59

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Borrow Source Survey for Evapotranspiration Covers at Los Alamos National Laboratory

Prepared for Shaw Environmental, Inc.
Los Alamos, New Mexico

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Table of Contents

Section **Page**

Table of Contents (Continued)

Section **Page**

List of Figures

List of Tables

List of Appendices

Executive Summary

A cover borrow source survey has been undertaken by the Environmental Stewardship–Remediation Services Project at Los Alamos National Laboratory (LANL) to determine sources and costs for the soil and rock materials needed for construction of final evapotranspiration (ET) covers over 12 mesa-top material disposal areas (MDAs). The borrow source survey was completed by Daniel B. Stephens & Associates, Inc., under subcontract to Shaw Environmental, Inc.

The borrow source survey developed planning level cost estimates for the materials needed for the MDA covers. This report presents descriptions of materials needed for cover construction, preliminary estimates of material quantities needed, potential sources of materials, and the associated material costs. For MDA C at TA -50 and MDA L at TA-54, where covers will next be constructed, preliminary cover layouts were prepared to provide more reliable material quantity and cost estimates for these two sites.

LANL is planning to use ET covers because of their performance in terms of infiltration reduction and erosion protection. ET covers consist of a thick soil rooting medium to support vegetation, thereby reducing infiltration through storage of soil moisture and removal of moisture through natural processes of evaporation and plant transpiration. A cover topsoil layer is used to establish vegetation, and the cover may be amended with gravel and cobble surface armoring, which is resistant to wind and water erosion. The ET cover materials usually selected for U.S. Department of Energy (DOE) sites use soil and rock materials and avoid use of geosynthetics, providing longevity to achieve a 1,000-year design life.

The 12 MDA final covers will include nearly 100 acres where 1.0- to 2.5-meter-thick covers will be constructed of soil or crushed tuff. The expected cover thickness is based on LANL estimates for cover performance requirements at the MDAs. A total of approximately 1,500,000 cubic yards of soil and rock materials will be needed. For planning purposes, LANL has requested identification of a borrow source for up to 200 120 percent of the estimated material quantity, or approximately 3,000,000 1,800,000 cubic yards. A single borrow pit for this quantity of material would cover nearly 50 acres with an excavation depth of approximately 40 24 feet.

Suitable geologic materials within the region that are potentially available and economically feasible for construction of ET covers at LANL include Santa Fe Group sedimentary units in the central Española Basin and rock units of the Jemez volcanic field near LANL, in particular, the Bandelier Tuff. Potential borrow sources for these materials include existing off-site commercial quarries and on-site borrow areas at LANL. Costs for these materials include excavation, purchase, and hauling costs. Additional costs include those for National Environmental Policy Act (NEPA) compliance, which can vary considerably from site to site and therefore influence the selection of borrow sites. Cost information was collected for the geographical region considered feasible for cost-effective import of material to LANL.

Preliminary ET cover configurations were developed for MDAs C and L to estimate material quantities for cover thicknesses ranging from 3 to 8 feet. The cover materials are expected to include soil or crushed tuff as the main soil rooting medium, topsoil, gravel, cobbles, angular rock (erosion control option), soil amendments, seed mix, and at MDA C, concrete or rock retaining walls. At MDA C, a cover of 9.9 to 10.8 acres is needed, requiring a total of 132,000 to 243,000 cubic yards of material; at MDA L, a cover of 1.6 to 2.4 acres is needed, requiring a total of 13,000 to 42,000 cubic yards of material.

At MDA C, material costs for a 3-foot-thick cover range from $1,400,000 to $3,000,000, and material costs for an 8-foot-thick cover range from $2,700,000 to $5,300,000. At MDA L, material costs for a 3-foot-thick cover range from $150,000 to $310,000, and material costs for an 8-foot-thick cover range from $400,000 to $850,000. The preliminary cost estimates show that on-site tuff excavation is the lowest-cost alternative for the soil rooting medium, with material costs approximately half those of imported commercial material. Some materials needed in small quantities, including gravel, cobbles, and boulders, will most likely need to be purchased commercially, because suitable material is probably not available within LANL.

Based on the cover layouts for MDAs C and L, the universal average material cost—considering all cover components, variable cover areas, thicknesses, and material sources—is estimated as approximately $22 per cubic yard of in-place material. For the site-wide MDAs needing final covers, material costs for the estimated 1.5 million cubic yards of material required are approximately $33,000,000, based on present costs without escalation. These costs can be

1. Introduction

The Environmental Stewardship–Remediation Services Project (ENV-RS) at Los Alamos National Laboratory (LANL) has undertaken efforts to plan for construction of final covers over certain waste disposal sites. As a preliminary financial planning step to estimate the costs of materials needed for final cover construction, Daniel B. Stephens & Associates, Inc. (DBS&A) completed a borrow source survey to determine sources and costs for the soil and rock materials that will make up the covers. The survey was conducted on behalf of LANL, under subcontract to Shaw Environmental, Inc. (Shaw). This borrow source survey report presents descriptions of materials needed for cover construction, preliminary estimates of material quantities needed, potential sources of materials, and the associated material costs.

1.1 Project Goals

The first goal of the borrow source survey is to determine reasonable material cost estimates for final covers over two LANL sites: Material Disposal Area (MDA) C at Technical Area (TA) 50 (TA -50) and MDA L at TA-54. A second goal is to identify potential material sources for covers at ten additional mesa-top disposal sites. The project requirements were established in a LANL Statement of Work dated March 3, 2004.

LANL's stated objective for the project was to establish planning level material quantities and baseline cost estimates for cover construction at MDAs C and L. To accomplish this, the borrow source survey identified various borrow sources of soil, tuff, gravel, and rock in order to obtain accurate information on the unit cost of materials. LANL provided DBS&A with preliminary cover design criteria (URS, 2004) and the overall material quantities estimated previously for cover construction at all of the MDAs where final covers are planned as part of this ENV-RS effort. In order to estimate material quantities more accurately for MDAs C and L, preliminary cover layouts were prepared for these sites to determine the approximate cover configuration in terms of area and thickness. The borrow source survey did not include design, performance assessment, or preparation of material specifications, which will be needed before final cover construction.

1.2 Evapotranspiration Cover Design and Performance

The final covers planned by LANL for the MDAs are evapotranspiration (ET) landfill covers. ET covers, also referred to as phytocovers, can provide exceptional performance in terms of infiltration reduction and erosion protection. A key feature of ET covers is a monolithic soil layer that provides a thick soil rooting medium to support vegetation. This layer reduces infiltration through storage of soil moisture and removal of moisture through natural processes of evaporation and plant transpiration. Establishment of sustainable vegetative communities is promoted, thereby minimizing wind and stormwater erosion. Because of these benefits, LANL has chosen to plan for use of ET covers at MDAs C and L and potentially at up to ten additional MDAs.

Depending on the types of waste, design criteria, and performance objectives, additional components may be added to the monolithic ET soil cover (ITRC, 2003). A topsoil layer with sufficient organic carbon and trace nutrients is generally used to promote establishment of vegetation. The cover surface may also be amended with gravel and cobble surface armoring, which is resistant to wind erosion and promotes vegetation by creating microclimates that support seed germination. Biota barriers can also be added to prevent cover penetration by burrowing animals; these generally consist of appropriate size cobbles to prevent burrowing by target species. The ET cover materials usually selected for DOE sites avoid use of geosynthetics, providing longevity to achieve a 1,000-year design life without material degradation (URS, 2004).

ET cover designs have been undergoing technical development and have gained widespread regulatory acceptance in recent years. In April 2004, new U.S. Environmental Protection Agency (EPA) regulations became effective that allow states to issue research, development and design permits for ET covers and other innovative technologies (Federal Register 69 FR 13242). A number of long-term ongoing field studies have provided data substantiating the performance of ET covers (U.S. EPA, 2003), including:

- EPA's Alternative Cover Assessment Program (ACAP) is researching alternative cover designs at 13 sites located in 8 states across the country.

- DOE's Alternative Landfill Cover Demonstration (ALCD), a large-scale field test of several alternative cover designs suitable for arid and semiarid climates, was conducted at Sandia National Laboratories in Albuquerque, New Mexico.

ET covers have been used at many sites in the western U.S. in the past several years because of their relatively low cost and generally good performance. ET cover applications have included both hazardous waste landfills (Resource Conservation Recovery Act [RCRA] Subtitle C) and municipal landfills (RCRA Subtitle D) (ITRC, 2003).

1.3 Plans for Site-Wide MDA Covers

LANL is planning for completion of final covers over a total of 12 MDAs covering nearly 100 acres. Preliminary estimates of final cover thicknesses, based on LANL expectations for the type of waste and cover performance requirements at each MDA, are in the range of 1.0 to 2.5 meters (LANL, 2004a). To plan for cover construction materials and costs, LANL's Statement of Work calls for identifying up to ~~200~~ 120 percent of the estimated material quantity needed.

A preliminary compilation of the MDAs where ET covers are planned is provided in Table 1. The acreage of each MDA is provided, along with an estimated cover volume based on a uniform cover soil thickness across each site. As shown in Table 1, the preliminary cover material quantity estimates for the site-wide MDAs range from 550,000 yd^3 to 1,520,000 yd^3, depending on the cover thicknesses. The preliminary cover quantity estimates presented in Table 1 include the cover materials for the specified thickness and an assumed increase for the additional subgrade materials needed to provide suitable configuration and slopes for final cover construction.

1.4 Description of MDAs C and L

MDAs C and L are two sites where LANL expects to complete the next ET final covers (Hopkins, 2004a); thus, these sites are the focus of this borrow source survey. Sections 1.4.1 and 1.4.2 describe the general features that dictate the cover configuration needs at each site.

Table 1. Preliminary Compilation of Site-Wide MDA Cover Quantities LANL Cover Borrow Survey

TA	MDA	Cover Area [a]		Minimum Cover Thickness		Maximum Cover Thickness		Cover Volume (yd^3)	
		(acres)	(ft^2)	(meters)	(feet)	(meters)	(feet)	Minimum	Maximum
50	C	11.8	514,008	1.0	3.0	2.5	8.2	57,112	156,106
54	L	1.2	52,272	1.0	3.0	2.5	8.2	5,808	15,875
	G	65.0	2,831,400	1.0	3.0	2.5	8.2	314,600	859,907
	H	0.3	13,068	1.0	3.0	2.5	8.2	1,452	3,969
21	A	1.3	54,450	1.0	3.0	2.5	8.2	6,050	16,537
	T	2.2	95,832	1.0	3.0	2.5	8.2	10,648	29,105
	B	6.0	261,360	1.0	3.0	2.5	8.2	29,040	79,376
	U	0.2	8,712	1.0	3.0	2.5	8.2	968	2,646
	V	0.9	38,333	1.0	3.0	2.5	8.2	4,259	11,642
49	AB	1.4	60,984	1.0	3.0	2.5	8.2	6,776	18,521
	Area 6	5.0	217,800	1.0	3.0	2.5	8.2	24,200	66,147
	Bottle house	0.3	13,068	1.0	3.0	2.5	8.2	1,452	3,969
Cover Subtotal		95.5	4,161,287					462,365	1,263,798
Subgrade fill (assume 20 percent of cover volume)								92,473	252,760
Total		95.5	4,161,287					554,838	1,516,558

TA = Technical area
MDA = Material disposal area
yd^3 = Cubic yards
ft^2 = Square feet

[a] Cover areas are LANL preliminary estimates (Rich, 2004)

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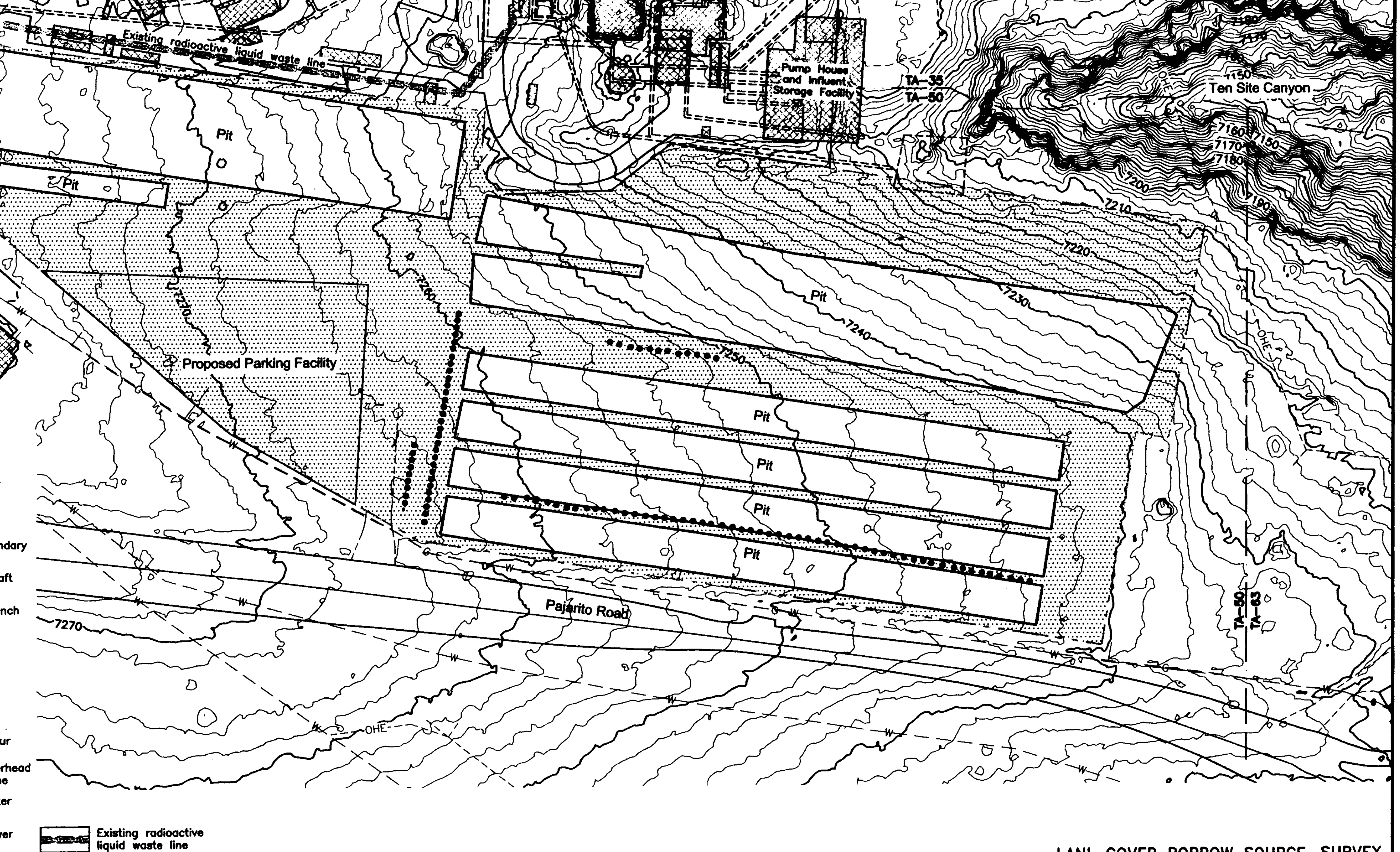
1.4.1 MDA C Site Description

MDA C is an 11.8-acre site within TA-50. The site was used from 1948 to 1974 to dispose of uncontaminated classified materials, inorganic chemicals, hazardous chemicals, and radionuclides (Advanced Geologic Services, 2001). Waste was disposed in 7 trenches (Pits 1 through 6 and Chemical Pit) and 108 vertical shafts (Figure 1). A final cover is planned over all waste disposal areas.

MDA C is bordered by Pajarito Road to the south, numerous buildings and roadways in TA-50 to the west and north, and open land to the east. The site slopes gradually to the northeast at slopes ranging from approximately 3 to 12 percent, steepening toward the northeast corner of the site. The head of steep-walled Ten Site Canyon is located just beyond the northeast corner of the MDA C boundary. A new pump house and influent storage facility is being constructed approximately 30 feet north of the MDA C boundary, across the boundary between TA-50 and TA-35 (Austin Company, 2003; Hopkins, 2004d). Several utility lines are located on and near the site, including a water line along Pajarito Road and a radioactive liquid waste line along the west half of the northern site boundary (Figure 1).

In 1984, most of MDA C was covered with crushed tuff and topsoil and seeded with grass (Advanced Geologic Services, 2001). The existing cover has established vegetation and does not show signs of excessive erosion or gully development. Asphalt-lined drainage swales have been constructed in locations at the edge of the cells where stormwater runoff is focused to convey stormwater runoff away from the MDA.

In 2001, a geophysical survey was completed at MDA C to delineate the waste disposal trenches and shafts and to determine the thickness of existing cover materials (Advanced Geologic Services, 2001). The survey identified buried utility conduits across the waste disposal trenches in the northwest portion of the site. A copy of a site map showing the interpreted thickness of cover materials across MDA C (Advanced Geologic Services, 2001) is included in Appendix A.



LANL COVER BORROW SOURCE SURVEY

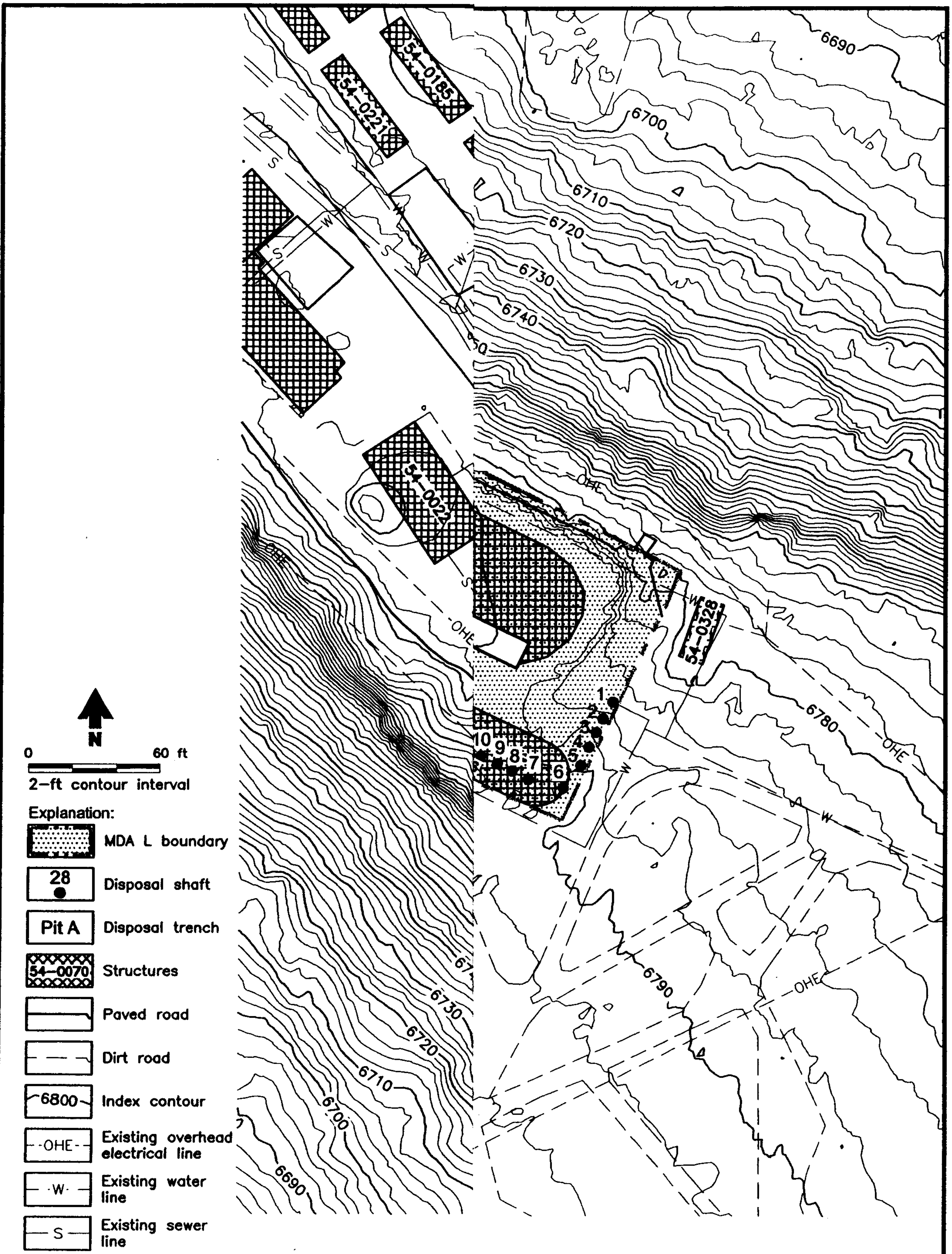
MDA C Site Plan with Disposal Trench and Shaft Locations

1.4.2 MDA L Site Description

MDA L is a 2.58-acre site on top of Mesita del Buey, within TA-54. The site was used until 1985 for disposal of hazardous (non-radioactive) waste (LANL, 2004b). Waste was disposed in 4 trenches (Pits A through D) and 36 vertical shafts (Shafts 1 through 36), as shown in Figure 2. The site is currently used as a permitted site for hazardous waste treatment and storage and for mixed (hazardous and radioactive) waste storage under interim status authority (LANL, 2004b).

A final cover is planned over Pits A through D and Shafts 1 through 34 (Hopkins, 2004b). Decommissioning of the other facilities and operations at MDA L is planned to make way for the final cover over the waste disposal areas. Shafts 35 and 36 will be removed during site decommissioning and will not be included within the cover area (Hopkins, 2004b).

MDA L is bordered by Cañada del Buey to the north and Pajarito Canyon to the south; other TA-54 facilities are located on the mesa to the east and west. A steep escarpment drops away from the northern boundary of the site. A 3- to 4-foot-high vertical retaining wall bounds the north and east sides of the site, and a stormwater diversion channel runs just outside this retaining wall, immediately above the escarpment. A buried electrical line is also located just outside the northern site boundary (Figure 2).



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LANL COVER BORROW SOURCE SURVEY

Disposal Trench and Shaft Locations

Figure 2

2. Preliminary Cover Performance and Configuration Criteria

To meet the project goal of developing cost estimates for cover materials, preliminary cover layouts were developed for MDAs C and L for the purpose of estimating material quantities. The cover thickness and configuration were formulated from pertinent regulations, industry standards, and professional judgments to develop reasonable configurations for the ET covers. The preliminary cover configuration and other considerations are summarized in Table 2 and outlined in Sections 2.2 through 2.12. Many of the cover performance and configuration criteria are specific requirements, while others are objectives that will require further analysis during cover design.

2.1 Cover Infiltration Performance

Waste site final covers are intended to minimize infiltration of moisture into the underlying waste. ET cover performance depends on several factors, including soil thickness, soil moisture retention characteristics, vegetation conditions, and local climate (U.S. EPA, 2003). The infiltration performance required for a specific site depends on waste type, applicable regulations, and a determination of the infiltration rate that will adequately limit potentially significant contaminant migration.

For the borrow source survey, specific standards for cover infiltration performance have not been established, but general technical guidance for ET cover configuration was followed to establish preliminary cover configurations. As requested in the LANL Statement of Work (LANL, 2004a), the following key technical references were considered in developing a cover configuration that can reasonably be expected to provide adequate infiltration performance.

- *Draft Design Guide for Material Disposal Area Covers at Los Alamos National Laboratory.* URS Corporation, April 2004.

- *Draft Technical Guidance for RCRA/CERCLA Final Covers.* U.S. EPA Office of Solid Waste and Emergency Response, April 2004.

Table 2. Preliminary Cover Configuration Criteria
Cover Borrow Source Survey
Material Disposal Areas C and L, Los Alamos National Laboratory
Page 1 of 2

Cover Element	Criteria	Comments
Longevity		
Longevity	1,000 years	Durable rock and soil will be used. If geosynthetics are used, it will be only for short-term applications such as initial erosion prevention at the time of seeding.
Slopes		
Minimum slope	3 percent	EPA design guidance for RCRA/CERCLA final covers. Provides positive drainage.
Maximum slope	33 percent	EPA design guidance for RCRA/CERCLA final covers. Generally suitable for slope stability.
Preferred maximum slope	15 to 25 percent	Reduced maximum slope reduces erosion rate for improved longevity.
Cover Thickness		
Minimum thickness	1.0 meter (3 feet)	LANL-specified.
Maximum thickness	2.5 meter (8 feet)	LANL-specified.
Cover Footprint Perimeter		
Extent of full cover thickness beyond edge of waste	2 times cover thickness	Performance-based approach for ET covers.
Side slope at cover edge	15 to 33 percent (standard) 45 percent (maximum)	Variable, based on site constraints
MDA C waste location	Pit and shaft drawings and geophysical survey report	Mapped waste boundaries and geophysical survey have significant departures and uncertainties.
MDA L waste location	Pit and shaft drawings	Pits A through D, Shafts 1 through 34. Shafts 35 and 36 will be removed and not covered.
Retaining walls (MDA C only)		
Setback distance	• 5 feet from radioactive liquid waste line • 10 feet from roads • 20 feet from proposed parking structure	LANL-specified to prevent cover side slope encroachment on existing TA-50 facilities.
Material options	Reinforced concrete or dry-set stone	Subject to design evaluation
Dimensions	Height, thickness, and footings variable	Subject to design evaluation
Cover Material Properties		
Soil rooting medium	Crushed tuff or fine-grained soil (2.5 to 7.5 feet)	Suitable moisture retention characteristics for ET cover performance.
Topsoil	Moderately permeable soil with organic content (0.5 feet)	Suitable to establish vegetation. Permeability specified to reduce erosion.
Erosion protection armoring	Gravel (10 percent of topsoil) Cobbles (10 percent of topsoil)	Gravel and cobbles reduce erosion and aid in establishing vegetation.
Slope armoring	Angular boulders	Erosion control on slopes exceeding 25 percent, only if necessary.

vegetation will stabilize the cover soils in a manner that is expected to provide longevity and adaptability to environmental changes.

An exception to the 1,000-year longevity criteria is made to provide for retaining walls at MDA C that are needed to provide for cover construction near existing structures, roads, and utilities. The retaining walls are described in Sections 2.6 and 4.2.1. The retaining walls at MDA C may not meet regulatory requirements to demonstrate 1,000-year longevity, but may be considered an interim measure to last throughout the useful life of the adjacent facilities.

2.3 Thickness

Cover thicknesses needed to provide the required infiltration reduction performance and erosion resistance will be determined as part of the cover design and performance assessment. For the borrow source survey, a range of reasonable cover thicknesses was considered, to provide a range of probable material costs. The range of cover thicknesses provides reasonable approximations of the likely cover design, based on experience with performance assessments of similar ET covers for other DOE sites in Colorado with similar climatic conditions (DBS&A, 2002; Chadwick et al., 1999). EPA (2003) indicates that ET covers have been constructed with thicknesses ranging from 0.6 meter (2 feet) to 3.0 meters (10 feet).

The LANL statement of work for the cover borrow source survey calls for cover thicknesses of 1.5, 2.0, and 2.5 meters. Planning discussions with LANL at the beginning of the borrow source survey resulted in expanding this range to include a 1.0-meter cover thickness (Hopkins, 2004c). It was agreed that for the borrow source survey, two cover thickness end-members would be analyzed: a 3-foot (0.91 meters, close to 1 meter) thickness and an 8-foot (2.4 meters, close to 2.5 meters) thickness. Units of feet were selected rather than meters, because conventional material pricing and contractor bidding practices use feet and yards.

Cover thicknesses of 3 and 8 feet were considered for material cost estimating at both MDAs C and L. However, because radiological contaminants are present at MDA C, but not at MDA L, the cover thickness is expected to be closer to 8 feet at MDA C and closer to 3 feet at MDA L.

The thicknesses required to meet performance and regulatory requirements, based on the type of contaminants present, will be determined during cover design.

2.4 Slopes

Cover slopes must provide sufficient grade to prevent ponding of stormwater, but be gentle enough to prevent excessive runoff velocity and to optimize long-term erosion control. Most modern landfills have maximum cover slopes in the range of 25 to 33 percent (4H:1V to 3H:1V). Cover slope requirements for both uranium mill tailings sites (U.S. NRC, 1990) and hazardous waste under RCRA Subtitle C and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) establish side slope design requirements without setting specific slope limits. EPA design guidance recommends a minimum 3 to 5 percent slope to provide drainage (40 CFR §264.310). New Mexico Solid Waste Regulations (20.9.1 NMAC) for non-hazardous municipal solid waste (RCRA Subtitle D waste) set a minimum 2 percent slope and a maximum 25 percent slope, with steeper slopes possible under an approved variance.

For the cover borrow source survey, the preliminary criteria for slopes were presumed to be a minimum of 3 percent and a maximum of 33 percent. To be somewhat more conservative for cost estimating purposes, side slopes were kept to a minimum of 15 percent wherever possible. Slopes of 25 to 33 percent were used in some areas due to site constraints such as canyon escarpments, drainage features, and roads. Slopes up to of 33 percent were used on portions of the 8-foot-thick covers for MDAs C. On a portion of the north slope of the MDA L cover, space constraints exist as natural slopes drop toward the nearby mesa edge, where the slope steepens to 100 percent (1H:1V). Consequently, a cover side slope of 45 percent (2.2H:1V) was used to tie the cover contours into the existing grade. For the preliminary cover layout, this slope was set based on the apparent topographic limit to construct the toe of the cover side slope. Solutions to these site constraints will need to be developed when designing the covers, to address side slope cover placement above steep natural slopes outside the area of waste disposal.

2.5 Cover Perimeter

The cover perimeter must be set at or outside the locations of waste disposal. The full cover thickness must be provided over all waste disposal areas, with the cover side slopes extending a wedge of gradually thinning soil outward to the perimeter of the full cover footprint.

In order to be conservative, the perimeter for the full cover thickness was set outside the waste disposal locations, by a distance of two times the cover thickness. This is a performance-based approach for the ET covers, to prevent infiltration at the cover side slopes from migrating laterally toward waste disposal areas. Thus, the perimeter of full cover thickness outside the waste limits for the 3-foot and 8-foot cover thicknesses was set at 6 feet and 16 feet, respectively. The side slopes extend further, to a distance that is variable depending on cover thickness, slope angle, and site topography.

2.6 Retaining Walls

At MDA C, use of the cover perimeter and slope criteria (Sections 2.4 and 2.5) would result in the cover encroaching on existing structures, roads, and utilities. In order to accommodate these constraints at the site perimeter, LANL has requested that retaining walls be planned at the edge of the cover where needed to maintain the existing facilities (Hopkins, 2004d). The retaining walls will terminate the cover side slopes at a specified setback distance from the existing facilities. Retaining walls are not needed at MDA L.

Two options for the retaining walls are considered in the borrow source survey for material quantity and cost planning purposes.

- *Reinforced concrete:* Cantilevered retaining wall with footing, constructed on level grade to 33 percent slope embankment (wall thickness and footing will have variable dimensions)

- *Dry-set stone:* Durable, random-size stone, 2 feet thick with 3-foot concrete footing (mortar-set stone is optional)

The retaining wall height will be variable depending on the cover thickness at the perimeter boundary established for necessary setbacks from existing facilities. Design requirements for the retaining walls will need to be established to determine the required thickness, footings, and materials. The retaining wall slope stability and expected longevity will need to be assessed to establish the feasibility of using retaining walls in this final cover application.

Additional details of the MDA C retaining wall configuration are provided in Section 4.2.1.

2.7 Cover Soil Properties

The ET covers will be constructed of native geologic materials that are readily available and possess relatively common properties. ET cover designs allow for a range of soil and rock properties that will provide suitable performance by adjusting layer thicknesses to account for specific properties of selected materials. A design assessment will be needed for the specific soils selected for an ET cover.

The primary component of the ET cover is the soil rooting medium, which is typically 3 to 4 feet thick in most common ET cover designs. The soil rooting medium should have a sufficient silt and clay fine fraction to provide good moisture retention characteristics. The tuff available locally in the Los Alamos area and other alluvial soils available in the region may both provide suitable qualities for ET covers. Other primary materials used in ET covers include topsoil, gravel, cobbles, and rock. All soil and rock materials needed for the ET covers are available from many locations within the region.

2.8 Biota Barrier

A biota barrier is sometimes included in final cover designs to prevent burrowing animals from reaching residual radioactive constituents present at a site. Biota barriers usually consist of a cobble layer with sufficient layer thickness and cobble size to prevent burrowing animals from penetrating the cover during its design life.

LANL does not plan to use biota barriers at MDAs C and L, based on the waste characteristics at each site (Hopkins, 2004a). Therefore, cobbles for a biota barrier were not specifically considered in this borrow source survey. However, if biota barrier material is needed for these or other MDAs, gravel and rock planned for other purposes in the borrow source survey provide reasonable prices for cobbles that can be used for financial planning.

2.9 Slope Stability

Slope stability was considered in a general sense in the borrow source survey, by following the slope limitations noted above. However, no specific slope stability analysis or design was completed, and soil geotechnical parameters for strength and cohesion related to cover veneer stability were not considered. The slope stability of the retaining walls planned for the MDA C cover will need to be evaluated.

2.10 Landfill Gas or Vapor Generation

ET covers can incorporate features to address landfill gas (methane from waste decomposition) or other hazardous vapors. LANL has indicated that landfill gas will not need to be considered for borrow source survey planning purposes.

2.11 Geosynthetics

Geosynthetics used in ET covers can include surface erosion mats and various reinforcements for steeper slopes. Because the planned covers need to meet the 200- to 1,000-year longevity criteria, geosynthetics are not planned. Possible short-term use of geosynthetics for erosion control following construction would be permissible.

2.12 Constructibility

The ET covers should provide for practical construction materials and methods. To promote the future constructibility of the ET covers at MDAs C and L, as well as at other MDAs, the borrow source survey identified materials that will be readily available at the time of construction. A variety of potential sources of soil and rock materials were examined, to ensure availability in off-site commercial quarries and/or existing or potential on-site borrow areas at LANL.

The soils used for ET cover construction should have favorable characteristics for excavation and handling. Material obtained from commercial quarries should have low to moderate moisture on delivery for ease of placing and grading the material. Material with excessive moisture or high clay content should be avoided, as these characteristics can make the material difficult to handle. For tuff, the degree of welding is important for constructibility. The tuff should have good excavation potential and should break down easily into a fine-grained aggregate when placed and spread on the cover.

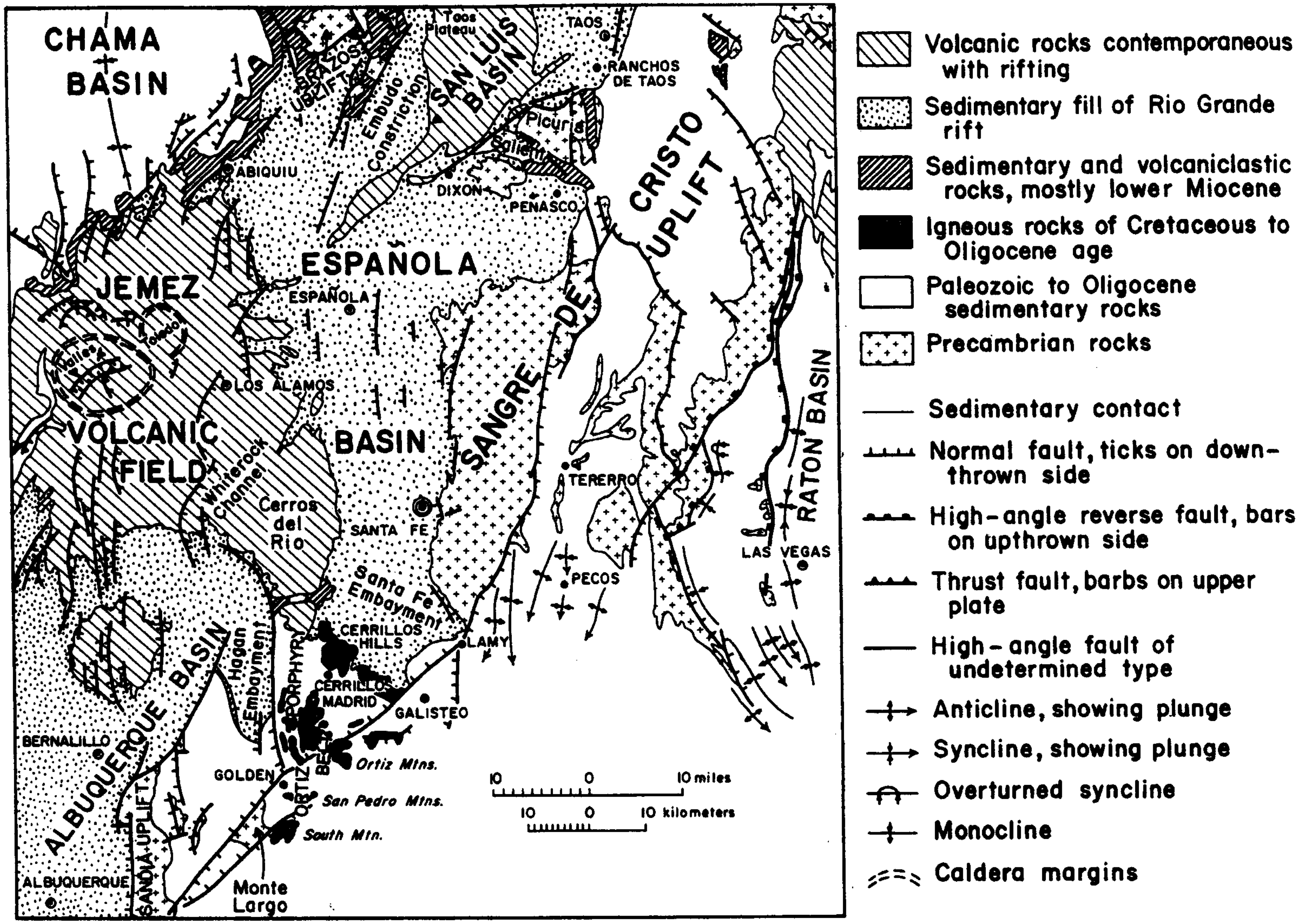
The earthwork associated with construction of the ET covers follows common practices in the U.S. construction industry, using conventional heavy equipment to place the soil rooting medium and erosion protection layers. Because ET covers are intended to promote rooting of vegetation, they do not have rigorous soil compaction requirements. Therefore, soil compaction properties were not considered in the borrow source survey.

3. Regional Geologic Setting and Materials Available

LANL is located on the Pajarito Plateau at the eastern edge of the Jemez Volcanic Field and near the western boundary of the Española Basin, one of a series of fault-bounded grabens that formed along the Rio Grande Rift. The Española Basin is bounded by the Precambrian-age Sangre de Cristo uplift to the east, by the Miocene-Pleistocene-age Jemez volcanic field to the west, by the San Luis Basin to the north, and by the Albuquerque Basin and Galisteo Basin to the south (Figure 3). The geologic materials within this region represent the borrow materials potentially available for construction of ET covers at LANL.

The Española Basin contains basin-fill sediments of the Miocene-Pliocene-age Santa Fe Group. Volcanic rocks of late Tertiary to Quaternary age overlie and are interbedded with Santa Fe Group sediments in the LANL vicinity. Paleozoic sedimentary rocks and Precambrian igneous and metamorphic rocks are exposed in the Sangre de Cristo Mountains east of the Rio Grande. The geologic structure and stratigraphy of the Española Basin and Valles Caldera are illustrated in the block diagram in Figure 4. A detailed geologic map of the region is provided in Figure 5.

This discussion focuses on potential borrow materials that are economically feasible for use in ET cover construction at MDAs C and L and other mesa-top sites. Thus it primarily addresses the Santa Fe Group sedimentary units deposited in the central Española Basin and the rock units of the Jemez volcanic field in the LANL vicinity, including the Pliocene-age Polvadera Group and Cerros del Rio volcanic field and the Quaternary-age Tewa Group. Omitted from the discussion are the rock units exposed in and adjacent to the Sangre de Cristo Mountains and some members from within the Santa Fe Group that occur in the northern part of the Basin, both because their distance from LANL and associated haulage costs outweigh their utility as borrow materials at the MDAs. In addition, numerous volcanic units within the Miocene-age Keres Group that are exposed south of LANL in Bandelier National Monument are unavailable for use as borrow materials and are therefore also omitted from the discussion.



Source: Modified from Woodward and Ingersoll, 1979

LANL COVER BORROW SOURCE SURVEY

Generalized Geology and Tectonic Map of the Española Basin and Vicinity

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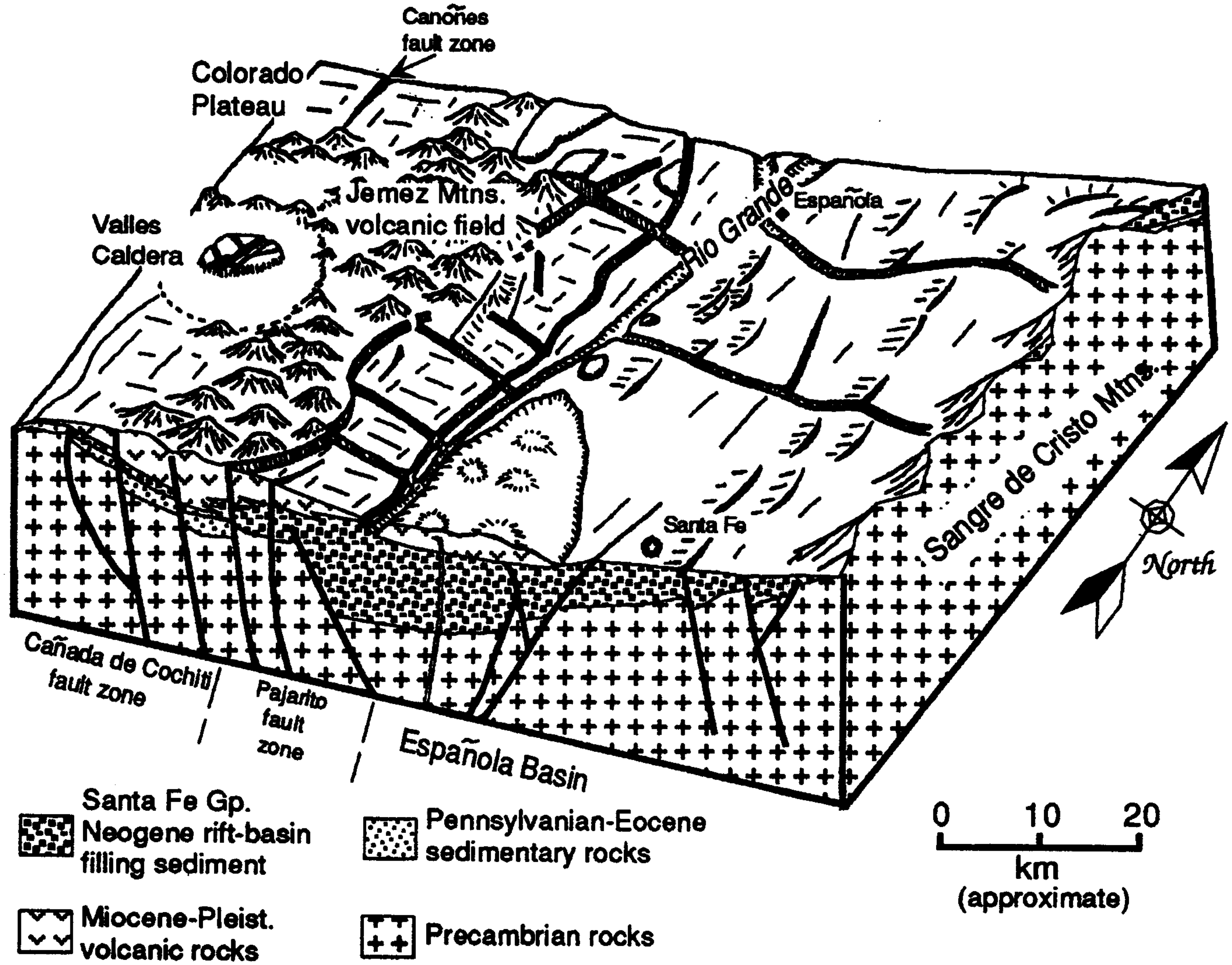
Figure 3



Source: Modified from Golombek et al., 1983

LANL COVER BORROW SOURCE SURVEY
General Structure and Stratigraphy of the Española Basin

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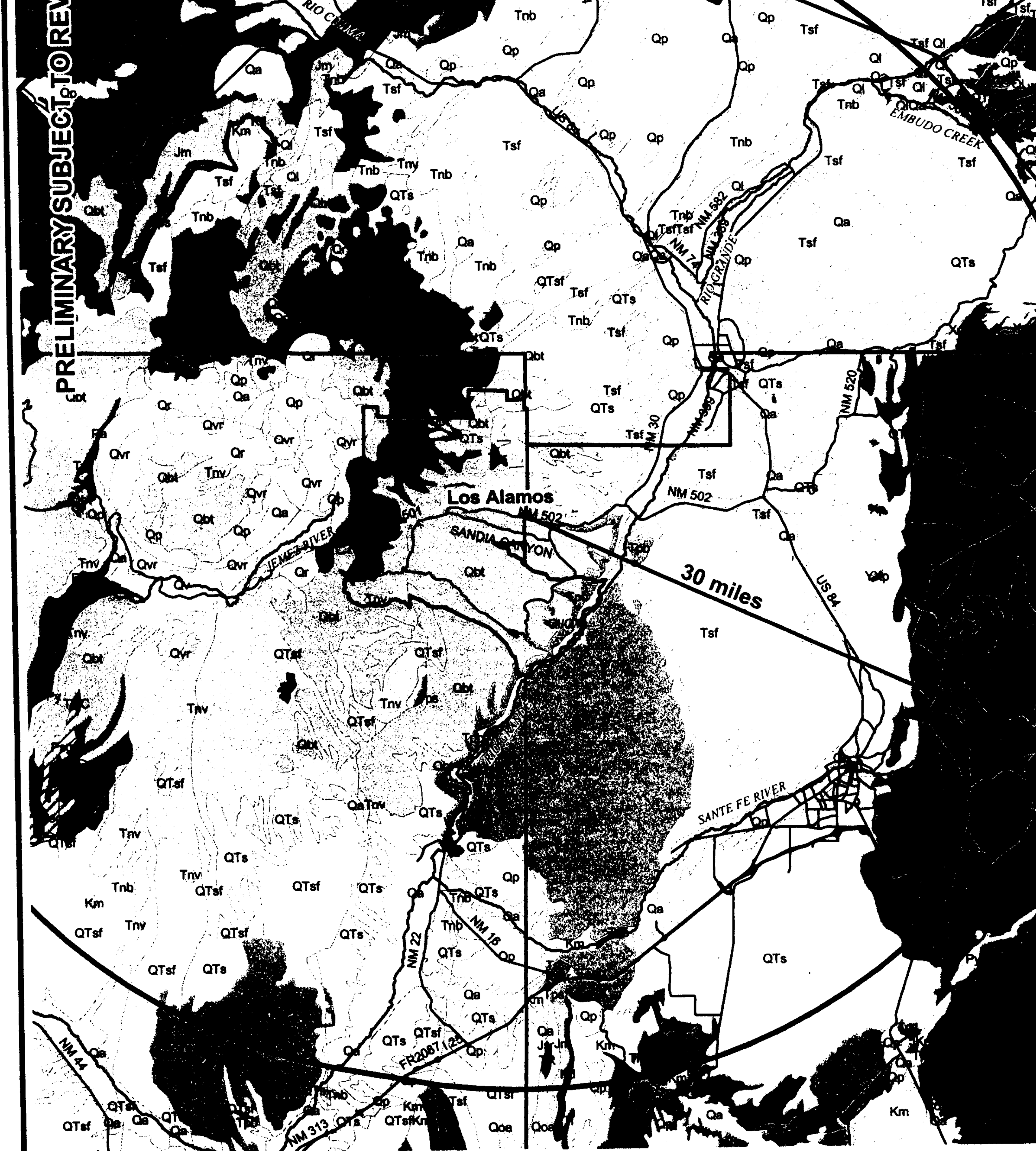
Figure 4



N

0 3 6 Miles

Explanation

	Jurassic rocks, Middle and Upper, undivided
Jm	Morrison Formation; Upper Jurassic nonmarine rocks present only in northern one-third of state
	Dakota Sandstone; includes Oak Canyon, Cubero, and Paguate Tongues plus Clay Mesa Tongue of Mancos Shale
Km	Shale; divided into Upper and Lower parts by Gallup Sandstone
	Mesaverde Group includes the Gallup Sandstone, Crevasse Canyon Formation
	Mississippian rocks, undivided; Arroyo Penasco Group in Sangre de Cristo
	Permian rocks, undivided
	Madera Formation (Limestone, or Group)
	Abo Formation; red beds, arkosic at base, finer and more mature above
	Pennsylvanian rocks, undivided
	Madera Formation (Limestone, or Group)
Pat	Artesia Group; shelf facies forming broad south-southeast trending outcrop
	Cutler Formation; used in northern areas and Chama embayment only
	Glorieta Sandstone; texturally and mineralogically mature, high-silica quartz sandstone
	San Andres Formation; limestone and dolomite with minor shale; Guadalupian in south, in part Leonardian to north
Psg	San Andres Limestone and Glorieta Sandstone; Guadalupian and Leonardian
Py	Yeso Formation; sandstones, siltstones, anhydrite, gypsum, halite, and dolomite; Leonardian
	Triassic rocks, undivided; continental red beds
	Chinle Group; Upper Triassic; includes Moenkopi Formation (Middle Triassic) at base in many areas
QTs	Upper Santa Fe Group
QTsf	Santa Fe Group, undivided. Basin fill of Rio Grande rift region
Qa	Alluvium; upper and middle Quaternary
Qbt	Bandelier Tuff; Jemez Mountains area only
Qe/Tnb	Eolian deposits/Basalt and andesite flows; Neogene. Includes flows interbedded with Santa Fe and Gila Groups
Ql	Landslide deposits and colluvium
Qp	Piedmont alluvial deposits: upper and middle Quaternary
Qp/QTs	Piedmont alluvial deposits: upper and middle Quaternary/ Upper Santa Fe Group
Qvr	Valles Rhyolite; Jemez Mountains area only
	Tertiary intrusive rocks; undifferentiated
Tnb	Basalt and andesite flows; Neogene. Includes flows interbedded with Santa Fe and Gila Groups
	Silicic to intermediate volcanic rocks; mainly quartz latite and rhyolite Neogene
Tnv	Neogene volcanic ro primarily in Jemez M
	Mostly Oligocene ar sedimentary and vol sedimentary rocks w to intermediate volca
	Paleogene sedimen Baca, Galisteo, El R
Tsf	Lower and Middle S
	Miocene to Oligocen intermediate intrusiv dikes, stocks, plugs
Tus	Upper Tertiary sedi
	Proterozoic metamo dominantly felsic vo volcaniclastic
Xmo	Lower Proterozoic dominantly mafic (1
	Lower Proterozoic (older than 1600 M
	Middle and Lower rocks, undivided

Source: The Digital Geologic Map of New Mexico, USGS, 2003
New Mexico Bureau of Mines and Mineral Resources

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LOS ALAMOS NATIONAL LAB
Geologic Map of the Los Alam

Daniel B. Stephens & Associates, Inc.
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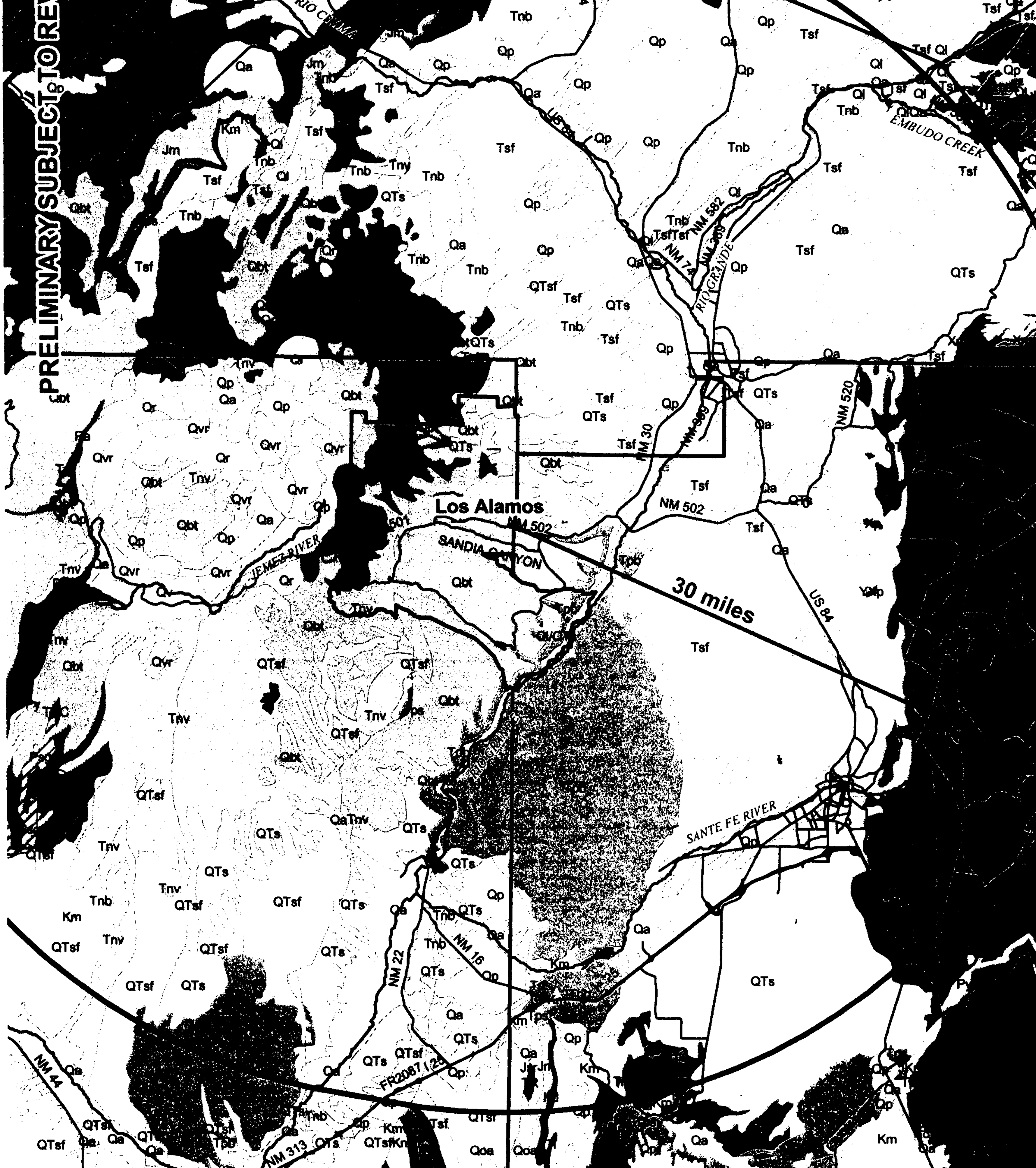
Figure 5



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Explanation

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	Mostly Oligocene and sedimentary and volca sedimentary rocks with to intermediate volcani
	Paleogene sedimentar Baca, Galisteo, El Rito
Tsf	Lower and Middle San
	Miocene to Oligocene intermediate intrusive dikes, stocks, plugs, a
Tus	Upper Tertiary sedime
	Proterozoic metamorp dominantly felsic volca volcaniclastic
Xmo	Lower Proterozoic me dominantly mafic (172
	Lower Proterozoic plu (older than 1600 Ma)
	Middle and Lower Pro rocks, undivided

Source: The Digital Geologic Map of New Mexico, USGS, 2003
New Mexico Bureau of Mines and Mineral Resources

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COVER BORROW SOURCE
LOS ALAMOS NATIONAL LABO
Geologic Map of the Los Alamo

Figure 5

3.1 Santa Fe Group

Sediments of the late Tertiary (Miocene-Pliocene age) Santa Fe Group are exposed throughout the Española Basin and comprise much of the aggregate materials commercially mined in the region. The sediments tend to be coarse-grained, with high fractions of sand, gravel, and cobbles. Fine-grained materials are also present in the Santa Fe Group, but these are generally not the materials sought for commercial aggregate mining. The Santa Fe Group can be moderately consolidated in places, but in most areas, the formation is weakly consolidated and the granular materials can be readily mined.

Units of the Santa Fe Group in the central Española Basin include, from oldest to youngest, the Tesuque and Ancha Formations. Deposits of Quaternary alluvium similar in character to the Santa Fe group sediments overlie the Tertiary deposits along the Rio Grande and its tributaries.

3.1.1 Tesuque Formation

The Tesuque Formation is composed of sandstone, siltstone, mudstone, and conglomerate, with sandstone comprising the most prevalent rock type. The sand is poorly to well sorted and subangular to subrounded. Bedding character varies from very thin to medium and from lenticular to tabular. The conglomerate is generally granitic, with 1 to 5 percent amphibolite and up to 5 percent muscovite schist. The Tesuque Formation of the central Española Basin consists of three members, from oldest to youngest, the Nambe Member, Skull Ridge Member, and Pojoaque Member. The formation comprises the primary aquifer for water supply in the region.

The basal Nambe Member is a fine- to coarse-grained to conglomeratic unit containing silt, clay, arkosic sandstone, and granite-dominated conglomerate derived from the granitic bedrock of the Sangre de Cristo Mountains that crops out on the east side of the basin. Total thickness of the Nambe Member is about 600 meters, but it may thicken extensively toward the west.

The middle Skull Ridge Member is composed of very fine- to medium-grained sandstone and siltstone with subordinate mudstone occasionally interbedded with volcanic ash. Total thickness of the Skull Ridge Member varies from about 50 to about 185 meters.

The upper Pojoaque Member contains fine- to medium-grained sandstone, siltstone, mudstone, subordinate claystone, and 15 to 40 percent pebble-conglomerate. Pebble-conglomerate beds are weakly consolidated to calcium carbonate indurated with clasts composed of granite and granite-derived feldspar and quartz, plus 1 to 30 percent calcium carbonate-indurated nodules of sandstone. The Pojoaque Member is also occasionally interbedded with volcanic ash. Total thickness of the Pojoaque Member varies from about 430 to about 800 meters (Koning, 2002; Koning and Maldonado, 2001).

3.1.2 Ancha Formation

The Ancha Formation in the central and southern Española Basin unconformably overlies the Tesuque Formation and is composed of generally unconsolidated coarse-grained sand and gravel underlying and locally interbedded with the Cerros del Rio volcanic flows. Beds are generally thin and planar to lenticular. Gravels in the Ancha Formation generally consist of poorly sorted pebbles with 5 to 20 percent cobbles. Gravel composition is predominantly granitic with minor amounts of quartzite and amphibolite and, locally, trace amounts of andesite or basalt clasts. The sand is generally coarse, subangular to subrounded, moderately sorted, and arkosic (Koning and Maldonado, 2001; Koning et al., 2002).

3.2 Stream Alluvium

Alluvial stream deposits may provide suitable materials if mined commercially or available in sufficient quantities. Holocene-age channel and floodplain deposits overlie the Santa Fe Group sediments along the Rio Grande and its tributaries. This young alluvium is similar to the fluvial sediments of the Santa Fe Group, and the borrow source survey has not attempted to distinguish which sediments are being mined at existing commercial sources.

The alluvial stream deposits consist of cross-bedded to planar-bedded sand, pebbly sand, pebble to cobble gravel, and thin beds of silty sand exposed along the Rio Grande, the Rio Pojoaque (immediately east of the Rio Grande), and beneath adjacent low terraces. Exposed thicknesses of 2 to 4 meters are common, while actual thicknesses probably exceed 10 meters along the Rio Grande.

Upper to middle Pleistocene-age alluvial deposits of well sorted cobble to boulder gravel, cross-bedded sand, and silty sand occur beneath terrace remnants 14 to 45 meters above the Rio Grande, exposed near the mouth of Los Alamos Canyon. These deposits overlie or are inset against rocks of the Santa Fe Group. Clasts are predominantly axial-river types, locally rich in dacitic rocks derived from the Jemez Mountains, with thicknesses of 4 to 20 meters (Dethier, 2003).

3.3 Polvadera Group

The Polvadera Group consists of volcanic rocks and volcanic-derived sediments. Much of this material may not be well suited for ET cover construction, as it tends to be coarse and blocky in texture with poor moisture retention characteristics, but some of this rock may be useful in erosion control components of the covers. Some fine-grained sediments are present in the Polvadera Group, which may provide suitable material for cover construction if sufficient quantities are identified. The units of the Pliocene-age Polvadera Group include, from oldest to youngest, the Tschicoma and Puye Formations (Goff et al., 2002).

3.3.1 Tschicoma Formation

The Tschicoma Formation includes the hornblende dacite of Cerro Grande and the dacite of Pajarito Mountain. These dome and flow complexes form the Sierra de los Valles Mountains west of LANL.

The hornblende dacite of Cerro Grande is composed of massive to sheeted porphyritic dacite containing phenocrysts of plagioclase, hypersthene, and hornblende. Thick flows contain intervals of flow breccia derived from the Cerro Grande to the west. This unit is exposed west of

LANL and underlies the dacite of Pajarito Mountain and the Tshirege Member of the Bandelier Tuff with a maximum exposed thickness of about 200 meters.

The dacite of Pajarito Mountain is composed of massive to sheeted, porphyritic dacite containing phenocrysts of plagioclase, hypersthene, clinopyroxene, and opaque oxides in a devitrified groundmass. This unit also includes thick flows containing intervals of flow breccia derived from Pajarito Mountain west of LANL. It overlies the hornblende dacite of Cerro Grande and locally underlies the Tshirege Member of the Bandelier Tuff with a maximum exposed thickness of about 220 meters (Goff et al., 2002).

3.3.2 Puye Formation

The Puye Formation is primarily a volcaniclastic alluvial fan complex derived from the eroded detritus of the volcanic rocks of the Polvadera Group. The major lithology is a volcaniclastic fanglomerate comprised of pebble to boulder gravel, boulder-rich debris flows, massive to planer sands, thin beds of tephra and pumiceous alluvium, beds of fine sand and silt, and numerous ash beds of dacitic to rhyolitic composition (Griggs, 1964; Gardner et al., 1986; Dethier, 1997; Goff et al., 2002). The fanglomerate facies are composed of intertonguing mixtures of stream flow, sheet flow, debris flow, block and ash flow, pumice fall, and ignimbrite deposits. The gravel fraction is primarily composed of dacitic rocks derived from Tschicoma Formation sources to the west, while the sand fraction is primarily composed of dacitic fragments and angular quartz grains.

The basal 10- to 20-meter section of the Puye Formation is predominantly composed of pumiceous alluvium and mudflows that overlie a coarse, poorly consolidated conglomerate consisting of pebble- to boulder-size clasts of quartzite, granite, pegmatite, and altered volcanics that in turn overlie a silty sand of the Santa Fe Group. The conglomeratic unit was previously named the Totavi Lentil by Griggs (1964), who defined it as the basal unit of the Puye Formation. Because its composition is similar to modern Rio Grande fluvial deposits, it is currently interpreted to contain deposits of the ancestral Rio Grande and is referred to as an axial facies of the Puye Formation (Dethier, 1997). However, its lithology suggests that it is more logically an axial facies of the Santa Fe Group (Goff et al., 2002).

The Puye Formation is locally interbedded with fluvial deposits of the Santa Fe Group in eastern Guaje and Los Alamos Canyons and central Santa Clara Canyon, and it unconformably overlies Santa Fe Group sediments elsewhere. Its maximum exposed thickness is about 120 meters, but the maximum thickness indicated by drill hole intercepts is about 660 meters (Goff et al., 2002).

3.4 Cerros del Rio Volcanic Field

The Pliocene-age Cerros del Rio volcanic field consists of volcanic flows, domes, plugs, and scoria primarily of basaltic composition. The lower part of the Cerros del Rio contains maar deposits formed by the contact of magma with shallow surface water or groundwater (Heiken et al., 1996). These deposits include cobbles, boulders, fragments, intact blocks, and depositional lenses of sediments resembling those in the Santa Fe Group and the axial facies of the Puye Formation. Cinder deposits consisting of basalt scoria, bombs, and associated thin lavas are exposed in Frijoles Canyon within the boundaries of Bandelier National Monument south of LANL.

The Cerros del Rio basalts are most exposed east of the Rio Grande as massive to sheeted flows generally showing broad columnar joints. The basalt and associated mafic lava flows generally contain phenocrysts of olivine, plagioclase, and clinopyroxene in a variety of ground mass types, and may contain abundant xenocrysts of quartz, microcline, and Precambrian rock fragments from sedimentary rocks beneath the Pajarito Plateau. The Cerros del Rio basalts are overlain by the Tshirege Member of the Bandelier Tuff in the eastern LANL area. The maximum exposed thickness of the basalt units is about 40 meters (Goff et al., 2002).

Upper Miocene-age olivine basalt and thin cinder deposits are exposed east of LANL in Bayo Canyon and at one location in Santa Clara Canyon, where they lie above and locally interlayered with the Santa Fe Group, underlying the Puye Formation (Dethier, 2003).

3.5 Tewa Group

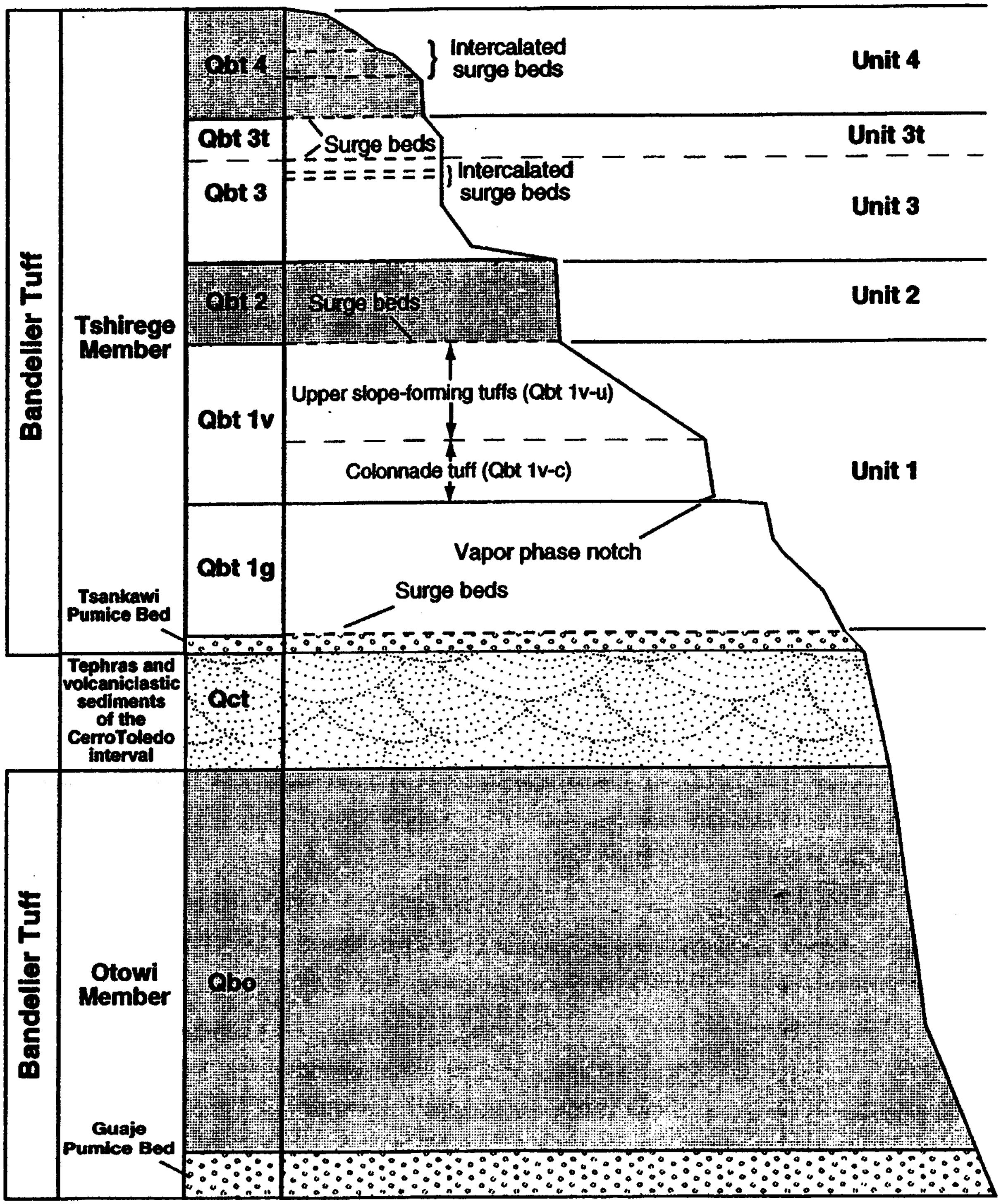
The volcanic rocks of the Quaternary-age (lower Pleistocene) Tewa Group include, from oldest to youngest, the lower Bandelier Tuff (Otowi Member), the Cerro Toledo interval, the upper Bandelier Tuff (Tshirege Member), and the El Cajete Pumice.

3.5.1 Bandelier Tuff

The Bandelier Tuff is the predominant formation exposed at the surface within LANL and the immediate vicinity and is a primary candidate for borrow material. The tuff has been studied at LANL for cover performance and has been used on existing LANL covers. The non-welded tuff members can be excavated with conventional equipment and crushed through normal handling into a fine-grained aggregate with good handling characteristics.

The Bandelier Tuff is comprised of pyroclastic flows of rhyolitic ash-flow tuff, more formally defined as ignimbrite (Broxton et al., 1995). The ignimbrite deposits of the Bandelier Tuff form the Pajarito Plateau on the east side of the Jemez volcanic field and range in thickness from about 300 meters in the western part of the plateau, thinning eastward to about 80 meters above the Rio Grande (Stoker et al., 1991). The Bandelier Tuff is subdivided into two primary members, the lower Otowi Member and the upper Tshirege Member, which are split by the intervening Cerro Toledo interval. The Tshirege Member is further subdivided into several units based on varying weathering patterns, degree of welding, and crystallization characteristics. A generalized depiction of the composite stratigraphy of the Bandelier Tuff is provided in Figure 6. Because the Bandelier Tuff is a primary candidate for borrow material, descriptions of the various subunits and their suitability for use as borrow material follow.

The lower Otowi Member of the Bandelier Tuff is generally poorly welded to nonwelded, making the Otowi Member a good candidate for use as borrow material. The Otowi Member is a rhyolitic ignimbrite, containing abundant phenocrysts of sanidine and quartz and sparse mafic phenocrysts. The ignimbrite is composed of pumice lapilli (intact pyroclastic rock fragments from 2 to 64 millimeters in diameter) supported by an ash matrix composed of glass shards, broken pumice fragments, phenocrysts, and fragments of nonvesiculated perlite. The pumice



Source: Modified from Gardner et al., 1999

LANL COVER BORROW SOURCE SURVEY

Composite Stratigraphy of the Bandelier Tuff

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Figure 6

P:_Es04-075\Borrow-Matls.1-05\F6_BandlrTuff_Strat.doc lapilli generally comprise from 10 to 30 percent of the rock but increase to about 40 percent near the top of the Otowi Member. The upper part of the Otowi Member also contains from 2 to 5 percent lithic clasts up to 3 centimeters in diameter with a dacitic composition (Broxton et al., 1995). The Guaje Pumice bed, a stratified pumice fall and surge deposit, occurs at base of the unit. The Otowi Member is distinguished from the upper Tshirege Member by its poorer degree of welding, a greater tendency to form slopes instead of cliffs, more abundant lithic fragments, and less abundant iridescent sanidine. It is exposed in the lower canyon slopes of middle Los Alamos Canyon and in lower Pueblo Canyon. Its maximum exposed thickness is about 75 meters (Goff et al., 2002).

The Cerro Toledo interval is a discontinuous unit of epiclastic sediments and tephras that lies between the two members of the Bandelier Tuff (Broxton and Reneau, 1995). This unit is composed primarily of well stratified tuffaceous siltstones and sandstones plus pyroclastic ash-fall and pumice-fall deposits generally less than 2 meters thick. It also includes poorly sorted sand, gravel, cobble, and boulder deposits derived from lava flows of the Tschicoma Formation. The Cerro Toledo interval is exposed in Los Alamos Canyon near TA-41, in DP Canyon east of DP Spring, and in Pueblo Canyon north of TA-21. The unit's maximum exposed thickness is about 20 meters, but it exceeds 30 meters in several wells drilled on Pajarito Plateau (Goff et al., 2002; Broxton et al., 1995). Because the Cerro Toledo interval is relatively non-uniform and contains dacite boulders and cobbles, it is probably less favorable for use as borrow material than other units of the Bandelier Tuff.

Overlying the Cerro Toledo interval is the upper Tshirege Member of the Bandelier Tuff. The Tshirege Member is a multiple flow ash-flow sheet that forms the prominent cliffs of the numerous mesas throughout the Pajarito Plateau. It is a compound cooling unit whose physical properties vary substantially both vertically and laterally depending on the degree of welding and crystallization (Broxton et al., 1995). Nonwelded to poorly welded intervals can provide favorable borrow material, but welded units will not readily crush into the fine-grained aggregate needed for cover construction. The Tshirege Member is composed of white to orange to pink, welded to nonwelded, rhyolitic ignimbrite containing abundant phenocrysts of sanidine and quartz (Goff et al., 2002). Several sub-units of the Tshirege Member defined on the basis of varying degrees of welding, physical, and mineralogical characteristics are described below.

The Tsankawi Pumice Bed is a thin (less than 1 meter) pumice fall at the base of the Tshirege Member. It is composed of clast-supported pumice lapilli up to 6 centimeters in diameter, grading upward into a coarse ash bed at the top of the unit (Broxton et al., 1995).

Overlying the Tsankawi Pumice is Unit 1g, the lowermost ignimbrite unit within the Tshirege Member. This unit is a nonwelded vitric ignimbrite composed of vitreous, crystal-rich pumice lapilli in a matrix of coarse ash, shards, pumice fragments, and abundant sanidine and quartz phenocrysts. Though it is primarily nonwelded, Unit 1g commonly forms cliffs because a resistant bench occurs at the top of the unit, forming a protective cap. The bench at the top of the unit marks the base of the vapor-phase notch. Weathered cliff faces exhibit numerous large holes formed by erosion, giving them a Swiss cheese appearance. Exposures of this unit range from 22 to 32 meters thick (Broxton et al., 1995).

Unit 1v overlies Unit 1g. The vapor-phase notch at the base of this unit is a thin, horizontal zone of preferential weathering used as a mappable marker horizon throughout the Pajarito Plateau. Unit 1v is a nonwelded, devitrified ignimbrite composed of tubular, crystal-rich pumice lapilli in a matrix of ash, shards, pumice fragments, and abundant phenocrysts. Unit 1v forms a combination of cliffs and slopes separating the resistant bench at the top of Unit 1g from the near vertical cliff of the overlying Unit 2. The lower 1 to 3 meters of the unit consist of a resistant colonnade tuff with columnar jointing, suggesting a slight degree of welding. The remainder of the unit is characterized by slope-forming tuffs. Exposures of this unit range from 16 to 20 meters thick (Broxton et al., 1995).

Overlying Unit 1v is Unit 2. This unit forms a vertical cliff that stands out in sharp distinction from the slope-forming tuffs above and below it. Unit 2 is a poorly sorted, vapor-phase altered ignimbrite composed of sparse crystal-rich pumice lapilli in a matrix of ash, shards, pumice fragments, and abundant phenocrysts. The unit is partially welded at its base and grades to moderately to highly welded at its top. Numerous well developed, near-vertical fractures are common in Unit 2, and some horizontal and low angle fractures are also present. Calcite lines the fractures, which are typically filled with clay. Exposures of this unit range from 10 to 27 meters thick (Broxton et al., 1995).

A nonwelded tuff from 5 to 10 meters thick underlies a broad, gently sloping bench developed on top of Unit 2. Talus from the overlying cliffs of Unit 3 commonly covers its outcrops. The nonwelded tuff is a pumice-poor, vapor-phase altered ignimbrite composed of ash, shards, pumice fragments, and abundant phenocrysts (Broxton et al., 1995).

Overlying the nonwelded tuff is Unit 3, a nonwelded to partially welded, vapor-phase altered ignimbrite composed of 10 to 20 percent crystal-rich pumice lapilli in a matrix of ash, shards, pumice fragments, and abundant phenocrysts of sanidine and quartz. Pumice lapilli occasionally comprise up to 30 percent of the rock in this unit, and lithic fragments locally comprise up to 5 percent of the unit. Although less steep than Unit 2, Unit 3 is also a prominent cliff-forming unit that forms the caprock of DP Mesa. Unit 3 is completely nonwelded at its base and grades to moderate degrees of welding upward. The top of Unit 3 is marked by a crystal-rich surge deposit and a sharp increase in the degree of welding in the overlying Unit 4. Exposures of Unit 3 range from 33 to 43 meters thick (Broxton et al., 1995; Gardner et al., 1999).

Unit 3T is a discontinuous, 0- to 10-meter-thick, commonly very densely welded, moderately porphyritic, vapor-phase altered ignimbrite composed of crystal-rich pumice lapilli in a matrix of ash, shards, pumice fragments, and abundant (20 to 25 percent) phenocrysts. This unit overlies Unit 3 in the western LANL area, its easternmost extent appearing south of TA-3 in Twomile Canyon and west of the Omega Bridge in Los Alamos Canyon (Gardner et al., 1999).

The uppermost unit of the Tshirege Member is Unit 4, which directly overlies Unit 3 or Unit 3T. Unit 4 is a thin ignimbrite that pinches out eastward at TA-55 but thickens to the west to up to 24 meters. This unit is typically nonwelded to partially welded except near TA-3, where the interior of the unit is densely welded. The ignimbrite of Unit 4 is relatively pumice- and crystal-poor with about 10 to 15 percent phenocrysts and less than 5 percent pumice content (Gardner et al., 1999).

The Tshirege Member units have been mapped in detail across LANL (Rogers, 1995), and this geologic mapping can serve as a guide to identify potential borrow source locations. While the degree of welding is variable within units, the favorable units for cover material (following the standard LANL unit designations [e.g., Broxton et al., 1995]) may be summarized as follows:

- *Non- to partially welded units favorable for use as borrow material:* Units 1g, 1v, and 3.
- *Welded to partially welded units less favorable for use as borrow material:* Units 2, 3t, and 4

MDAs C and L are both located in areas underlain by the Tshirege Member of the Bandelier Tuff. Details of the units exposed at these sites are described in Section 3.6.

3.5.2 El Cajete Pumice

The uppermost member of the Tewa Group is the El Cajete Pumice. This unit consists of moderately sorted, pyroclastic fall deposits of vesicular rhyolite. It is primarily composed of pumice clasts up to about 15 centimeters in diameter that contain sparse phenocrysts of quartz, biotite, and plagioclase and rare microphenocrysts of hornblende and clinopyroxene. The El Cajete Pumice has been extensively reworked by erosion and collects on east facing slopes and on benches cut into the upper flow unit and/or cooling unit boundaries of the Tshirege Member of the Bandelier Tuff. It forms extensive mesa top cover within Bandelier National Monument and in the southern portions of LANL. Its maximum exposed thickness is about 10 meters within Bandelier National Monument, and it thins to the northeast on mesa tops (Goff et al., 2002).

3.6 Geology at MDAs C and L

At MDAs C and L, geologic maps prepared by Rogers (1995) show the specific unit designations underlying the sites and surrounding areas. MDA C is underlain by El Cajete Pumice in the southern and western portions of the site and the Tshirege Member of the Bandelier Tuff in the northeast part of the site. The Tshirege Member under MDA C is mapped as Unit D by Rogers (1995), which correlates to Unit 3 in the current standard LANL stratigraphic nomenclature (e.g., Broxton et al., 1995). MDA L is underlain by the Tshirege

Member of the Bandelier Tuff; mapped as Unit C by Rogers (1995), which correlates to Unit 2 in the unit designations of Broxton et al. (1995).

The materials in the vicinity of MDA C appear suitable for on-site borrow material. The El Cajete Pumice and Bandelier Tuff Unit 3 are relatively soft and amenable to excavation. Properties of the Bandelier Tuff for cover construction have been examined at LANL previously, but the suitability of the El Cajete Pumice for this application is uncertain; its moisture retention characteristics and suitability as a soil rooting medium would need to be examined. Because the El Cajete Pumice is less than 10 m thick (Goff et al., 2002) and may be much thinner at this location, excavation of this material for an on-site borrow source may soon penetrate into the underlying Unit D; thus, excavation on or near MDA C may generate borrow material that is a mixture of El Cajete Pumice and Bandelier Tuff.

The materials in the vicinity of MDA L appear poorly suited for on-site borrow material. Unit 2 of the Bandelier Tuff is partially to highly welded, and at MDA L, it appears to be relatively strongly welded, since it forms a steep escarpment at this location.

4. Preliminary Cover Layout and Material Quantities

As described in Section 2, preliminary ET cover configurations for MDAs C and L were developed for use in the cover borrow source survey to develop estimates of material quantities for two cover thicknesses: 3 and 8 feet. This section describes the cover materials and the thickness of each layer within the cover following the configuration criteria described in Section 2. Layout drawings are presented to show the cover configurations used as the basis for estimating material quantities.

4.1 System Components

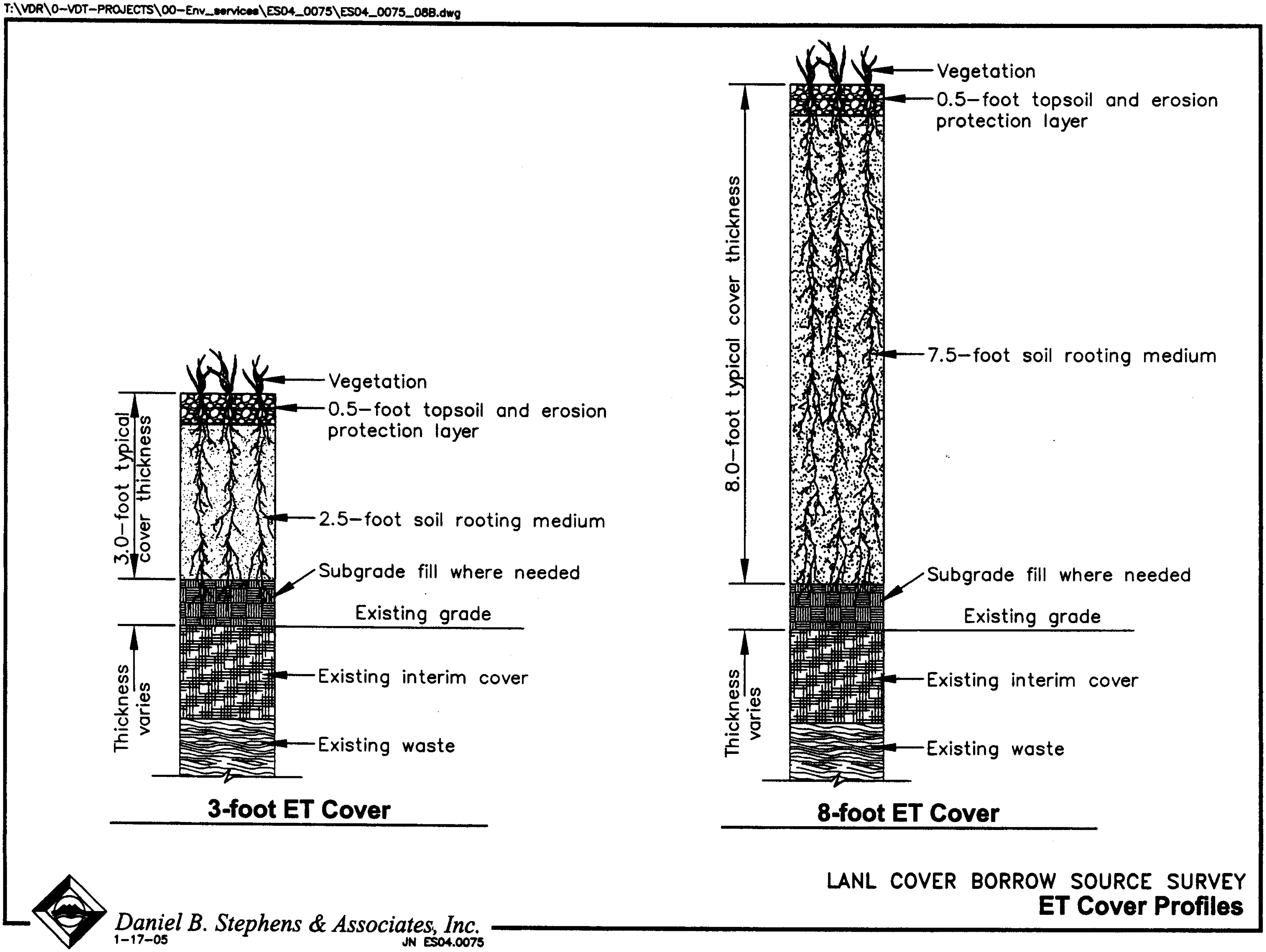
The ET covers for MDAs C and L will be constructed of native geologic materials that will provide long-term performance. Preliminary cover profiles are shown in Figure 7. The ET covers include a topsoil and erosion protection layer on the surface and an underlying soil rooting medium layer. In addition, subgrade fill is needed to provide a suitably sloped cover configuration. Material descriptions for each of the ET cover components are provided in Sections 4.1.1 through 4.1.6.

4.1.1 Topsoil and Erosion Protection Layer

A topsoil and erosion protection layer will be used to promote the establishment of vegetation and prevent erosion. The erosion protection layer will require a soil suitable for a rooting medium with a significant percentage of gravel and cobbles to inhibit the erosive forces of wind and water.

4.1.1.1 Topsoil

In an ET cover, the topsoil effectively works along with the underlying soil rooting medium to provide a thick layer to support vegetation. Typical topsoil for cover applications includes sandy, silty, or clayey loams that contain significant fines (passing No. 200 sieve) to provide good moisture storage characteristics. Significant organic matter content and nutrients and optimal pH are beneficial for the topsoil, but can also be adjusted through soil amendments (Section 4.1.4). The required thickness of the topsoil layer may vary depending on slope grades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Vegetation
0.5-foot topsoil and erosion protection layer
3.0-foot typical cover thickness
2.5-foot soil rooting medium
Subgrade fill where needed
Existing grade
Thickness varies
Existing interim cover
Existing waste
3-foot ET Cover
Vegetation
0.5-foot topsoil and erosion protection layer
8.0-foot typical cover thickness
7.5-foot soil rooting medium
Subgrade fill where needed
Existing grade
Thickness varies
Existing interim cover
Existing waste
8-foot ET Cover
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ET Cover Profiles
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JN ES04.0075

Figure 7

and lengths, which are based on erosion rates calculated during cover design. The thickness of the topsoil layer was assumed for the purposes of the borrow source survey to be 6 inches thick, based on the standard design requirement for RCRA Subtitle D municipal landfills (40 CFR §258.60). Other cover design guidelines (RCRA Subtitle C and Uranium Mill Tailings Remedial Action Project) do not set a specific topsoil thickness.

In order to minimize erosion, the topsoil should have sufficient permeability to promote the infiltration of stormwater at the surface and reduce runoff. Stormwater erosion is minimized through the use of coarse-textured topsoil, while fine-grained soils at depth in the soil rooting medium provide moisture storage capacity. Coarse surface soils can enhance ET cover performance through (1) increased surface infiltration of precipitation, (2) increased uniformity of infiltration, and (3) reduced runoff. The infiltration of water also encourages plant growth and evapotranspiration, providing a cycle of positive feedback to prevent long-term erosion.

A cover that allows water to infiltrate at or near the rate of precipitation will greatly reduce runoff and erosion. Sands have a high permeability on the order of 10 to 30 centimeters per hour (cm/hr), while sandy clay loams have a lower permeability of around 1 cm/hr. A heavy rainfall has an intensity of about 2 cm/hr, a downpour has an intensity of about 5 cm/hr, and a cloudburst has an intensity of about 10 cm/hr.

4.1.1.2 Coarse Aggregate

The erosion protection layer is planned to include gravel and/or rock-armoring with approximately 20 percent coarse fraction by mass. Ultimately, this produces a vegetated surface, partially covered with gravel and cobbles, that is resistant to erosion by wind and water. Rocky soils with appropriate characteristics that can be excavated and used directly for this purpose may be identified, or alternatively, soils may be augmented with additional rock as needed.

The coarse aggregate can be placed by mixing the aggregate with the topsoil prior to placement or by placing the aggregate over the topsoil layer and mixing the aggregate into the upper topsoil by tilling. The coarse aggregate particle size and percentage of gravel or cobbles used for armoring will need to be determined in erosion rate calculations conducted as part of the cover design.

4.1.1.3 Angular Boulders

As needed, angular boulders may be used to reinforce areas with steep slopes. LANL has considered use of angular basalt boulders as a buttress or retaining structure on steep slopes for other projects (Hopkins, 2004a), and for the borrow source survey, the possible use of angular boulders was included as an option on areas of steeper slopes. However, for slopes up to 33 percent, vegetated soil covers are commonly used without excess erosion, so the boulder reinforcement may not be needed. The boulders were included in the borrow source survey to consider potential sources for this material and establish unit costs, should boulders be needed when the cover design is completed.

4.1.2 Soil Rooting Medium

The primary functional component of the ET cover is the soil rooting medium, which stores soil moisture and supports vegetation that uses and removes the moisture, thereby preventing percolation below this layer. The soil rooting medium is constructed of soils with a significant fraction of fine-grained silt and clay-size particles to ensure suitable moisture retention characteristics. An advantage of the ET cover is that a fairly wide range of rooting medium soil properties may provide satisfactory performance.

The thickness of soil rooting medium needed to meet a particular performance standard varies depending on the moisture retention characteristics of the selected soils. For the borrow source survey, the thicknesses considered ranged from a minimum of 2.5 feet to a maximum of 7.5 feet. All of the variability in ET cover thickness (3 to 8 feet total) is accommodated in the soil rooting medium, with the thickness of other layers unchanged.

4.1.3 Select Fill Subgrade

Select fill material will be needed below the primary cover layers, where additional fill is needed to prepare a subgrade with appropriate slopes and where minor irregularities exist in the current ground surface. The select fill may be comprised of the same material as the soil rooting medium or may be composed of other suitable fill material with adequate strength and compaction properties. Most common fill and on-site materials are likely to meet the needs for select fill.

At MDAs C and L, similar site layout factors dictate the quantities of select fill needed. The existing site slopes at both sites generally conform to the minimum slope requirements, keeping subgrade fill quantities lower. However, both sites include disposal areas that are separated from one another, thus requiring additional subgrade fill to extend necessary slopes and establish positive drainage over the entire area. Some select fill is needed at both sites to cover irregularities in the existing ground surface and build slopes that provide favorable stormwater runoff patterns. Regrading during site decommissioning at MDA L will provide some soil and asphalt materials, which may be used as select fill to provide appropriate base grades. The material quantities required for select fill can be obtained from common sources, either on-site at LANL or from commercial quarries.

4.1.4 Soil Amendments

Soil amendments added to the topsoil may be considered as an option to aid in establishing vegetation on the ET covers. The need to add soil amendments will depend on nutrient testing of the selected borrow soil. If the erosion protection layer and soil rooting medium are composed of a Bandelier Tuff available at LANL, the material may be poor in organic matter and nutrients. Testing for soil nutrients and pH should be conducted and decisions made regarding the value of adding soil amendments to improve revegetation efforts.

Possible soil amendments may include commercial fertilizer, compost, sewage sludge, manure, other agricultural wastes, and lime. Selection of soil amendments should be investigated near the time of construction, because local availability of sludge, compost, and agricultural fertilizers can change rapidly depending on local government and commercial recycling programs. Avoiding the introduction of unwanted weed seeds is an important consideration in selecting soil amendments.

Use of soil amendments may provide LANL an opportunity to aid local governments or agricultural industries in developing solutions to organic waste reuse challenges. Many communities seek beneficial end uses for compost and sewage sludge, and LANL may look for soil amendment sources that can provide local communities with applications for available organic materials. Such a solution may provide LANL a low-cost soil amendment, while helping to meet local waste diversion goals.

4.1.5 Vegetation

Establishing vegetation on the ET covers is a key element of cover performance. Seed mix will be selected based on seed specifications that meet LANL requirements. Revegetation of the ET cover with native species provides compatibility with the surrounding environment and promotes cover longevity. Because local native seed availability varies from year to year, the proposed mixture should be reviewed before seeding to determine functional requirements and seed availability. Adjustments may be made to the specified seed mix depending on the construction schedule and the season when seeding occurs.

Revegetation plans can include irrigation during the initial revegetation effort, but if plants are well suited to the local conditions, revegetation can sometimes rely solely on natural precipitation and seed germination to promote growth. In dry years, however, seeding may fail without irrigation, which can result in additional establishment and maintenance costs. In any case, irrigation is an option for improved seed germination and establishment of plant stands on the ET covers.

The key vegetation requirement is that available soil water be fully used by the plant community during the growing season. In addition, the cover soil must provide sufficient moisture storage capability to store precipitation while plants are dormant (approximately October to March). These goals are achieved by having roots actively uptake water at different depths and times. Thus, a mixture of warm and cool season plants with varying rooting depths, as found in native prairies, should be used for effective control of infiltration. Cool season plants green up in early spring and rapidly transpire water accumulated in the soil profile during winter. Warm season plants transpire more effectively during the warm summer months. In addition, the specified seed mix should be adaptable to microclimates such as those on north- or south-facing slopes.

4.1.6 Retaining Walls at MDA C

Retaining walls planned for portions of the MDA C cover perimeter may be constructed of reinforced concrete or durable rock materials. Other retaining wall types may be considered, and more than one type may be appropriate to meet the design needs for retaining walls with various heights and subgrade slopes. The retaining wall design will need to be integrated with all of the existing facilities at the MDA C perimeter in areas where retaining walls are needed. In particular, the retaining walls will need to be designed to allow stormwater conveyance at the perimeter of the cover.

The materials used for retaining walls will be commercially available construction materials meeting the necessary design specifications. Material requirements will need to be determined through a design evaluation to consider alternatives and select the preferred design.

4.2 Preliminary Cover Layout Drawings

Preliminary drawings of the cover layout were prepared for MDAs C and L following the performance and configuration criteria described in Section 2. Two cover drawings, showing 3-foot and 8-foot cover thicknesses, were prepared for each site. The preliminary layout drawings were then used as the basis for estimating material quantities.

The preliminary cover grading was developed based on the goals of minimizing erosion and promoting cover longevity. The covers are sloped to shed stormwater relatively uniformly around the entire ET cover, eliminating focused or channelized flow. Since the ET covers promote infiltration of precipitation at the surface of the cover to minimize runoff, conventional runoff channels and detention basins are not part of the preliminary cover layouts. The cover grading provides for overland flow from the cover that is dispersed to surrounding areas without contacting waste materials or residual contaminants. Overall, the ET cover design should provide runoff characteristics similar to undisturbed native areas at LANL.

Developing cover layouts that provide for dispersed overland flow of stormwater provides advantages in meeting the ET cover longevity criteria. Eliminating conventional stormwater control systems that use conveyance channels on the cover to route stormwater to detention basins precludes the need to address the following stormwater issues, all of which represent potential obstacles to meeting the 1,000-year criterion:

- Conveyance channels and detention basins must be sized for a 1,000-year or greater design storm.
- Synthetic materials for piping and channel liners cannot be used under the longevity criteria.
- Concrete structures cannot be used, because exposed concrete will degrade over time.
- Structures must be oversized to the extent necessary to accommodate sedimentation.
- Routine maintenance, typical of most engineered stormwater systems, cannot be planned for the 1,000-year timeframe

The preliminary cover layouts provide general accommodation of existing stormwater drainage features. The layouts preserve existing drainage ditches outside the waste disposal areas and provide sufficient areas at the cover perimeter to allow future design of stormwater diversion systems.

The cover layouts assume that other LANL facilities, such as buildings, roadways, and utilities, are maintained in their current locations and configurations. As described in Section 4.2.1, the cover layout at MDA C requires accommodation of many facilities near the cover perimeter. At MDA L, facility decommissioning is planned in the areas of waste disposal, so few constraints exist (Section 4.2.2).

Existing site contours were developed at a 2-foot contour interval, to establish base grading plans of existing topography for both sites. The cover layouts use 2000 topographic data, provided by LANL as a 1-foot bare-earth digital elevation model (DEM) created by Airborne Laser Swath Mapping (ALSM; also known as light detection and ranging [LIDAR]). The LIDAR data were collected on July 1 through 9, 2000. DBS&A generated 2-foot contours from the LIDAR data using the Spatial Analyst extension of ArcMap by ESRI. The cover layouts were developed on the contour drawings of existing topography.

The cover layouts for MDAs C and L are described in detail in the following sections. Table 3 provides a summary of the cover areas.

Table 3. Summary of ET Cover Areas

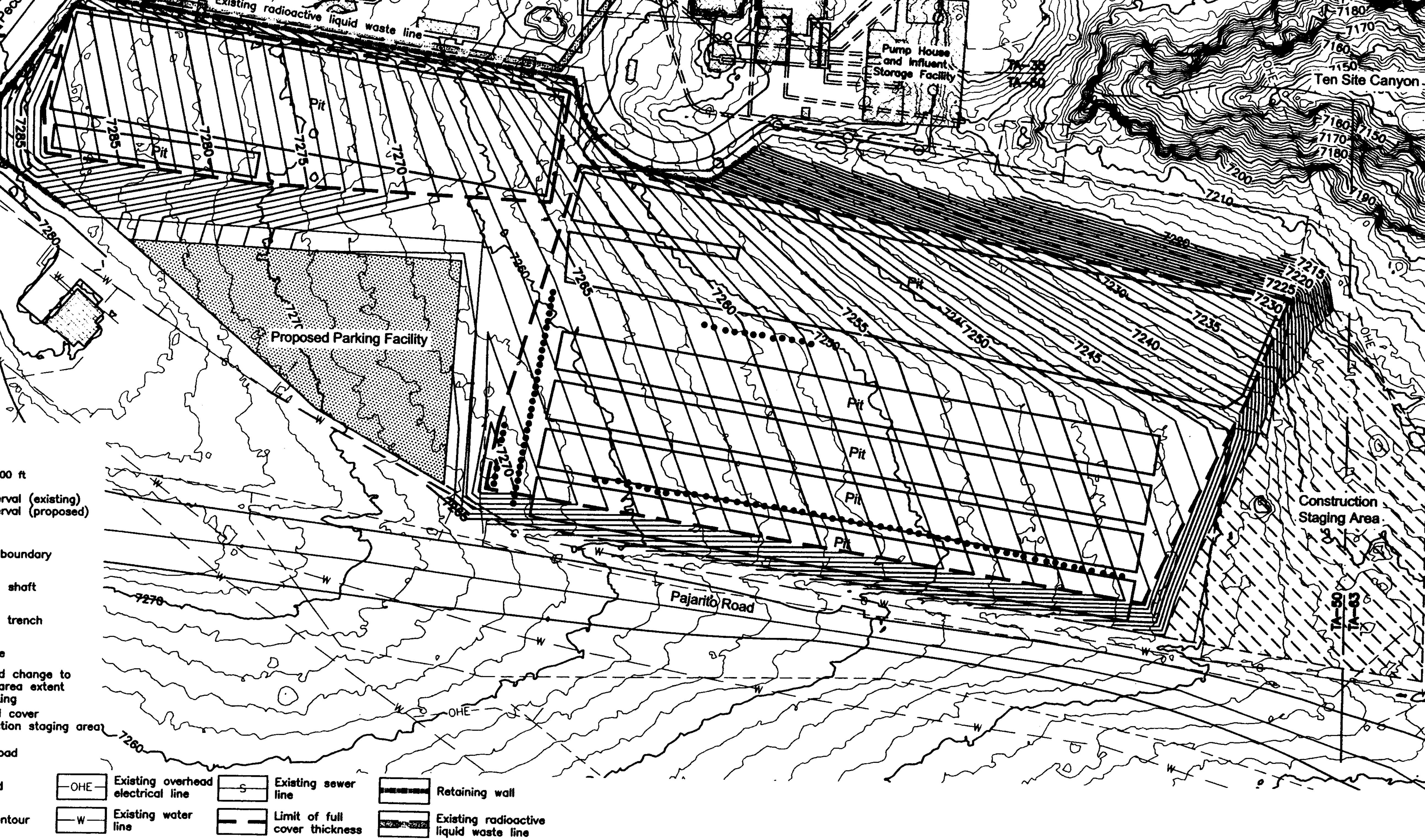
	Cover Area (acres)			
	MDA C		MDA L	
Cover Component	3-foot	8-foot	3-foot	8-foot
Waste Area [a]	7.03	7.42	0.67	0.92
Side slope	2.85	3.42	0.97	1.44
Total	9.88	10.84	1.65	2.36

[a] Area where the cover is the full specified thickness, including waste disposal area and the extension of full cover thickness outside the disposal areas.

4.2.1 MDA C

MDA C has an existing vegetated soil cover that gently slopes toward the northeast. The existing slopes range from approximately 3 to 12 percent. The slopes are graded on relatively uniform planes, with distinct slope breaks over different portions of the waste trenches. The existing soil cover at MDA C contains moderate vegetation and does not show evidence of significant erosion or gully development. The existing grades generally meet the slope criteria for the ET cover, and the cover can be constructed by placing soil over the existing grades.

The preliminary MDA C cover layout drawings for 3- and 8-foot cover thicknesses are provided in Figures 8 and 9. The MDA C footprint is 9.9 acres for the 3-foot cover and 10.8 acres for the 8-foot cover.



LANL COVER BORROW SOURCE SURVEY

MDA C Preliminary Cover Layout for 3-foot Thickness

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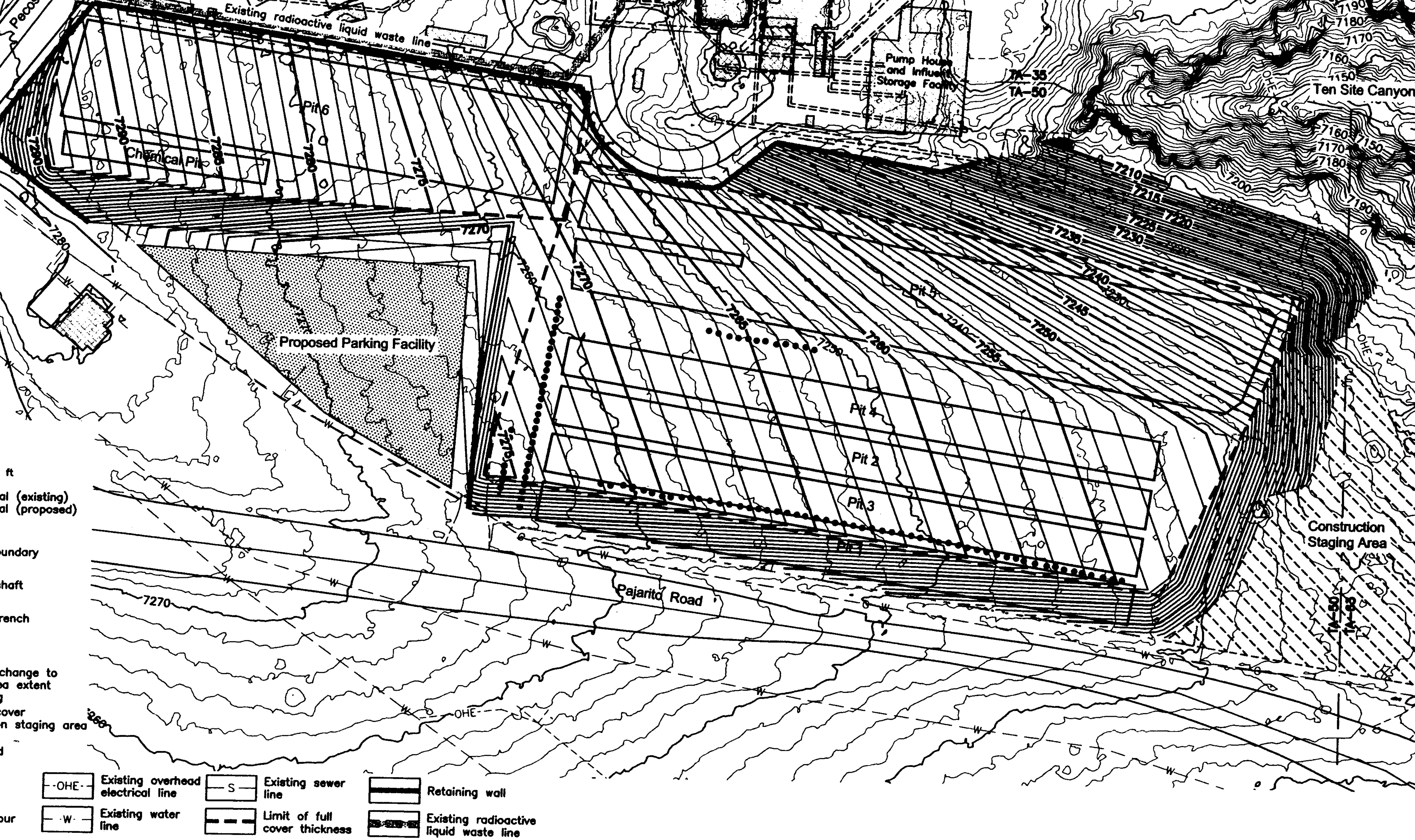

LANL COVER BORROW SOURCE SURVEY

MDA C Preliminary Cover Layout for 8-foot Thickness

B. Stephens & Associates, Inc.

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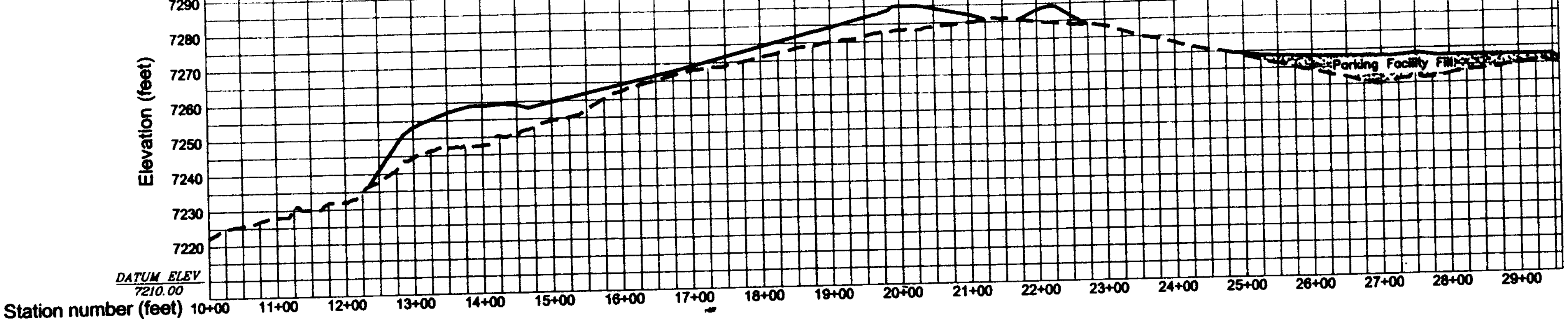
To plan a cover profile that disperses stormwater away from the cover and avoids channelized flow, the MDA C cover grading plan includes a single cover that extends across the eastern and western waste disposal areas. In the southwest portion of the site, the natural topography slopes to the northeast, toward the waste disposal areas. The run-on directed toward the waste disposal areas is focused toward an unfilled area, approximately 30 feet wide, between the eastern and western waste trenches. Rather than allowing run-on toward the waste disposal areas, with stormwater focused in a channelized area where erosion control would be difficult, the preliminary cover layout plans for a wedge of soil spanning the area between the eastern and western trenches, to shed stormwater away from the waste disposal areas. The slopes are crowned outward to disperse the overland flow.

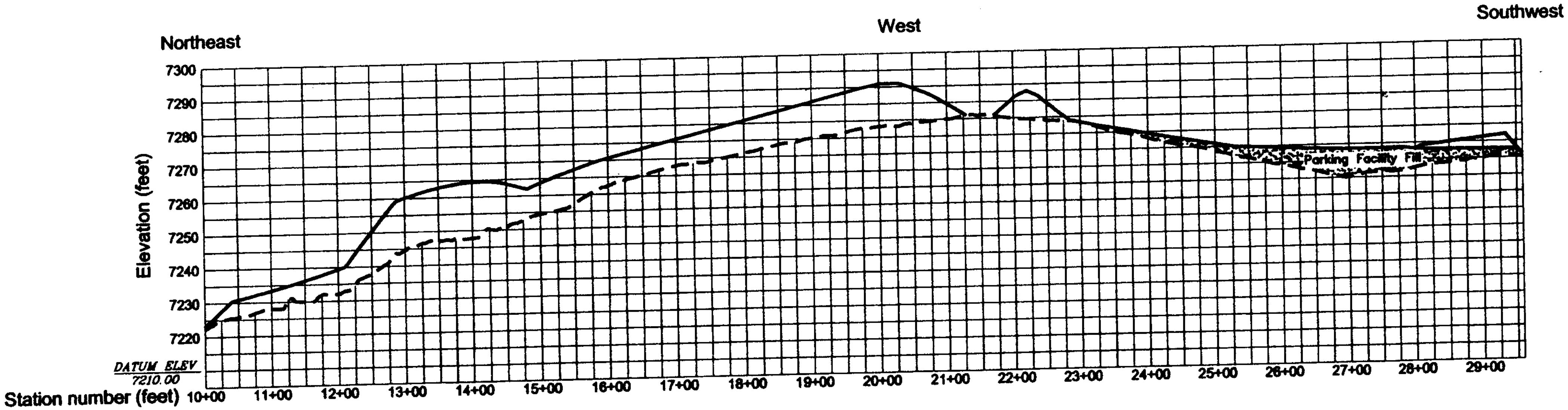
Several constraints exist at the perimeter of the cover, including buildings, roadways, existing drainage channels, temporary storage containers, and buried utilities. To provide a cover layout meeting the criteria described in Section 2—that is, full cover thickness extending two times the cover thickness outside the waste boundary and moderate side slopes of 25 to 33 percent—would require that these facilities be relocated or covered. In order to preserve the existing infrastructure, LANL has requested that the preliminary cover layout include retaining walls that terminate the cover edge to provide a setback from existing and proposed facilities (Sections 2.6 and 4.1.6). The retaining wall locations are shown in Figures 8 and 9, and profiles of the retaining wall height for the 3-foot and 8-foot covers are shown in Figure 10. The following perimeter facilities are addressed in the preliminary cover layouts:

- *TA-50 pump house and influent storage facility.* This new building is currently being constructed approximately 30 feet north of the MDA C boundary. The site drainage plan provides stormwater routing to a drainage swale located along the MDA C fence line (Austin Company, 2003). A retaining wall is provided at a 10-foot setback inside the fence line.

- *Proposed parking facility.* A new parking facility has been proposed that would occupy the southwest portion of MDA C, away from the waste disposal areas. A possible land reclassification boundary has been proposed to remove a parcel from MDA C for the parking structure (Plannerer, 2004). A 20-foot setback from the proposed boundary is provided to allow for future construction activities and a stormwater conveyance channel.



3-foot Cover Layout



8-foot Cover Layout

00 ft
ion 5X

retaining wall

ground

LANL COVER BORROW SOURCE SURVEY
MDA C Preliminary Retaining Wall Profiles

Figure 10

- *Radioactive liquid waste line.* A buried radioactive liquid waste line is located approximately 10 feet outside the western half of the northern MDA C boundary (Figure 1). A retaining wall is provided at a 5-foot setback from the radioactive liquid waste line.

- *TA-50 roadways.* Roads to TA-50 facilities are located within approximately 10 to 20 feet of the MDA C western and northern boundaries. The cover layout provides retaining walls to maintain these existing roadways. At the northwest corner of MDA C, the roadway is within the 16-foot distance for full cover thickness of the 8-foot thick cover, as called for in the preliminary cover layout criteria (Section 2.5). Retaining walls are provided at a 10-foot setback from existing roadways.

- *Pajarito Road.* Along the southern boundary of MDA C, the cover potentially encroaches on Pajarito Road, particularly for the thicker 8-foot cover. To avoid impacting this primary roadway, the preliminary layout sets the cover limit north of Pajarito Road, preserving an existing drainage ditch that runs between MDA C and the roadway. This layout was selected for two reasons:

  - Realigning Pajarito Road would be a significant expense and disruption to transportation.

  - The geophysical survey of MDA C (Appendix A) shows that the southernmost waste trench is already generally covered with between approximately 3 and 6 feet of existing soil cover.

  Limiting the extension of the side slope along the southern boundary of MDA C takes advantage of the existing soil cover to function as a part of the ET cover soil rooting medium and avoids the need for a retaining wall in this area.

- *Ten Site Canyon.* Near the northeastern corner of MDA C, relatively steep natural slopes of approximately 18 percent drop toward an escarpment at the head of Ten Site Canyon. This steep slope requires that the cover side slope be increased from the preferred slope angle of 15 percent to a maximum slope of 33 percent, in order to tie in to the existing grades above the canyon escarpment.

- *MDA C boundaries.* Around much of the MDA C perimeter, waste trenches and shafts are located very near the site boundary fence line. As a result, the cover extends beyond the existing boundary by up to 80 feet (Figure 9). In order to minimize the cover's extension beyond the boundary, side slopes were set at 25 to 33 percent in these areas. At the northeast corner of the site, the cover extends beyond the TA-50 boundary, into TA-63.

The design issues related to perimeter facilities will need to be addressed during future cover design efforts. In particular, the impacts of retaining walls on cover longevity and stormwater runoff will need to be evaluated. For the borrow source survey, the preliminary cover layout is intended to provide for reasonable planning level estimates of material quantities and costs.

4.2.2 MDA L

MDA L is the current site of a hazardous waste storage and transfer facility. Prior to construction of the ET cover, site preparation work to remove the existing infrastructure will be needed. The LANL Statement of Work for the borrow source survey indicates that the existing surface structures and asphalt surface will be removed, and the asphalt material may be considered for use in the cover.

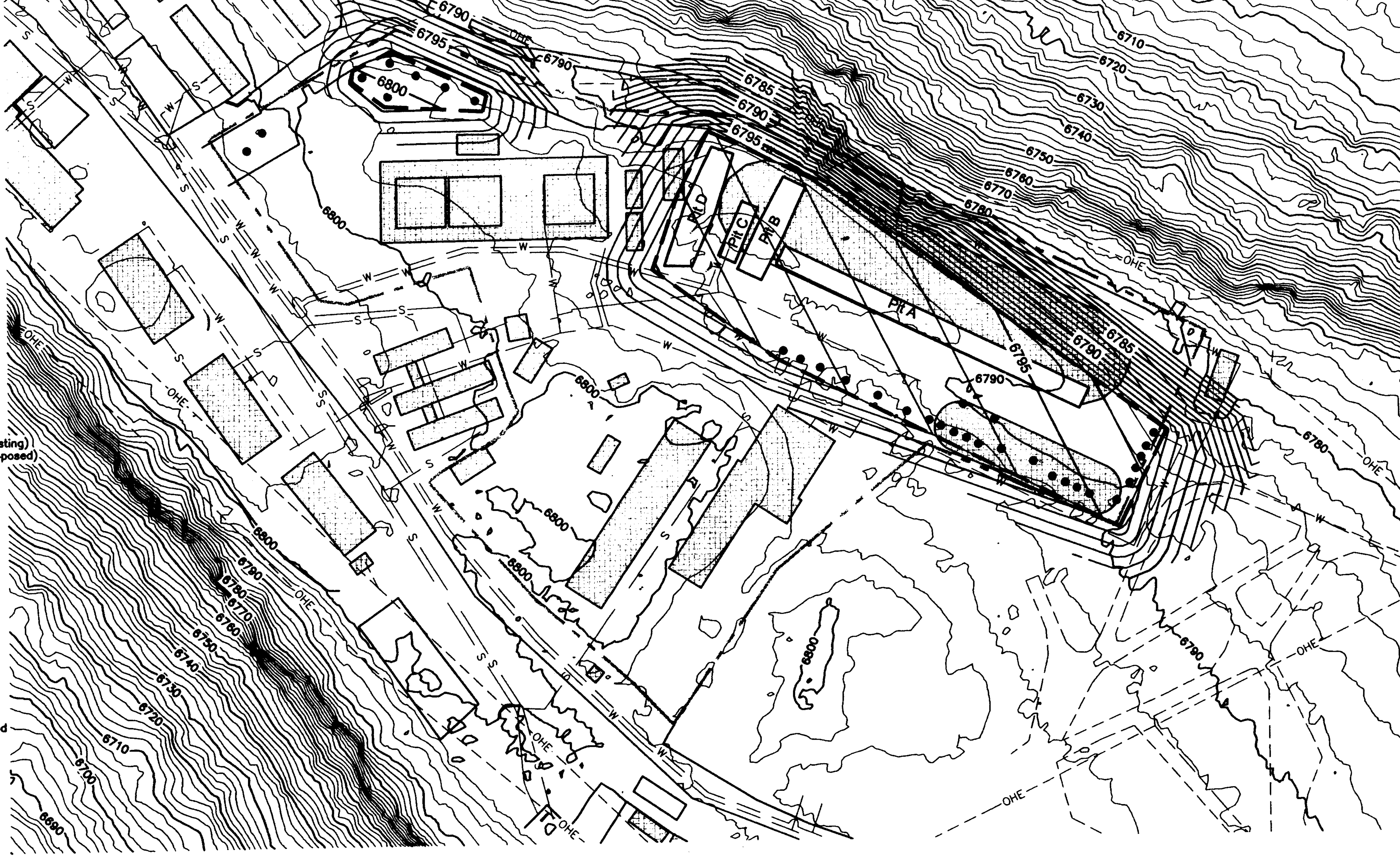
Starting with the 2000 site topography (Figure 2), a modified base grading plan (Figure 11) was developed to address asphalt removal and the gabion retaining wall that currently exists along the northern and eastern site boundaries, which will presumably need to be removed to meet the longevity criteria. The modified base grading plan reduces the existing slopes by providing minor regrading of on-site material, with the excavated material used for select fill subgrade to develop suitable cover subgrade slopes. The modified base grading plan allows for excavation of material only in areas away from the waste disposal trenches and shafts.

The MDA L cover layout for the 3-foot cover thickness includes two separate covers over the waste disposal areas (Figure 12). For the 8-foot cover thickness, the larger perimeter footprint leads to a single cover that includes all waste disposal areas (Figure 13). The cover footprint envelops 1.6 acres for the 3-foot cover and 2.4 acres for the 8-foot cover. The cover slopes are crowned outward to disperse runoff and avoid channelized flow.

For the 8-foot cover (Figure 13), a small area south of the cover perimeter will need minor regrading as part of site decommissioning efforts to avoid run-on of stormwater against the south side slope of the cover. Drainage plans can be addressed during cover design with minor regrading, but this was not planned in the preliminary cover layout, because the specific regrading needed depends upon the continued use or decommissioning of buildings in this area.

Along the northern boundary of MDA L, the cover side slope is limited at the edge of the mesa, where a steep (100 percent) northerly sloping escarpment exists. In this area, a cover slope of 45 percent is used for the side slope grading to tie in to the existing grades above the mesa edge escarpment, based on the apparent topographic limit for construction of the toe of the cover side slope. This preliminary cover layout is solely for the purpose of estimating material quantities; solutions to the escarpment site constraint at MDA L will need to be developed when designing the covers. Design solutions for the MDA L cover will be simplified if, as expected, the MDA L cover thickness is closer to 3 feet than 8 feet. Also, because radiological contaminants are not present, longevity requirements are reduced, which may allow for steeper side slopes.

The cover layout along the northern MDA L boundary also encroaches on the existing stormwater channel and the buried electrical conduit (Section 1.3). For the ET cover, the stormwater channel will not be needed, but the borrow source survey did not consider the site stormwater retention requirements that may be associated with other MDA L facilities or future land use. Eliminating the stormwater channel may have benefits in reducing infiltration just outside the limits of the waste disposal trenches. The cover also extends over the buried electrical conduit. For the borrow source survey preliminary layout, this was assumed to be acceptable. If necessary, a retaining wall could be added to the MDA L cover in this area,



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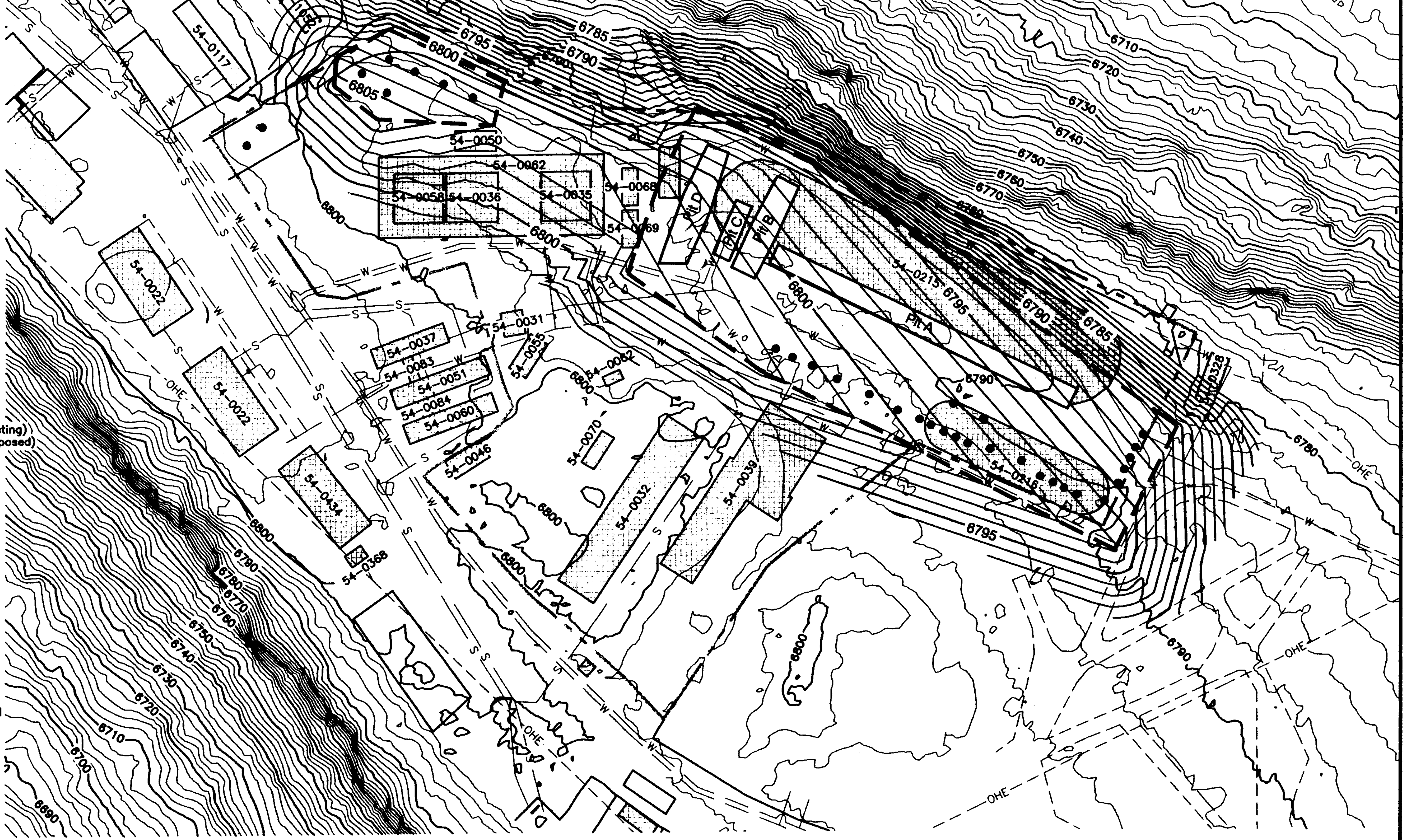
LANL COVER BORROW SOURCE SURVEY

MDA L Preliminary Cover Layout for 3-foot Thickness

Figure 12



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LANL COVER BORROW SOURCE SURVEY

MDA L Preliminary Cover Layout for 8-foot Thickness

similar to the retaining walls planned for MDA C, to prevent cover encroachment over the stormwater channel and buried conduit. The requirements for stormwater structures and utilities will need to be considered in more detail when completing the cover design.

4.3 Material Quantities

Material quantities needed for construction of the ET covers have been calculated based on the preliminary layout of final cover contours shown in Figures 8, 9, 12, and 13. The preliminary cover layouts provide reasonable general estimates of the material quantities needed. To optimize performance and cost factors, the quantities will need to be refined during the design process.

Material quantities for the construction materials described in Section 4.1 are provided in Table 4. The estimated quantities are based on the in-place material quantities in the covers, at the soil density specified when the project is designed. Soil materials used for cover construction that are purchased from commercial quarries or hauled from off-site borrow sources will generally be measured according to either the loose haul volume or tonnage. In order to account for the soil consolidation that will occur when the cover soil is placed, the quantity required for material purchase was estimated as 20 percent higher than the in-place quantity. ET covers have a relatively low compaction density of 75 to 85 percent of standard Proctor density. The final quantity calculations will need to be based on site-specific soil testing that reflects differences in density, so that such differences are accounted for in the design.

Soil quantities needed for cover construction were calculated by two methods to verify the results and provide for added quality assurance for accurate calculations. First, preliminary hand calculations were completed based on the cover area, thickness, and side slopes. More accurate final quantities were then calculated using Land Development Desktop (LDD) software linked to the AutoCAD-based cover grading plans. LDD calculates material quantities between various elevation surfaces; thus, the material quantity was determined independently for each cover layer. Finally, a 10 percent contingency was added to all quantities provided.

Table 4. Quantities of Materials for MDAs C and L

Material	3-Foot Cover			8-Foot Cover		
	In-Place Cover Volume (yd^3)	Delivered Material Quantities[a]		In-Place Cover Volume (yd^3)	Delivered Material Quantities[a]	
		yd^3	Tons[b]		yd^3	Tons[b]
MDA C						
Soil rooting medium	37,237	49,153	63,899	117,942	155,683	202,388
Top soil	7,943	10,485	13,630	8,730	11,524	14,981
Select fill	51,544	68,038	88,449	51,964	68,592	89,170
Gravel	794	1,048	1,363	873	1,152	1,498
Cobbles	794	1,048	1,363	873	1,152	1,498
Angular boulders (1- to 2-foot-diameter)[c]	1,094	1,444	1,877	2,911	3,843	4,995
Soil amendment/compost[d]	397	524	524	436	576	576
Retaining walls						
Reinforced concrete (linear foot)	1,001	1,001	1,001	1,412	1,412	1,412
Dry-stack rock (square foot)	4,571	4,571	4,571	12,333	12,333	12,333
Total[e]	99,803	131,740	171,105	183,729	242,522	315,106
MDA L						
Soil rooting medium	5,052	6,669	8,670	26,153	34,522	44,879
Top soil	1,344	1,774	2,306	1,918	2,532	3,291
Select fill	2,942	3,883	5,048	2,784	3,675	4,777
Gravel	134	177	230	192	253	329
Cobbles	134	177	230	192	253	329
Angular boulders (1- to 2-foot-diameter)[c]	543	717	932	555	733	952
Soil amendment/compost[d]	67	88	88	96	127	127
Total	10,216	13,485	17,504	31,890	42,095	54,685

[a] Delivered material quantities were calculated using the following assumptions:
Delivered volumes are 20% greater than in-place compacted volumes.
A 10% contingency factor is added to the final volumes.

[b] 1 cubic yard (yd^3) = 1.3 tons

[c] Angular boulders optional on slopes of 25 to 33 percent.

[d] Soil amendment density: 1 yd^3 = 1.0 ton

[e] Retaining wall quantities omitted from material quantity total.

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Table 4 provides quantities for 3-foot and 8-foot covers for MDAs C and L. Total material quantities for the two cover thicknesses range from 132,000 to 243,000 yd^3 for MDA C and 13,000 to 42,000 yd^3 for MDA L. For intermediate cover thicknesses that may be designed, material quantities can be estimated by linear extrapolation between the two end-member thicknesses. Typical ET cover designs for semiarid climatic conditions similar to those at LANL achieve adequate infiltration reduction performance with a cover thickness of 3 to 4 feet.

The quantities are broken down into the various component materials, including soil rooting medium, topsoil, gravel, cobbles, boulders, select fill, and soil amendments. The material quantities for the soil rooting medium, topsoil, and select fill are based on direct calculations. Quantities of gravel, cobbles, and soil amendments for the topsoil and erosion protection layer were based on a percentage of the topsoil volume. To be conservative, these material quantities were simply added to the topsoil, without deducting the equivalent volume in the 6-inch topsoil layer.

For the possible alternative to use angular boulders for reinforcement on steep slopes, the boulder volume was estimated as 30 percent of a 2-foot layer of rock and soil on the side slope areas with slopes of 25 percent or greater. Whether boulder armoring is needed and, if so, whether the boulder armoring uses only boulders, a boulder and soil admixture, or buttress structures will need to be determined during cover design.

Material quantities for retaining walls at MDA C are provided in terms of linear feet for the reinforced concrete option and square feet for the dry-stack rock option. As shown in Figures 8 and 9, the retaining wall profile follows a line around the western and northern perimeter of the cover, beginning at the southwest corner of the cover and ending at the northeast corner of the cover. Most of the northern and western limits of the cover are bounded by retaining walls. The retaining wall length ranges from 1,000 to 1,400 feet for the 3-foot and 8-foot thick covers, respectively (Table 5). The maximum retaining wall height exceeds the planned cover thickness in places due to irregularities in the existing ground surface and cover layouts that provide relatively uniform grades.

Table 5. Summary of MDA C Retaining Wall Quantities

MDA C Cover	Retaining Wall Dimensions			
	Length (feet)	Height (feet)		Surface Area (square feet)
		Average	Maximum	
3-foot	1,001	4.6	11	4,571
8-foot	1,412	8.7	16	12,333

5. Borrow Source Identification

The borrow source survey examined a wide range of potentially feasible options to obtain materials for the ET covers. Potential borrow sources include existing commercial providers of earthen materials and new borrow sites where suitable material could be obtained. This section describes the materials available, borrow source locations, and contacts made to obtain information on material availability and costs.

This section also outlines strategies that LANL may consider pursuing to obtain and stockpile materials that may be periodically available at low cost. Through material procurement practices and contract incentives, LANL may be able to obtain materials in conjunction with other LANL construction projects, or from other construction in the local area, at lower costs than if material is procured at the time of ET cover construction.

Information presented in this section was obtained in part from regional reports and GIS databases. More detailed information was obtained by contacting commercial quarries, earthwork contractors, and land owners (including LANL). Information was collected for the geographical region considered feasible for cost-effective import of material to LANL.

5.1 Preliminary Borrow Source Selection Criteria

A variety of soil borrow sources, including on-site material at LANL, off-site commercial quarries, and off-site public and private land owners, may be considered as sources of suitable soil for construction of the ET covers at MDAs C and L and the other MDAs where final covers will be needed. Numerous factors must be considered in selecting the final borrow sources for various materials. This section describes the primary criteria for selection of material borrow sources. These selection criteria are preliminary; final decisions on borrow source selection will be made after the cover design and material specifications are developed and material testing is completed.

5.1.1 Land Ownership

Land ownership in the region is shown in Figure 14. The likely sources of borrow material include land owned by LANL, private owners, pueblos, the Bureau of Land Management (BLM), and the State of New Mexico. Land controlled by the U.S. Forest Service and National Park Service, which dominates the area west of LANL, is considered an unlikely source of borrow material.

5.1.2 Commercial or New Site

Borrow material may be obtained from existing commercial quarries or from new borrow pits opened specifically for ET cover construction. Many potential sources and types of soil and rock materials are available for construction of the ET covers.

Commercial quarries are described in the directory of mines, mills, and quarries in New Mexico, published biennially (most recently 2001) by the New Mexico Mining and Minerals Division (available at http://www.emnrd.state.nm.us/Mining/etc/MinesComplete.pdf). The locations of mines listed in the directory are shown on the land ownership map in Figure 14, and copies of the directory's listings for Los Alamos, Rio Arriba, Sandoval, and Santa Fe Counties are included in Appendix B. Most of the mines in this area are sand and gravel mining operations; 11 are located within a radius of approximately 30 miles from LANL.

Commercial sand and gravel mines generally produce high-value gravel and rock products and avoid much of the fine-grained material at the mine. Because larger cobbles and gravel are separated by screening for commercial purposes, the remaining fines are often stockpiled and unused. This material can be well suited for construction of ET covers, and because it has minimal commercial value, it may be obtained at favorable prices.

Opening a new borrow site at LANL may provide a cost-effective option to obtain material, particularly if suitable soil or tuff can be excavated near the cover construction projects. Material costs are much lower for materials excavated and hauled short distances using heavy construction equipment (i.e., scrapers or excavators and haul trucks) than for material loaded and hauled in over-the-road trucks.

Explanation

- Highway/road
- Borrow pit
- River/stream
- 30-mile Buffer

Land ownership

- Bureau of Land Management
- Department of Defense
- Department of Energy
- U.S. Forest Service
- Tribal
- National Park Service
- Private
- State

Source:
Land ownership data: BLM New Mexico, Geo Sciences Team.
Quarry pit locations: New Mexico Energy, Minerals and Natural Resources Department and New Mexico Bureau of Geology and Mineral Resources

LANL COVER BORROW SOURCE S

Potential Borrow Source Pits and Land Own

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7-06-04
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Figure 14

Because suitable soils or tuff on nearby property may provide cost-effective material acquisition, LANL properties near the MDAs should be carefully considered for on-site excavation. New material borrow areas may also be used to accommodate future development planned by LANL, by locating borrow areas at the sites of future construction projects and designing excavation plans to create the final contours needed for the new construction. A new borrow site may be opened adjacent to specific MDAs or at a location that will serve multiple cover construction projects at several MDAs. Open land on and adjacent to MDA C may provide locations where a new borrow source could be considered. At MDA L, nearby borrow sources may not be available, due to the limited land base on the narrow Mesita del Buey.

5.1.3 Haul Distance

Hauling costs to transport off-site material to LANL represent the majority of the cost for material purchased from commercial quarries. Since hauling costs rise with increasing distances, the borrow source survey examined only potential borrow sources within a radius of approximately 30 miles around LANL. More distant borrow sources may be considered, but ultimately, the most cost-effective acquisition of materials will likely be from closer material sources. For material cost estimating purposes, limiting the area considered for material acquisition provides the most likely reasonable costs.

5.1.4 Transportation Impacts

Off-site borrow sources within LANL or from more distant quarries will require that suitable haul routes be established to transport materials. Transport from an off-site source will involve hauling over public roadways, which will impact local traffic and public safety. The material quantities for this project are significant, and depending on the design options selected and quantity of off-site materials used, many thousands of truckloads of material may be shipped. Possible restrictions on the number of haul trucks allowable on public roadways may be a limiting factor in the construction schedule. In this case, access routes and transportation plans to haul soil from off-site sources will be a key constructibility issue.

Customary haul trucks for aggregate materials carry approximately 22 tons per load, with capacity limited by highway weight restrictions. Thus, approximately 17,000 truckloads will be required to transport the 370,000 tons expected for cover construction at MDAs C and L. For a typical construction schedule (3 to 6 months for covers with the acreage of MDAs C and L), the daily traffic impact may be on the order of 100 to 200 truckloads per day. The impact of this truck traffic will need to be evaluated before the projects begin and may require extending the timeframe when material transportation occurs, in which case interim stockpiling on-site would be needed.

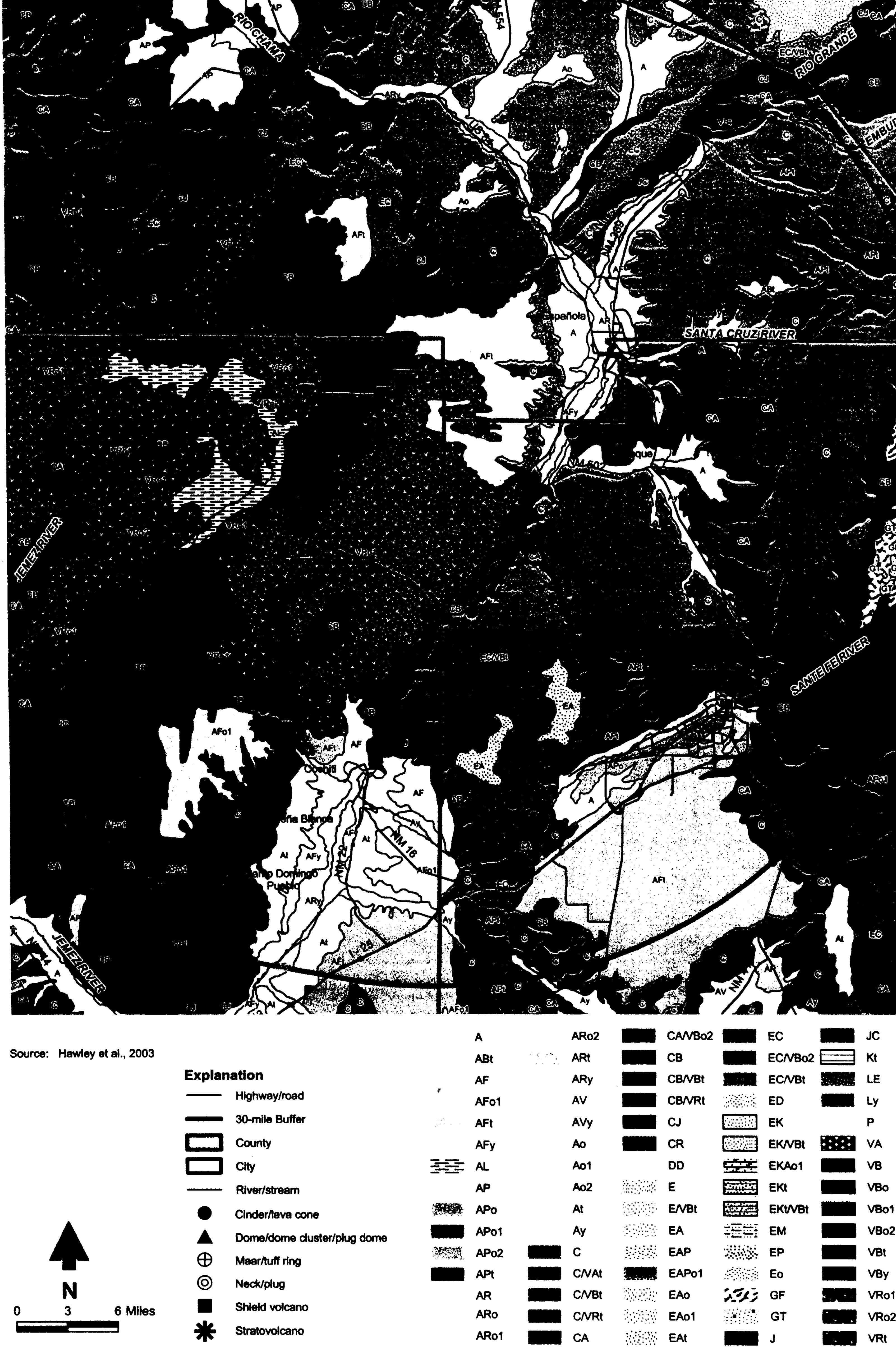
For transport of all material for the site-wide MDA covers, a total of approximately 200,000 truckloads of material could be required. This is based on in-place cover material volumes up to approximately 3,000,000 yd^3 (Section 1.3), a 20 percent bulking factor in haul trucks, and a loose soil density of 1.3 tons per cubic yard, yielding a total of 4,680,000 tons. This material will be transported during various phases of cover construction over several years. Traffic impact studies will be needed for haul routes to each MDA.

5.1.5 Excavation Potential

The excavation potential of soil and rock materials is an important consideration in selecting a new borrow site, especially when considering excavation of tuff at or near LANL. Excavation potential should also be considered if new borrow sites are considered in the Santa Fe Group, which contains some zones of moderately consolidated sediments. Of course, this is not a consideration for materials purchased from commercial quarries.

Figure 15 presents a map of surficial geology, which provides valuable information on the excavation potential in areas surrounding Los Alamos. More detailed descriptions of the surficial geology associated with this map are provided in Appendix C. The surficial geology map describes the physical properties of materials in the upper 50 to 100 feet of ground surface and is more useful to determine excavation potential than a typical soils map.

In the LANL area, the Bandelier Tuff contains both welded and non-welded units. The non-welded units will provide much easier and more cost-effective excavation and also provide superior handling and material properties for ET cover construction. The welded units may be difficult to excavate with conventional excavation practices, in which case excavation costs would increase.



LANL COVER BORROW SOURCE S

Surficial Geologic Ma

Figure 15

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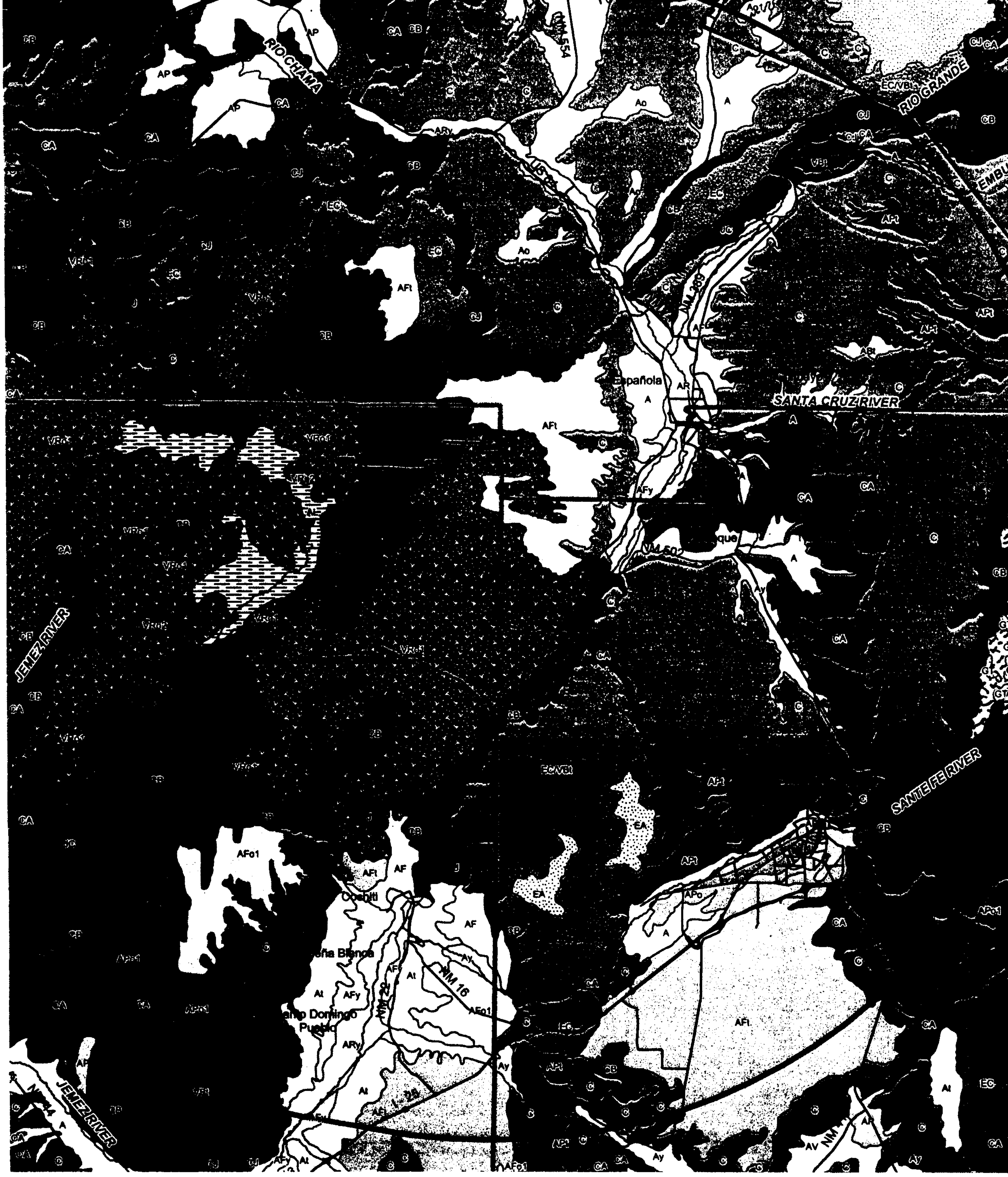

Source: Hawley et al., 2003

Explanation

- Highway/road
- 30-mile Buffer
- County
- City
- River/stream
- Cinder/lava cone
- Dome/dome cluster/plug dome
- Maar/tuff ring
- Neck/plug
- Shield volcano
- Stratovolcano

N

0 3 6 Miles

A	ARo2	CA/VBo2	EC	JC
ABt	ARt	CB	EC/VBo2	Kt
AF	ARy	CB/VBt	EC/VBt	LE
AFo1	AV	CB/VRt	ED	Ly
AFt	AVy	CJ	EK	P
AFy	Ao	CR	EK/VBt	VA
AL	Ao1	DD	EKAo1	VB
AP	Ao2	E	EKt	VBo
APo	At	E/VBt	EKt/VBt	VBo1
APo1	Ay	EA	EM	VBo2
APo2	C	EAP	EP	VBt
APt	C/VAt	EAPo1	Eo	VBy
AR	C/VBt	EAo	GF	VRo1
ARo	C/VRt	EAo1	GT	VRo2
ARo1	CA	EAt	J	VRt

Note: Explanations of symbols are attached

LANL COVER BORROW SOURCE S

Surficial Geologic Ma

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7-06-04
JN ES04.0075

Figure 15

ol	Surficial Geology Description [b] Description
	Alluvium-undivided
	Alluvium; undifferentiated ay and a_2
	Bolson-floor alluvium-undivided
	Alluvial-Pliocene and lower Pleistocene
	Fan alluvium-undivided
	Fan alluvium
	Fan alluvium--older (undivided)
	Fan alluvium - older (early phase)
	Alluvium-older (undivided)
	Alluvium-older (early phase)
	Fan alluvium--middle Pleistocene to Pliocene
	Fan alluvium—younger
	No description
	Alluvium on erosion surfaces--piedmont and escarpment footslopes
	Erosion-surface-cover
	Erosion-surface-cover alluvium--older (undivided)
	Alluvium-older (early phase)
	Erosion-surface cover alluvium--older (early phase)
	Alluvium-older(late phase)
	Erosion-surface-cover--older (late phase)
	Alluvium on erosion surfaces--piedmont and escarpment footslopes
	Alluvial-Pliocene and lower Pleistocene
	River alluvium
	River alluvium-older (undivided)
	River alluvium-older (undivided)
	Alluvium-older (early phase)
	River alluvium-older (early phase)
	River alluvium-older (undivided)
	Alluvium-older (late phase)
	River alluvium-older (late phase)
	River alluvium-Pliocene and lower Pleistocene
	River alluvium-younger
	Valley-fill Alluvium
	Valley fill

Map Symbol	Surficial Geology Description [b] Symbol	Description
AVy	avy	Valley fill-younger
Ao	ao	Alluvium-older (undivided)
Ao1	ao	Alluvium-older (undivided)
	a_1	Alluvium-older (early phase)
Ao2	ao	Alluvium-older (undivided)
	a_2	Alluvium-older (late phase)
At	at	Alluvial-Pliocene and lower Pleistocene
Ay	ay	Alluvium-younger
C	c	Colluvium-undivided
C/VAt	c	Colluvium-undivided
	v	Volcanic Rocks-undivided
	at	Alluvial-Pliocene and lower Pleistocene
C/VBt	c	Colluvium-undivided
	vbt	Basaltic volcanic--Pliocene to early Pleistocene
C/VRt	c	Colluvium-undivided
	vrt	Dacitic to rhyolitic volcanoes
CA	---	No description
CA/VBo2	---	No description
CB	cb	Block-rubble Colluvium
CB/VBt	cb	Block-rubble Colluvium
	vbt	Basaltic volcanic--Pliocene to early Pleistocene
CB/VRt	cb	Block-rubble Colluvium
	vrt	Dacitic to rhyolitic volcanoes
CJ	jc, cj	Colluvium-landslide complexes
CR	cr	Colluvium with large areas of bedrock outcrop (usually >50%)
DD	dd	Fills of deflational depressions
E	e	Eolian deposits - undivided
E/VBt	e	Eolian deposits - undivided
	vbt	Basaltic volcanic--Pliocene to early Pleistocene
EA	---	No description
EAP	---	No description
EAPo1	---	No description
EAo	---	No description
EAo1	---	No description

Map Symbol	Surficial Geology Description [b] Symbol	Description
EAt	---	No description
EC	---	No description
EC/VBo2	---	No description
EC/VBt	vbt	Basaltic volcanic--Pliocene to early Pleistocene
ED	ed	Dune sand
EK	---	No description
EK/VBt	vbt	Basaltic volcanic--Pliocene to early Pleistocene
EKAo1	---	No description
EKt	ekt	Eolian veneer up to 1-3 m thick on kt
EKt/VBt	ekt	Eolian veneer up to 1-3 m thick on kt
	vbt	Basaltic volcanic--Pliocene to early Pleistocene
EM	em	Eolian loamy sand to sandy clay loam--older
EP	---	No description
EO	---	No description
GF	---	No description
GT	---	No description
J	j	Landslides-undivided
JC	jc, cj	Colluvium-landslide complexes
Kt	kt	Caprock Calcrete
LE	le	Complex of ly and el
Ly	ly	Lacustrine deposit--younger
P	p	Playa deposit
VA	va	Andesite
VB	vb	Basalt flows
VBo	---	No description
VBo1	vb_1	Basaltic volcanics—older (early to middle Pleistocene)
VBo2	vb_2	Basaltic volcanics—older (Middle to late Pleistocene)
VBt	vbt	Basaltic volcanic--Pliocene to early Pleistocene
VBy	vby	Late Wisconsin--Holocene
VRo1	---	No description
VRo2	vr_2	Rhyolitic volcanics
VRt	vrt	Dacitic to rhyolitic volcanoes

J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico*. Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.
vided with map are included as Appendix C.

--- = No symbol provided similar to that found on the map

The upper Tshirege Member of the Bandelier Tuff is present at both MDAs C and L. The Tshirege Member contains interbedded layers of welded and non-welded units, as described in Section 3.5. Non-welded tuff in the Tshirege Member near MDA C may provide a good borrow material source. The lower Otowi Member of the Bandelier Tuff, which is entirely non-welded, may also provide a material source with good excavation potential where the Otowi is exposed on the east side of LANL.

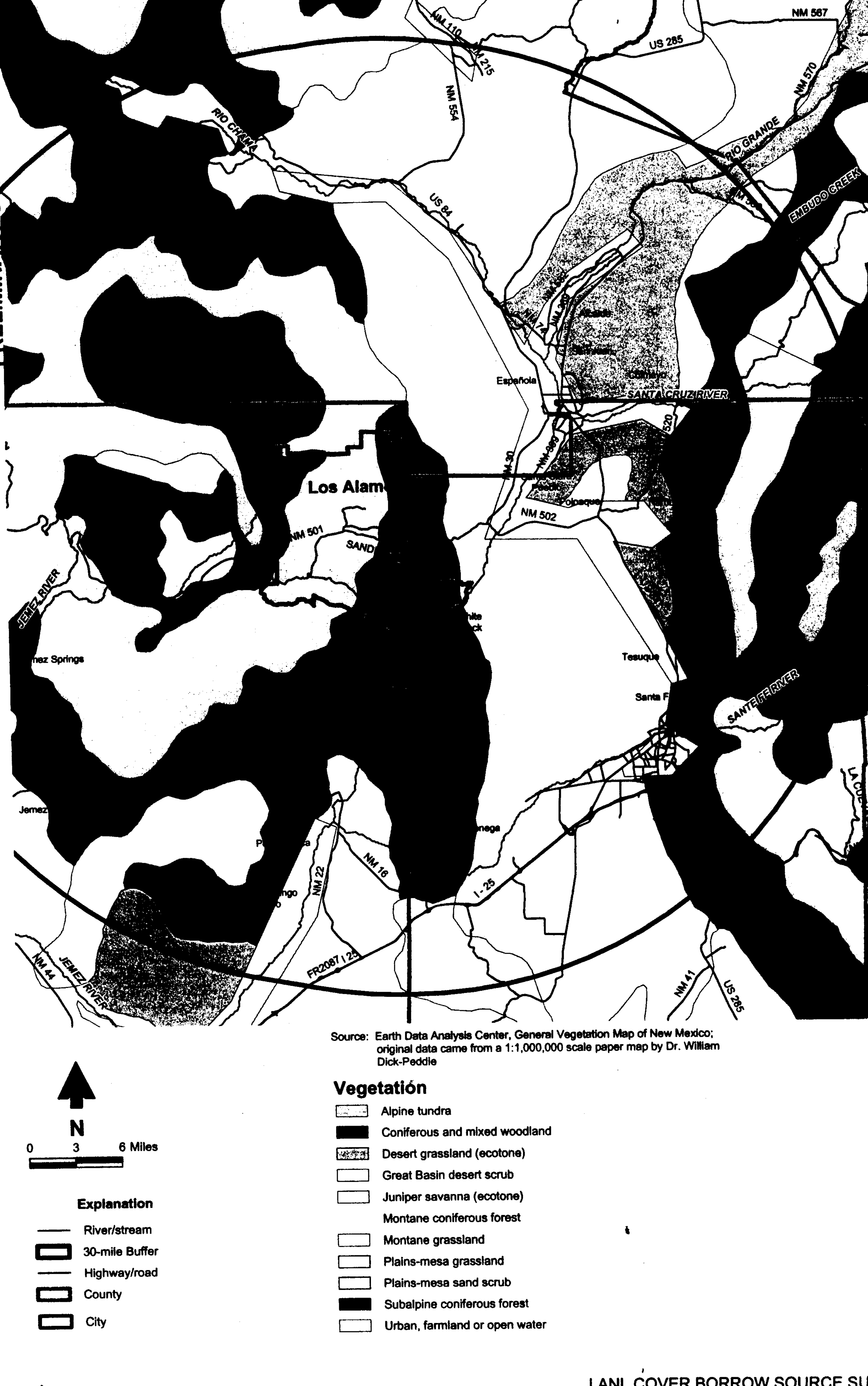
5.1.6 Environmental or Cultural Impacts

Environmental and cultural impacts must be evaluated in accordance with National Environmental Policy Act (NEPA) requirements. These requirements include completing either (1) a Finding of No Significant Impact (FONSI), (2) an Environmental Assessment (EA), or (3) an Environmental Impact Statement (EIS). These requirements will apply to the ET cover projects whether on-site or off-site borrow sources are selected, although for off-site commercial quarries, the requirements are likely to be less stringent (likely FONSI) than the requirements associated with developing a new borrow source at LANL (likely EA or EIS). Specific planning under the LANL site-wide EIS with LANL NEPA personnel will help to steer the search for potential borrow sources to locations where NEPA compliance is feasible and avoid locations where significant obstacles may exist.

Within LANL, archaeological sites are abundant and place significant limitations on siting new borrow sources. Information on archaeological sites is available with LANL, but is restricted from publication, so is not included here in detail.

A regional vegetation map is provided in Figure 16. In general, favorable areas for borrow sources will be located in urban and developed areas, where most of the commercial quarries are located, and in open plains and grassland. Areas away from watercourses are preferred to avoid endangered species habitat and wetlands. Forested areas will generally present more of a challenge in siting a new borrow source location.

The level of effort and associated cost of NEPA compliance is highly variable at different sites and therefore must be considered on a site-specific basis. Further consultation with NEPA



LANL COVER BORROW SOURCE SU

Vegeta

Figure 16

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experts regarding the LANL site-wide EIS will be needed to develop site-specific cost estimates and timelines for NEPA compliance for the borrow sources under consideration.

5.2 Material Stockpile Strategies

Earthwork materials become available periodically from a variety of construction projects at LANL and regionally, and acquiring low-cost material when available may provide LANL a cost-effective approach to obtaining the ET cover materials. LANL can consider strategies to promote acquisition of suitable low-cost material when available, and this material may be stockpiled until needed for ET cover construction. For instance, in researching material costs, DBS&A found two examples of large quantities of material that became available in recent months. In the first example, approximately 200,000 yd^3 of sediment was reportedly removed from a sediment retention structure and used for off-site fill. In another case, approximately 500,000 yd^3 of stockpiled soil became available from a shopping center construction project. While the details of these cases have not been verified, they illustrate situations that can generate low-cost borrow material.

Material procurement must follow LANL procurement and contracting processes. LANL can consider developing contract mechanisms that will provide for procurement and stockpiling of low-cost material when sources are identified. Procurement processes will need to facilitate the rapid purchase and transport of excess material that can become available on short notice from various construction projects.

Construction projects sometimes generate excess fill, and fill is sometimes needed. A common goal of many earthwork design projects is to design for a soil balance--that is, to cut soil in one area and use it to fill in another area--to make best use of on-site soils and minimize costs. LANL could consider implementing a system of contractual incentives to generate and stockpile material from LANL construction projects. For example, LANL might establish a payment schedule for suitable material delivered to an MDA stockpile area or other central stockpile location. The payment schedule could be structured such that a design engineer for a given project may find it advantageous to design for the generation of excess material. The construction contractor on the project would then receive payment for material excavated from a construction site and delivered to the stockpile location.

A list of construction projects proposed by LANL Planning and Development for 2005 through 2012 is provided in Appendix D. To illustrate the potential to generate material from LANL construction projects, consider the earthwork to level an area for a new parking lot at one of these proposed facilities. The entire parking lot may be designed 3 feet lower in elevation, generating a great deal of excess soil or tuff. This material could be purchased by LANL and stockpiled for use in the ET covers. In turn, the parking lot construction would save the expense of recompacting soil that would normally be performed with a cut-to-fill soil-balance design. Since this approach would generate material near the ET cover construction projects, transportation costs would be kept low, and material costs might be kept well below the costs for material from commercial sources. This approach would also avoid NEPA compliance requirements beyond the NEPA process already conducted for the construction project.

At MDA C, sufficient land is available on-site to begin stockpiling soil prior to cover construction. At MDA L, stockpiling may not be feasible unless stockpiles are established after the planned decommissioning of the existing facilities. For many years, soil, concrete, and other earthwork materials have been periodically stockpiled at the LANL Sigma Mesa site and the Los Alamos County Landfill. These or other locations could serve as interim stockpile sites for ET cover materials. For material stockpiled at an off-site location, the added cost to reload and transport the material a second time must be considered.

5.3 Potential LANL Borrow Sources

The borrow source survey identified certain potential borrow sources at LANL, and other new borrow sources may also be developed within LANL property. LANL owns the mineral rights within its property, so the material is available for potential borrow source development (Louderbough, 2004). To move forward with on-site borrow at LANL, the primary issues needing further consideration concern NEPA compliance and costs for specific sites.

To examine potential LANL borrow sources in detail, four U.S. Geological Survey geologic quadrangle maps are provided in Appendix E. These maps have been adapted for the borrow source survey by overlaying the LANL TA boundaries and the locations of MDAs where covers are planned (Table 1). The maps can be used for specific examination of potential LANL borrow sources to consider both the geology and operations at a particular TA.

Detailed geologic maps of the Bandelier Tuff units at LANL are also available (Rogers, 1995). This information is a key resource to identify areas of non-welded tuff, which can be excavated cost-effectively and possesses moisture retention and handling properties favorable for ET cover construction. Open parcels near MDA C, in areas of non-welded tuff, may be suitable for on-site borrow sources. Additional efforts should be made to secure a borrow site near MDA C that is compatible with future land use plans. A borrow source at MDA C might also provide a source of material for nearby MDA L.

LANL has an existing tuff borrow pit at TA-61 (Booth, 2003). This site should be considered in more detail by characterizing the potential tuff quantity available and determining the management plans for the site. The TA-61 borrow pit is also a potential site being considered by LANL and Los Alamos County for a new County landfill (Booth, 2003). A second site at TA-60, the East Sigma Mesa site, is also being considered for development as a solid waste landfill. Because landfill development requires excavation of disposal cells, these sites may provide excess tuff that can be used in ET covers. Whether or not one of these sites is developed as a landfill, they may provide feasible locations for borrow material excavation. Each site is approximately 50 acres, which could provide a significant quantity of material for construction of the covers at MDAs C and L and at additional sites.

Two sediment retention/flood control structures were built at LANL following the 2000 Cerro Grande fire (Tickner, 2000; Veenis, 2000), and the planned removal of these structures between 2005 and 2010 as the watersheds become revegetated (NNSA, 2002) may provide a source of material for cover construction. The largest structure is a 72-foot-high retention dam, constructed of roller-compacted concrete (RCC) across Pajarito Canyon upstream from TA-18. The other is the "low-head weir" in Los Alamos Canyon near State Route 4. Either the dam materials themselves or accumulated sediments may provide materials that could be used for cover construction. The sediments may provide suitable material for ET covers, as long as contaminants do not restrict their use. The RCC to be removed amounts to approximately 50,000 yd^3 (U.S. DOE, 2002), but this material can probably only serve as the select fill for subgrade preparation in covers that require significant fill to develop suitable slopes. The RCC may be useful at MDA C, where approximately 68,000 yd^3 of subgrade fill are needed. Whether this proves feasible will depend on the timing of retention dam removal and cover construction.

5.4 Potential Off-Site Borrow Sources

Potential off-site borrow sources include commercial quarries and new borrow excavations on land owned by private owners, BLM, the State of New Mexico, and nearby Pueblos. These potential sources include operations that produce aggregate materials, but also sources of other materials needed for ET cover construction, such as seed mix and soil amendments. Included in this category are publicly owned wastewater treatment works that may sell or otherwise provide sludge as a soil amendment. A list of entities contacted for the borrow source survey, including commercial sources and other public entities where borrow sources may be obtained, is included in Table 6.

Various private land owners may be sources of borrow material. In making contacts for the borrow source survey, information was obtained concerning various land owners who from time to time seek out construction contractors for possible sale of materials from their land. In the case of an advertised procurement for materials, additional property owners may come forward with proposals for sale of materials.

5.5 Quantities Potentially Available

The total quantity of material needed for ET covers at both MDAs C and L is not expected to exceed 370,000 yd^3. The LANL Statement of Work for the borrow source survey requests that material sources be identified that can provide up to 200 percent of the material required; thus, to be conservative, up to 740,000 yd^3 should potentially be available, and as discussed in Section 1.3, up to approximately 3,000,000 yd^3 of material could be required for the site-wide

MDA covers. Based on contacts with commercial quarries and earthwork contractors, material quantities of this magnitude are readily available.

Table 6. Contacts for Potential Off-Site Borrow Sources

Agency	Address
Commercial	
Espanola Transit Mix	P.O. Box 38, Espanola, NM 87532
Western Mobile, Inc. / LaFarge	P.O. Box 27328, Albuquerque, NM 87125-7328
SG Western Construction	P.O. Box 729 Los Alamos, NM 87544
Central Concrete Products, Inc.	3 Demas Rd, Santa Fe, NM 87505
KSL Services, Inc.	P.O. Box 80, Los Alamos, NM 87544
Paul Parker Construction	P.O. Box 549, Los Alamos, NM 87544
Ulibarri Landscaping Material, Inc.	Route 6 Box 5, Santa Fe, NM 87501
MRT, Inc.	7335 Second St, Albuquerque, NM
MCT Transportation, Inc.	7451 Pan American Freeway NE, Albuquerque, NM 87109
Pueblos	
Pojoaque Pueblo	Tribal Works Office
Santa Clara Pueblo	Governor's Office
Government	
Los Alamos County	Waste Water Treatment Plant
	Pavement and Roads Division
City of Espanola	Waste Water Treatment Plant
Bureau of Land Management	Taos Field Office, 2226 Crux Alta Rd, Taos, NM 87571-5893
New Mexico Department of Transportation	District 3 Engineer

If an on-site borrow source at LANL is used, the size of a borrow pit becomes quite significant. Tuff could be excavated from one large borrow source or multiple smaller sources. Assuming that 3,000,000 yd^3 of tuff were to be excavated at one location, a 40-foot-deep pit over nearly 50 acres would be needed. Thus, for LANL to plan for on-site borrow material for all covers, a site with suitable material covering more than 50 acres will need to be identified.

6. Cover Material Cost Estimates

This section presents material cost information obtained for the soil borrow survey and compiles a complete cost estimate for the materials needed for ET covers at MDAs C and L. Cost information was obtained from commercial sources, earthwork contractors, trucking companies, and standard cost-estimating guides. Using the preliminary cover layouts and material quantity estimates, cost estimates were developed for the typical costs expected for on-site and off-site borrow sources.

The preliminary cost estimates include acquisition, excavation, and hauling of all the materials required for the covers. The costs are considered to be reasonable planning-level estimates, and a contingency percentage is added for financial planning. Of course, the final cost for material acquisition will depend on whether on-site or off-site borrow sources are selected and on actual competitive bid prices that are obtained at the time of construction. In addition, the preliminary cost estimates are not complete project cost estimates including design, construction, and all associated costs. Costs for environmental studies that are associated with material acquisition need to be considered; however, because these costs vary greatly, depending on whether a FONSI, EA, or EIS is needed, environmental cost estimates should be addressed along with selection of the borrow sources. Costs are reported in current dollars, with financial planning and present worth considerations related to the MDA cover construction schedule left for LANL to consider.

6.1 Cost Estimate Approach

For the purpose of establishing reasonable material cost estimates, material cost information was obtained from numerous sources. Cost information was obtained from contacts made with local commercial material providers, haulers, owners of land from which borrow material has been obtained, and construction contractors. These types of sources provide cost estimating accuracy by reflecting local knowledge and pricing. These sources are also representative of the actual material sources that will be among the feasible options when material is actually obtained for construction.

In similar cost estimating efforts, DBS&A has found that commercial businesses can be reluctant to provide cost information for projects that are being planned years in advance of actual construction. The businesses sometimes feel they may lose some competitive advantage in bidding on future projects if pricing information is made public. In order to facilitate gathering of accurate cost information from multiple sources, the cost information is presented in a non-specific manner. A list of contacts providing information is reported in Section 5.4, but the various cost details do not indicate which specific companies provided the information, so that no company gains any particular advantage. DBS&A has used the price quotes collected to develop reasonable average prices that can be expected when future cover construction bids are solicited. The unit pricing information is compiled in Table 7.

Cost information was also obtained from RSMeans *Heavy Construction Cost Data* (2004), the most commonly used standard guide for construction cost estimating. This cost guide was used to compare the general reasonableness of local pricing information for material acquisition and transportation. As discussed in Section 6.2.1, the RSMeans cost data were also used to estimate on-site excavation costs for potential tuff borrow sources near the MDAs, where heavy construction equipment would be used for excavation, loading, and hauling.

6.2 Cost Basis for Each Material

This section describes the cost information obtained from various sources and explains the cost basis for various materials, excavation, and transportation. Costs are considered on a unit cost basis. Since the timing of various cover construction projects has not yet been established, the cost information is presented on an average unit cost basis that can be applied to any of the MDA covers. In all likelihood, larger projects will have somewhat more favorable pricing than small projects due to economies of scale and typical contractor bidding practices.

6.2.1 Excavation Costs

On-site excavation and haul costs were estimated from the RSMeans data for excavating (RSMeans, 2004, Reference R02315-400, p. 372). Excavating costs were calculated based on a trackhoe excavator with a 1½-yd^3 bucket working 15 feet deep and four 10-yd^3 dump trucks

Table 7. Summary of Price Quotes for Potential Borrow Materials

Type of Material	Specifications	Volumes Available	Unit	Price Quotes ($) Unit Price	Price Quotes ($) Unit Price	Price Quotes ($) Unit Price	Average Unit Price ($)
Soil rooting medium (SRM)	Well graded soil, greater than 50% passing 200 sieve.	Unlimited	ton	14.00	10.50	10.00	11.50
Top soil	Similar to SRM soil with higher organic content and 5 to 10% gravel and cobbles.	Unlimited	ton	16.00	38.00	---	27.00
Select fill	Non-swelling, easily handled fine- to coarse-grained soil.	Unlimited	ton	14.00	10.50	---	12.25
Gravel	Gravel and cobbles ranging in size from ½- to 6-inch diameter. For amending top soil as needed. Crushed or rounded.	Unlimited	ton	16.00	11.00	---	13.50
Cobbles	Same as above	Unlimited	ton	18.00	15.00	---	16.50
Angular boulders (1- to 2-foot diameter)	As needed to provide armoring of steeper slopes and drainage areas.	Unlimited	ton	20.00	---	---	20.00
Tuff (on-site, i.e., up to 1-mile haul)	Easily handled or crushed to use as fill		cubic yard	5.49 [a]	---	---	5.49
Soil amendment/compost	Organic compost, manure, sludge, etc.	Unlimited	ton	8.40 [a]	---	---	8.40
Reinforced concrete retaining wall	Cantilever wall with footing. Level to 33% subgrade slope. 6-foot average height 10-foot average height	Unlimited	linear foot	 191.00 [a] 320.00 [a]	---	---	 191.00 320.00
Dry-stack rock retaining wall	Durable stone, 2-foot-thick wall with 3-foot-deep footing.	Unlimited	square foot	27.00 [a]	---	---	27.00

--- = Quote not provided

[a] RSMeans (2004)

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hauling the soil a round trip distance of 2 miles, a typical cover construction earthwork approach. Alternatively, belly-load scrapers can also be used for excavation and hauling, with generally similar costs. For the on-site tuff, use of an excavator may be more effective than using scrapers and is probably a more likely scenario. The 2-mile round-trip haul distance is conservatively high, and borrow sources nearer the cover location would reduce costs. Estimated haul cycle times of 23 minutes were used to estimate daily quantities in cubic yards moved. Hourly rates for all personnel and equipment were totaled for one day and divided by the daily quantity moved to arrive at a unit cost of $5.49 per cubic yard.

This unit cost for on-site excavation is on the upper end of costs DBS&A has experienced on recent projects. Excavation and hauling bids in New Mexico are often closer to $3.00 to $4.00 per cubic yard for an operation of this nature. Therefore, the calculated cost of $5.49 per cubic yard is somewhat conservative.

6.2.2 Purchase Costs

The material purchase costs received from commercial quarries were all provided on the basis of cost for material purchased and delivered to LANL. The various price quotes and average material purchase costs are provided in Table 7. Material purchase prices are generally quoted on a tonnage rather than cubic yard basis. Because the quantities needed for construction are determined on a cubic yard basis, the quantities needed for purchase were converted based on a loose haul density of 1.3 tons per cubic yard.

The material required in the greatest amounts is soil rooting medium. Unit costs for soil rooting medium range from $10 to $14 per ton. Costs for topsoil are higher, at $16 to $38 per ton, and costs for gravel, cobbles, and boulders range from $11 to $20 per ton. All materials were reported by the providers to be available in "unlimited" quantities.

The costs for commercially purchased and delivered materials are considerably higher than costs for excavation of on-site tuff material. If commercial borrow sources are selected, suitable soil and rock materials are available within reasonable distances. An active and competitive market exists in the aggregate materials and hauling business, which will help to keep material costs to a minimum. Through later design and procurement processes, materials and sources will be selected. Ultimately LANL will either select borrow sources in advance or identify sources with suitable material through competitive bid solicitations.

6.2.3 Hauling Costs

Hauling costs represent a significant portion of the overall materials costs. These costs are included in the excavation and purchase costs above, but this section addresses the hauling costs specifically, to show the substantial cost impacts of increasing distances to obtain materials. Considering the material tonnage required for cover construction, materials must be acquired within the local area in order to be cost-effective.

Commercial haulers generally provide hauling costs on an hourly, rather than a mileage, basis. Hauling rates are generally \$60 to \$65 per hour for round-trip transportation. This hourly rate is for a standard 20-yd^3 trailer, which effectively carries 18 yd^3 per load or approximately 22 tons per load. At MDAs C and L, LANL security measures will be a factor that increases the travel time, with an associated cost impact based on the hourly rate.

Transportation costs for the cover material increases proportionally to the hauling distance and may constitute as much as 75 percent of the total delivered costs at longer hauling distances. The impact of hauling costs on total cost is illustrated in Table 8, which shows the costs of hauling the total tonnage of material needed for cover construction at MDAs C and L from borrow sources of 5 to 50 miles. Table 8 also shows the number of truckloads needed to transport sufficient material quantities to MDAs C and L for cover construction. The hauling rate will vary based on the total mileage, routes traveled, and specific costs for each hauling company. The significance of hauling costs shows the importance of developing ET cover designs that provide the needed performance using materials that are available locally.

Table 8. Material Hauling Cost Summary

Facility	Cover	Material Quantity		Hauling Cost [a] ($)		
		Tons	Truckloads [b]	5 Miles	25 Miles	50 Miles
MDA C	3-foot	171,105	7,778	171,105	855,525	1,711,050
	8-foot	315,106	14,323	315,106	1,575,530	3,151,060
MDA L	3-foot	17,504	796	17,504	87,520	175,040
	8-foot	54,685	2,486	54,685	273,425	546,850

[a] Assumes $0.20 per ton per mile
[b] Assumes 22 tons per truckload

6.2.4 Soil Amendment Costs

Soil amendment costs are highly variable; numerous materials may be considered including commercial fertilizer, compost, sewage sludge, or manure. For cost estimating purposes, a sewage sludge compost available from Los Alamos County free of charge was considered.

The Los Alamos County wastewater treatment plant (WWTP) produces Class A sludge that is composted to remove pathogens, which in a Class A sludge cannot exceed certain levels set by the EPA. Although the material is available free of charge, costs to load and haul the material would still be incurred. Using RSMeans (2004) data, preliminary costs were estimated at $8.40 per ton for transportation of composted sludge.

6.2.5 Revegetation Costs

Revegetation will be needed for two purposes: (1) to revegetate the ET cover and surrounding areas that may be disturbed by construction activities and (2) to revegetate areas disturbed by on-site excavation. Costs for revegetation using a hydromulch technique range from $5,000 to $6,000 per acre. Temporary irrigation installed to enhance the growth of the vegetation, if desired, would cost an additional $1,400 per acre.

A total unit cost of $7,400 per acre provides a conservative cost for revegetation. For cover construction projects, revegetation costs generally amount to a relatively small portion of the overall material costs.

6.2.6 MDA C Retaining Wall Costs

Costs for the retaining walls planned for the MDA C cover perimeter are significant and quite variable depending on the type of wall necessary (reinforced concrete or dry-stack rock) and the design dimensions. Based on RSMeans (2004) standard unit costs for constructed retaining walls, the cost for a reinforced concrete retaining wall is $191 per linear foot for a 6-foot average height and $320 per linear foot for a 10-foot average height. The cost for a dry-stack rock retaining wall 6 to 10 feet in height is $27 per square foot. These average costs are reasonable estimates for the retaining walls with average heights of 4.6 to 8.7 feet, based on the preliminary cover layouts. Unit costs escalate for retaining walls of increasing heights, because the wall thickness and footing requirements increase.

6.3 Cost Compilation

Comprehensive materials cost estimates for MDAs C and L are presented in Tables 9 and 10. For each MDA, costs are provided for both 3- and 8-foot cover thicknesses. A 20 percent contingency has been added to the total costs at the bottom line. Costs for the primary cover materials needed (soil rooting medium, topsoil, and select fill) are provided for on-site and off-site borrow sources. Secondary materials used in relatively small quantities (gravel, cobbles, boulders, soil amendment, revegetation seed, and concrete) are not expected to be available on-site at the MDAs, so they will likely be imported.

At MDA C, material costs for a 3-foot-thick cover range from $1,450,000 to $3,000,000, and material costs for an 8-foot-thick cover range from $2,690,000 to $5,260,000. At MDA L, material costs for a 3-foot-thick cover range from $152,000 to $315,000, and material costs for an 8-foot-thick cover range from $406,000 to $853,000.

For both MDAs, costs for on-site cover material are less than half the costs for import of off-site material from commercial sources. At MDA C, borrow sources of suitable material are potentially available nearby; use of these sources could hold costs near the low end of estimated costs. At MDA L, located on a narrow mesa composed of strongly welded tuff, use of imported borrow material is likely, with costs near the upper end of the estimates in Table 10.

Table 9. Preliminary Cost Estimate for MDA C Evapotranspiration Cover Materials

Material	Material Quantity (tons)		Off-Site Borrow Source Cost[a] ($)			On-Site Borrow Source Cost[a] ($)		
			Unit	Total		Unit	Total	
	3-Foot Cover	8-Foot Cover		3-Foot Cover	8-Foot Cover		3-Foot Cover	8-Foot Cover
Primary Cover Materials								
Soil rooting medium	66,899	202,388	11.50	769,338	2,327,462	5.49	367,276	1,111,110
Top soil	13,630	14,981	27.00	368,010	404,487	5.49	74,829	82,246
Select fill	88,449	89,170	12.25	1,083,500	1,092,332	5.49	485,585	489,543
Primary Cover Materials Total				2,220,848	3,824,281		927,690	1,682,899
Secondary Cover Materials								
Gravel	1,363	1,498	13.50	18,400	20,223	13.50	18,400	20,223
Cobbles	1,363	1,498	16.50	22,490	24,717	16.50	22,490	24,717
Angular boulders	1,877	4,995	20.00	37,540	99,900	20.00	37,540	99,900
Soil amendment/compost	524	576	8.40	4,402	4,838	8.40	4,402	4,838
Revegetation/irrigation (per acre)	9.88	10.84	7,400.00	73,112	80,216	7,400.00	73,112	80,216
Retaining walls[b]								
6-foot concrete (linear foot)	1,001	NA	191.00	191,191	NA	---	191,191	NA
10-foot concrete (linear foot)	NA	1,412	320.00	NA	451,840	---	NA	451,840
Dry-stack rock (square foot)	4,571	12,333	27.00	123,417	332,991	---	123,417	332,991
Secondary Cover Materials Total				279,361	562,885		279,361	562,885
Subtotal				2,500,209	4,387,166		1,207,051	2,245,784
20% Contingency				500,042	877,433		241,410	449,157
Total				3,000,251	5,264,599		1,448,461	2,694,941

[a] Taxes are not included in cost estimates
[b] One type of retaining wall will be selected between the two options. Lower-cost option included in total.

NA = Not applicable
--- = Materials not available on-site

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Table 10. Preliminary Cost Estimate for MDA L Evapotranspiration Cover Materials

Material	Material Quantity (tons)		Off-Site Borrow Source Cost[a] ($)			On-Site Borrow Source Cost[a] ($)		
			Unit	Total		Unit	Total	
	3-Foot Cover	8-Foot Cover		3-Foot Cover	8-Foot Cover		3-Foot Cover	8-Foot Cover
Primary Cover Materials								
Soil rooting medium	8,670	44,879	11.50	99,705	516,108	5.49	47,598	246,386
Top soil	2,306	3,292	27.00	62,262	88,884	5.49	12,660	18,073
Select fill	5,048	4,777	12.25	61,838	58,518	5.49	27,714	26,226
Primary Cover Materials Total				223,805	663,510		663,510	290,685
Secondary Cover Materials								
Gravel	230	329	13.50	3,105	4,442	13.50	3,105	4,442
Cobbles	230	329	16.50	3,795	5,428	16.50	3,795	5,428
Angular boulders	932	952	20.00	18,640	19,040	20.00	18,640	19,040
Soil amendment/compost	88	127	8.40	739	1,067	8.40	739	1,067
Revegetation/irrigation (per acre)	1.65	2.36	7,400.00	12,210	17,464	7,400.00	12,210	17,464
Secondary Cover Materials Total				38,489	47,441		38,489	47,441
Subtotal				262,294	710,951		126,461	338,126
20% Contingency				52,459	142,190		25,292	67,625
Total				314,753	853,141		151,753	405,751

[a] Taxes are not included in cost estimates.

DBS&A also developed an estimate of average material unit costs that may be applied to estimating overall material costs for all of the mesa-top MDAs where ET covers are planned. The universal average unit price brings together costs for covers that vary in size, thickness, and on-site and off-site borrow sources, and is estimated to be $22 per cubic yard of in-place material. This average cost assumes that half the materials are obtained from lower-cost on-site sources. This is the material cost only; additional construction costs for material placement and grading can typically be achieved in the range of $3 to $5 per cubic yard, after the material is on-site.

7. Summary and Recommendations

The borrow source survey established preliminary material cost estimates for ET covers at MDAs C and L and identified potential material sources with sufficient material for these and ten additional mesa-top disposal sites. In order to develop cost estimates sufficiently reliable for financial planning purposes, the borrow source survey included preliminary cover layouts for two alternative cover thicknesses at each site. The preliminary cover layouts follow ET cover configuration criteria for layer thicknesses and types of materials, consistent with regulatory requirements and cover design guidance used at LANL and other DOE sites.

The materials recommended in the preliminary cover layouts are intended to make the ET covers practical, constructible, and affordable. The bulk of the materials recommended for the covers consist of soil and rock with relatively common properties. ET covers are fairly flexible in allowing for a range of material properties that will provide suitable performance, with design optimization possible by adjusting layer thicknesses to account for specific properties of selected materials. The proposed ET covers use native geologic materials to provide sufficient longevity for LANL site closures. The longevity of retaining walls needed at MDA C will need to be evaluated.

To be cost-effective, the materials recommended for the ET covers should be available in the local area. Either Bandelier Tuff or common alluvial soils can provide the moisture retention characteristics needed for ET cover performance. Thus, the tuff and alluvial soil are the most likely materials to make up the bulk of the ET covers, and both are available locally in sufficient quantities and at reasonable unit prices.

A variety of potential sources of soil and rock materials are available, including both off-site commercial quarries and on-site borrow areas at LANL. The preliminary cost estimates show that on-site tuff excavation is the lowest-cost alternative for the soil rooting medium, with material costs approximately half those of imported commercial material. Some materials needed in small quantities, including gravel, cobbles, and boulders, will most likely need to be purchased commercially, because suitable material is probably not available within LANL.

Depending on the cover thickness and material sources, the ET cover material costs range from $1,400,000 to $5,300,000 at MDA C and from $150,000 to $850,000 at MDA L. The universal average material cost, considering variable cover areas, thicknesses, and material sources, is estimated at approximately $22 per cubic yard of in-place material. To be conservative in estimating costs, contingencies have been added to both material quantities and costs.

For the site-wide MDAs needing final covers, the material costs for the approximately 1.5 million cubic yards needed are estimated to be approximately $33,000,000, based on present costs without escalation. These costs can be used by LANL for overall cost planning for the site-wide ET cover effort.

Two actions are recommended for LANL to advance toward selection of cost-effective materials for ET cover construction.

- Initiate efforts to identify specific parcels within the LANL complex where tuff may be excavated, considering future land use plans, security, and environmental and cultural issues. In selecting sites, consider NEPA compliance under the LANL site-wide EIS.

- Initiate efforts to obtain and stockpile suitable materials that may be available periodically at low cost by developing LANL procurement incentives to promote development of borrow materials in the design and construction process.

These measures provide approaches that have the potential to provide significant cost savings over bid prices obtained through procurement at the time of construction.

Advancing the ET cover design and performance assessment process is also recommended, to refine the material properties needed and to more definitively establish the cover thickness needed to meet performance requirements. Detailed materials property information available from LANL researchers should be compiled and evaluated. Collection of additional tuff and soil samples at LANL or at other potential borrow sources for laboratory testing may also be considered to supplement available data. In particular, tuff and soil moisture retention characteristic testing results are needed to evaluate cover performance. ET cover designs should be developed that provide for an adequate range of material specifications to make the eventual procurement of material and construction practices practical in meeting the specifications at reasonable cost.

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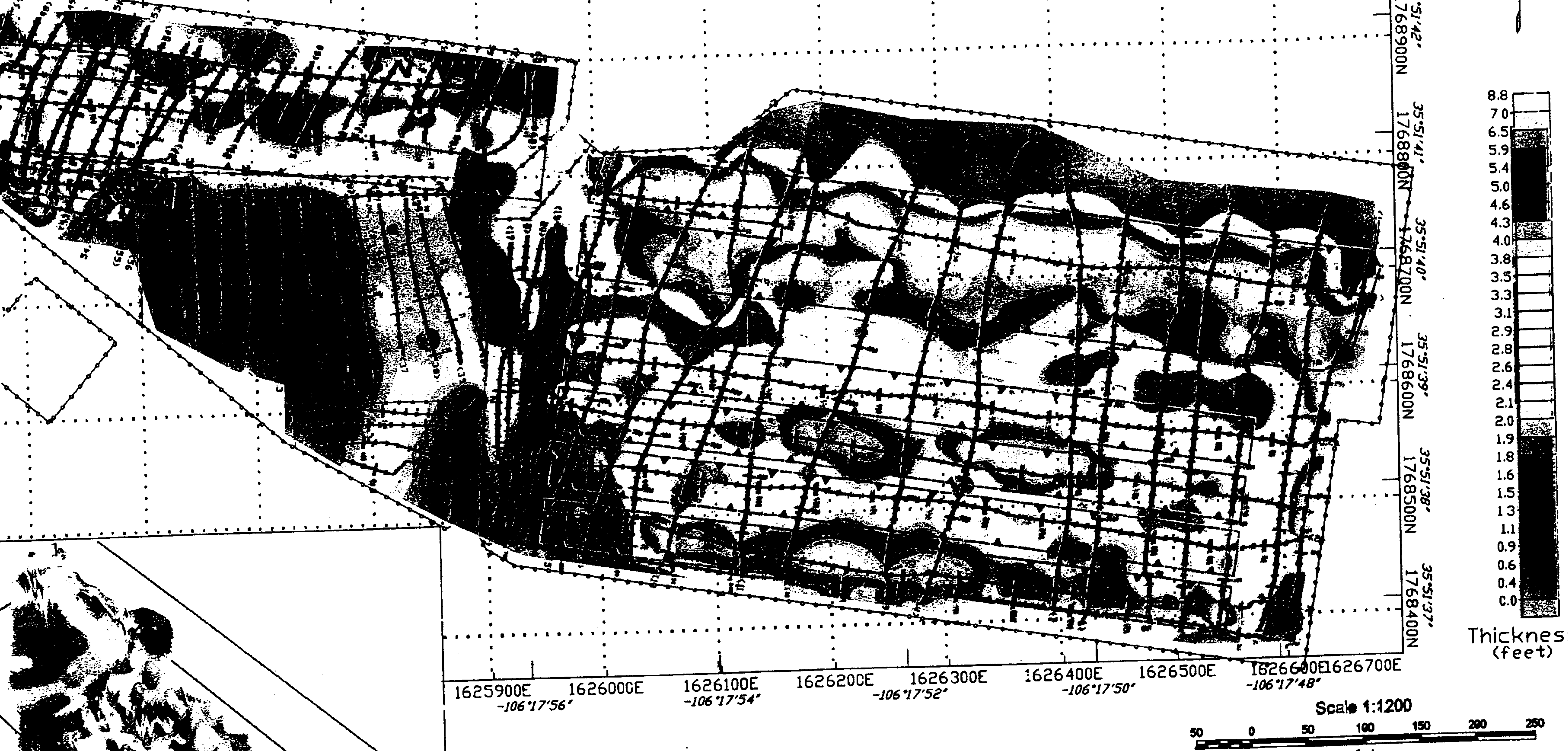
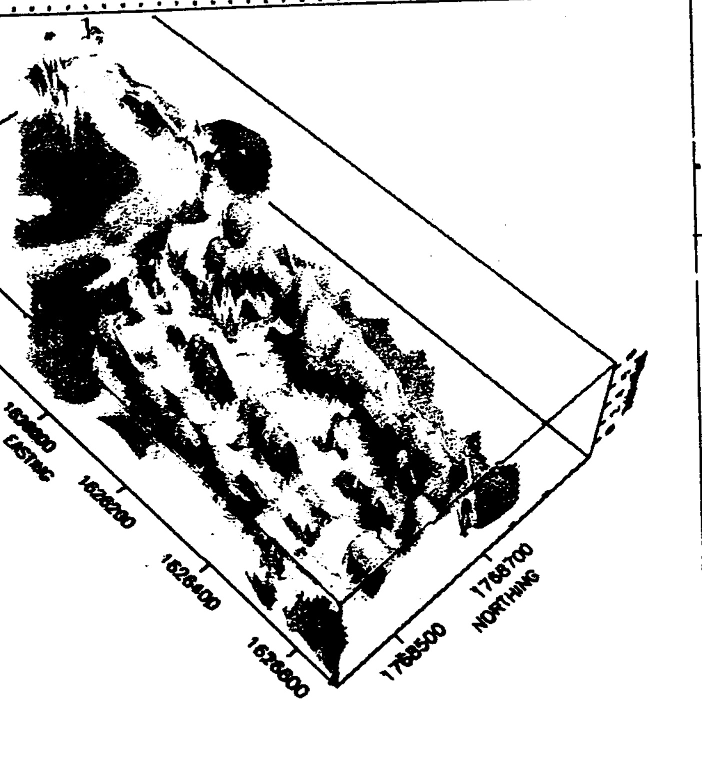
Appendix A

Geophysical Survey of MDA C





3D VIEW

LEGEND

- 8> GPR survey line showing line number and direction. Major and minor ticks at 50ft and 10ft, respectively
- Chain-link fence
- Former pit location based on historical data
- Ground surface topography (provided by FIMAD)

Los Alamos National Laboratory ER Project

Figure 4: Interpreted Thickness of Cover Materials
Survey Area MDA C
Los Alamos, New Mexico

Prepared for: Los Alamos

Prepared by: ADVANCED GEOLOGICAL SERVICES

September 31, 2001

Appendix B

Mines in Counties Surrounding LANL

Los Alamos County

No mines, mills, or quarries listed in Los Alamos County

Rio Arriba County

ABIQUIU SAND & GRAVEL PIT
Sand & Gravel
Abiquiu Sand & Gravel
PO Box 406, Abiquiu, NM 87510
(505) 685-4666
Type of Operation: Surface Mine
Status: Under Development
Location: Sec 19 T23N R6E
USGS Quad: Abiquiu
Mineral Estate: Private Land; Bob A. Trujillo; PO Box 406, Abiquiu, NM 87510
Surface Estate: Same

EL GUIQUE PIT
Sand & Gravel
Espanola Transit Mix Co.
PO Box 38, Espanola, NM 87532
(505) 753-2176
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2901712
Location: Sec 26 T22N R8E
USGS Quad: San Juan Pueblo
Mineral Estate: Private Land; Piedra Inc.; PO Box 38, Espanola, NM 87532
Surface Estate: Same

LOWDERMILK
Sand & Gravel
Espanola Transit Mix Co.
PO Box 38, Espanola, NM 87532
(505) 753-2176
Type of Operation: Mill
Status: Active Mining
MSHA Number: 2901990
Location: NW Sec 26 T21N R8E
USGS Quad: San Juan Pueblo
Mineral Estate: Indian Land; San Juan Pueblo
Surface Estate: Espanola Transit Mix; PO Box 38, Espanola, NM 87532

VELARDE PIT
Sand & Gravel
Espanola Transit Mix Co.
PO Box 38, Espanola, NM 87532
(505) 753-2176
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2901712
Location: Sec 3 T22N R9E
USGS Quad: Velarde
Mineral Estate: Private Land; Cook Brothers; PO Box 38, Espanola, NM 87532
Surface Estate: Same

Sandoval County

LOCATION #1802, PENA BLANCA
Base Course/Sand/Crushed Rock
Western Mobile New Mexico, Inc./LaFarge Corp.
PO Box 27328, Albuquerque, NM 87125-7328
(505) 343-7800
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2901771
Location: Sec 5 T15N R6E
USGS Quad: Santo Domingo Pueblo
Mineral Estate: Private Land

PENA BLANCA PIT - ULMI
Sand & Gravel
Rt 6 Box 5, Santa Fe, NM 87501
(505) 471-7661
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2901871
Location: Sec 5 T15N R6E
USGS Quad: Santo Domingo Pueblo
Mineral Estate: Private Land

SANTA FE RIVER PIT
Sand & Gravel/Base Course/Fill Dirt/Other
Central Concrete Products, Inc.
3 Demas Rd, Santa Fe, NM 87505
(505) 471-3553
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2900822
Location: Sec 32 T16N R6E
USGS Quad: Santo Domingo Pueblo
Mineral Estate: Private Land; Nevarez C De Baca; 217 Mildred NW, Albuquerque, NM 87107
Surface Estate: Same

Santa Fe County

GALISTEO RIVER SAND AND GRAVEL
Base Course/Fill Dirt
Galisteo River Sand And Gravel
HC 75, Box 62, Lamy, NM 87540-
(505) 989-7032
Type of Operation: Surface Mine
Status: Active Mining
Location: Sec T15N R10E
USGS Quad: Galisteo
Mineral Estate: Private Land; Onderdonk Live Stock Co.; Philadelphia, PA
Surface Estate: Joe and Alma Miller; HC 75, Box 34, Lamy, NM 87540

LEEDER PIT
Crushed Rock/Base Course
R. L. Leeder Co.
PO Box 15147, Santa Fe, NM 87506
(505) 473-1360
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2901962
Location: Sec 1 T16N R8E
USGS Quad: Agua Fria
Mineral Estate: State Land; State of New Mexico; PO Box 1148, Santa Fe, NM 87504
Surface Estate: Same

W. AIRPORT ROAD PIT
Base Course/Gravel/Fill Dirt
Western Mobile New Mexico, Inc./LaFarge Corp.
PO Box 27328, Albuquerque, NM 87125-7328
(505) 343-7800
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2901961
Location: Sec 10 T16N R8E
USGS Quad: Agua Fria
Mineral Estate: Private Land
Surface Estate: John & Margaret McIntosh; 156 Calle Ojo Feliz, Santa Fe, NM 87501

Taos County

PENASCO PIT
Sand & Gravel/Base Course/Rip Rap (Gabion)/Fill Dirt
Fernandez Gravel
PO Box 353, Penasco, NM 87553
(505) 587-2666
Type of Operation: Surface Mine
Status: Active Mining
MSHA Number: 2902083
Location: Sec 25 T23N R
USGS Quad: Trampas
Mineral Estate: Federal; BLM; Taos, NM
Surface Estate: Same

Appendix C

Descriptions of Surficial Geology Symbols

CLASS FIRST-ORDER SYMBOLS -- MAJOR GENETIC MATERIAL CLASSES*

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a Alluvium-undivided. Stream deposits; fine to coarse grained, with local cementation by secondary carbonates, gypsum, or silica accumulation commonly present in older subunits. Derived from diverse lithologic terranes and landforms including: mountains, high plateaus and table lands, intermontane basins (bolsons), and regional plains. Deposited in diverse settings including: valley of streams ranging from small ephemeral to large perennial systems; shallowly- or non-incised drainageways on alluvial fans, piedmont alluvial plains, and bolson floors; and restricted closed depressions of solution subsidence, deflation, volcanic or structural origin.

Remarks: 1. Symbol when used only with lithologic and textural composition modifiers (without age modifier--u, o, u, t, etc.) indicates unit of Late Quaternary age (younger than 200-300 ka.). 2. Special subclasses include: 1) river alluvium (ar); 2) valley-fill alluvium (av); 3) thin deposits on piedmont and footslope erosion surfaces; 4) fan alluvium, and 5) bolson-floor alluvium.

*See NOTE on page 49

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

af — Fan alluvium-undivided. Stream deposits, and lesser amounts of sheetflood and debris-flow deposits of fan-distributaries. Includes deposits of individual fans and interfan valleys in proximal piedmont areas (adjacent to mountain fronts and high escarpments), and coalescent-fan (bajada) deposits on medial to distal parts of piedmont slopes. Proximal piedmont facies are transitional to piedmont erosion-surface covers (ap) and distal facies grade to bolson (basin) floor units (ab). Unit also includes fan and coalescent-fan alluvium in terrains with lower local relief, such as the borders of major stream valleys and footslopes of low escarpments of structural or erosional origin.

Remarks: 1. symbol also used in lower-relief terrains to denote fan deposits on constructional toeslopes to valley sides and escarpments.

ab — Bolson-floor alluvium-undivided. Streamflood and sheetflood deposits of distributary channels and interchannel areas at the distal part of bolson drainage systems; includes fine- to medium-grained deposits partly impregnated with calcium and sodium sulphate salts (abs); also includes small playas in widely scattered closed depressions and discontinuous eolian veneers.

Remarks: 1. Components with extensive eolian cover shown with "e" superscript.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Alluvium - First-order Subclasses

a — Alluvium; undifferentiated ay and a_2; includes deposits of widespread, ephemeral and intermittent stream systems in valley, plains, and bolson (intermontane basin) settings; terraced units are usually within 50 m of valley floors. Zones of secondary calcium carbonate and clay accumulation occur in older deposits (a_2 and equivalents) as relict soil horizons; nonpedogenic carbonate zones include calcite-cemented older alluvium and spring deposits (travertine and tufa). Up to 50 m thick. Late Quaternary; coeval with ar, av, ap, af, and ab; with vertebrate faunas of Rancholabrean provincial age.

ay — Alluvium-younger; includes deposits of widespread ephemeral and intermittent stream systems in valley, plains, and bolson settings. Pedogenic horizons of clay and carbonate accumulation are weak or absent. Up to 40 m thick. Correlative with Fort Selden and Lakewood morphostratigraphic units and younger alluvium of the Rio Grande and Pecos valleys (late Wisconsin and Holocene).

ah — Alluvium-Holocene; includes deposits of ephemeral and intermittent stream systems as in unit ay; excludes basal valley fill (mostly channel deposits) of late Wisconsin age. Up to 20m thick.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

a_2 Alluvium-older(late phase); includes stream deposits of intermediate-level valley-border and piedmont surfaces (terrace fills, fan alluvium, and erosion-surface veneers); with relict soil horizons of carbonate (kg) and clay accumulation; nonpedogenic carbonate zones include calcite-cemented sandstones, conglomerates, and spring deposits. Up to 40 m thick. Correlative with Pichacho and Tortugas, and Orchard Park and Blackdom morphostratigraphic units, respectively, of the Rio Grande and Pecos valleys (mainly late Pleistocene).

a_1 Alluvium-older (early phase); includes stream deposits of high-level valley-border and piedmont surfaces; with prominent relict and buried soil horizons of carbonate (km) and clay accumulation; secondary carbonate zones also include nonpedogenic conglomerates and sandstones. Up to 50 m thick. Correlative with younger members of Camp Rice, Sierra Ladrones, Garuña, Tule, Mimbres, and "upper Gila" formations; with tephra deposits including Lava Creek (Pearlette-O), Bishop, Tsankawe, Cerro Toledo, and Guaje ashes; vertebrate faunas are of Irvingtonian provincial age.

ao Alluvium-older (undivided); undifferentiated a_1 and a_2; up to 50 m thick.

at Alluvial-Pliocene and lower Pleistocene; includes stream deposits of 1) high-level valley-border and piedmont surfaces and 2) summit areas of major drainage

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

divides; with prominent buried and relict soil horizons of carbonate (Kt, km) and clay accumulation, as well as thick, nonpedogenic calcite-cemented conglomerates and sandstones. Up to 50 m thick. Correlative with Blanco Formation of west Texas and older members of Camp Rice, Sierra Ladrones, Garuña, Mimbres, and "upper Gila" formations; with tephra deposits including Huckleberry Ridge (Pearlette-B), and "Blanco" ashes (west Texas); vertebrate faunas of Blancan and early Irvingtonian(?) provincial ages.

au — Alluvium-undivided ay and ao

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Alluvium-River

ar — River alluvium; mainly sand and pebble gravel, with loamy to clayey surficial layers; fluvial (floodplain and channel) deposits of major perennial streams (Rio Grande, Pecos, San Juan, Gila,, Canadian); including terrace fills (ar_2) within 50 m of valley floors, with discontinuous, partly-indurated horizons of soil-carbonate accumulation and nonpedogenic, calcite-cemented zones; includes lesser amounts of colluvium and locally derived alluvium. Up to 40 m thick. Undifferentiated equivalent of ary and ar_2; coeval with a, ag.

ary — River alluvium-younger; mainly sand and pebble gravel with loamy to clayey surficial layers; floodplain and channel deposits of major perennial streams, including distributary channels of lower Mimbres River (with bye inclusions); secondary carbonate zones usually absent. Up to 40 m thick. Coeval with ay, agy, by, bye.

arh — River alluvium-Holocene; like unit ary, but excludes basal valley fill (mostly channel sand and gravel) of late Wisconsin age. Up to 20 m thick.

ar_2 — River alluvium-older (late phase); mainly sand and gravel (pbls, cbls), with discontinuous, loamy surficial layers; fluvial deposits of major perennial streams

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

in terraces within 50 m of valley floors; with relict soil horizons of carbonate (ig) clay accumulation; nonpedogenic carbonate zones include calcite-cemented sandstones and conglomerates. Up to 40 m thick. Correlative with fluvial facies of Picacho and Tortugas morphostratigraphic units of the Rio Grande Valley; with vertebrate faunas of Rancholabrean provincial age. Coeval with a_2, $\dot{a}g_2$.

ar_1 River alluvium-older (early phase); mainly sand and gravel (pbls, cbls), with loamy to clayey interbeds and surficial layers; deposits of ancestral rivers beneath high terraces and relict bolson floors 75 to 200 m above valley floors; with prominent relict and buried soil horizons of carbonate (km) and clay accumulation, as well as nonpedogenic, calcite-cemented sandstones and conglomerates. Up to 50 m. thick. Correlative with younger fluvial facies of Camp Rice, Sierra Ladrones, Garuña, Mimbres, and "upper Gila" formations; with tephra deposits including Lava Creek Bishop, Tsankawi, Cerro Toledo, and Guaje ashes; with vertebrate faunas of Irvingtonian provincial age; coeval with a_1.

aro River alluvium-older (undivided); sand to loam and clay; fluvial deposits of ancestral Mimbres River in relict bolson-floor position; with prominent relict soil horizons of carbonate (k, km) and clay accumulation. Up to 50 m thick. Undifferentiated equivalent of ar_1 and ar_2. Includes younger alluvial (a) and playa

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

(p) deposits in scattered depressions and linear swales, as well as discontinuous veneers of eolian sediments (e).

aru River alluvium-undivided; undifferentiated equivalent of ary and aro; coeval with au. Up to 50 m thick.

art River alluvium-Pliocene and lower Pleistocene; sandy fluvial deposits like ar; with prominent buried and relict soil horizons of carbonate (Kt, km) and clay accumulation, as well as nonpedogenic, calcite-cemented sandstones and conglomerates. Up to 200 m thick. Correlative with older fluvial facies of Camp Rice, Sierra Ladrones, Gatuña, and "upper Gila" formations; with tephra deposits including the Juckleberry Ridge (Pearlette-B) ash; vertebrate faunas of Blancan and early Irvingtonian(?) provincial age.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Alluvium-Valley Fill

av Valley fill; sand, gravel, and loam to clay; stream and colluvial deposits in upland-valley and canyon areas. Includes: alluvium of valley floors, commonly loam to clay in upper part and gradational downward and laterally to sand and gravel; intermediate terrace remnants of older stream deposits (commonly gravelly); and gravelly to loamy colluvium on valley sides, which grades to stream deposits. Partly-indurated zones of secondary carbonate occur both as relict soil horizons in terrace and older colluvial deposits, and as nonpedogenic accumulations including spring deposits (tufa and travertine). Up to 35 m thick. Undifferentiated avy and av_2; coeval with a, ca.

avy Valley fill-younger; loam, clay and sand, grading downward and laterally to gravel and gravelly sand to loam; includes stream alluvium of valley floors, and marginal fan and colluvial deposits on valley sides; secondary-carbonate zones generally absent except for local spring deposits in limestone terranes. Up to 35 m thick; coeval with ay.

av_2 Valley fill-older (late phase);vloam to sand, grading downward and laterally to gravel and gravelly loam to sand; includes intermediate stream-terrane deposits (generally within 50 m of valley floors), and marginal fan alluvium and

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

colluvium; with relict soil horizons of carbonate (k, km), and clay accumulation; nonpedogenic carbonate zones include local sandstones, conglomerates, and spring deposits in limestone terranes. Up to 35 m thick. Coeval with a_2.

av_1 Valley fill-older (early phase); loam to sand, grading downward and laterally to gravel and gravelly loam to sand; includes high-level terrace deposits and marginal fan alluvium and colluvium; with prominent relict soil horizons of carbonate (k, km) and clay accumulation; nonpedogenic calcite-cemented sandstones and conglomerates also locally present. Up to 35 m thick. Coeval with a_1.

avo Valley fill-older (undivided); loam to sand, grading downward and laterally to gravelly alluvium; includes terrace and fan deposits, and colluvium on valley sides. Up to 35 m thick. Undifferentiated av_1 and av_2; coeval with ao.

avu Valley fill-undivided; sand, gravel, and loam to clay; stream and colluvial deposits in deep valleys and canyons within major upland areas (mountains, plateaus, dissected piedmont terrain). Undifferentiated avy and avo; coeval with au.

ap Erosion-surface-cover; gravel (pbl to bldr), and gravelly sand to loam; alluvium and some debris-flow deposits forming thin covers on piedmont-erosion surfaces;

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

zones of calcium carbonate accumulation are locally present in buried and relict soil horizons. Up to 10 m thick. Undifferentiated apy and ap_2; coeval with a, f.

apy — Erosion-surface-cover--younger; gravel, and gravelly sand to loam; alluvial and some debris-flow deposits on piedmont-erosion surfaces; zones of soil-carbonate accumulation are weak or absent. UP to 10 m thick. Correlative with Organ and Isaacks Ranch morphostratigraphic units of Jornada del Muerto Basin; coeval with fy, ay.

ap_2 — Erosion-surface-cover--older (late phase); grave, and gravelly sand to loam; alluvial and some debris-flow deposits on piedmont-erosion surfaces; wit relict soil horizons of carbonate (kg) and clay accumulation. Up to 10 m thick. Correlative with Jornada II morphostratigraphic unit of Jornada del Muerto Bolson; coeval with f_2, a_2.

ap_1 — Erosion-surface cover alluvium--older (early phase); gravel, and gravelly sand to loam; alluvial and some debris flow deposits on piedmont-erosion surfaces; with prominent relict soil horizons of carbonate (km) and clay accumulation; nonpedogenic carbonate zones include calcite-cemented conglomerates and sandstones. Up to 10 m thick. Correlative with younger piedmont facies of Camp Rice, Sierra Ladrones, and Mimbres formations; coeval with f_1, a_1.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

apo Erosion-surface-cover alluvium--older (undivided); dominantly coarse-grained alluvium and some debris-flow deposits forming thin covers on piedmont erosion surfaces. Up to 10 m thick. Undifferentiated equivalent of ap_1 and ap_2.

apu Erosion-surface-cover alluvium--undivided; dominantly coarse-grained alluvium and some debris-flow deposits forming thin covers on piedmont-erosion surfaces (including rock pediments and surfaces cut on older piedmont deposits). Up to 10 m thick. Undifferentiated apy and apo; coeval with au.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Fan Alluvium

af Fan alluvium; stream and lesser amounts of debris-flow deposits in piedmont and valley-border areas marginal to mountain fronts, tableland escarpments, and steep valley sides. Partly-indurated zones of calcium carbonate accumulation are locally present as buried and relict soil horizons. Unit designated "afs" where partly impregnated with gypsum. Up to 35 m thick. Undifferentiated afy and af_2; coeval with a.

afy Fan alluvium--younger; includes fan and coalescent-fan deposits marginal to valley and bolson floors; zones of soil-carbonate accumulation are weak or absent. Up to 25 m thick. Correlative with Fort Selden, Organ and Isaacks Ranch morphostratigraphic units of Rio Grande valleys and adjacent bolsons (late Wisconsin and Holocene); coeval with ay.

af_2 Fan alluvium--older (late phase); fan and coalescent-fan deposits of valley borders, piedmont slopes, and escarpment footslopes; with buried and relict soil horizons of carbonate (kg) and clay accumulation. Up to 35 m thick. Correlative with mostly interfacial alluvial facies of the Picacho, Tortugas, and Jornada II morphostratigraphic units of the Rio Grande Valley and adjacent bolsons; coeval with a_2.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

af_1 Fan alluvium - older (early phase); fan and coalescent-fan deposits of piedmont slopes; with prominent relict and buried soil horizons of carbonate (kg, m) and clay accumulation; nonpedogenic carbonate zones include calcite-cemented conglomerates and sandstones. UP to 70 m thick. Correlative with younger piedmont facies of Camp Rice, Sierra Ladrones, and Mimbres formation; coeval with a_1.

afo Fan alluvium--older (undivided); undifferentiated f_1 and f_2. Up to 100 m thick.

afu Fan alluvium--undivided; undifferentiated afy and afo; alluvial and some debris-flow deposits of footslope areas marginal to mountain fronts, escarpments, and valley sides; coeval with au.

aft Fan alluvium--middle Pleistocene to Pliocene; partly indurate alluvial and debris flow deposits; with prominent buried and relict soil horizons of carbonate (Kt, km) and clay accumulation; thick, nonpedogenic carbonate zones include calcite-cemented conglomerates and sandstones. Up to 100 m thick. Correlative with piedmont facies of the Camp Rice, Sierra Ladrones, and Mimbres formations; coeval with at.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Bolson Floor Alluvium

ab — Bolson-floor alluvium-undivided; undifferentiated equivalent of aby and ab_2; loam, clay, and sand; with less than 15% pebble gravel, except for pebbly sand zones in basal parts of some units; distributary streamflood and sheetflood deposits associated with active and relict alluvial flats; with buried and relict soil horizons of carbonate (k) and clay accumulation in older units (b_2). Up to 30 m thick. Coeval with a.

abs — Bolson-floor alluvium-saline; loamy, clayey, and sandy deposits similar to "b"; partly impregnated with calcium sulfate or sodium salts. Undifferentiated equivalent of absy and abs_2.

aby
absy — Bolson-floor alluvium--younger; loamy, clayey, and sandy; with less than 15% pebble gravel, except for pebbly sand zones in basal part of some units (by); deposits partly impregnated with calcium sulfate or sodium salts (bsy); distributary streamflood and sheetflood deposits in areas of active alluvial-flat sedimentation; includes playa (p) deposits in scattered depressions and discontinuous eolian (e) veneers. Up to 10 m thick. Transitional with "ay" in Lower Mimbres River basin; coeval with ay.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

ab_2
abs_2 Bolson-floor alluvium--older (late phase); loamy, clayey and sandy; generally less than 15% pebble gravel, with local gravelly sand zones (b_2); deposits partly impregnated with calcium sulfate or sodium salts (bs_2); includes streamflood and sheetflood deposits associated with relict alluvial flats; with buried and relict soil horizons of carbonate (k) and clay accumulation. Up to 15 m thick. Transitional with "aro" in lower Mimbres River basin and correlative with Petts Tank morphostratigraphic unit in Jornada del Muerto Basin; coeval with a_2.

ab_1 Bolson-floor alluvium--older (early phase); sandy, loamy and clayey; generally less than 15% pebble gravel, with local gravelly sand zones; includes streamflood and sheetflood deposits emplaced prior to entrenchment of Rio Grande and Gila valley systems; with prominent relict and buried soil horizons of carbonate (k, km) and clay accumulation. Up to 35 m thick. Correlative with younger members of "upper Gila", Mimbres, Camp Rice, and Sierra Ladrones formations; coeval with a_1.

abo Bolson-floor alluvium--older; undifferentiated equivalent of b_1 and b_2.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

abso Sandy to clayey; with local pebble gravel zones (abo); deposits partly impregnated with calcium sulfate or sodium salts (abso); with prominent relict and buried soil horizons of carbonate (k, km) and clay accumulation. Up to 50 m thick.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Eolian Deposits

e — Eolian deposits - undivided. Wind-deposited sand, silt and clay, with active and stabilized dune forms and sheet-like morphology; includes quartz to feldspathic-quartz sand, and calcareous silt-clay-fine sand (loamy) aggregates. Zones of pedogenic clay and carbonate accumulation occur locally as buried and relict-surface soil horizons. Generally less that 15 m thick.

Remarks: Larger deposits are in areas downwind of river floodplains, and basin-floor alluvial and lacustrine plains. Symbol used in combination with other categories where eolian deposits form thin veneers on genetic material classes including alluvium, colluvium and lacustrine sediments.

Eolian Deposits; First Order Subclasses

ex — Eolian sand-undivided of quartz of feldspathic quartz composition. Deposits with dune and sheet morphology; of primarily areas of vegetation-stabilized deposits, with localized active dunes. Pale to reddish brown, fine to medium sand; zones of pedogenic clay and carbonate accumulation occur as buried and relict soil horizons. Generally less than 10 m thick.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

es — Eolian deposits-gypsiferous. Eolian sand and silt, primarily calcium sulfate; with dune and sheet morphology; with alkali-flat deposits in scattered interdune depressions. Generally less that 15 m thick. Coeval with e.

Remarks: Occurs in complexes with, and downwind of, relict gypsiferous and alkalic lake plains and playas central bolson areas (e.g. Tularosa and Estancia Valleys).

ed — Dune sand of quartz to feldspathic quartz composition. In addition to active parabolic and barchanoid forms, dune complexes include vegetation-stabilized coppice mounds and longitudinal ridges. Up to 10 m thick.

Remarks: Most dune complexes include small interdune flats and sheetlike eolian deposits, lake beds, and basin-floor alluvium. Unit for the most part postdates maximum expansion of Wisconsin pluvial lakes, and includes presently active forms.

eds — Dune sands-gypsiferous. Dune complexes include large areas of active transverse forms (parabolic and barchanoid) with restricted areas of vegetation stabilized coppice mounds and longitudinal ridges. Unit includes alkali-flat deposition scattered interdune depressions. Up to 15 m thick. (See le)

Remarks: Unit for the most part postdates maximum expansion of Wisconsin pluvial lakes, and include presently active forms.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

ey — Eolian sand to loam--younger; deposits with active and stabilized dune forms or sheet-like morphology; includes quartz to feldspathic-quartz sand, and calcareous clay-silt-fine sand aggregates. Up to 15 m thick. Undifferentiated dune deposits (ed and el), and other eolian sediments postdating last major expansion of pluvial lakes.

em — Eolian loamy sand to sandy clay loam--older; deposits with stabilized dune forms or sheet-like morphology; includes quartz to feldspathic-quartz sand and calcareous clay-silt-fine sand aggregates; with prominent buried and relict soil horizons of clay and carbonate accumulation. Generally less than 10 m thick.. Coeval with ao.

Remarks: Bulk of unit deposited in middle to late Pleistocene prior of expansion of Wisconsin pluvial lakes. Unit includes thousands of small (<1 km^2) depressions with thin playa deposits, widely scattered narrow swales with thin alluvial deposits, and local areas of younger eolian cover. Correlative in part with Blackwater Draw Formation.

e- (prefix) — Eolian cover-discontinuous; thin sandy deposits, including vegetation stabilized ridges and coppice dunes over designated substrate (for example, ea_1, ekm). Up to 3 m thick. Primarily equivalent to ey.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Lacustrine Deposits

l Lacustrine deposits. Sediments deposited in permanent bodies of standing water, including medium- to coarse-grained shore facies, fine- to medium-grained floor facies, and local fine- to coarse-grained deltaic facies.

Remarks: Primarily to deposits of Pleistocene to early Holocene pluvial lakes; includes numerous deposits of playa lakes in small deflation depressions, and associated eolian deposits.

ls Lacustrine deposits with evaporites. Sediments deposited during desiccation phases of pluvial lakes and after ephemeral flooding of playa areas. Dominant evaporites are sodium and calcium sulfates; zeolites and dolomitic marks are locally present, with high magnesium and calcium clays including sepiolite and montmorillonite.

Line symbol showing approximate upper limit of late Pleistocene expansion in the Basin and Range province. 6225' late Lake Estancia; 6350' Lake Estancia; 7000'+ Lake San Agustin; 3950' Lake Otero; 4200' Lake Animas; 5200' Lake Cloverdale; 4500' Lake Goodsight; and 4695' Lake Trinity.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Lacustrine Deposits - First Order Subclasses

l	Lacustrine deposit--undivided; light gray and greenish to brownish gray, calcareous clay to sand (or offshore facies), sand and pebble gravel (near shore and shore facies), and clay to loam (playa facies-p); with local fine-grained evaporite phases (ls). Up to 30m thick. Undifferentiated equivalent of ly (lsy) and l_2; coeval with a, ab.
ly lsy	Lacustrine deposit--younger; light gray and greenish to brownish gray, calcareous clay to sand (bottom facies), sand and pebble gravel (shore facies), and clay to loam with local evaporite phases; includes small playas (p, ps); fine-grained, locally dolomitic deposits, with calcium-sulfate and sodium salts (lsy). Up to 5 m thick. Coeval with ay, aby; in part correlative with Tahoka Formation of Llano Estacado.
l_2	Lacustrine deposit--older (late phase); greenish to brownish gray, clay to sand with peripheral sand to gravel; with local evaporitic (l_2s), alluvial, and eolian facies. Up to 30 m thick. Correlative with Tahoka and double Lakes Formations of Llano Estacado.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

l_1 Lacustrine deposit--older (early phase); light gray to brownish gray, clay to sand, and some dolomitic marl; with relict soil horizons of carbonate accumulation. Up to 30 m thick. Correlative in part with Tule Formation of Llano Estacado; with tephra deposits including Lava Creek, Bishop and Tsankawi ashes.

lo Lacustrine deposit--older (undivided); undifferentiated equivalent of l_1 and l_2.

le Complex of ly and el.

ls_2

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

PLAYA DEPOSITS

p Playa deposit. Clay to loam of ephemeral lakes in a variety of geomorphic setting, including deposits of bolson floors, solution-subsidence basins, deflation basins, lava field depressions, structural depressions, and former valleys blocked by subsequent eolian and alluvial deposition or lava flows. Up to 5 meter thick. Remarks: Thousands of playas less than 2 km in width not shown. Also included in "depression fill" units (d).

ps Playa deposit with evaporites. Clay or loam deposited in ephemeral lakes subject to ground-water discharge or in deflation basins in older saline lake deposits (ls) or wind reworked evaporites (es). Dominant salts are calcium and sodium sulfates. Up to 5 meters thick.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

GLACIAL DEPOSITS

t Glacial till, and associated ice contact stratified drift in alpine valley areas of southern Rocky Mountains and on Sierra Blanca (Roswell Sheet). Glacial outwash mapped with av and ar units.

Remarks: Only larger areas shown. Line and spot symbols used for areas less than 2 km wide.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

COLLUVIUM

c — Colluvium-undivided. Deposits on mountain and hill slopes emplaced by mass-wasting processes, including creep, small landslides, debris flows, rock falls and slides, and unconcentrated slopewash; with wide range of textures and composition. Area of bedrock outcrop generally less than 25%. Includes thin residuum, and narrow belts to thin sheets of alluvium deposited by low order streams (up to 25% a and av equivalents). Surface and buried horizons of pedogenic-clay and/or carbonate accumulation are commonly present in older subunits.

ca — Colluvium in combination with valley-fill alluvium. In many areas, larger colluvium-alluvium complexes shown by "ca" "cra", "cwa" and "cba" symbols. In combination with small landslides in areas of high local relief with steep slopes underlain by weak bedrock types capped by resistant units. Larger colluvium-landslide complexes shown by "cj" symbol.

cr — Colluvium with large areas of bedrock outcrop (usually >50%); used in combination with Second-order symbols denoting bedrock terranes

Remarks: Used primarily in arid parts of the state: includes extensive mudstone-siltstone-shale badlands; and very high relief terrains with erosion-resistant rocks.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

cw — Colluvium with large areas of weakly-consolidated sedimentary-rock outcrops (w).

cb — Block-rubble Colluvium. Mantle of angular to subangular very-coarse rock fragments, or steep slopes capped by resistant bedrock types. Clasts primarily of boulder size, but including blocks. Fabric ranges from clast supported to matrix supported with matrix including sandy (s), loamy (m), and clayey (c) textures. Includes lesser amounts of non-blocky colluvium and small landslides.

cf — Colluvium-high altitude. Includes c and cb in alpine or subalpine areas of northern and central NM (elevations >3900 m).

j — Landslides-undivided. Large, broken to coherent masses of bedrock units on steep, high-relief slopes underlain by weak rock types and capped with resistant units. Includes up to 50% blocky colluvium. Only larger areas shown (>2 km wide).

jc, cj — Colluvium-landslide complexes. Colluvium.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

CALCRETES

k Calcretes-undivided. Primarily soil petrocalcic horizons (K2m, Ccam) formed in surficial alluvial and eolian deposits (upper 2-4 m), with local occurrences on bedrock surfaces and in rock fractures. Sediments and fracture fillings are impregnated with alluvial calcium carbonate and lesser amounts of alluvial clay. Upper indurated laminar to platy horizons usually grade downward to non-indurated, massive to nodular horizons of carbonate impregnation. Locally includes minor amounts of carbonate-cemented conglomerate, sandstone, and mudstone with nonpedogenic, secondary carbonate introduced by ground water or deeply percolating vadose water.

Remarks: K2m (Bkm) horizons-morphogenetic Stage IV (gravelly and non-gravelly) of Gile and others, 1965-1966), and States V and VI of Bachman and Machette (1977).

Unit mapped only where it is generally within 1 m of the land surface and is a really extensive (>4 km^2).

May include genetically-related overlying horizons of clay accumulation (Bt), or thin overlays of eolian and/or alluvial deposits (usually <1 m thick).

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

ki Incipient calcrete - plugged, weakly indurated stage III-IV.

kg Gravelly calcrete. Primarily soil petrocalcic horizons formed in very gravelly alluvium (>35% granule to cobble size). Sediments are impregnated with alluvial calcium carbonate and many clasts are supported by a carbonate-cemented sand to loam matrix. Upper, moderately-well-indurated horizons 0.3 to 2 m thick, form thin caprock units with platy structure and laminar internal fabric; calcrete bulk densities range up to 2.2 g/cm^3. Lower-weakly indurated, massive horizons grade downward into uncemented gravel or gravelly sand to loam with carbonate-coated clasts.

Remarks: K2m (Bkm) horizons-State IV (gravelly) of gile et al. (1965-1966) to Stage V of Bachman and Machette (1977). Primarily associated with relict constructional geomorphic surface of Pleistocene age.

km Calcrete. Thick soil petrocalcic horizons formed in sandy to loamy alluvial and eolian deposits with <15% granule and pebble gravel; including lesser amounts of gravelly alluvium (15 to 35% >2 mm); most primary grains are dispersed in a matrix of alluvial calcium carbonate. Upper moderately-well-indurated horizons, 0.3 to 2 m thick, form thin caprock units with platy structure and laminar internal fabric; calcrete bulk densities range up to 2.2 g/cm^3. Lower weakly-indurated,

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

massive to nodular, horizons grade downward in to uncemented sand and gravelly sand to loam.

Remarks: K2m (Bkm) horizons-Stage IV (nongravelly) of Gile et al. (1965, 1966) to Stage V of Machette (1985).

Primarily associated with relict constructional geomorphic surfaces of early to middle Pleistocene age, with older (early Pleistocene to Pliocene) surfaces in the Great Plains region.

kt Caprock Calcrete. Thick soil petrocalcic horizons formed in alluvial and eolian deposits, late Miocene to early Pleistocene age, generally with <15% granule and pebble gravel; most primary grains are dispersed in a matrix of alluvial calcium carbonate; with very thin zones of silica cementation. Upper, well-indurated horizons 2 to 4 m thick, form caprock units with tabular structure, and laminar and pisolitic internal fabric; calcrete bulk densities range from 2.4 to 2.7 g/cm^3. Lower weakly-indurated, massive to nodular horizons grade downward into partly-cemented sand to loam with or without interbedded pebble gravel.

Remarks: Morphogenetic Stages V and VI of Machette (1985).

Primarily formed in loamy to gravelly deposits associated with relict construction and erosional geomorphic surfaces of Pliocene and late Miocene age. Major

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

parent sediments are the upper Miocene Ogallala and Pliocene Blanco Fms of the Great Plains province and equivalent units. Unit includes some areas where calcrete has formed in the veneers of eolian, colluvial and residual material and comprises crusts and fracture fillings, on and in bedrock units (primarily limestone (k·c), sandstone (k·s), and basalt (k·b).

ktg	As above with pebble and cobble gravel within 9 m of surface.
ekt	Eolian veneer up to 1-3 m thick on kt; wtkt exposed along rims of escarpments, HP depressions and draws with local HP depression fills and alluvial channels.
akt	Shallow draws of high plains.
cakt	Deep draws of high plains.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

VOLCANICS

v — Volcanic Rocks-undivided. Includes flows and vent units of Pliocene age.

vb — Basalt flows. Primarily alkali olivine basalt and olivine tholeiite, with lesser amounts of feldspathoidal basalt and basaltic andesite. Holocene to Pliocene.

vby — Late Wisconsin--Holocene.

vb_2
vb_1
$vb_{\o}$ — Basaltic volcanics--older; primarily alkalic basalts, with some feldspathoidal basalts and basaltic andesites; locally extensive flow from a variety of vent types. Middle to late Pleistocene (vb_2), early to middle Pleistocene (vb_1) and undivided ($vb_{\o}$).

vbt — Basaltic volcanic--Pliocene to early Pleistocene; primarily alkalic basalts, with some feldspathoidal basalts and basaltic andesites; locally extensive flows from a variety of vent types. Younger than 5 my, in part correlative with vb_1.

vbs — Tuff rings (basaltic associated w/maare).

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

vr_2 Rhyolitic volcanics. Ash-flow tuffs, mostly welded, lava, and tephra from Pleistocene caldera-forming eruptions in the Jemez Mountains. Includes Bandelier Tuff and Cerro Toledo Rhyolite (vr_1); and intracaldera domes, flows, pyroclastics, sedimentary fill (vr_2).

vrt   Dacitic to rhyolitic volcanoes. Includes lavas and vent units to Pliocene and early Pleistocene emplacement of domes and stratovolcanoes in the Mount Taylor, Raton and San Luis Valley areas.

va   Andesite. Includes lavas and vent units related to Pliocene and early Pleistocene emplacement of stratovolcanoes and shield volcanoes in the Rio Grande rift, Raton and Mount Taylor areas.

Symbols.

Volcanic Vents Shown by Spot Symbols

□ cinder and lava cones or cone clusters - basalt and basaltic andesite

× necks and plugs - basalt and basaltic andesite

+ maare and tuff rings, with local basaltic flows

■ shield volcanoes - basalt and andesite

* stratovolcanoes - rhyolite, dacite and andesite

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Symbol definitions provided with
NMBGMR Open-File Digital Map[1]

 domes, dome clusters, plug domes - rhyolite and dacite

 caldera margin

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

<u>Rhyolitic tephra deposits occurring as lenses in sedimentary sequences shown by spot symbols</u>

_ Yellowstone-derived tephra (Pearlette)

- _ Lava Creek
- _ Huckleberry Ridge (west Texas and Arizona)

○ Long Valley-derived tephra (Bishop)

□ Jemez-derived tephra

- □ Tsankawi (Bandelier)
- □ Cerro Toledo
- □ Guaje (Bandelier)

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

DEPRESSION FILLS

d Depression Fill-undivided. Complexes of alluvial, colluvial lacustrine, and eolian deposits of large closed depressions or interconnected systems of depressions that range in area from about 10 to as much as 200 km^2 and closure relief ranging from several meters to 50 m. Major mechanisms of depression formation, (usually operating in combination) include: solution-subsidence in carbonate and evaporite tenures; deflation; large-scale piping; basalt extrusions; local structural subsidence; and blocking of former valleys by alluvial or eolian processes, mass wasting or lava flows.

Remarks: Tens of thousands of small depressions and associated fill complexes not shown due to map scale limitations. These are included in categories ar, ab, e, ex, em, vb, km, kt, and in ea, ec, and ek complexes.

ds Filled Solution-subsidence Depressions in salme-gypsum evaporite terrane. Depressions significantly modified by stream erosion and deposition, deflation and eolian deposition, pluvial-lake and playa deposition, and mass wasting. Complex alluvial, colluvial, eolian and lacustrine fills locally as thick as 100 m, generally less than 30 m thick.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Remarks: Active formation and filling of depressions since late-middle Pleistocene time (past 300-500 ka). Includes extensive modern subsidence at San Simon Sink (Hobbs sheet).

dc Fills of Solution-subsidence Depressions in gypsiferous carbonate terrane. Depressions significantly modified by stream erosion and deposition, and mass wasting and are aligned along zones of faulting and structural warping. Alluvial and colluvial fills with minor playa and eolian deposits usually less than 10 m thick.

Remarks: Includes depressions near Vaughn (Ft. Sumner sheet) along north-south-trending structural subsidence.

dk Karst-plain deposits - pitted upland plains on carbonate rocks.

dd Fills of deflational depressions in eolian sheet and dune deposits, and in sandstone and calcrete caprock terranes; modification by carbonate and sulfate dissolution and stream erosion is of secondary importance. Eolian and playa deposits form the major fill components; usually <10 m thick.

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

genetically related to flow emplacement, including intraflow collapse basins and extraflow valley blockage depressions. Eolian, playa, and colluvial deposits form the major fill components, usually <10 m thick.

db Fill of depressions on and adjacent to basalt flows;

[1] Source: Hawley, J.W., D.J. McCraw, D.W. Love, and S.D. Connell. 2003. *Map of surficial geologic materials of northern New Mexico.* Open-File Digital Map, New Mexico Bureau of Geology and Mineral Resources.

Appendix D

Proposed LANL Construction Projects

Proposed Construction Projects at Los Alamos National Laboratory
Fiscal Years 2005 to 2012
Page 1 of 2

Facility Name	Funding Type	Projected Footprint (square feet)	Notes
Fiscal Year 2005			
DYNEX Assembly Building	GPP	15,000	
DX Shock & Detonator Physics Bldg	GPP	18,000	
Beryllium Tech Facility - Cartridge Filter House Install	GPP	3,100	Existing facility
Replace High Voltage Electrical Panels TA-48-1	GPP	100	Existing facility
Fiscal Year Total		36,200	
Fiscal Year 2006			
Center for Integrated Nanotechnology (CINT)	LI	34,000	Excavation ongoing
National Security Sciences Building	LI	275,000	Excavation complete
LASO (Part of NSSB)	LI	22,000	
IM Division Office Replacement	GPP	18,000	Prefabricated structure
Fiscal Year Total		349,000	
Fiscal Year 2007			
Communication Shop Building	GPP	5,000	
Electronics/Data Systems Building	GPP	16,000	
LANSCE Lab/Office Building	GPP	18,000	
FY06 IGPP #1	GPP	18,000	
FY06 IGPP #2	GPP	18,000	
Fiscal Year Total		75,000	
Fiscal Year 2008			
GTS SLEP Support Building	GPP	5,000	
Fiscal Year Total		5,000	
Fiscal Year 2009			
Support Services Consolidation	LI	40,000	
Calibration Laboratory	GPP	12,000	
Vessel Facility 1 of 4	GPP	6,700	
Lab at TA-22	GPP	6,000	
DX High Explosives Characterization Consolidtion	LI	32,000	
Fiscal Year Total		96,700	
Fiscal Year 2010			
Center for Stockpile Stewardship Research, TA-3	LI	400,000	No funding source identified
Vessel Facility 2 of 4	GPP	4,200	
Replace Machine Shop At TA-22	GPP	10,000	
Fiscal Year Total		414,200	

Source: Electronic correspondence from Rae Anne Tate, Los Alamos National Laboratory, to Gwinn Hall, Daniel B. Stephens & Associates, Inc., June 29, 2004.

Proposed Construction Projects at Los Alamos National Laboratory
Fiscal Years 2005 to 2012
Page 2 of 2

Facility Name	Funding Type	Projected Footprint (square feet)	Notes
Fiscal Year 2011			
Vessel Facility 3 of 4	GPP	4,200	
Fiscal Year Total		4,200	
Fiscal Year 2012			
CMR Replacement Project	LI	228,000	
Fabrication Facility Replacement	LI	50,000	
Classified HE Storage	GPP	2,000	
Joint DX/ESA Conference Facility	GPP	5,000	
Vessel Facility 4 of 4	GPP	4,200	
Fiscal Year Total		289,200	

Source: Electronic correspondence from Rae Anne Tate, Los Alamos National Laboratory, to Gwinn Hall, Daniel B. Stephens & Associates, Inc., June 29, 2004.

Appendix E

USGS Geologic Quadrangle Maps

Appendix E. USGS Geologic Quadrangle Maps

The maps for this appendix will be provided in the final report.