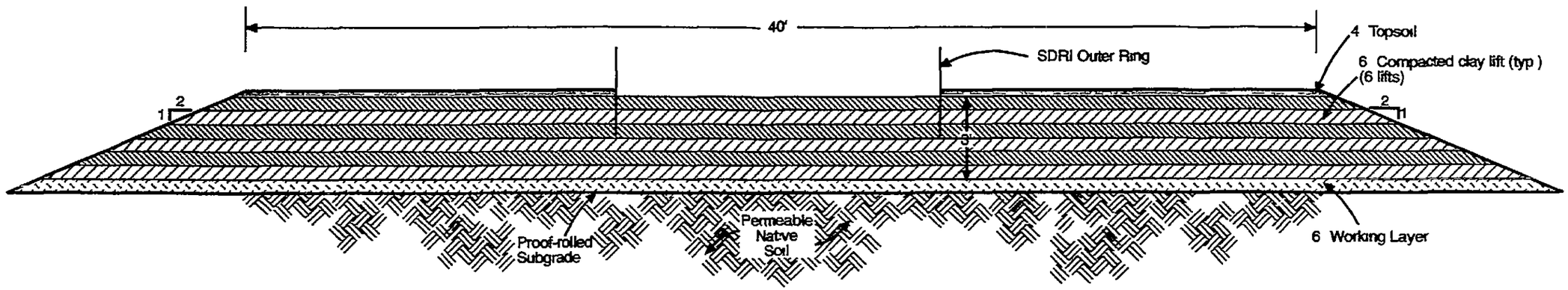
Figure 3 1

Testfill and Borrow Area Location Map

RMA 1232 6 3/8/95 LAM

Typical Test Fill Cross Section



1.25" = 5

Note. Maximum slope shall be 2H:1V on long sides, 3H:1V on ends of test fill. Minimum slope shall be 3H:1V on long sides and 4H:1V on ends of test fill.

0 2.5 5

Scale in feet

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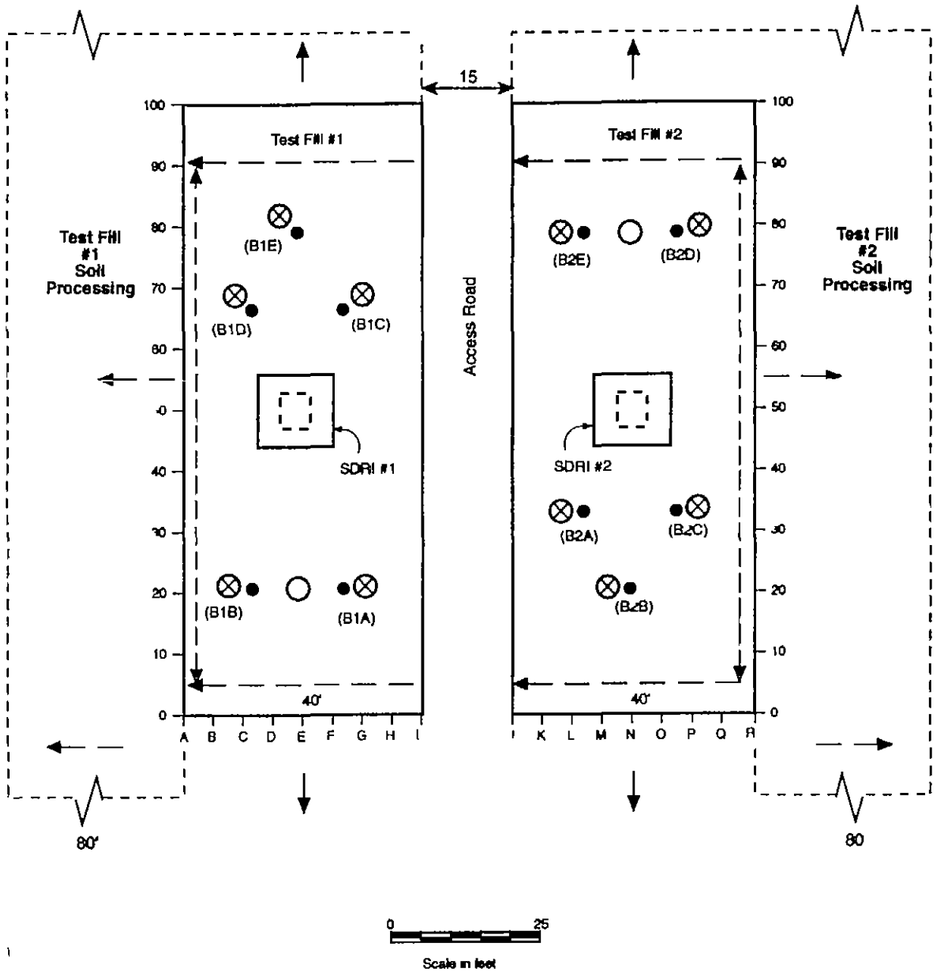
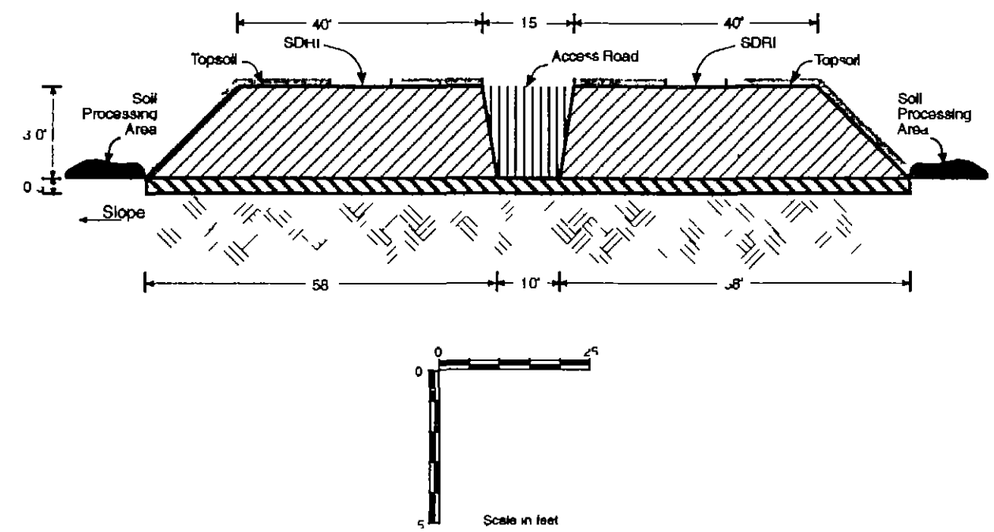
Figure 3.2

Typical Test Fill Cross Section

Plan View



Typical Cross Section



Explanation

SDRI	Sealed double-ring infiltrometer
(B1A) ●	Two-stage borehole (borehole number)
○	Two-stage borehole temperature effect gauge
⊗	Shelby tube sample location
	Top soil
	Access road
	Working layer
	Clay test fill
←— —→	Compaction direction
— —→	Slope direction

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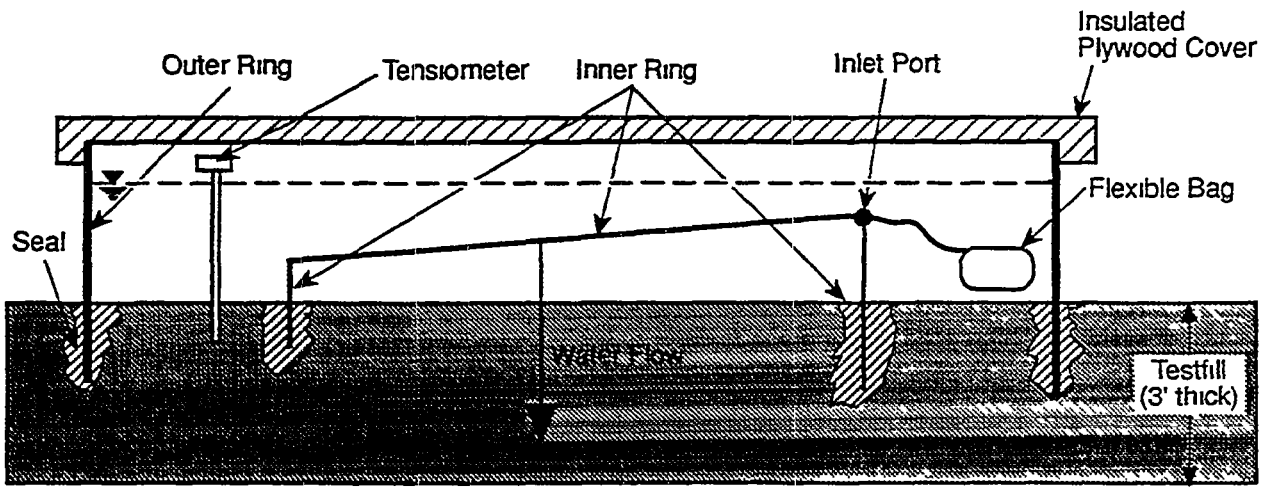
Figure 3 3

Testfill Plan View
and Cross Section

RMA 1232.3b 3/24/95 NLM

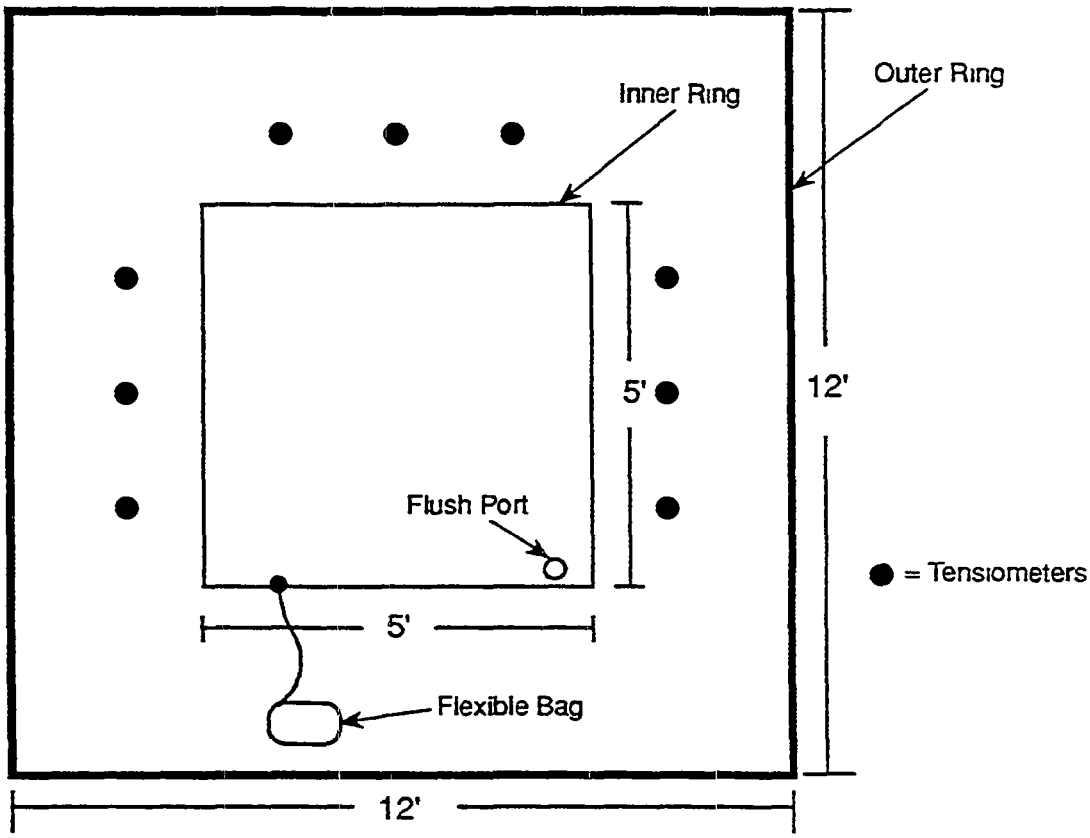
RMA 1240 3/24/94 NLM

Cross Section



Not to scale

Plan View



Not to scale

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure 3 4 Sealed Double-Ring Infiltrometer Schematic

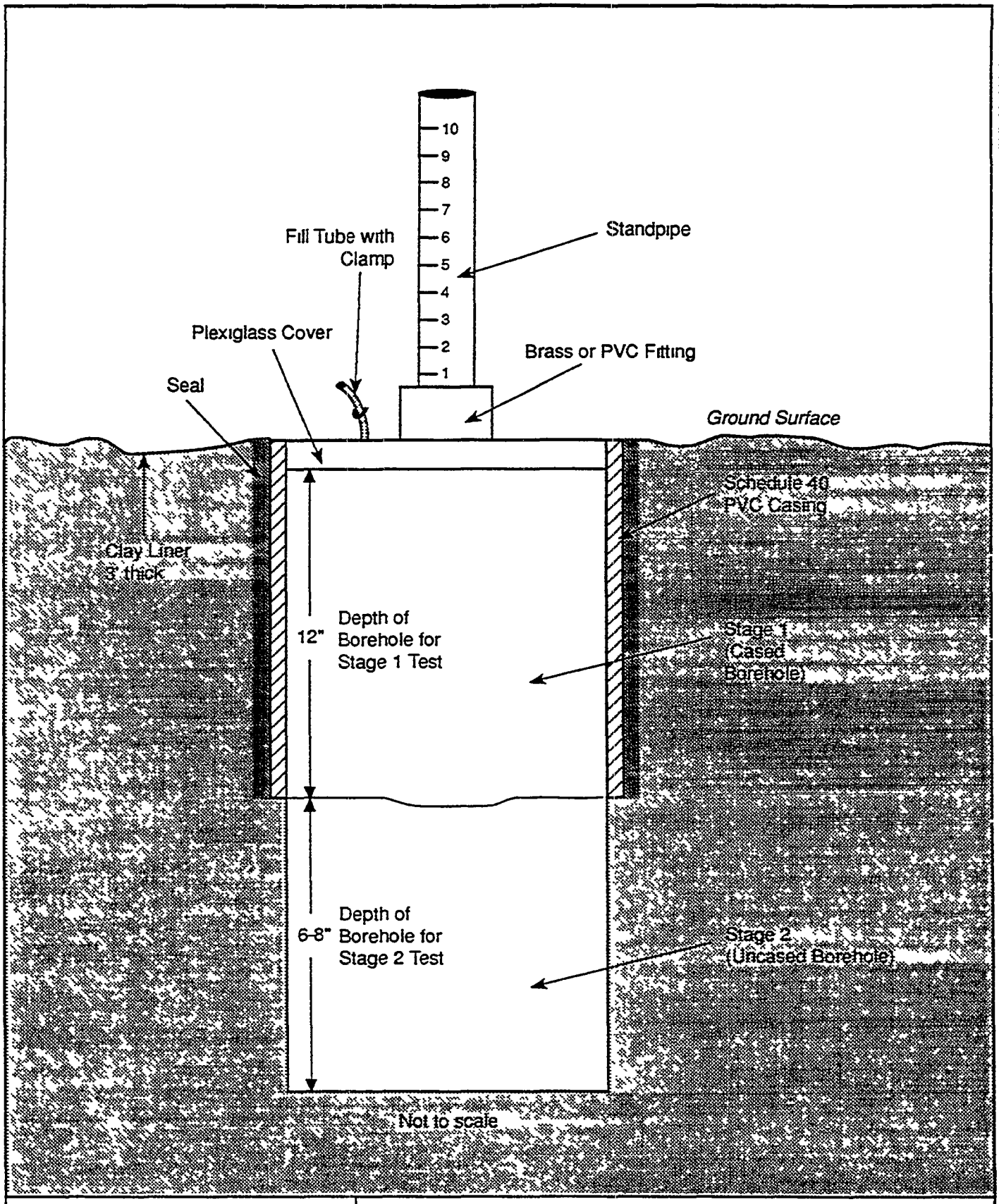


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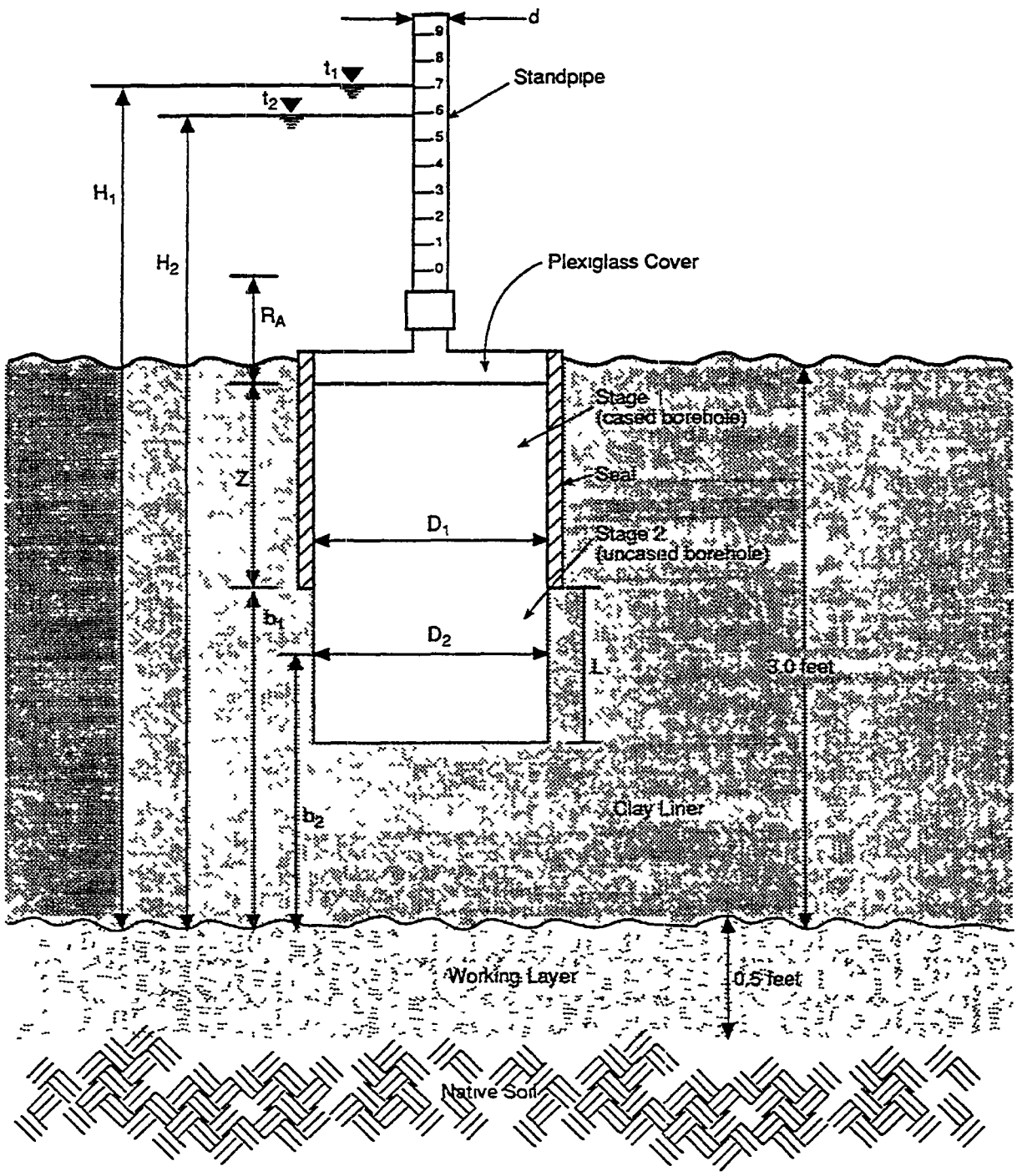
Figure 3 5

Two-stage Borehole Permeameter Installation (cross section)

RMA 12A0 1 12/18/94 LAM



Explanation

d	Inside diameter of standpipe	Z	Length of Stage 1 borehole	t_2	Final time
D_1	Inside diameter of Stage 1 borehole	L	Length of Stage 2 extension	R_a	Distance between standpipe scale and bottom of plexiglass cover
D^2	Inside diameter of Stage 2 borehole	H_1	Initial head at t_1		
b_1	Depth of test medium below bottom of casing	H_2	Final head at t_2		
b^2	Distance from center of Stage 2 extension to bottom of test medium	t_1	Initial time		

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Figure 3 6

Two-stage Borehole Permeameter
Nomenclature for Stage 1 and Stage 2

RMA 1228 6 2/3/95 LAM

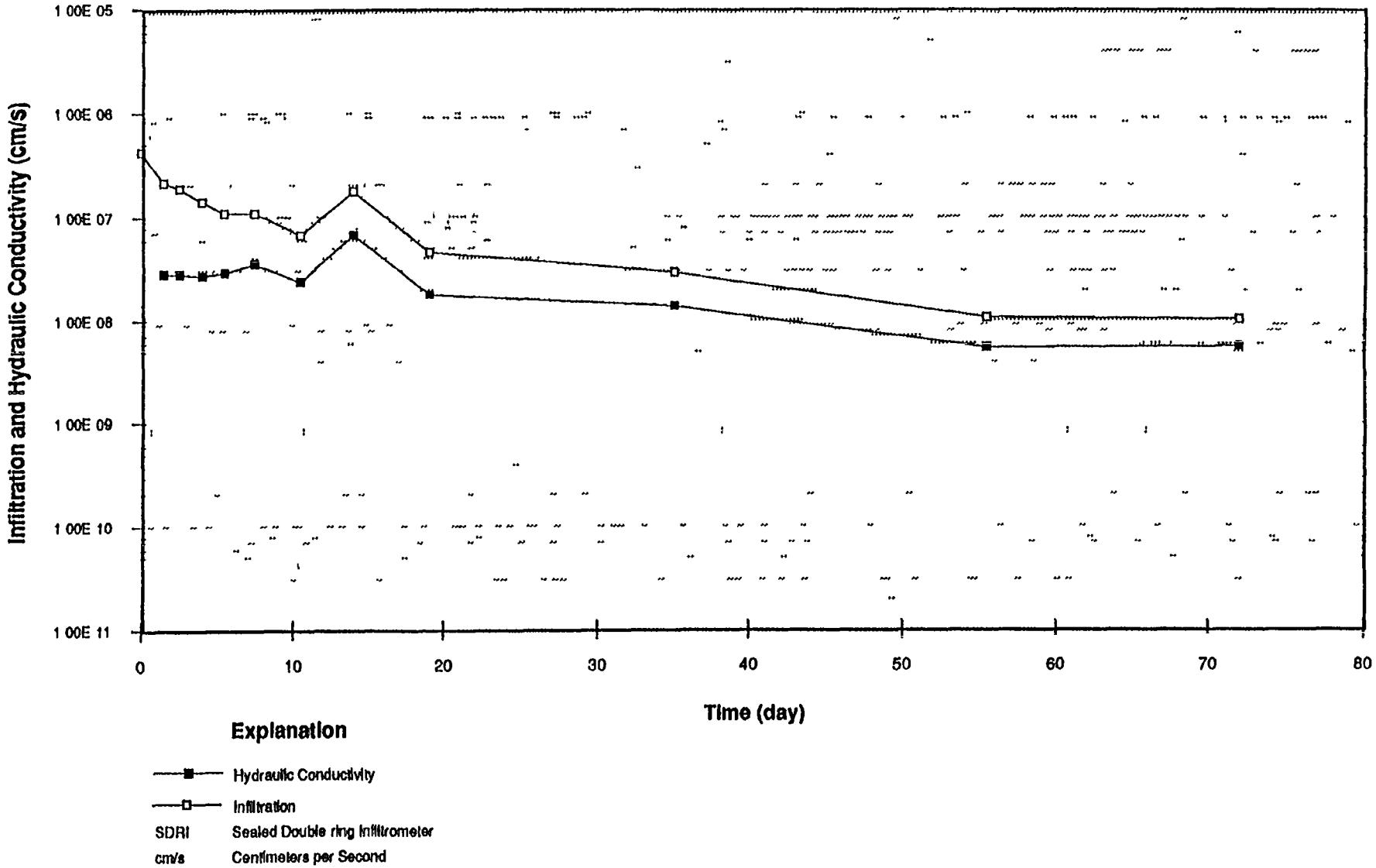

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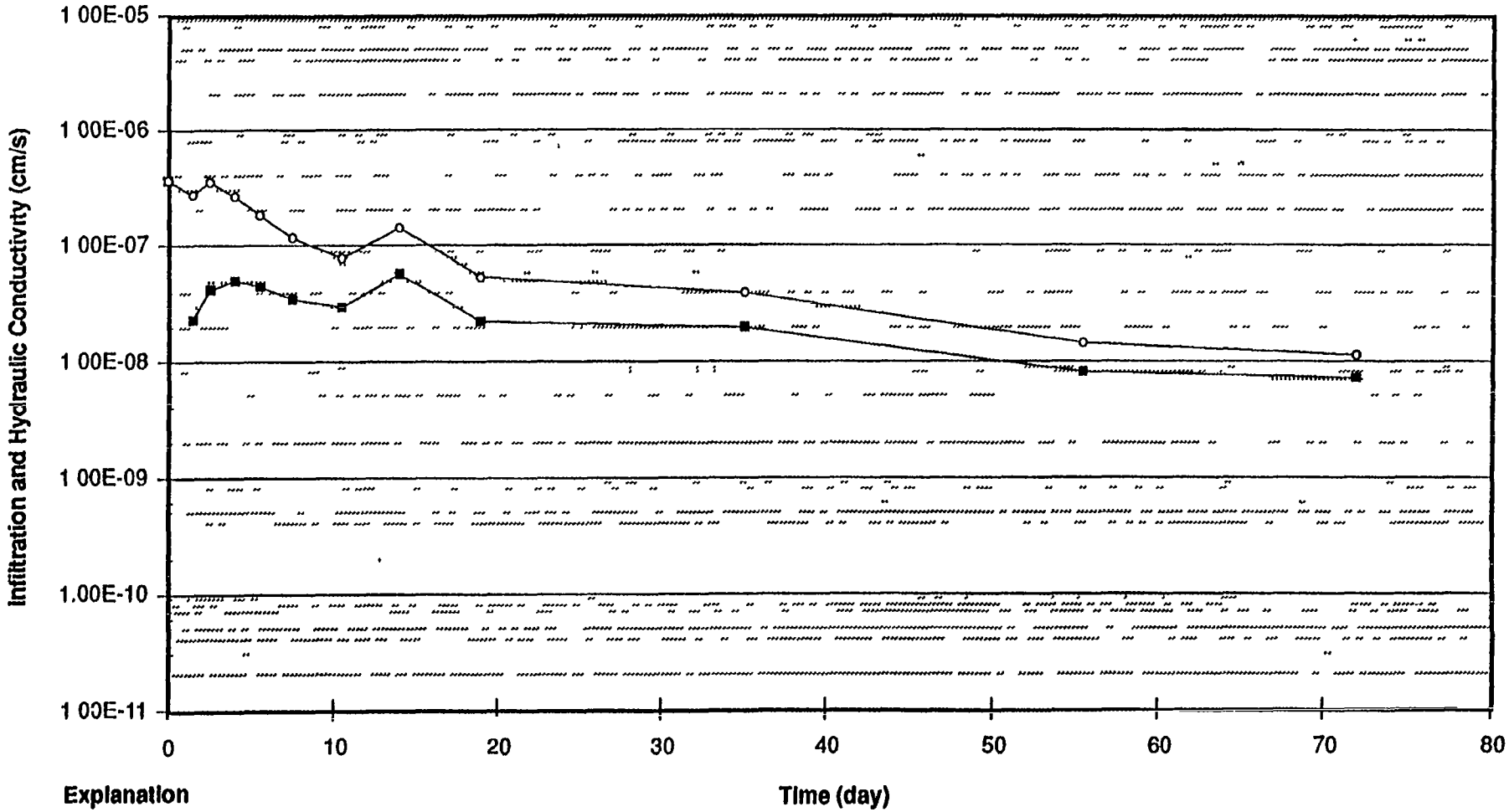
Figure 3 7

Infiltration Rate and Hydraulic Conductivity
SDRI 1
Testfill 1

RMA 12403 3/24/95 NLM



Explanation

—■— SDRI #1

—○— SDRI #2

cm/s Centimeters per Second

SDRI Sealed Double ring Infiltrometer

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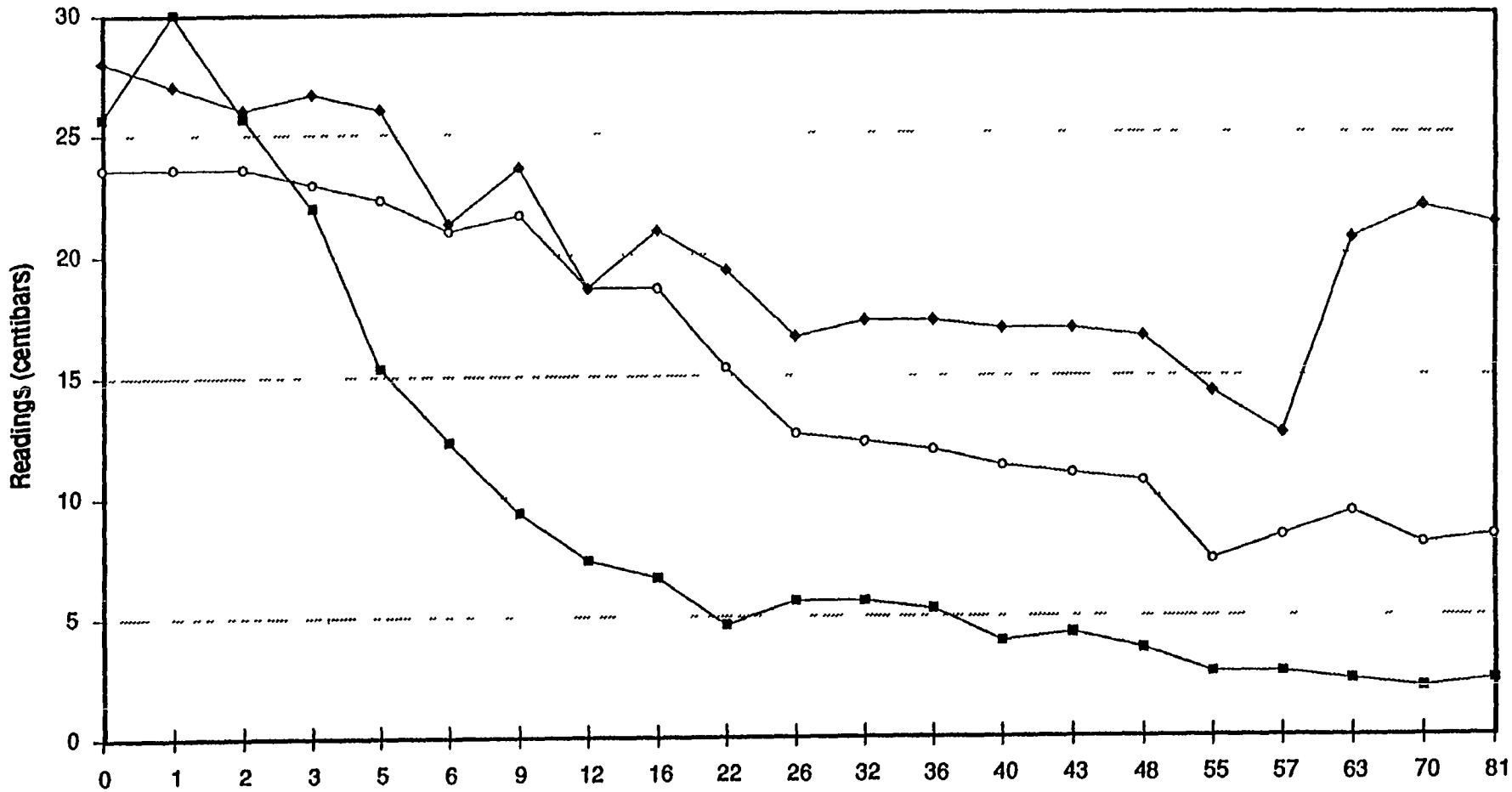
Figure 3 8

Infiltration Rate and Hydraulic Conductivity
SDRI 2
Testfill 1

RMAG 10517.5 3/24/95 NLM



Explanation

- Group 1 (6 Inch)
- Group 2 (12 Inch)
- Group 3 (18 Inch)

SDRI Sealed Double ring Infiltrometer

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Figure 3 9

Average Tensiometer Readings
SDRI 1
Testfill 1

RMAG 10511.6 3/24/95 NLM

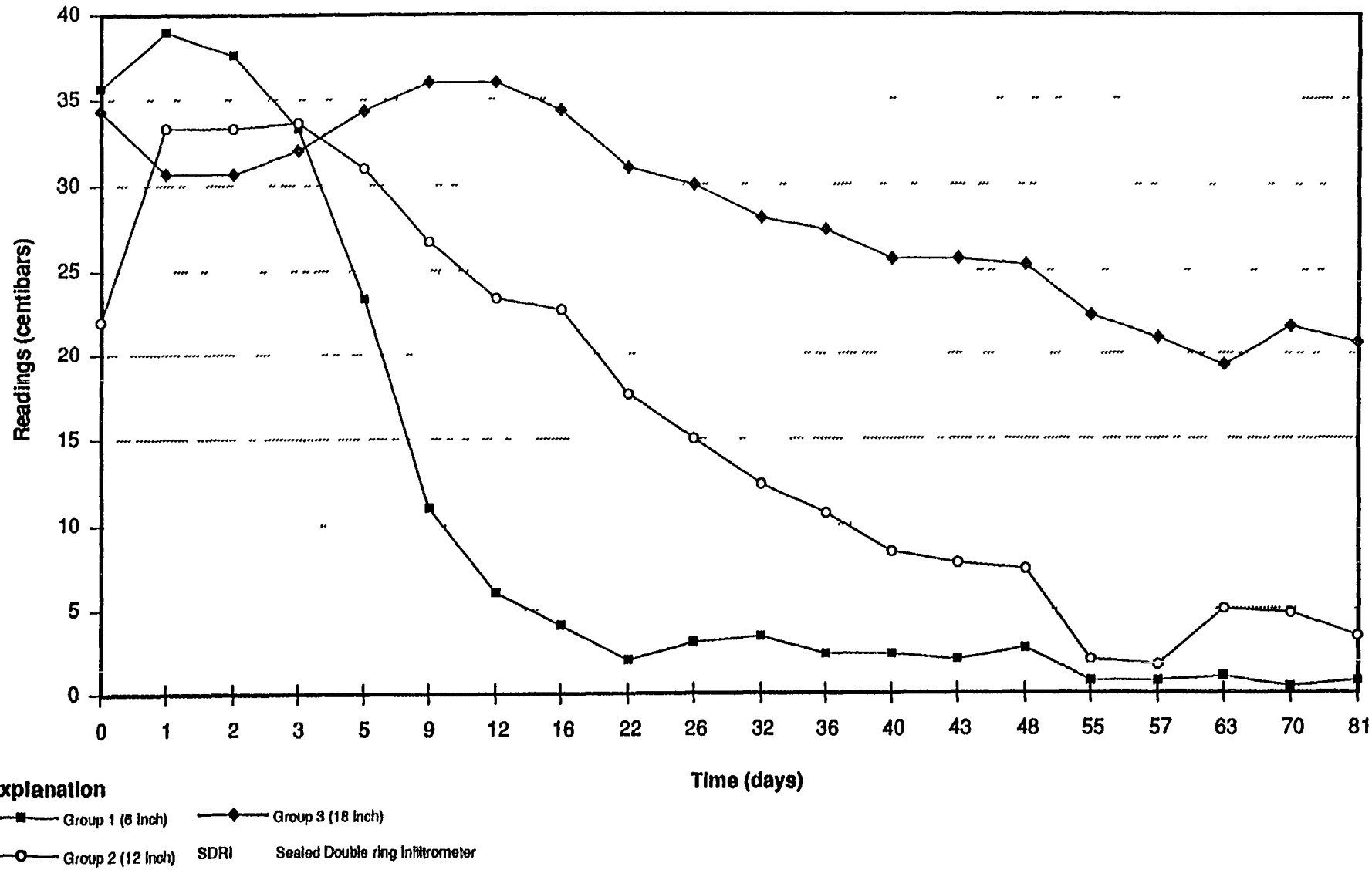

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Figure 3 10

Average Tensiometer Readings
SDRI 2
Testfill 2

RMAG 1051.3 2/24/9 NLM

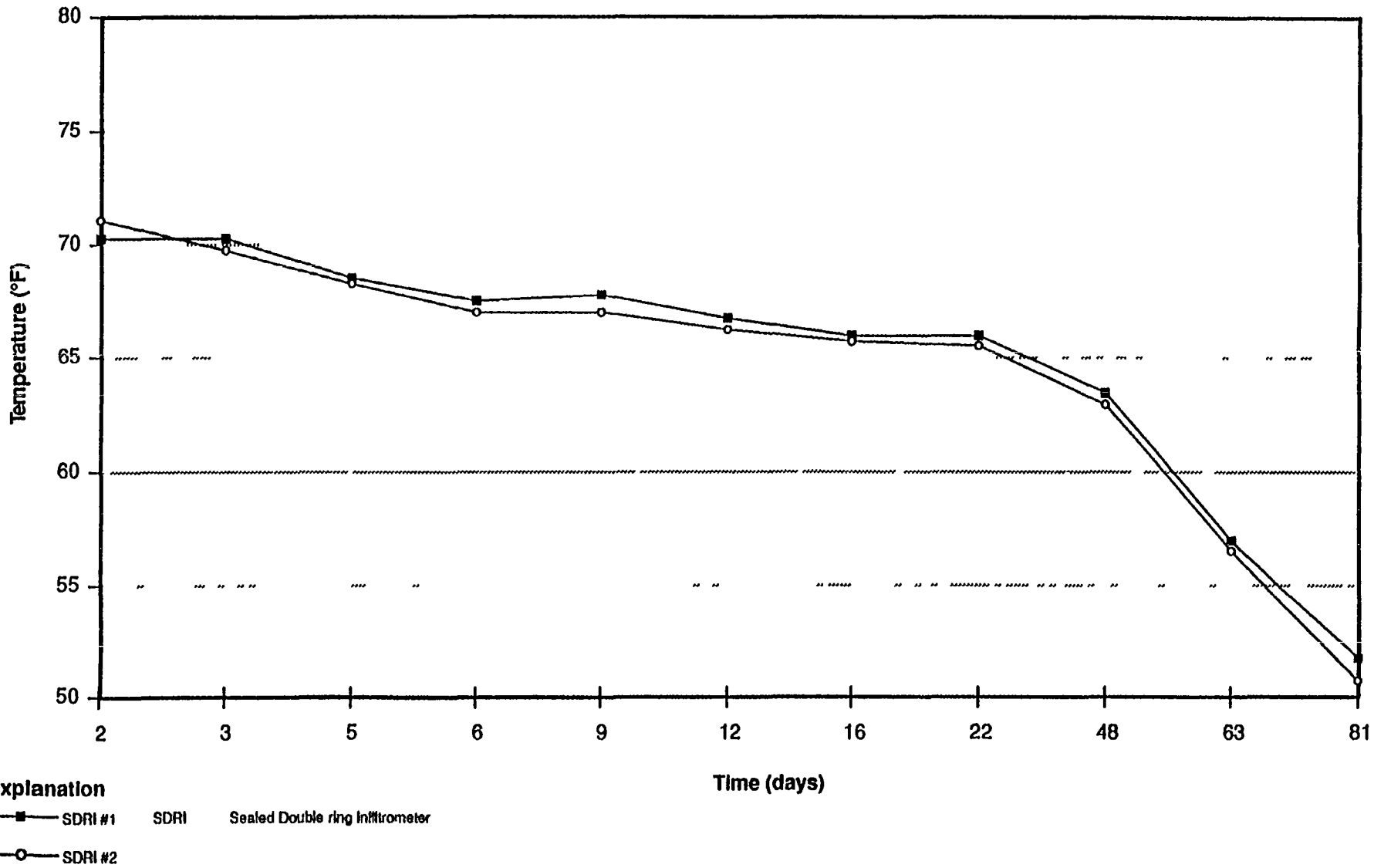

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Figure 3 11

Outer Ring Water Temperature

RMAG 10514 3/10/95 CRR

4.0 AREA FEASIBILITY STUDY

This section presents the results of the Area Feasibility Study that identify suitable areas for the location of the proposed hazardous waste landfill at RMA. The Area FS included a literature review, development of landfill area suitability criteria, identifying potential areas feasible for landfill construction based on the suitability criteria, and results of the geologic and geotechnical program in the identified areas (Section 25 at RMA) The Area FS was organized and performed in the following sequence

- Literature and Database Review (Section 4 1)
- Landfill Criteria and Policies (Section 4.2)
- Identification of Potential Areas (Section 4 3)
- Geologic and Geotechnical Investigation (Section 4 4)
- Area FS Conclusions

The literature and database review was performed to review existing data pertaining to landfill siting studies conducted at RMA and Highway 36 Landfill (the only commercial permitted hazardous waste landfill in Colorado) Previous landfill siting criteria and policies were reviewed and used to help develop Section 4 2, Landfill Criteria and Policies Previous geologic and hydrogeologic studies were also reviewed to evaluate if additional field investigations (Section 4 4, Geologic and Geotechnical Investigation) would be required to help evaluate area feasibility

In Section 4 2, the landfill siting criteria and policies were identified and evaluated for their relevance to siting a hazardous waste landfill at RMA. The landfill criteria and policies identified in Section 4 2 were used in Section 4 3 to screen RMA for suitable landfill siting areas that meet the relevant criteria and policies Once a suitable area for siting the landfill was selected, a geologic and geotechnical investigation was performed in the selected area. The geologic and geotechnical investigation provided further information on the suitability of the selected area for construction of a

hazardous waste landfill. The results of the Area FS were used in the Site FS (Section 5 0) to further refine the preferred location for the landfill within the suitable area.

Soil and groundwater chemical analyses, geochemical interpretations, and hydrogeologic conditions used for this report were based on previous studies performed at RMA.

4.1 Literature and Database Review

The literature and database review was performed to evaluate previous landfill siting studies and geologic and hydrogeologic studies at RMA. The information provided in this section was used to assemble the landfill siting criteria and policies (Section 4 2) and perform the GIS analysis discussed in Section 4.3 The GIS analysis integrated information to screen RMA for areas that were deemed suitable for landfill construction based on the landfill siting criteria provided in Section 4 2.

4.1.1 Previous Landfill Siting Studies

Three independent studies, Waterways Experiment Station (WES), 1983, U S Army Toxic and Hazardous Materials Agency (USATHAMA), 1984, and Ebasco, 1988a, were conducted at the direction of the Program Manager for Rocky Mountain Arsenal (PMRMA) to identify potential sites for the location of a hazardous waste landfill at RMA Each of the studies is summarized below with emphasis on the objectives and approach of the report, siting criteria used, site selection, and recommendations The siting criteria and results of the three studies are compared with the latest regulatory and institutional siting criteria presented in Section 4 2

4.1.1.1 Waterways Experiment Station Report

The purpose and objective of the report entitled "Proposed Hazardous Waste Landfill Siting and Suitability, Rocky Mountain Arsenal, Denver, Colorado" (WES, 1983) was two-fold

- To identify a potential landfill site and determine the suitability of the site for hazardous waste disposal
- To provide the necessary background data and assessments for compliance with regulatory requirements

The study included the following

- Developing geotechnical landfill siting criteria
- Review of the RMA environmental database
- Evaluating RMA sites based on landfill siting criteria
- Conducting a geologic field investigation at the potential landfill site

The geotechnical landfill siting criteria were developed based on Colorado guidelines for a Resource Conservation and Recovery Act (RCRA) landfill site (Hynes and Sutton, 1980) Specifically, the report identified five siting requirements

- Above the 100-year Standard Projected Floodplain
- Depth to the water table greater than 40 feet
- No saturated alluvium
- Thirty feet or less above the top of the Denver Formation and no Denver sand channels in contact with the alluvium
- A minimum of one mile inside the RMA boundary

RMA was screened for potential landfill sites using the five siting criteria and a preliminary site was identified in Sections 25 and 36 (see Figure 4 1) Following the preliminary site selection, a field program including geologic and hydrogeologic data collection and interpretation was initiated to collect further data on the potential site Field work involved drilling 28 exploratory borings and constructing 22 monitoring wells Soil samples were collected from the borings for geotechnical property testing The monitoring wells were installed to evaluate the potentiometric surface and baseline water chemistry Additionally, two falling head slug tests were performed to evaluate groundwater flow rates

The conclusions of the WES, 1983 report included identification of the two sites in Section 25 and northern Section 36 One site was eliminated because of its concurrence with the North Plants facilities and the presence of sand channels The second site, located in the southern part of

Section 25 and the northern part of Section 36, met or exceeded the siting criteria identified in the report Features of the identified site include

- Located on a topographic high outside of the 100-year floodplain
- Underlain by unsaturated alluvium that is 5- to 20-feet thick
- On average, at least 40 feet above the water table
- An alluvial vertical permeability of less than 6 0 x 10^{7} cm/s (determined by falling head permeability slug tests at two sites)
- An estimated groundwater flow velocity of about 0 5 feet per day (based on laboratory tests)
- Low levels of contaminants detected in some of the wells (outside the boundaries of the preferred area)

4.1.1.2 USATHAMA Report

The purpose and objective of the report entitled "Decontamination Assessment for Land and Facilities at Rocky Mountain Arsenal" (USATHAMA, 1984) was to document the results of a multi-year study assessing the feasibility and cost of decontaminating all or portions of RMA. The approach for the USATHAMA report included

- Reviewing applicable federal and state requirements
- Reviewing existing data to define areas, types, and volume of contamination at RMA
- Developing technical approaches to decontaminate RMA property
- Estimating decontamination costs for both partial and total unrestricted use of RMA

Eighty-eight contaminated sites were identified at RMA. The volume of contaminated materials within the 88 sites was estimated Based on the data and volume calculations, it was estimated that about 16 million cubic yards of contaminated buildings, equipment, and soil are present at RMA.

Two technical approaches for decontamination of the 16 million cubic yards of material were evaluated The first technical approach included decontamination of the material through excavation and treatment including incineration, wet chemical processing, solar heating, ultraviolet destruction,

and solidification and stabilization The second technical approach included in situ treatment of the material through soil activation, vegetative uptake, and biodegradation. Based on the feasibility, previous history, and economics, the preferred treatment technologies identified during the assessment were

- Excavation and landfilling
- Excavation, incineration, and landfilling

The study included identification of an onsite location for the landfill based on four siting criteria

- Location outside the 100-year floodplain
- Depth to groundwater greater than 20 feet
- Located greater than 200 feet from a Holocene fault
- Underlain by thick impermeable formations with no aquifers present

Based on the siting criteria, a location in the northeast quarter of Section 36 was selected for the landfill site Figure 4 1 illustrates the proposed location.

4.1.1.3 Ebasco Report

The purpose of the report entitled "Final Report, Task Number 27, Hazardous Waste Land Disposal Facility Assessment Report" (Ebasco, 1988a) was to assess the feasibility of an onpost land disposal facility that is compatible with federal and state regulations under CERCLA and capable of containing all RMA waste (estimated a 16 million cubic yards) The specific objectives were.

- Characterize the various wastes requiring land disposal
- Select the most suitable site for a land disposal facility at RMA
- Prepare a conceptualization of a land disposal facility with enough detail for a feasibility-level estimate of schedule and cost
- Estimate schedules and cost for construction and post-construction monitoring

The assessment process included two components, site selection, and design feasibility The site selection process was similar to WES and USATHAMA processes whereby criterion and site selection assumptions were made, exclusion and avoidance overlay maps were produced to identify potential sites The design feasibility process included selection of design criteria, evaluation of cell technology, evaluation of facility layouts, preparation of construction schedules, cost estimates, and constructions specifications with QC procedures. This review focuses on the site selection process Further discussion of the design feasibility process is included in Section 5 0

The site selection process included an evaluation of the entire RMA site with regard to seven siting criterion. The siting criteria included

- Location outside the 100-year floodplain
- Maximize the depth to groundwater with a target value of greater than 40 feet
- Located more than 1000 feet from a Holocene fault
- No saturated alluvium beneath the site
- Not within RMA avoidance areas of dedicated land use
- Initial target location size of greater than 1000 acres
- A minimum of 1000 feet inside the RMA boundary

Along with the site selection criteria, a list of site selection assumptions was prepared that included issues such as facility shape, number of sites, current and projected land use, and location of the waste centroid The facility shape was not considered a constraining factor in site selection because the waste cell arrangement could be changed to fit the site conditions. One contiguous site was preferred over multiple sites to minimize monitoring costs To address the current and projected land use issue, the site location was selected to avoid proximity to offsite high-density population areas and to be compatible with future onsite land uses

Based on the siting criteria and assumptions, six potential sites were identified Figure 4 1 illustrates the sites and lists the subsites identified within each of the six areas After thorough review of the sites, only two sites, 1B and 6B, were recommended based on the siting criteria achieved.

4.1.1.4 Limitations of Previous Landfill Siting Studies

The three siting studies provided PMRMA with insight into many of the pertinent issues related to siting a hazardous waste landfill at RMA. However, each siting study reviewed above contained certain limitations Specifically, the siting criteria used in the three studies are non-defensible by today's permitting standards These previous studies did not address certain regulatory criteria (as noted in Table 4 1) such as airport safety, wetlands, isolation, and sensitive habitats Each report is based on the CERCLA process and do not address other potential regulatory regimes, such as RCRA permitting The geologic and hydrogeologic databases used to evaluate RMA on a site-wide basis for geologic and hydrogeologic suitability are dated. More recent geologic and hydrogeologic information is currently available for selection of the onsite hazardous waste disposal site. Based on the current waste volumes projected for landfilling, site selection assumptions, such as site size, can be refined Finally, for the permitting process to begin (or to meet substantive RCRA requirements), site-specific geologic and hydrogeologic information, as described in Sections 5 0, must be completed.

4.1.2 Geologic Studies

The regional geology of the Front Range surrounding Denver, Colorado, has been studied for several decades and includes numerous publications The geology at RMA has been studied for more than 15 years General studies of the geology at RMA as well as specific studies of the bedrock and alluvium have been published. Site-specific geologic studies were reviewed as part of this Area FS. The regional geologic studies reviewed are included in the bibliography (Section 8 0)

Reports that provide a thorough overview of geology at RMA include Regional Groundwater Study of Rocky Mountain Arsenal, Denver, Colorado (May, 1982), Final Water Remedial Investigation Report, Volume III, Version 3 3 (Ebasco, 1989), and White Paper Evaluation of the Denver Formation

at RMA (Morrison-Knudsen Environmental Services, Inc. [MKE], 1994) There are many area-specific reports that were reviewed as part of this study and are also included in the bibliography (Section 8 0)

RMA boring logs were reviewed to assist in screening areas suitable for siting a hazardous waste landfill RMA was screened to establish potential areas feasible for siting a landfill (as discussed in Section 4.3), using site suitability criteria. Based on this screening process and previous landfill siting studies, borings and cross sections from Section 25 were reviewed Cross sections from the Proposed Hazardous Waste Landfill Siting and Suitability Report, RMA (WES, 1983) and from White Paper Evaluation of the Denver Formation at RMA (MKE, 1994) were reviewed Table 4 2 presents a list of boring logs in Section 25 that were specifically reviewed (many of the boring logs are included in the cross sections constructed as part of the study and presented in Section 4 4) A detailed geologic and geotechnical study of the western half of Section 25 at RMA was conducted to gain additional geologic and geotechnical information, and to establish the feasibility of constructing a hazardous waste landfill A description of this geologic and geotechnical study and summary of the study results are presented in Section 4 4 of this report.

Geotechnical Data

Geotechnical testing results from the Landfill Siting Study (WES, 1983) and Final FS Soils Support Program Report (HLA, 1995a) were reviewed. The 20 samples collected by WES were from five borings in Sections 25 and 36 as part of a landfill siting study HLA drilled 98 borings to identify potential cap, liner, and structural fill materials Potential cap and liner materials were identified in Sections 20, 24, 25, 27, and 36 (HLA, 1995a) Additional geotechnical data were acquired in Section 25 during a shallow boring and geotechnical program performed during this task and are presented in Section 4 4 of this report. This additional geotechnical data provide information concerning the feasibility of Section 25 for locating a hazardous waste landfill

Geophysical Surveys

HLA prepared a Summary of Historical Geophysical Assessments at RMA as part of the Final Geophysical Assessment Report (HLA, 1994a) In the report, four geophysical studies were identified near the preferred potential landfill area (as identified in this section) Seismic refraction and reflection studies were performed in western Section 25 as part of the Basin F Area II study An electromagnetic and magnetic geophysical survey was performed in the southeast corner of Section 25 to investigate suspected disposal areas Electromagnetic and magnetic surveys were also performed in a suspected disposal area in north central Section 36 Plate 1 of the 1994 HLA Final Geophysical Report summarizes the locations of geophysical surveys at RMA.

Hydrogeology

The regional hydrogeology of the Front Range surrounding Denver, Colorado, has been reported in several publications The regional and site-specific hydrogeology at RMA has been studied and published for more than 15 years RMA regional and site-specific hydrogeologic studies were reviewed as part of this literature review The Front Range regional hydrogeologic studies as well as the RMA regional and specific studies are included in the Bibliography (Section 8.0)

Several reports that provide an overview of the regional hydrogeology at RMA include

- Evaluation of the Hydrogeological System and Contaminant Migration Patterns, RMA (R L. Stollar and F Van der Leeden, 1981)
- Regional Groundwater Study of Rocky Mountain Arsenal, Denver, Colorado, Report 1, Hydrogeologic Definition (May, 1982)
- Hydrogeologic Description of Rocky Mountain Arsenal Groundwater Module, (Little, 1979)
- Final Water Remedial Investigation Report (Ebasco, 1989)

Several site-specific hydrogeologic studies have been published and include Proposed Hazardous Waste Landfill Siting and Suitability, RMA (WES, 1983), the Comprehensive Monitoring Program (CMP) and Groundwater Monitoring Program (GMP) (HLA, 1992a, 1995b, Pacific Western Technologies, 1993), Results of Treatability Studies for Groundwater Containment and/or Control and

Subsurface Drains Final Report (HLA, 1992b), and Final Fourth Year Reevaluation Report for Complex Disposal Trenches Interim Response Action RMA (HLA, 1994b)

The site-specific studies mentioned above include varied hydrogeologic information. The WES 1983 report included monitoring well installation and some falling head slug tests in Section 25 and a discussion of the site-specific hydrogeology As part of the CMP and GMP, groundwater flow and chemistry were routinely monitored across RMA. As reported in the Results of Treatability Studies for Groundwater Containment and/or Control Report (HLA, 1992b), two monitoring wells were installed in Section 25 and an extended aquifer test was performed in the alluvium Wells were installed and aquifer tests were performed in Section 36, south of Section 25 The Final Fourth Year Reevaluation Report for Complex Disposal Trenches IRA (HLA, 1994b) reviews and discusses the hydrology of Section 36 (south of the preferred landfill area)

Groundwater Chemistry

Releases of a variety of contaminants to the environment of RMA have resulted in groundwater contamination both onpost and offpost (Environmental Science and Engineering, Inc [ESE], and others, 1988, HLA and ESE, 1992, Ebasco and others, 1991) The distance a groundwater contamination plume extends from its source area depends on numerous factors including the contaminants' behavior in the environment and the amount of time of release The extent of the groundwater contaminant plumes at RMA ranges from a few hundred feet from their source to several miles (HLA, 1995b) In 1975, the Army initiated regional surface-water and groundwater monitoring programs to assess both onpost and offpost contamination. The programs implemented to monitor groundwater contamination at RMA have changed in scope several times since 1975 and are currently administered under the GMP The results of the GMP were reviewed and utilized in this investigation to assess the extent of known groundwater contamination. Screening of suitable areas for the landfill includes avoiding areas of known groundwater contamination (see the discussion of Avoidance Areas in Section 4 2 1) Groundwater contamination plume maps presented in the

Proposed Final DAA (Ebasco, 1994) were also utilized in the potential landfill screening process (Section 4.3 1)

4.1.3 Highway 36 Chemical Waste Treatment/Solidification and Disposal Facility Plan

HLA reviewed the Chemical Waste Treatment Solidification and Disposal Facility Plan (Howard Needles Tammen & Bergendoff, 1981) to evaluate the requirements for siting a hazardous waste landfill in Colorado The plan was intended to meet or exceed the applicable federal requirements under the RCRA, Adams County regulations, and the Colorado Department of Public Health and Environment (CDPHE) (formerly the Colorado Department of health [CDH]) regulations for hazardous waste treatment and disposal facilities at the time it was published.

The requirements and prime considerations in 1981 for the Highway 36 Facility site selection included

- Suitable geologic conditions
- Located near waste sources
- Sparsely populated area
- Good transportation access
- No adverse environmental impact anticipated
- Availability of utilities
- Land availability and size requirements
- No nearby airports
- Favorable topography
- Soil suitable for liner material
- Not located within growth corridor
- Not within fault zone
- Not within 100-year floodplain
- Not located within wetland area

- No impact on endangered or threatened species and critical habitats
- Extensive buffer zone
- Not located in aquifer recharge zone
- Favorable evaporation rates with minimal rainfall

These regulatory requirements and siting conditions are still generally applicable as a guide for identifying potential landfill areas at RMA.

4.2 Landfill Siting Criteria and Policies

The landfill siting criteria and policies were identified using current, applicable State of Colorado and federal regulations and RMA specific policies developed by PMRMA and the USFWS These landfill siting criteria and policies were used to identify potential landfill areas in Section 4 3

The following subsections present brief discussions of each landfill siting criteria listed in Table 4.3 and the primary and secondary criteria used It should be noted that the regulatory criteria are always the primary criteria adopted and the secondary criteria are included to strengthen the site screening process for further assurance of waste isolation.

Faults

According to Colorado regulations (6 CCR 1007-3, 264 18[a]), hazardous waste landfills may not be located within 1000 feet of a fault that has had displacement in Holocene time (i e , the last 10,000 years) This regulatory citation is the primary criteria adopted No evidence of faulting during the Holocene Epoch has been established at RMA.

There has been some discussion of potential faulting within the Denver Formation (WES, 1983) at RMA. Recognizing faulting within the Denver Formation is complicated by the discontinuous nature of the sedimentary deposits Faults were generally identified by displacement of distinct lithologic units within a formation. If, however, the units within the formation are discontinuous because of lateral facies changes that occurred during deposition, it is difficult to assess whether discontinuities

are due to faulting or sedimentary facies changes For this reason, the question of whether minor discontinuities within the Denver Formation are due to faulting or depositional changes is difficult to answer It is recognized, however, that any faulting that did occur within the Denver Formation probably occurred concurrently with settlement of the Denver Basin during the Laramide Orogeny in Late Cretaceous (i e , 65 million years before present) and Early Tertiary (i e , 55 million years before present) It has yet to be determined if these suspected areas are due to Denver Basin settling deformation, lithologic changes, or minor faulting The Denver Formation was deposited in the Upper Cretaceous and early Tertiary Periods, which ended approximately 65 million years ago.

Floodplain

Colorado regulations state that new landfills must be located outside the 100-year floodplain (6 CCR 1007-3, 264 18[b]), which is defined as any area subject to a 1 percent or greater chance of flooding in any given year from any source

The U S Army Corps of Engineers (COE) (1983) produced a 100-year floodplain map for the area encompassing RMA is shown in Figure 4 2 This regulatory citation is the primary criterion adopted

Salt Formations

Noncontainerized or bulk liquid hazardous waste may not be placed within salt dome formations, salt bed formations, underground mines and caves (6 CCR 1007-3, 264.18[c]). This Colorado regulatory citation is the primary criterion adopted. However, no known salt formations exist at RMA.

Surface Water/Groundwater

The Colorado regulatory citation states that "hazardous waste disposal facilities shall not place wastes directly under or into surface water or groundwater that has a potential or existing beneficial use or that is in direct communication with an aquifer" (6 CCR 1007-3, 264 18[d]) This citation is the primary criterion adopted The previous landfill siting studies at RMA (see Section 4 1) suggest

using target depths to groundwater (Table 4 1) to ensure this criterion is met The secondary target criteria stated in Table 4 3 are to maximize the depth to groundwater

Airport Safety

Colorado regulations state that new landfill facilities within a five-mile radius of an airport runway shall notify the CDPHE, local governing body having jurisdiction and the Federal Aviation Administration (6 CCR 1007-2, 3 1.1) This regulatory citation is the primary criteria adopted Denver International Airport runways are within five miles of RMA but are over five miles from the preferred landfill site

Wetlands and Sensitive Habitats

According to Colorado regulations, new landfills shall not be located in wetlands, unless the restrictions set forth in 40 CFR 258.12 can be met (6 CCR 1007-2, 3 1.2). Wetlands (as defined by 6 CCR 1007-2) means those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions Wetlands generally include swamps, marshes, bogs, and similar areas The USFWS delineated an area (shown in Figure 4 3) that is acceptable to landfill siting and does not include any areas impacted by the Endangered Species Act (ESA) (16 United States Code [USC] Sections 1531 to 1543) This area has been screened by USFWS to exclude critical habitat such as wetlands and riparian areas, raptor roosts and nesting sites within the Bald Eagle Management Area (BEMA), most prairie dog towns, unique vegetation communities, and high public use area. According to ESA, the term "critical habitat" for a threatened or endangered species means (16 USC Section 1532[5][A]).

(i) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of Section 4 of this Act, on which are found those physical or biological features (1) essential to the conservation of the species and (2) that may require special management considerations or protection, and

(ii) Specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provisions of Section 4 of this Act,

upon a determination by the Secretary that such areas are essential for the conservation of the species

This regulatory citation is the primary criterion adopted The avoidance of sensitive wildlife habitats is adopted as a secondary criterion

Seismic Impact Zones

Colorado regulations state that new landfills shall not be located in seismic impact zones, unless the owner or operator can demonstrate to CDH that all components are designed to resist the maximum horizontal acceleration in lithified earth material for the site (6 CCR 1007-2, 3 1 4) This regulatory citation is the primary criterion adopted RMA is located in an area of low seismic activity and therefore is not in a seismic impact zone.

Unstable Areas

Owners and operators of new landfills located in an unstable area must demonstrate that engineering measures have been incorporated into the facility's design to ensure that the integrity of the structural components will not be disrupted (6 CCR 1007-2, 3 1 5) Onsite soil conditions that may result in significant differential settling, geologic, or geomorphological features and onsite local or man-made features or events must be considered (6 CCR 1007-2, 3.1 5) This regulatory citation is the primary criterion adopted

Topography

The topography of the site shall maximize protection against prevailing winds onsite and minimize the amount of precipitation catchment area upgradient of the site (6 CCR 1007-2, 3.1.6) This regulatory citation is the primary criteria adopted Figure 4 4 presents a topographic elevation map of RMA. The topography of potential areas will be evaluated based on this criterion.

Isolation

Colorado regulations state that landfills shall isolate wastes from the public and environment (6 CCR 1007-2, 3.1 8) Emphasis will be placed on favorable geologic conditions over engineered

improvements of marginal geological conditions (6 CCR 1007-2, 3.1 8) This regulatory citation is the primary criterion adopted (See Hydrogeology and Geology, below.)

Hydrogeology and Geology

The geological and hydrological conditions of new hazardous waste landfill sites shall provide reasonable assurance that the wastes are isolated within the disposal area and away from natural environmental pathways that could expose the public for 1000 years, or some demonstrated shorter period in which the wastes are transformed to an innocuous condition (6 CCR 1007-2, 2 5.3) The assurance of 1000-year isolation is based on the following considerations

- Geomorphic conditions either will not vary significantly from the present state or will occur to a predictable degree which can be accommodated in the facility design
- The immediate area of the site is in strata of minimal groundwater flow
- The geologic strata surrounding the site combined with engineered barriers included in the design shall provide a minimum permeability of 10^{-7} cm/s or equivalent of sufficient thickness between the disposal location and the nearest domestically or agriculturally useable aquifer to isolate any materials to be disposed therein
- The juxtaposition of the site and any free flowing or standing natural surface waters shall be such that disposal locations will not impact nor be impacted by such surface waters
- The terrain is such that good drainage exists for movement of precipitation away from the disposal area, and such that water and wind erosion will be minimal
- The geochemical characteristics of the geologic strata at the site are compatible with the waste categories proposed to be disposed at the site especially in terms of providing high adsorption, absorption, or chemical fixation of any wastes that may migrate from the immediate areas where disposed (6 CCR 1007-2 2.5 3)

This regulatory citation is the primary criterion. Secondary criteria for hydrogeology and geology were developed to help in the site screening process The secondary criterion for hydrogeology is to avoid areas containing saturated alluvium The secondary criterion for geology is to minimize the depth to bedrock.

Location

The location of any hazardous waste facility shall be within a distance controlled by the owner/operator by an acceptable means to prevent adverse effects on the public health should

unexpected discharges of hazardous waste occur (6 CCR 1007-2, 2 5 6) This Colorado regulatory citation is the primary criterion adopted A secondary criterion developed by PMRMA is to centrally locate any hazardous waste facility within RMA to keep an adequate area around a facility controlled by PMRMA.

Buffer Zone

Colorado regulations state that sound levels of noise radiating from a property line at a distance of twenty-five feet or more in excess of 80 decibels (for an industrial zone) between 7:00 a.m and 7.00 p.m shall constitute a public nuisance (Colorado Revised Statute [CRS] Sections 25-12-101 to 108) This regulatory citation is the primary criterion adopted

Avoidance Areas

Avoidance areas are not a regulatory criteria but are important when considering the feasibility of siting a hazardous waste landfill. Avoidance areas at RMA include groundwater plumes containing RMA-related contaminants, human health exceedance areas, and contaminated subsurface soil areas as delineated in the Proposed Final DAA (Ebasco, 1994) Figure 4 5 shows groundwater plumes at RMA and Figure 4.6 shows human health exceedance and contaminated subsurface soil These avoidance areas are a secondary criterion adopted

Area Required

The exact area required for a hazardous waste landfill at RMA has yet to be defined, and may be adjusted depending on the preferred remediation alternative selected for cleanup and or stabilization at RMA. The area required is not a primary criterion since it is not regulatory based, however, based on the results of Section 5.0, at least 87 contiguous acres are required to accommodated the largest volume of waste to be landfilled.

National Historic Preservation Act of 1966

The National Historic Preservation Act of 1966 (NHPA) (16 USC Section 470) requires that alteration of terrain that may cause irreparable harm, loss, or destruction of significant artifacts or prehistorical,

historical, or archaeological data, be required to recover and preserve the artifacts and/or data. This citation is not considered a suitability criterion, and was not used as part of the screening process Cataloging of prehistorical, historical, and archaeological sites is currently in progress at RMA. The presence of prehistorical or archaeological artifacts should not impact the siting of the landfill However, if prehistorical or archaeological artifacts are identified, they must be recovered before construction can proceed

Archaeological and Historical Preservation Act

The Archaeological and Historical Preservation Act (AHPA) (16 USC Sections 469 to 469C-1) establishes procedures for preservation of historical and archaeological data that might be destroyed through alteration of terrain as a result of a federal construction project or a federally licensed activity or program If archaeological artifacts are identified in potential landfill areas, AHPA may be applicable However, this does not eliminate areas from being considered for landfill siting because archaeological artifacts (if found) can be cataloged and removed before disturbance takes place as long as the site is not considered a national historic site If a site contains significant archaeological artifacts, then the Archaelogical Resources Protection Act of 1979 may apply, eliminating the area from future use

4.3 Identification of Potential Landfill Areas

The identification of potential landfill areas was performed using the literature and database review from Section 4 1 and the landfill siting criteria and policies from Section 4 2 to screen RMA. The potential landfill area identified in this section was used as the study area for the geologic and geotechnical investigation (Section 4 4)

4.3.1 Potential Landfill Areas Screening Process

Potential landfill areas were screened using the landfill siting criteria developed in Section 4 2 (Table 4.3) A series of overlay maps containing physical data, and exclusion and avoidance data, were integrated using a GIS format. The following map data were input into GIS for integration·

Figure 4 2	100-year floodplain map (COE, 1983)
Figure 4 3	Wetlands and sensitive wildlife habitat avoidance areas (USFWS, 1994)
Figure 4 4	Topographic elevation contour map of RMA (2-foot contour intervals) provided by D P Associates (surveyed 1988)
Figure 4 5	Organic groundwater contamination plumes (Ebasco, 1994)
Figure 4 6	Human health exceedance areas map (Ebasco, 1994)
Figure 4 7	Bedrock elevation contour map of RMA (compiled by HLA in 1992)
Figure 4 8	Water-level elevation contour map of RMA (HLA, 1992a)
Figure 4 9	Depth to groundwater contour map as measured from ground surface (compiled from the water-level contour map and topographic elevation map)
Figure 4 10	Depth to bedrock contour map as measured from ground surface (compiled from the bedrock elevation map and topographic elevation map)

USFWS avoidance areas (Figure 4 3), organic contaminant groundwater plumes (Figure 4 5), 100-year floodplain avoidance areas (Figure 4 2), and human health exceedances areas (Figure 4 6) were removed from consideration as potential areas to site a hazardous waste landfill

The secondary siting criteria used to identify potential landfill areas listed in Table 4.2 for surface water/groundwater, hydrogeology, geology, and location, respectively, are

- Maximize depth to groundwater
- Avoid saturated alluvium
- Minimize depth to bedrock
- Located centrally within RMA boundary

The secondary siting criteria for groundwater hydrogeology and geology mentioned above were used to maximize hazardous waste isolation If in the event there was a breach in the landfill liner system and a leak was to occur, the leachate would flow from the base of the landfill through the vadose zone to groundwater Colorado hazardous waste regulations are written to protect the potential downstream receptors and the most probable flowpath in this scenario would be through

groundwater flow Maximizing the depth to groundwater contributes to waste isolation by increasing the thickness of the vadose zone and, therefore, the time required for any potential contamination to reach groundwater Avoiding saturated alluvium contributes to waste isolation because the saturated alluvium is in general more hydraulically conductive than the saturated Denver Formation. Minimizing depth to bedrock helps isolate waste because, generally, the bedrock below the alluvium has a lower vertical hydraulic conductivity than the alluvium and, therefore, creates a longer travel time to groundwater The secondary criteria of centrally locating a landfill within RMA boundary is a policy developed by PMRMA to minimize potential waste hauling distances and create the largest buffer to the public as possible

To identify suitable potential landfill areas, a series of maps were generated by applying different combinations of suitable depths to groundwater and bedrock (five different depths to groundwater and four different depths to bedrock) The potential maximum contiguous acreage identified through this GIS analysis using the various depths to groundwater and depths to bedrock is listed in Table 4 4 and are presented and evaluated in the following subsection.

4.3.2 Potential Landfill Areas

The results of the potential landfill areas screening process are presented in six maps (Figure 4 11 through Figure 4 16) These figures represent the potential landfill areas available using the depths to groundwater and bedrock parameters in Table 4 4 The suitable areas based on the applied selection criteria increase in size as the depth to groundwater and the depth to bedrock parameters become less restrictive

The six maps (Figure 4 11 through Figure 4 16) each show a consistent grey pattern that represents the suitable areas identified using the primary landfill siting criteria A spatial analysis was performed to eliminate those areas at RMA deemed unsuitable with respect to the primary landfill siting criteria. The primary landfill siting criteria (Table 4 3) include avoidance of wetlands, sensitive habitats, 100-year floodplain, organic groundwater contamination plumes, and human

health exceedance areas As noted in Table 4 3, some regulatory criteria are not relevant because they are not encountered at RMA.

The most restrictive parameters listed in Table 4 4 are

- Depth to groundwater of 70 feet or greater
- Depth to bedrock of 10 feet or less

The least restrictive parameters (while still maintaining unsaturated alluvium) listed in Table 4.4 are:

- Depth to groundwater of 40 feet for greater
- Depth to bedrock of 40 feet or less

Figure 4 11 presents the potential landfill area generated using the most restrictive parameters, and Figure 4 16 presents the potential landfill area using the least restrictive parameters The most restrictive parameters yield 1 contiguous acre of potential landfill area (Figure 4 11), while the least restrictive parameters shown in Figure 4.12 yield 371 contiguous acres A balance is required to (1) meet the siting criteria of maximizing the depth to groundwater and minimizing the depth to bedrock and (2) retain enough acreage to facilitate the construction of a hazardous waste landfill capable of containing the volume of waste generated during sitewide remediation at RMA. The potential landfill areas identified in this section indicate that the western half of Section 25 at RMA contains the most suitable area based on the landfill siting criteria and policies and screening iterations

Section 5 0 will discuss the acreage required to construct a hazardous waste landfill with three different waste volume assumptions (1 million, 2 3 million, and 6 million cubic yards).

4.4 Geologic and Geotechnical Investigation

This section presents the methods, results, and conclusions of a detailed geologic investigation performed in the western half of Section 25. As described previously, based on a GIS analysis

performed as part of the Area FS study, the western half of Section 25 is the preferred area for the location of the proposed hazardous waste landfill at RMA. This geologic investigation was performed to obtain further information on the suitability of the proposed area. Section 4 4.1 presents the field and laboratory methods employed in the geologic investigation. Section 4 4 2 presents a detailed description of the results of the investigation. Section 4 4 3 summarizes the results and presents conclusions on the geologic suitability of the proposed area.

4.4.1 Geologic Investigation Methodology

A total of 33 boreholes were drilled in the western half of Section 25 for this investigation (Figure 4 17) Three of the boreholes were deep (drilled to a total depth of 175 feet bgs) and thirty were shallow (drilled to a maximum depth of 50 feet bgs) The boreholes were surveyed by a State of Colorado-licensed surveyor using the 1983 horizontal datum and the 1988 vertical datum The equipment and procedures used for drilling the two types of boreholes are summarized separately below More detailed information on the drilling, sampling, geophysical logging, and laboratory testing methodology was provided in the Final Work Plan for Material and Area FS Soils Support Program (HLA, 1994c) (Appendix I)

4.4.1.1 Deep Coring and Geophysical Logging Program

Three deep boreholes were drilled by a U.S Army Corps of Engineers (COE) WES drilling crew using a Failing 1500 rig The drilling rig was capable of both auger and rotary drilling Drilling in the alluvium was accomplished using an 8-inch-outside-diameter (OD) solid auger Continuous core samples of the alluvium were collected using a 24-inch, split-barrel sampler in the open borehole Drilling in bedrock was accomplished by mud-rotary drilling and samples were collected using a 5-foot-long, 4 5-inch-OD, 2 5-inch-inside-diameter (ID) core barrel using a wireline system. A temporary casing was set in the alluvium of each deep borehole and grouted in place to prevent the unconsolidated materials from caving into the borehole

The field crew consisted of a two-person drilling crew from WES and an HLA geologist The HLA geologist documented the daily drilling activities including the following boring number, drilling progress, pertinent observations such as equipment decontamination, photoionization detector (PID) readings, weather, and surface conditions

The HLA geologist prepared a lithologic log of the split-spoon and core samples recovered from the borehole The logs included alluvium and bedrock descriptions using the USCS and the Munsell color chart. Information on stratigraphic features such as bedding or laminations, and structural features such as fracturing or slickensides, along with other pertinent geologic information, was noted on the boring logs The soil and bedrock cores recovered from the drilling program were packaged, labeled, and stored in RMA Building 728

Immediately upon completion of the drilling and sampling, the boreholes were geophysically logged by Colog, Inc (Colog), of Golden, Colorado Colog used the following geophysical logging tools

- Normal resistivity
- Spontaneous resistivity
- Single-point resistivity
- Gamma
- Full waveform sonic
- Neutron

After the boreholes were geophysically logged, they were grouted to the ground surface with a cement/bentonite grout mixture using a tremmie pipe A stake was placed at the borehole location with the appropriate boring identification number The location and ground surface elevation of the boring was surveyed by a Colorado-licensed surveyor

4.4.1.2 Shallow Boring and Geotechnical Testing Program

Thirty shallow boreholes (Figure 4 17) were drilled by a Layne Environmental drilling crew using a mobile Central Mine Equipment (CME 75 or 750) drilling rig The rig was equipped with 3-1/4-inch hollow-stem augers and 2-foot long, 2.5-inch-ID, split-spoon soil samplers The split-spoon samplers were driven using a drilling rig-mounted 140-pound automatic slide hammer at a 30-inch drop

The field crew consisted of a two-person drilling crew from Layne Environmental, an HLA geologist, and an HLA engineering technician. As described in the deep drilling program, the HLA geologist was responsible for documentation of the daily drilling activities The HLA engineering technician was responsible for sample handling, packaging, and shipment.

The HLA geologist prepared a lithologic log of each shallow borehole in the same manner described in the deep drilling program. While drilling through the alluvium and to a depth of at least 5 feet into the weathered bedrock, continuous split-spoon samples were collected Samples were collected from the split-spoon samplers at 4-foot intervals in 500 ml plastic jars for geotechnical testing At the same 4-foot interval, 5-gallon bucket samples were collected from the auger cuttings for additional geotechnical testing Once drilling had advanced at least 5 feet into the weathered Denver Formation, no further split-spoon samples were collected (due to split-spoon refusal) and from that point on, lithologic logging and soil samples were collected from auger cuttings

Samples collected from the boreholes were shipped to HLA's laboratory in Houston, Texas, for geotechnical property testing The samples were analyzed for the following geotechnical properties·

Test Name	Test Method	Percentage of Samples Tested
Particle size	ASTM D422	100
Atterberg limits	ASTM D4318	100
Natural moisture content	ASTM D2216	100
Remolded compaction	ASTM D698	10
Remolded permeability	EM1110-2-19096	10
Shrink swell	ASTM D427 and D4546	10

Test Name	Test Method	Percentage of Samples Tested
Organic content	ASTM D2974	10
Shear strength	ASTM D4767 and D2850	1

Upon completion of the drilling and sampling, the boreholes were grouted to the ground surface using a cement/bentonite grout A stake was placed at the borehole location with the appropriate boring identification number. The location and ground surface elevation of the boring was surveyed by a Colorado-licensed surveyor.

4.4.2 Geologic Investigation Results

The following sections present the results of the geologic investigation. As described above, two types of soil borings were drilled for different data objectives and, therefore, the results of the two programs are presented separately In this section, the results of the two drilling programs are integrated and conclusions on the suitability of the proposed area are presented

4.4.2.1 Geologic Setting

The geologic setting of RMA has been described in detail by MKE (1988), and Ebasco (1989), and the groundwater hydrology beneath the site has been described by May (1982) A brief overview of the geologic site conditions is described below to provide a framework for understanding the results of the geologic investigation in Section 25

RMA is located within the Denver Basin, a north-south trending syncline The syncline is asymmetrical with steeply dipping beds that are faulted against the Colorado Front Range on the west and gently dipping beds on the east that extend into western Kansas and southwestern Nebraska. The basin extends from north of Cheyenne, Wyoming, to south of Colorado Springs, Colorado RMA is near the structural axis of the southern portion of the syncline where the uppermost beds dip on average less than 1° to the southeast.

The topography at RMA is expressed as gently rolling hills, wide plains, and shallow basins. The elevation above mean sea level ranges from 5340 feet in the southeastern part of RMA to 5120 feet in the northern part of RMA

Before the formation of the Denver Basin, the area near what is now RMA received an influx of various types of sediment as a result of primarily alluvial depositional processes The Denver Basin was downwarped to a syncline during the Laramide Orogeny in Late Cretaceous and Early Tertiary time, and the Fox Hills Sandstone, the Laramie Formation, the Arapahoe Formation. and the Denver Formation were deposited (Figure 4 18) Additional alluvial sediment was deposited over the Denver Formation until the late Tertiary period, when regional uplift caused the erosion of this additional sediment at RMA, as well as part of the Denver Formation Subsequently, Quaternary sediment was deposited at RMA

This report focuses on the Denver Formation and Quaternary deposits because they contain the principal aquifers in contact with potential contaminant sources within RMA A claystone layer forms the base of the Denver Formation and provides a confining layer between the Denver Formation and the underlying Arapahoe Formation.

Alluvium The Quaternary surficial deposits, commonly called the Quaternary alluvium, consist of unconsolidated alluvial and colluvial fill and eolian sand The alluvial and colluvial material is composed of volcaniclastic material and glacial outwash containing cobbles and boulders in a matrix of clay, silt, sand, and gravel Older coarse-grained alluvial deposits generally are in areas along the South Platte River and the western part of RMA. Paleochannels eroded into the Denver Formation are also filled with coarse-grained sand and gravel Younger eolian and alluvial deposits are finer grained than the older surficial deposits and commonly form the uppermost alluvial deposits throughout much of RMA

The Quaternary alluvium typically ranges from 0 to 50 feet in thickness but locally fills paleochannels eroded into the Denver Formation to a depth of 130 feet (May, 1982) The surficial geology at RMA is almost entirely alluvial material and the Denver Formation is exposed at the surface in only a few locations (Figure 4 19) Eolian deposits consisting of fine sand, clay, and silt occur as a thin discontinuous veneer that overlies most of the surficial material at RMA.

Denver Formation. The Denver Formation is believed to have been originally about 900 feet thick over the RMA area (MKE, 1988), but it has been eroded to a maximum of 500 feet thick in the south-eastern corner of RMA. The formation thins to the northwest and is absent beneath the South Platte River, where it has been completely eroded. As much as 40 feet of the upper Denver Formation are weathered and the weathered zone is in direct contact with the Quaternary alluvium

The Denver Formation consists of a thick sequence of shale and claystone with interbedded siltstone and sandstone lenses, deposited by low-energy fluvial processes in a distal alluvial plain environment. Olive, bluish-gray, and brown colors dominate the upper part of the formation because of lithic fragments derived from the erosion of basaltic and andesitic volcaniclastic material Sandstone lenses are tan to brown and consist of well-defined fluvial channels and laterally variable crevasse splay sands and overbank deposits Lignite beds and carbonaceous shales are also present.

Stratigraphic correlation of units within the Denver Formation is difficult because of the discontinuous nature of the sandstone lenses and the lateral variability in thickness and composition of other units A relatively thick, laterally continuous lignite layer, known as lignite A, occurs within the South Plants, North Plants, and Basin A area. Lignite A has been used as a marker bed from which all other zones in the Denver Formation have been referenced (Ebasco, 1989a, 1989b) Denver Formation stratigraphy (Figure 4.20) has been interpreted using this and other lignite layers as marker beds The stratigraphy illustrated in Figure 4 20 was adopted for the stratigraphic correlations presented in this report.

The Denver Formation dips slightly to the southeast and the erosional bedrock surface slopes to the northwest. Therefore, progressively deeper stratigraphic units are erosionally truncated from southeast to northwest. Examples of the truncation of the Denver Formation due to the slope of the erosional bedrock surface are presented in the cross sections described in Section 4 4 2 3

4.4.2.2 Deep Coring and Geophysical Program Results

Three deep boreholes (BRB11094, ASB11194, and SAB11294) were successfully lithologically and geophysically logged (Figure 4.17) The lithologic boring logs for the three boreholes are included in Appendix E, and Appendix F includes the boring survey locations, and surface and bedrock elevations The geophysical logs are included in Appendix G

Geophysical logging of the three boreholes was completed by Colog Results of the investigation are presented the Geophysical Logging Services Report in Appendix G Based on the results presented in the report, there was good correlation between the geophysical log response and the lithologic core descriptions in the three deep boreholes The geophysical log responses were consistent with fine-grained, clay-rich, poorly consolidated sediments

Variations in geophysical response recorded on the geophysical logs illustrate the lithologic differences between the three borings Borings BRB11094 and SAB11194 correlate on both the lithologic and the geophysical logs The correlation of Boring ASB11294 with the other two borings is less definitive According to the geophysical logging report, the differences in the geophysical logs between ASB11294 and the other two borings may be attributed to the shallower bedrock depth and a lower depth to water table at ASB11294 A more apparent difference between the borings is lithologic. A lignitic zone identified in BRB11094 and SAB11194 between 5178 and 5184 feet elevation is not identifiable in the geophysical logs of ASB11294

Cross sections were developed using the lithologic boring logs developed during the deep boring program to evaluate the differences identified in the geophysical response between the three

boreholes The cross sections are presented in Section 4 4 2.3 and illustrate the interpretations of the lithologic correlation across the study area.

4.4.2.3 Shallow Boring Geotechnical Program Results

Stratigraphic and Lithologic Relationships

The site-specific lithologic and stratigraphic relationships of the Quaternary alluvium and the Denver Formation were studied in the western half of Section 25 in detail through the construction and interpretation of 16 cross sections A cross section grid was constructed across the study area and is illustrated in Figure 4 17 Ten cross sections were oriented subparallel to strike (A-A′ to J-J′) and six were oriented subparallel to structural dip (K-K′ to P-P′) Eight of the sixteen cross sections in the grid, considered most representative of the study area geology, are included in this report to illustrate the interpretations presented herein (Figures 4 21 through 4.28)

Lithologic information used to construct the cross sections was taken from the 30 shallow borings and the 3 deep borings drilled as part of this investigation. Additionally, boring logs generated during the installation of existing monitoring wells in the study area were used in the cross sections Correlations of similar lithologic units were made for each cross section over relatively short distances and by correlating the points at which the cross sections intersect (tie points) This method of correlating site geologic data allows for an evaluation of the stratigraphy and specific lithologic intervals in a three-dimensional framework.

Quaternary Alluvium. The geologic strata characterizing the site include the Quaternary alluvium and Denver Formation The alluvium encountered in the 33 borings consists of clay, silt, very fine- to fine, to medium-grained sand and minor amounts of coarse-grained sands. On the cross sections, the different types of alluvium are grouped based on the particle size analysis performed on the soil samples Those samples with greater than 50 percent of the sample passing the number 200 sieve are identified as clay or sandy clay (CL or CH according to USCS classifications) Those samples that had less than 50 percent passing through the number 200 sieve are identified as sand, silty sand,

or clayey sand (SP, SM, SC, or SW) None of the samples was classified as "gravels" according to the particle size analysis, however, if a significant amount of gravel was noted in the boring log, this was identified on the cross section. The finer grained deposits are probably loess or colluvial deposits, and the coarser grained deposits may represent alluvial channels or terrace gravel deposits

The alluvium ranges in thickness from approximately 5 to 58 feet bgs as measured in boreholes within the study area The interpretation of alluvial thickness is not always straight-forward in the study area because the differences between alluvial sand deposits and weathered sandstone deposits are often subtle and difficult to immediately recognize in the field When a question arose about the interpretation of a sand as alluvium or bedrock, the following guidelines were used: (1) increased blow counts are indicative of a weathered bedrock deposit, (2) oxidation zones such as iron and manganese oxide are indicative of weathered bedrock, and (3) fine- to medium-grained sands with little or no clay component are more indicative of weathered bedrock deposits

Denver Formation. In the study area, the Denver Formation consists of predominantly thick sequences of claystone with interbedded and interfingering thin, lenticular sands and locally thick channel sands In this area, carbonaceous and lignitic coal seams are common.

Stratigraphic correlation of the Denver Formation was based on the vertical position of sand units relative to two distinct lignite marker beds, Lignite A and Lignite B The stratigraphy shown on the cross sections is comparable to that reported in the Water Remedial Investigation and Study Area Reports (Ebasco, 1989b) and adopted by subsequent studies at RMA (HLA, 1992b, MKE, 1994). Based on the available boring data, individual "sand units" were mapped that fall within the stratigraphic Zones A, 1U, and 1 (See Figure 4 20 illustrating the stratigraphic nomenclature) Cross section D-D' (Figure 4.22) best illustrates the stratigraphy in the study area since both lignites and the three sand units are present in the cross section.

As proposed by MKE, 1994, the designation of "sand units" as distinguished from "sand zones" (from Ebasco, 1989b) was adopted for this report. The "sand unit" designation means that the sand beds identified in this report, such as "A Sand" correlate across the study area based on the cross sections presented in this report. The subtle difference between a "sand unit" in this report and a "sand zone" in the Ebasco (1989b) can be illustrated in the following manner. The sand unit identified as "A Sand" in this study is interpreted to be the depositional equivalent to, for example, the "A Sand" that underlies Lignite A identified in the South Plants area (HLA, 1992b) The sand unit "A Sand" identified in the study area is not, however, interpreted to correlate across Basin A into South Plants without further interpretation across the Basin A area. To summarize, the two "A sands" were deposited in the same stratigraphic sequence, however, the lateral correlation of this discrete package of sand, "sand unit," outside the study area is not implied

The sandstone units within the Denver Formation were deposited primarily as overbank and channel sands The channel sand facies consists of fining-upward sequences that begin with coarse gravelly sand (channel lag), fining upward to medium-grained sands, with fine-grained sands at the top The channel sand facies were deposited in meandering river belts and are flanked by the overbank sand facies The overbank sand facies consists of lenticular, laterally discontinuous sand beds composed of very fine- to fine-grained sand with an increased silt and clay-sized fraction.

On the basis of the cross section evaluation and previous investigations at RMA, the inferred lateral extent and subcrop pattern of the three sand units identified in the study area are illustrated in Figures 4 29 to 4 31 The A Sand is the uppermost sand unit encountered in the study area. It is laterally discontinuous and subcrops into the alluvium as illustrated in Figure 4.29 The 1U Sand underlies the A Sand and subcrops into the alluvium to the north of the A Sand in the north central portion of the study area. The 1U Sand (Figure 4 30) extends across most of the study area and subcrops in the northeast corner The 1 Sand unit probably represents a channel sand deposit that is

oriented southwest to northeast. Thick sequences of sand (up to 50 feet in Figure 4.31) lie within the central portion of the study area and are flanked by thinner, overbank deposits

Hydrogeologic Results. A detailed hydrogeologic investigation of the hydrogeology at the preferred landfill location was not included in the scope of this investigation. For clarity, however, a brief overview of the hydrogeologic information known about the site is presented. The two groundwater flow systems of interest in the study area are the unconfined and confined flow system. In the western half of Section 25, the quaternary alluvium is primarily unsaturated which means that the flow in the unconfined flow system occurs within the weathered Denver Formation. Confined flow occurs in the unweathered Denver Formation. Figure 4 32 illustrates the water-table map and areas of unsaturated alluvium for the unconfined flow system generated under the GMP for water year 1993 (HLA, 1995b) In Section 25, since the unconfined flow system occurs primarily in the weathered bedrock, the groundwater flow direction is controlled primarily by the bedrock surface For example, as illustrated on the map (Figure 4.32), the areas of high groundwater elevation overlie areas where the bedrock surface is high.

Geotechnical Program Results

Geotechnical tests were preformed on samples collected during the shallow boring program (1) to evaluate the material at the proposed landfill site for use in the construction of the landfill, (2) to evaluate certain properties of the soil such as shear strength for engineering requirements such as slope stability (3) further characterize the site-specific geology This section presents the results of the following geotechnical properties tested

- Particle size analysis
- Atterberg limits
- Natural moisture content
- Compaction or Proctor tests
- Permeability

- Shear strength
- Organic content

Particle-Size Analyses and Atterberg Limits. Particle size analyses and Atterberg limits were performed on 335 soil samples Table 4 5 lists the results of the analyses. Of the 335 samples analyzed, 65 percent had greater than 50 percent of the sample pass through the No 200 sieve and are therefore classified as clay The remaining 35 percent of the samples were classified as follows 30 percent were clayey sand (SC), 3 percent were silty sand (SM), and the remaining 2 percent were classified as SP-SM, SW-SM, SC-SM, MH, and ML.

Additional classification of the fine-grained or clay samples was based on the plasticity chart As illustrated in Figure 4 33, the Atterberg limits indicate that 29 percent are classified as high plasticity clay (CH) and 36 percent classified as low plasticity clay (CL). The liquid limits ranged from 25 to 88 percent. The plasticity indices ranged from 5 to 75 percent.

Moisture Content. The natural moisture content was measured in 318 soil samples The results indicated the natural moisture content of the soil samples ranged from 2 to 33 percent. The average moisture content of the soil samples was 12 percent.

Compaction Tests. Compaction tests were conducted on 29 soil samples As listed in Table 4 6, the optimum moisture content ranged from 12 3 to 18 7 percent. The maximum dry densities ranged from 102 2 to 117.6 pcf.

Permeability Tests Fifty-eight permeability tests were conducted on 29 soil samples (two tests per soil sample) to evaluate the hydraulic conductivity of the compacted soil. The tests were conducted on samples compacted to 90 and 95 percent relative compaction at approximately 2 percent above optimum moisture content. Table 4.6 lists the results of the permeability tests The permeability of the compacted soil samples ranged from 1 58 x 10^{-5} to 1 11 x 10^{-8} cm/s

Shrinkage Limits and Swell Pressure Twenty-nine samples were analyzed for shrinkage limits and swell pressure and the results are listed in Table 4 6. The shrinkage limits ranged from 11 6 to 42.1 percent. The swell pressures ranged from 20 8 to 312 2 pounds per square foot (psf)

Organic Content. The organic content of 29 soil samples was measured, and Table 4 6 lists the results of the tests The organic content measured by weight of the sample ranged from 1.3 to 8 8 percent. In general, the samples with the highest organic content were collected from the surface to a depth of 4 feet. The increased organic content is primarily due to roots penetrating into this shallow zone.

Shear Strength. Shear strength tests were to be performed on samples collected in Shelby tubes from the 30 shallow borings. Shear strength tests were not performed on the samples because the samples could not be successfully extruded intact from the Shelby tubes due to the unconsolidated nature of the samples For information on shear strength of the alluvium at RMA, shear strength test results were presented in the Final FS Soils Support Program Report (HLA, 1995a) The tests were performed on soil samples collected from the proposed low permeability soil borrow areas in Sections 20, 23, 25, and 29

4.4.3 Geologic Investigation Summary

The results of the geologic and geotechnical investigation performed in the western half of Section 25 are summarized as follows The site-specific lithologic and stratigraphic relationships of the Quaternary alluvium and the Denver Formation were studied in detail through lithologic and geophysical logging techniques The site is underlain by approximately 5 to 60 feet of alluvium that unconformably overlies the Denver Formation. The alluvium consists primarily of clay, silt, and very fine- to medium-grained sand with minor amounts of coarse sand and gravel. The alluvium is unsaturated throughout most of the study area except in the northwest corner of Section 25 where it becomes saturated

In the study area, the Denver Formation consists of thick sequences of claystone, with interbedded sandstone (channel sand and overbank deposits) and lignite beds Stratigraphic correlation of the sand units within the Denver Formation was based on the vertical position of the sands in relation to lignite beds A and B that occur in the study area. Three sand units were identified in the study area as the A sand, 1U sand and 1 sand The sand units are up to 50 feet thick, and each sand unit subcrops into the alluvium within the study area as illustrated in the cross sections and subcrop maps (Figures 4 20 through 4.31) Two groundwater flow systems occur within the Denver Formation. the unconfined flow system that occurs within the upper weathered portion of the Denver Formation and the confined flow system that occurs within the primarily unweathered Denver Formation

The geotechnical test results indicate approximately 65 percent of the samples collected from the study area are classified as clay and 35 percent are clayey sands Permeability tests were performed on one compacted clay sample from each borehole Approximately half of the samples tested achieved vertical permeability values less than 1×10^{-7} cm/s Thus, approximately half of the boreholes in the study area have clay soil that could potentially be used in the construction of the landfill Further evaluation of the feasibility of using the onsite clay soil in construction of a hazardous waste landfill is presented in Section 5 0

4.5 Area Feasibility Study Conclusions

Conclusions of the Area FS are as follows

- Previous landfill siting studies conducted at RMA do not take into account current regulatory requirements for siting landfills in the State of Colorado.
- Seventeen siting criteria were adopted for use in locating a preferred area at RMA for a hazardous waste landfill The criteria are based on regulatory requirements, institutional requirements and concerns regarding future land use of RMA by the USFWS. The criteria adopted are presented in Table 4.3
- Using the siting criteria established in this report, a GIS analysis was performed to identify areas at RMA that meet the suitability criteria. Based on the GIS analysis, the western half of Section 25 was selected as the most suitable area for locating the landfill.

- Geologic and geotechnical results indicate the site is conducive to construction of the landfill with primarily clay and claystone underlying the site Sand units were mapped in the area. However, based on the size of the landfill required, the areas where the sand units subcrop into the alluvium may be avoided, if necessary, as described in the following section.

- Based on the results of this study, groundwater occurs primarily within the Denver Formation in both unconfined and confined flow systems A detailed hydrogeologic study should be conducted to evaluate groundwater flow velocities and vertical gradients between the two flow systems in the area

Table 4.1: Previous Rocky Mountain Arsenal Landfill Siting Criteria

Siting Criteria	Previous Landfill Siting Studies		
	WES, 1983	USATHAMA, 1984	EBASCO, 1988
Faults	Not addressed	>200 feet from a Holocene fault	>1000 feet from a Holocene fault
Floodplain	Outside 100 year floodplain	Outside 100 year floodplain	Outside 100 year floodplain
Salt formations	Not addressed	Not addressed	Not addressed
Surface water/groundwater	>40 feet to groundwater	>20 feet to groundwater	Maximize depth to groundwater, target >40 feet
Airport safety	Not addressed	Not addressed	Not addressed
Wetlands	Not addressed	Not addressed	Not addressed
Seismic impact zone	Not addressed	Not addressed	Not addressed
Unstable areas	Not addressed	Not addressed	Not addressed
Topography	Not addressed	Not addressed	Not addressed
Isolation	Not addressed	Not addressed	Not addressed
Hydrogeology	No saturated alluvium	Not addressed	No saturated alluvium
Geology	<30 feet to bedrock and no sand channels in the Denver Formation	Not addressed	Not addressed
Locations	Not addressed	Not addressed	Not addressed
Buffer zone	>1 mile from RMA boundary	Not addressed	>1000 feet from RMA boundary
Avoidance areas	Not addressed	Not addressed	Not within RMA avoidance areas or dedicated land use
Area required	Not addressed	Not addressed	>1000 acres initial target
Sensitive habitats	Not addressed	Not addressed	Not addressed

Ebasco Ebasco Services, Inc
USATHAMA U S Army Toxic and Hazardous Materials Agency
WES Roy F Weston Environmental Services

21907 703030
0103032495 RAF

Table 4.2 Boring Logs for Section 25

Well No	Bore No	Well No	Bore No.	Well No	Bore No
25002-25004	777	25040	LM-8 (2)	26073	804
25003	907	25041*	—	26074	804
25005-25006	824 (N-24)	25042*	—	26075	804
25007	827	25043*	—	26091	491
25008-25010	1186 (E5)	25044*	—	26097	640
25011-25014	1168 (E6)	25046*	—	26123	905
25015-25017	1195 (E9)	25047*	—	26143	825
25018-25020	1187 (E10)	25048	EP-29	26144	825
25021	1230 (AP3)	25048	EP-29A	26150	EP-49B2D3
25022	LM-2 (1)	25049*	—	26150	EP43
25023	LM-2 (3)	25050*	—	26155	EP-49B2D2
25024	LM-2 (2)	25051*	—	26159	—
25025	LM-3 (3)	25052*	—	26500	MK91261
25026	LM-3 (2)	25053*	—	36151	1229
25027	LM-4 (1)	25054*	—	—	787
25028	LM-4 (3)	25055*	—	—	156
25029	LM-4 (2)	25056*	—	—	826
25030	LM-5 (1)	25057	—	—	130
25031	LM-5 (2)	25058	—	—	L-5
25034	LM-6 (1)	25059	—	—	L-3
25035	LM-7 (1)	25060	25-1 P1	—	L-4
25036	LM-7 (3)	25061	25-1 P2	—	19
25037	LM-7 (2)	25062	25-1 EX	—	61
25038	LM-8 (1)	25500#	—	—	12
25039	LM-8 (3)	26056	644		

AP Basin F - South Plants borings
E Borings located in the east section of the arsenal (regional study)
EP Environmental Science and Engineering, Inc. borings
L Hazardous landfill borings sites
LM Hazardous landfill borings sites
N Borings located in the Basin A neck area (regional study)

* Ebasco borings
\# Morrison-Knudsen Engineering (MKE) borings

Table 4.3: Current Rocky Mountain Arsenal Landfill Siting Criteria

Siting Criteria	Landfill Siting Criteria Regulations		Regulatory Criteria Adopted HLA, 1984	
	Description	Citation	Primary Siting Criteria Adopted	Secondary Siting Criteria
Faults	>1000 feet from a Holocene fault >200 feet from a Holocene fault	6 CCR 1007 3, 264 18(a) 6 CCR 1007 2, 3 1 3	>1000 feet from a Holocene fault	
Floodplain	Outside 100 year floodplain Not located in "floodplain" as defined in regulation	6 CCR 1007 3, 264 18(b) 6 CCR 1007 2, 3 1 7	Outside 100 year floodplain	
Salt formations	Not within salt formations	6 CCR 1007 3, 264 18(c)	Not within salt formations	
Surface water/groundwater	No waste placed below or into surface water or groundwater No waste placed below or into surface water or groundwater	6 CCR 1007 3, 264 18(d) 6 CCR 1007 2, 3 1 9	No waste placed below or into surface water or groundwater	Maximize depth to groundwater
Airport safety	Notification if facility is within 5 miles of runway	6 CCR 1007 2, 3 1 1	Notification if facility is within 5 miles of runway	
Wetlands	Not located in wetlands	6 CCR 1007 2, 3 1 2	Not within wetland	
Seismic impact zone	Not located in seismic impact zone without demonstration	6 CCR 1007 2, 3 1 4	Not located in seismic impact zone without demonstration	
Unstable areas	Not within unstable area	6 CCR 1007 2, 3 1 5	Not within unstable area	
Topography	Maximize protection from wind and precipitation catchment area	6 CCR 1007 2, 3 1 6	Maximize protection from wind and precipitation catchment area	
Isolation	Isolate waste from public and environment	6 CCR 1007 2, 3 1 8 6 CCR 1007 2 4 1	Isolate waste from public and environment	
Hydrogeology	Reasonable assurance that waste isolated for 1000 years	6 CCR 1007 2, Part 2, 2 5 3	Reasonable assurance that waste isolated for 1000 years	Avoid saturated alluvium
Geology	Reasonable assurance that waste isolated for 1000 years	6 CCR 1007 2, Part 2, 2 5 3	Reasonable assurance that waste isolated for 1000 years	Minimize depth to bedrock

Table 4.3 (continued)

Siting Criteria	Landfill Siting Criteria Regulations		Regulatory Criteria Adopted HLA, 1994	
	Description	Citation	Primary Siting Criteria Adopted	Secondary Siting Criteria
Location	Within distance controlled by Army to prevent adverse effects to public health	6 CCR 1007-2, Part 2, 2 5 6	Within distance controlled by Army to prevent adverse effects to public health	Centrally located within RMA boundary
Buffer Zone	Noise levels within limits	CRS Sections 25-12-101 to 108	Noise levels within limits	
Avoidance Areas	None	None	None	Avoid areas with future land use and areas of known groundwater or soil contamination
Area Required	None	None	None	To be evaluated
Sensitive Habitats	None	None	None	Avoid sensitive habits
Historic Preservation	Inventory, preserve or recover historical, prehistorical, or archaeological artifacts/data	NHPA, AHPA, ARPA	To be evaluated	Avoid prehistoric and historic areas

AHPA Archaelogical Historic Preservation Act
ARPA Archaelogical Resources Protection Act, 1979
CCR Code of Colorado Regulations
CRS Colorado Revised Statute
HLA Harding Lawson Associates
NHPA National Historic Preservation Act, 1966
RMA Rocky Mountain Arsenal

Table 4.4 Depth to Bedrock and Groundwater Parameters Used During Geographic Information System Screening

Depth to Groundwater (feet)	Depth to Bedrock (feet)	Maximum Contiguous Acreage (acres)	Figure Number
30	10	12	NA
30	20	152	NA
30	30	301	NA
40	10	7	NA
40	20	142	NA
40	30	273	NA
40	40	371	4 12
50	10	6	NA
50	20	114	NA
50	30	217	4 15
50	40	299	4.16
60	10	4	NA
60	20	76	4.13
60	30	128	NA
60	40	138	4 14
70	10	1	4 11
70	20	13	NA
70	30	32	NA

NA Not applicable

Table 4.5: Particle Size, Atterberg Limits, and Moisture Content Results

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB11394	4 00	68 32	11 0	41	22	CL	Brown sandy lean clay
SAB11394	8 00	52 64	9 9	45	29	CL	Brown sandy lean clay
SAB11394	12 00	16 60	5 5	NA	NA	SM	Brown silty sand
SAB11394	16 00	17 41	5 6	NA	NA	SM	Brown silty sand
SAB11394	17 00	28 22	4 6	22	4	SC-SM	Brown silty clayey sand
WEB11494	4 00	18 02	10 0	41	23	CL	Brown sandy clay
WEB11494	8 00	62 32	10 1	41	24	CL	Brown sandy lean clay
WEB11494	12 00	50 90	8 9	31	13	CL	Brown sandy lean clay
WEB11494	16 00	69 50	14 1	42	24	CL	Brown sandy lean clay
WEB11494	20 00	59 46	14 5	44	26	CL	Brown sandy lean clay
WEB11494	24 00	35 92	10 7	40	24	SC	Brown clayey sand
WEB11494	28 00	23 23	10 0	39	23	SC	Brown clayey sand
WEB11494	29 60	27 65	7 4	58	36	SC	Brown clayey sand
WEB11494	30 50	80 17	13 8	66	41	CH	Brown fat clay with sand
WEB11494	31 00	98 11	21 7	72	47	CH	Brown fat clay
WEB11494	31 50	99 08	20 9	69	43	CH	Brown fat clay
WEB11494	32 50	92 87	21 9	75	50	CH	Brown fat clay
WEB11494	33 00	82 70	17 8	55	37	CH	Brown fat clay with sand
WEB11494	33 50	90 34	18 1	52	33	CH	Brown fat clay
WEB11494	33 70	79 82	19 1	56	37	CH	Brown fat clay with sand
ASB11594	4 00	69 20	11 3	40	22	CL	Brown sandy lean clay
ASB11594	8 00	14 57	9 0	43	26	CL	Light brown sandy clay
ASB11594	10 00	34 52	6 5	41	24	SC	Brown clayey sand
ASB11594	16 00	14 77	5 9	NA	NA	SM	Brown silty sand
ASB11594	20 00	18 44	4 8	28	9	SC	Brown clayey sand
ASB11594	24 00	31 65	3 8	28	10	SC	Brown clayey sand
ASB11594	27 00	16 96	4 5	30	11	SC	Brown clayey sand
ASB11694	4 00	58 39	7 3	42	24	CL	Brown sandy lean clay
ASB11694	8.00	22 63	3 8	40	17	SC	Brown clayey sand
ASB11694	12 00	14.20	3 6	NA	NA	SM	Brown silty sand
ASB11694	16 00	13 71	4 1	32	8	SM	Brown silty sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB11694	20 00	18 31	4 9	34	16	SC	Brown clayey sand
ASB11694	24 00	17 87	4 9	31	11	SC	Brown clayey sand
ASB11694	28 00	52 45	16 0	54	36	CH	Brown sandy fat clay
ASB11694	32 00	82 71	30 5	69	39	CH	Brown fat clay with sand
ASB11694	36 00	68 37	17 5	56	39	CH	Brown sandy fat clay
ASB11694	40 00	70 18	19 6	41	20	CL	Brown lean clay with sand
SAB11794	4 00	56 15	10 3	57	37	CH	Brown sandy fat clay
SAB11794	8 00	47 65	12 3	46	28	SC	Brown clayey sand
SAB11794	12 00	12 07	10 8	36	20	CL	Brown sandy clay
SAB11794	16 00	36 17	7 6	38	23	SC	Brown clayey sand
SAB11794	20 00	25 11	8 0	39	23	SC	Brown clayey sand with gravel
SAB11794	24 00	11 66	5 6	45	27	SP-SC	Brown sand with clay
SAB11794	35 00	32 06	4 6	31	14	SC	Brown clayey sand
SAB11794	40.00	36 38	6 8	31	15	SC	Brown clayey sand
ASB11894	4 00	83 11	10 4	44	23	CL	Brown lean clay with sand
ASB11894	8 00	61 15	9 4	43	24	CL	Brown sandy lean clay
ASB11894	12.00	53 50	12 8	51	31	CH	Brown sandy fat clay
ASB11894	16 00	58 61	17 7	57	31	CH	Brown sandy fat clay
ASB11894	20 00	71 76	17 6	49	31	CL	Brown lean clay with sand
ASB11894	24 00	84 52	18 0	48	31	CL	Brown lean clay with sand
ASB11894	28 00	33 05	6 2	39	17	SC	Brown clayey sand
ASB11894	32 00	37 89	5 5	45	29	SC	Brown clayey sand
ASB11994	4 00	56 46	8 2	41	22	CL	Brown sandy lean clay
ASB11994	8 00	58 37	7 7	42	24	CL	Brown sandy lean clay
ASB11994	12 00	36 32	4 0	38	20	SC	Brown clayey sand
ASB11994	16 00	23 01	3.7	37	18	SC	Brown clayey sand
ASB11994	20.00	20.18	4 1	40	21	SC	Brown clayey sand
ASB11994	24 00	21 40	4 2	39	21	SC	Brown clayey sand
ASB11994	28 00	19 16	4 8	35	17	SC	Brown clayey sand
ASB11994	32 00	19 93	3 8	29	10	SC	Brown clayey sand
ASB11994	36 00	25 14	4 7	32	15	SC	Brown clayey sand
ASB11994	40 00	25 78	4 2	30	14	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB11994	44 00	48 27	14 6	42	25	SC	Brown clayey sand
ASB11994	50 00	59 53	22 2	75	44	CH	Brown sandy fat clay
ASB12094	4 00	69 45	7 8	32	8	ML	Brown sandy silt
ASB12094	8 00	57 03	13 7	47	27	CL	Brown sandy lean clay
ASB12094	12 00	58 92	12 9	44	24	CL	Brown sandy lean clay
ASB12094	16 00	17 14	3 0	47	29	SC	Brown clayey sand with gravel
ASB12094	20 00	11 48	1 9	NA	NA	SP-SM	Brown sand with silt and gravel
ASB12094	24 00	8 25	1 6	NA	NA	SW-SM	Brown sand with silt and gravel
ASB12094	28 00	16 67	4 2	NA	NA	SM	Brown silty sand
ASB12094	32 00	28 67	4 2	39	20	SC	Brown clayey sand
ASB12094	36 00	26 48	4 2	41	24	SC	Brown clayey sand
ASB12094	40 00	23 15	4 0	42	24	SC	Brown clayey sand
ASB12094	44 00	22 04	4 3	37	17	SC	Brown clayey sand
ASB12094	48 00	26 23	5 3	40	22	SC	Brown clayey sand
SAB12194	4 00	74 40	10 4	39	19	CL	Brown lean clay with sand
SAB12194	8 00	56 05	7 8	39	24	CL	Brown sandy lean clay
SAB12194	16 00	44 92	6 9	27	10	SC	Brown clayey sand
SAB12194	20 00	67 65	9 5	44	27	CL	Brown sandy lean clay
SAB12194	24 00	88 86	14 0	53	35	CH	Brown fat clay
SAB12194	28 00	96 65	28 6	73	43	CH	Brown fat clay
SAB12194	32 00	88 64	24 9	75	52	CH	Brown fat clay
SAB12194	36 00	97 56	23 8	88	62	CH	Brown fat clay
SAB12194	40 00	90 00	16 3	66	48	CH	Brown fat clay
SAB12194	44 00	91 59	15 1	54	38	CH	Brown fat clay
SAB12194	48 00	49 15	9 0	46	28	SC	Brown clayey sand
SAB12294	4 00	71 08	10 0	38	17	CL	Brown lean clay with sand
SAB12294	8 00	63 47	11 2	44	26	CL	Brown sandy lean clay
SAB12294	12.00	52 59	11.6	48	31	CL	Brown sandy lean clay
SAB12294	16 00	69 08	12 7	46	30	CL	Brown sandy lean clay
SAB12294	20 00	53 15	8 6	44	28	CL	Brown sandy lean clay
SAB12294	24 00	29 36	4 0	37	20	SC	Brown clayey sand
SAB12294	28 00	11 75	2 5	63	42	SP-SC	Brown sand with clay and gravel

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB12294	32 00	41 21	8.4	47	27	SC	Brown clayey sand with gravel
SAB12294	36 00	93 55	22 0	50	35	CH	Brown fat clay
SAB12294	40 00	93 88	20 7	75	49	CH	Brown fat clay
SAB12294	44 00	94 71	20 3	72	53	CH	Brown fat clay
SAB12294	48 00	83 87	16 0	56	43	CH	Brown fat clay with sand
SAB12394	4 00	54 76	9 6	39	15	CL	Brown sandy lean clay
SAB12394	8.00	59 21	10 2	50	31	CH	Brown sandy fat clay
SAB12394	12.00	66 78	12 8	49	35	CL	Brown sandy lean clay
SAB12394	16 00	49 68	12 6	56	38	SC	Brown clayey sand
SAB12394	20 00	7 13	1 5	NA	NA	SW-SM	Brown sand with silt
SAB12394	24 00	56 97	22 9	78	47	CH	Brown sandy fat clay
SAB12394	28 00	63 60	21 3	60	34	CH	Brown sandy fat clay
SAB12394	32 00	74 74	14.1	56	41	CH	Brown fat clay with sand
SAB12394	36 00	86 08	16 3	64	47	CH	Brown fat clay
SAB12394	40 00	70 00	13 6	49	33	CL	Brown sandy lean clay
ASB12494	4 00	61 09	9 3	41	19	CL	Brown sandy lean clay
ASB12494	8 00	41 94	5 3	32	14	SC	Brown clayey sand
ASB12494	12 00	19.84	4 1	NA	NA	SM	Brown silty sand
ASB12494	16 00	21 82	3 0	NA	NA	SM	Brown silty sand
ASB12494	20 00	18 93	3 2	27	9	SC	Brown clayey sand
ASB12494	28 00	19 09	3 5	28	7	SC-SM	Brown silty clayey sand
ASB12494	32 00	19 55	3 2	36	18	SC	Brown clayey sand
ASB12494	36 00	17.65	3 4	51	25	SC	Brown clayey sand
ASB12494	40 00	19 92	3 4	40	21	SC	Brown clayey sand
ASB12494	44 00	81 52	17 7	61	43	CH	Brown fat clay with sand
ASB12494	48.00	91 64	17 4	65	46	CH	Brown fat clay
ASB12594	4.00	78 12	9 5	39	20	CL	Brown lean clay with sand
ASB12594	8 00	56 54	7.3	32	18	CL	Brown sandy lean clay
ASB12594	12.00	43 91	6 9	35	21	SC	Brown clayey sand
ASB12594	16.00	53 51	7 5	38	21	CL	Brown sandy lean clay
ASB12594	20 00	69 84	11 1	42	24	CL	Brown sandy lean clay
ASB12594	24.00	72.35	16 7	60	41	CH	Brown fat clay with sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB12594	28 00	77 22	17 7	76	56	CH	Brown fat clay with sand
ASB12594	32 00	83 93	18 0	94	75	CH	Brown fat clay with sand
ASB12594	36 00	86 79	13 7	59	42	CH	Brown fat clay
ASB12594	40 00	87 87	17 6	78	58	CH	Brown fat clay
ASB12594	44 00	93 76	22 8	88	65	CH	Brown fat clay
ASB12594	48 00	75 31	25 0	79	56	CH	Brown fat clay with sand
SAB12694	4 00	49 63	8 8	35	18	SC	Brown clayey sand
SAB12694	8 00	63 10	8 4	31	14	CL	Brown sandy lean clay
SAB12694	12 00	59 06	10 6	37	19	CL	Brown sandy lean clay
SAB12694	16 00	60 24	9 0	41	25	CL	Brown sandy lean clay
SAB12694	20 00	71 31	11 2	44	27	CL	Brown lean clay with sand
SAB12694	24.00	51 81	11 2	43	29	CL	Brown sandy lean clay
SAB12694	28 00	53 27	14 5	52	35	CH	Brown sandy fat clay
SAB12694	32 00	52 85	13 8	46	27	CL	Brown sandy lean clay
SAB12694	36 00	53 16	14 5	55	36	CH	Brown sandy fat clay
SAB12694	40 00	87 16	15 2	56	39	CH	Brown fat clay
ASB12794	4 00	66 62	9 4	33	13	CL	Brown sandy lean clay
ASB12794	8 00	50 78	9 0	33	14	CL	Brown sandy lean clay
ASB12794	12 00	63 06	12 1	43	22	CL	Brown sandy lean clay
ASB12794	16 00	88 10	20 6	71	46	CH	Brown fat clay
ASB12794	20 00	56 38	9 4	35	18	CL	Brown sandy lean clay
ASB12794	24 00	59 73	8 8	30	14	CL	Brown sandy lean clay
ASB12794	28 00	81 03	9 2	36	18	CL	Brown lean clay with sand
ASB12794	32 00	72 05	12 1	48	31	CL	Brown lean clay with sand
ASB12794	36 00	97 67	19 6	77	51	CH	Brown fat clay
ASB12794	40 00	88 65	11 3	48	31	CL	Brown lean clay
ASB12794	44 00	86 93	12 2	57	39	CH	Brown fat clay
ASB12794	48 00	86 71	19 4	88	67	CH	Brown fat clay
SAB12894	4 00	54 39	7 5	31	14	CL	Brown sandy lean clay
SAB12894	8 00	56 11	6 8	34	18	CL	Brown sandy lean clay
SAB12894	12 00	44 80	9 2	33	17	SC	Brown clayey sand
SAB12894	16 00	42 14	9 6	37	23	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB12894	20 00	57 44	12 0	37	22	CL	Brown sandy lean clay
SAB12894	24 00	51 40	11.9	36	20	CL	Brown sandy lean clay
SAB12894	28.00	51 35	12.4	35	19	CL	Brown sandy lean clay
SAB12894	32 00	64 28	14 7	39	25	CL	Brown sandy lean clay
SAB12894	36 50	89 41	20 8	50	31	CH	Brown fat clay
SAB12894	40 00	63 01	17 5	44	24	CL	Brown sandy lean clay
SAB12894	44 00	29 82	13.0	47	23	SC	Brown clayey sand
SAB12894	48 00	7 61	4 5	NA	NA	SP-SM	Brown sand with silt
BRB12994	4 00	49 45	8 3	34	16	SC	Brown clayey sand
BRB12994	8 00	52 67	11 5	32	16	CL	Brown sandy lean clay
BRB12994	12 00	37 67	13 0	51	30	SC	Brown clayey sand
BRB12994	16 00	39 73	9 1	41	26	SC	Brown clayey sand
BRB12994	20 00	62 02	9 2	37	22	CL	Brown sandy lean clay
BRB12994	24 00	47 16	10 0	44	20	SC	Brown clayey sand
BRB12994	28.00	24 88	5 6	41	24	SC	Brown clayey sand
BRB12994	32 00	32 03	4 2	27	9	SC	Brown clayey sand
BRB12994	36.00	50 76	10 3	45	31	CL	Brown sandy lean clay
BRB12994	40.00	77.48	18 7	46	25	CL	Brown lean clay with sand
BRB12994	44 00	49 90	19.5	28	8	SC	Brown clayey sand
BRB12994	48.00	54.29	26 3	48	30	CL	Brown sandy lean clay
BRB13094	4 00	28 19	5 6	26	5	SC-SM	Brown silty clayey sand
BRB13094	8.00	58.72	7.4	33	14	CL	Brown sandy lean clay
BRB13094	12.00	36 96	6 2	41	23	SC	Brown clayey sand
BRB13094	16 00	44 23	11.0	48	25	SC	Brown clayey sand
BRB13094	20 00	39 83	9 7	48	30	SC	Brown clayey sand
BRB13094	24 00	53 29	11 2	42	27	CL	Brown sandy lean clay
BRB13094	28.00	81.28	10 4	50	34	CH	Brown fat clay with sand
BRB13094	32.00	62 33	12.3	50	33	CH	Brown sandy fat clay
BRB13094	36 00	64.80	11 1	53	37	CH	Brown sandy fat clay
BRB13094	40 00	87.48	20 7	71	48	CH	Brown fat clay
BRB13094	44 00	88 09	11 9	55	38	CH	Brown fat clay
SAB13194	4 00	48 53	8 6	34	15	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB13194	8 00	76 01	7 8	34	14	CL	Brown lean clay with sand
SAB13194	12 00	59 01	6 2	27	11	CL	Brown sandy lean clay
SAB13194	16 00	62 24	8 7	38	21	CL	Brown sandy lean clay
SAB13194	20 00	64 77	9 4	41	21	CL	Brown sandy lean clay
SAB13194	24 00	68 10	9 8	38	19	CL	Brown sandy lean clay
SAB13194	28 00	63 11	10 4	42	22	CL	Brown sandy lean clay
SAB13194	30 00	54 85	8 3	40	21	CL	Brown sandy lean clay
SAB13194	36 00	57 69	9 9	44	25	CL	Brown sandy lean clay
SAB13194	37 00	97 11	15 7	50	32	CH	Brown fat clay
SAB13194	40 00	77 73	16 5	68	46	CH	Brown fat clay with sand
SAB13194	44 00	84 72	17 6	77	56	CH	Brown fat clay with sand
SAB13194	48 00	85 98	14 2	64	47	CH	Brown fat clay
ASB13294	4 00	54 09	8 6	33	15	CL	Brown sandy lean clay
ASB13294	8 00	60 12	9 1	34	12	CL	Brown sandy lean clay
ASB13294	12 00	48 56	9 9	48	28	SC	Brown clayey sand
ASB13294	16 00	56 18	7 1	38	23	CL	Brown sandy lean clay
ASB13294	20 00	39 92	8 1	53	36	SC	Brown clayey sand with gravel
ASB13294	24 00	46 20	10 6	59	37	SC	Brown clayey sand with gravel
ASB13294	28 00	80 19	15 3	45	29	CL	Brown lean clay with sand
ASB13294	32 00	69 63	17 4	62	42	CH	Brown sandy fat clay
ASB13294	36 00	84 74	19 1	75	52	CH	Brown fat clay with sand
ASB13294	40 00	68 88	13 3	51	32	CH	Brown sandy fat clay
ASB13294	44 00	73 58	14 0	54	36	CH	Brown fat clay with sand
ASB13294	48 00	84 87	17 6	76	51	CH	Brown fat clay with sand
ASB13394	4 00	65 36	8 7	32	16	CL	Brown sandy lean clay
ASB13394	8.00	58 14	7 8	33	17	CL	Brown sandy lean clay
ASB13394	12 00	50 01	6 9	28	13	CL	Brown sandy lean clay
ASB13394	16 00	50 50	8 2	33	19	CL	Brown sandy lean clay
ASB13394	20 00	35 23	4 6	30	15	SC	Brown clayey sand with gravel
ASB13394	24 00	64 61	6 8	41	25	CL	Brown sandy lean clay
ASB13394	28 00	58 54	7 0	38	23	CL	Brown sandy lean clay
ASB13394	32 00	41 11	8 0	53	37	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB13394	36 00	61 52	11 1	58	41	CH	Brown sandy fat clay
ASB13394	40 00	79 07	15 2	55	36	CH	Brown fat clay with sand
ASB13394	44 00	78 99	15 8	55	34	CH	Brown fat clay with sand
ASB13394	48 00	93 00	19 6	40	19	CL	Brown lean clay
BRB13494	4 00	63 11	6 7	30	9	CL	Brown sandy lean clay
BRB13494	8 00	61 48	6 9	31	12	CL	Brown sandy lean clay
BRB13494	12 00	37 61	6 3	34	17	SC	Brown clayey sand
BRB13494	16 00	31 31	5 8	33	17	SC	Brown clayey sand
BRB13494	20 00	39 79	9 3	32	14	SC	Brown clayey sand
BRB13494	24 00	51 87	11 8	34	15	CL	Brown sandy lean clay
BRB13494	28.00	41 86	11 0	32	14	SC	Brown clayey sand
BRB13494	32 00	38.17	10 4	35	17	SC	Brown clayey sand
BRB13494	36 00	46 35	13 8	30	10	SC	Brown clayey sand
BRB13494	40 00	52 76	14 6	38	20	CL	Brown sandy lean clay
BRB13494	44 00	83 25	19 8	49	29	CL	Brown lean clay with sand
BRB13494	48.00	80 72	22 2	49	28	CL	Brown lean clay with sand
BRB13494	50.00	68 87	26 2	47	26	CL	Brown sandy lean clay
BRB13594	4 00	34.83	6 0	36	17	SC	Brown clayey sand
BRB13594	8 00	50.01	5 8	28	12	CL	Brown sandy lean clay
BRB13594	12 00	50.95	7 3	35	16	CL	Brown sandy lean clay
BRB13594	16.00	51 14	7 4	37	20	CL	Brown sandy lean clay
BRB13594	20 00	48 06	8 1	43	25	SC	Brown clayey sand
BRB13594	24 00	54 00	9 4	48	31	CL	Brown sandy lean clay
BRB13594	28 00	59 96	8 3	39	20	CL	Brown sandy lean clay
BRB13594	32 00	59 79	12 1	54	31	CH	Brown sandy fat clay
BRB13594	36.00	61.48	NA	NA	NA	CH	Brown sandy fat clay
BRB13594	40 00	19 87	7 2	46	24	SC	Brown clayey sand
BRB13594	42 00	34 77	14 0	48	30	SC	Brown clayey sand
BRB13694	4 00	32 90	5 1	48	30	SC	Brown clayey sand
BRB13694	8 00	52.38	5 7	32	16	CL	Brown sandy lean clay
BRB13694	12 00	67 27	6 9	32	15	CL	Brown sandy lean clay
BRB13694	16 00	65.17	8 3	39	23	CL	Brown sandy lean clay

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
BRB13694	20 00	51 51	10 2	41	26	CL	Brown sandy lean clay
BRB13694	24 00	53 20	9 1	33	20	CL	Brown sandy lean clay
BRB13694	28 00	65 67	9 1	43	28	CL	Brown sandy lean clay
BRB13694	32 00	91 81	12 3	44	24	CL	Brown lean clay
BRB13694	36 00	86 98	16 9	58	37	CH	Brown fat clay
BRB13694	40 00	98 44	18 3	68	46	CH	Brown fat clay
BRB13694	44 00	96 86	19 6	69	47	CH	Brown fat clay
BRB13694	48 00	97 48	20 8	77	56	CH	Brown fat clay
BRB13794	4 00	41 85	6 8	30	11	SC	Brown clayey sand
BRB13794	8 00	51 82	5 3	31	15	CL	Brown sandy lean clay
BRB13794	12 00	51 90	6 7	30	14	CL	Brown sandy lean clay
BRB13794	16 00	47 29	9 2	39	22	SC	Brown clayey sand
BRB13794	20 00	49 33	8 9	40	20	SC	Brown clayey sand
BRB13794	24 00	63 14	12 6	48	28	CL	Brown sandy lean clay
BRB13794	28 00	96 02	20 7	82	55	CH	Brown fat clay
BRB13794	32 00	86 34	20 0	77	52	CH	Brown fat clay
BRB13794	36 00	94 42	15 3	61	41	CH	Brown fat clay
BRB13794	40 00	97 38	8 2	58	38	CH	Brown fat clay
BRB13794	44 00	95 12	13 7	59	42	CH	Brown fat clay
BRB13794	48 00	96 57	14 9	58	38	CH	Brown fat clay
BRB13894	4 00	52 81	8 7	34	15	CL	Brown sandy lean clay
BRB13894	8 00	66 23	6 9	31	11	CL	Brown sandy lean clay
BRB13894	12 00	40 29	7 0	33	16	SC	Brown clayey sand
BRB13894	16 00	44 22	6 9	36	18	SC	Brown clayey sand
BRB13894	20 00	46 64	7 4	30	11	SC	Brown clayey sand
BRB13894	24 00	39 71	7 2	33	16	SC	Brown clayey sand
BRB13894	28 00	53 46	11 2	37	21	CL	Brown sandy lean clay
BRB13894	32 00	52 54	10 9	41	26	CL	Brown sandy lean clay
BRB13894	36 00	93 72	21 6	53	31	CH	Brown fat clay
BRB13894	40 00	77 81	21 3	50	30	CH	Brown fat clay with sand
BRB13894	44 00	17 41	7 4	41	22	SC	Brown clayey sand
BRB13894	48 00	24 39	10 2	46	27	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
WEB13994	4 00	24 77	4 3	30	12	SC	Brown clayey sand
WEB13994	8 00	22 38	3 8	NA	NA	SM	Brown silty sand
WEB13994	12.00	40 83	4 8	25	8	SC	Brown clayey sand
WEB13994	16 00	49 93	10 2	38	20	SC	Brown clayey sand
WEB13994	20 00	58 84	10 9	36	17	CL	Brown sandy lean clay
WEB13994	24 00	63 51	12 6	39	22	CL	Brown sandy lean clay
WEB13994	28.00	64 98	15 2	37	20	CL	Brown sandy lean clay
WEB13994	32 00	36 79	12 0	40	19	SC	Brown clayey sand with gravel
WEB13994	36 00	89 95	15 9	50	28	CH	Brown fat clay
WEB13994	40 00	93 77	19 4	57	38	CH	Brown fat clay
WEB13994	44.00	96.96	17 8	57	39	CH	Brown fat clay
WEB13994	48 00	91 88	18.0	54	36	CH	Brown fat clay
BRB14094	4 00	27 95	5 7	33	17	SC	Brown clayey sand
BRB14094	8 00	23 17	4 0	29	14	SC	Brown clayey sand
BRB14094	12 00	40 84	9 8	35	15	SC	Brown clayey sand
BRB14094	16 00	32 10	5 6	29	20	SC	Brown clayey sand
BRB14094	20 00	60 96	30 1	69	29	MH	Brown sandy elas silt
BRB14094	22.00	37.72	27 1	61	27	SM	Brown silty sand
BRB14094	24 00	78 08	29 5	82	53	CH	Brown fat clay with sand
BRB14094	28 00	86 52	31 9	95	61	CH	Brown fat clay
BRB14094	32 00	85 88	32 9	101	71	CH	Brown fat clay
BRB14094	36 00	81 14	31.7	100	69	CH	Brown fat clay with sand
BRB14094	40 00	81 05	21 1	77	55	CH	Brown fat clay with sand
BRB14094	44 00	75 23	20 5	64	44	CH	Brown fat clay with sand
BRB14094	48 00	79 45	20.3	78	55	CH	Brown fat clay with sand
BRB14194	4.00	41.33	5 5	30	9	SC	Brown clayey sand
BRB14194	8.00	46 13	5 4	30	11	SC	Brown clayey sand
BRB14194	12.00	62.50	9 0	31	13	CL	Brown sandy lean clay
BRB14194	16 00	47 40	7 9	37	20	SC	Brown clayey sand
BRB14194	20 00	44.35	6 7	32	14	SC	Brown clayey sand
BRB14194	24 00	45 45	7 2	35	19	SC	Brown clayey sand
BRB14194	28 00	67 00	21 9	61	31	CH	Brown sandy fat clay

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
BRB14194	32 00	59 70	17 2	60	40	CH	Brown sandy fat clay
BRB14194	36 00	63 68	15 2	59	45	CH	Brown sandy fat clay
BRB14194	40 00	56 80	17 3	37	21	CL	Brown sandy lean clay
BRB14194	44 00	82 54	18 2	59	41	CH	Brown fat clay with sand
BRB14194	48 00	71 19	17 3	51	35	CH	Brown fat clay with sand
BRB14294	4 00	49 89	6 7	35	17	SC	Brown clayey sand
BRB14294	8 00	56 66	8 5	37	20	CL	Brown sandy lean clay
BRB14294	12 00	70 74	10 7	55	28	CH	Brown fat clay with sand
BRB14294	16 00	67 27	11 1	36	20	CL	Brown sandy lean clay
BRB14294	20 00	53 04	11 1	41	23	CL	Brown sandy lean clay
BRB14294	24 00	56 02	13 7	48	28	CL	Brown sandy lean clay
BRB14294	27 50	74 97	18 1	49	23	CL	Brown lean clay with sand
BRB14294	32 00	58 63	16 9	48	22	CL	Brown sandy lean clay
BRB14294	36 00	53 83	17 9	51	29	CH	Brown sandy fat clay
BRB14294	40 00	48 86	18 4	52	27	SC	Brown clayey sand
BRB14294	44 00	38 40	13 8	40	20	SC	Brown clayey sand
BRB14294	48 00	48 90	18 3	40	21	SC	Brown clayey sand
BRB14294	50 00	46 64	27 3	55	31	SC	Brown clayey sand

% Percent
ASTM American Society for Testing and Materials
NA Not analyzed
USCS Unified Soil Classification System

* ASTM D 422
\# ASTM D 4318

Table 4.6: Compaction, Permeability, Shrink, and Swell Results

Boring Number	Sample Depth (feet)	Optimum Moisture Content[a] (%)	Maximum Dry Density[b] (pcf)	Permeability at 90 percent[c] (cm/s)	Permeability at 95 percent[c] (cm/s)	Shrinkage[d] (%)	Swell Pressure[e] (psf)	Organic Content[f] (%)
WEB11494	4 00	18 4	102 2	$1\ 31 \times 10^{6}$	$1\ 54 \times 10^{6}$	14 4	35 3	3 4
ASB11594	8 00	15 0	109 7	$2\ 14 \times 10^{7}$	$5\ 42 \times 10^{7}$	42 0	67 5	2 2
ASB11694	4 00	17 1	105 8	$5\ 11 \times 10^{7}$	$7\ 81 \times 10^{7}$	13 6	35 8	3 3
SAB11794	12 00	12 5	117 4	$1\ 66 \times 10^{7}$	$7\ 92 \times 10^{8}$	42 1	117 4	1 3
ASB11894	8 00	14 0	112 4	$6\ 29 \times 10^{8}$	$3\ 58 \times 10^{8}$	12 9	26 2	2 5
ASB11994	8 00	15 2	109 6	$7\ 20 \times 10^{8}$	$1\ 11 \times 10^{8}$	16 3	41 2	1 6
ASB12094	8 00	15 1	111 3	$2\ 54 \times 10^{8}$	$1\ 10 \times 10^{7}$	12 8	40 6	1 8
SAB12194	8 00	15 3	111 8	$8\ 37 \times 10^{8}$	$4\ 47 \times 10^{-8}$	13 2	43 1	1 9
SAB12294	20 00	17 0	110 2	$5\ 28 \times 10^{7}$	$3\ 03 \times 10^{7}$	11 6	88 1	1 6
SAB12394	8 00	18 7	104 0	$1\ 76 \times 10^{6}$	$1\ 38 \times 10^{6}$	14 2	79 4	2 0
ASB12494	4 00	17 8	105 9	$2\ 80 \times 10^{8}$	$1\ 67 \times 10^{8}$	14 5	50 2	2 2
ASB12594	8 00	14 4	114 7	$1\ 08 \times 10^{7}$	$7\ 64 \times 10^{8}$	14 8	113 8	1 9
SAB12694	16 00	15 3	113 9	$6\ 77 \times 10^{-6}$	$5\ 00 \times 10^{6}$	13 7	136 2	1 7
ASB12794	4 00	15 5	111 8	$3\ 70 \times 10^{-8}$	$1\ 54 \times 10^{8}$	14 8	27 8	2 9
SAB12894	16 00	14 1	115 1	$5\ 47 \times 10^{6}$	$2\ 61 \times 10^{8}$	13 0	30 7	1 6
BRB12994	4 00	13 5	115 8	$6\ 09 \times 10^{6}$	8.16×10^{6}	14 2	50 5	1 9
BRB13094	24 00	16 4	113 2	$1\ 70 \times 10^{7}$	$1\ 34 \times 10^{7}$	41 8	23 1	1 8
SAB13194	12 00	14 2	114 7	$1\ 98 \times 10^{5}$	$2\ 39 \times 10^{5}$	13 2	38 3	1 3
ASB13294	8 00	15 8	110 5	$3\ 89 \times 10^{7}$	$4\ 96 \times 10^{7}$	14 6	161 6	1 5
ASB13394	4 00	15.3	110 2	$7\ 18 \times 10^{8}$	$4\ 01 \times 10^{8}$	18 4	27 8	2 2
BRB13494	4 00	17 2	103 9	$3\ 66 \times 10^{8}$	$2\ 08 \times 10^{8}$	23 3	35 7	4 5
BRB13594	12 00	14 2	114 9	$1\ 43 \times 10^{7}$	$1\ 16 \times 10^{7}$	16 6	63 5	1 4
BRB13694	16 00	15 1	111 0	$4\ 74 \times 10^{8}$	$2\ 55 \times 10^{8}$	12 4	56 2	1 9
BRB13794	8 00	12 3	117 6	$8\ 05 \times 10^{8}$	$2\ 30 \times 10^{8}$	15 1	46 7	1 3
BRB13894	12 00	14 6	112 7	$8\ 24 \times 10^{-8}$	$3\ 96 \times 10^{-8}$	17 1	29 3	1 5
WEB13994	20 00	16 0	110 7	$5\ 46 \times 10^{8}$	$4\ 51 \times 10^{-8}$	13 5	312 1	1 9
BRB14094	16 00	13 2	115 7	$1\ 17 \times 10^{7}$	$8\ 02 \times 10^{-8}$	13 0	27 8	1 3
BRB14194	4 00	13 8	114 2	$4\ 42 \times 10^{-8}$	$3\ 42 \times 10^{8}$	15 2	58 8	8 8
BRB14294	20 00	17 6	106 1	$2\ 73 \times 10^{8}$	$1\ 38 \times 10^{-8}$	15 8	20 8	2 0

Table 4.6 (continued)

%	Percent
ASTM	American Society for Testing and Materials
pcf	Pounds per cubic foot
cm/s	Centimeters per second
psf	Pounds per square foot

a	ASTM D 2216
b	ASTM D 698
c	EM 1110-2-19096
d	ASTM D 427
e	ASTM D 4546
f	ASTM D 2974