Final Cover Design for Cells 14 and 15 Permit Modification for Alternative Evapotranspiration Final Cover US Ecology Idaho

Volume 1: Report, Figures, Tables, Appendices A–D

Prepared for **US Ecology Idaho, Inc.**
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1. Introduction

On behalf of US Ecology Idaho, Inc. (USEI), Daniel B. Stephens & Associates, Inc. (DBS&A) has prepared a Part B permit modification for the closure of Cells 14 and 15 at the USEI facility in Grand View, Idaho (USEI Site B). The purpose of the permit modification is to demonstrate that an alternative evapotranspiration (ET) cover design will provide performance that meets or exceeds the Resource Conservation and Recovery Act (RCRA) prescriptive standards as set forth in the Idaho Administrative Procedures Act (IDAPA) 58.01.05.008 [40 CFR §264.310(a)]. The permit modification has been prepared in accordance with the closure plan included as Attachment 9 of the permit, as required by IDAPA 58.01.05.008 [40 CFR §264 Subpart G] and 40 CFR §264.310(a).

Based on the specific climatological conditions at USEI Site B, the ET cover design provides a superior landfill final cover design that achieves the best possible performance by:

- Minimizing surface infiltration of precipitation through the cover efficiently enough to meet or exceed prescriptive standards,
- Providing a highly effective cover designed for site-specific climate, soils, and vegetation,
- Sustaining vegetation and minimizing erosion,
- Using materials that flexibly respond to minor settlements or movements, and
- Providing superior long-term performance and stability.

The cover design for Cells 14 and 15 in the current permit includes the implementation of a standard Subtitle C RCRA cover. The alternative cover design for Cells 14 and 15 is for an ET cover similar to the covers approved for Trenches 10 and 11 at USEI. The basis for the ET cover design is presented in this permit modification.

2. ET Cover Design and Performance

ET landfill covers store water within the soil profile that may be released to the atmosphere through surface evaporation and/or transpiration (evapotranspiration). ET covers function well in dry climates, where they have been shown to exceed conventional regulatory designs in terms of moisture percolation reduction and erosion protection. ET covers consist of a monolithic soil layer designed with an acceptable thickness, based on soil texture, to adequately store soil water until it can be removed by ET. Establishment of sustainable vegetation is necessary to remove moisture from the cover by transpiration and to minimize wind and stormwater erosion from the cover surface. Exploiting soil moisture storage and ET has been demonstrated to provide effective final cover performance in many projects throughout the arid western U.S.

2.1 Performance Standards

The primary regulatory consideration for ET cover approval is to demonstrate that the alternative cover will meet performance standards equivalent to the conventional design standards prescribed by state and federal regulations. ET covers (alternative designs) may be approved based on a demonstration of performance. ET cover designs have been undergoing technical development and have been gaining widespread regulatory acceptance (U.S. EPA, 2003; ITRC, 2003). ET cover applications have included municipal solid waste landfills (RCRA Subtitle D), hazardous waste landfills (RCRA Subtitle C), and radioactive waste facilities. A number of ongoing, long-term field studies have provided data substantiating the performance of ET covers.

Both the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE) have sponsored research projects to study wider application of ET covers. Two major projects funded by these agencies are the Alternative Cover Assessment Program (ACAP), which is evaluating alternative cover performance for EPA's solid waste sites (Albright et al., 2004) and the Alternative Landfill Cover Demonstration (ALCD), which examined alternative cover performance in a direct, side-by-side comparison with prescriptive covers (Dwyer, 1997, 1998, and 2001). ACAP has evaluated alternative covers at 19 sites across the U.S., focusing

primarily on ET cover performance in the arid western states. The ALCD is a large-scale field test at Sandia National Laboratories, located on Kirtland Air Force Base in Albuquerque, New Mexico. Both ALCD and ACAP have shown results favorable for ET cover deployment.

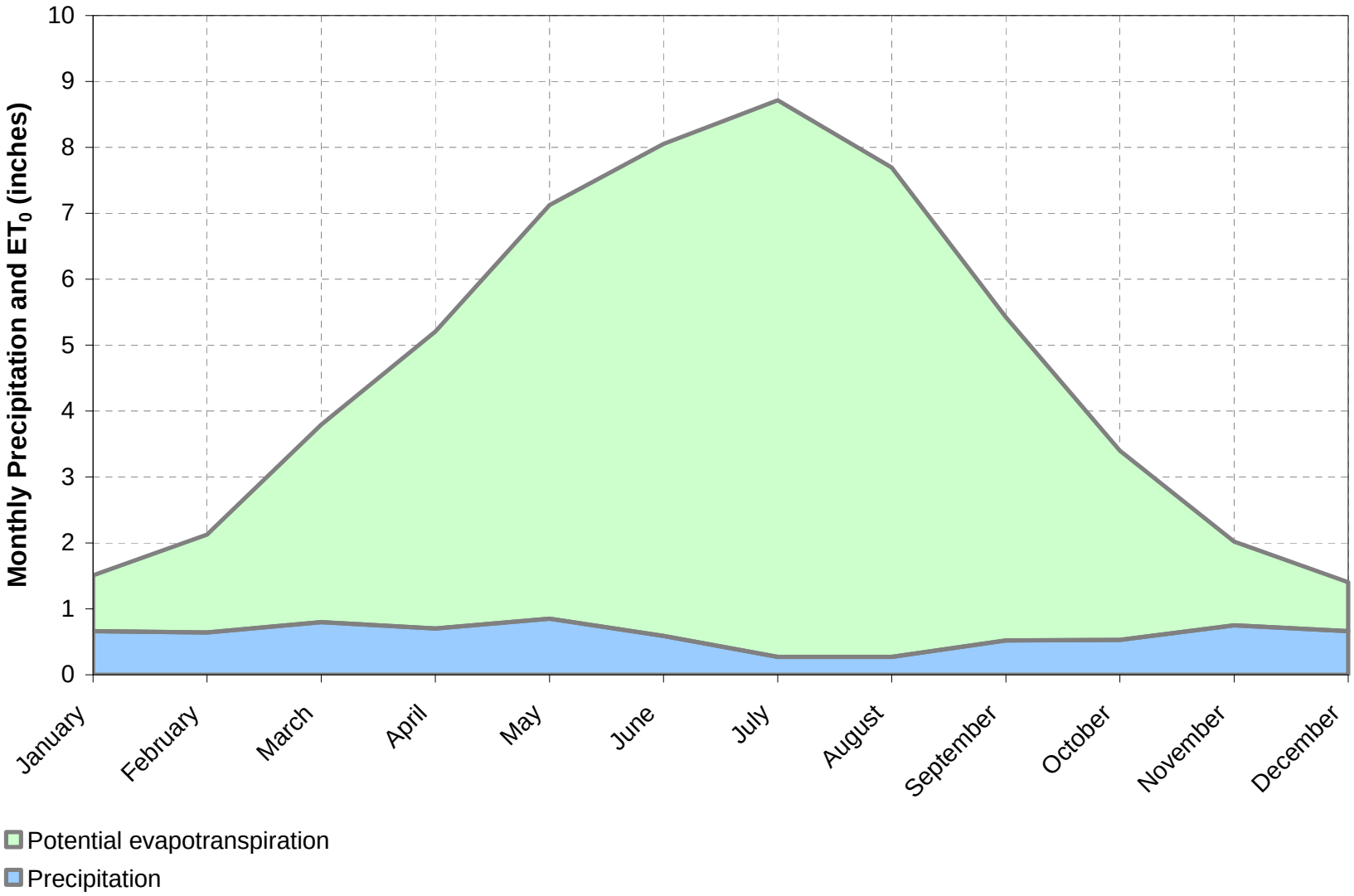
The regulatory requirements and performance standards for approval of an alternative ET cover are addressed in detail in Section 3.

2.2 Design Approach

The ET covers proposed for Cells 14 and 15 at USEI Site B are consistent with the conventional designs currently approved. The ET covers reach the same maximum height as the current designs and provide similar side slopes. Slopes range from a minimum of 5 percent to a maximum of 3:1 (3 horizontal to 1 vertical or 33 percent). ET covers are more stable than conventional covers because slippage planes that can result from prescribed geosynthetic layers are eliminated. Stormwater runoff is reduced by the ET cover's permeable surface and vegetation; therefore, the site's stormwater control system is not affected by the design change for the Cell 14 and 15 covers.

2.2.1 Climate Conditions

The climate at USEI Site B is well suited to an ET cover design. The climate is arid, with average annual precipitation of 7.2 inches. Figure 1 shows average monthly precipitation compared to average monthly potential ET (ET_0) at nearby Grand View, Idaho (WRCC, 2009). ET_0 was calculated using the Hargreaves and Samani (1982) method and average daily maximum and minimum temperature values. Throughout the year, ET_0 greatly exceeds precipitation. Average annual ET_0 is 49.2 inches per year (in/yr). These arid conditions provide for a high degree of moisture removal from the ET cover. The revegetation strategy for the ET cover will include species adapted to the local climate conditions, which will sustain the ET rates on a permanent basis.



US ECOLOGY IDAHO

Average Monthly Total Precipitation and Potential Evapotranspiration

Figure 1

Daniel B. Stephens & Associates, Inc.

10/24/10

2.2.2 Performance Modeling

DBS&A completed a modeling evaluation of ET cover performance for the covers designed for Trenches 10 and 11 at USEI Site B (DBS&A, 1998). HELP (Schroeder et al., 1994) and UNSAT-H (Fayer and Jones, 1990) models were used to evaluate and compare the performance of the alternative earthen cover. A geotechnical soil testing program was performed to acquire site-specific data as model input. The modeling showed that an ET cover with a 5-foot-thick soil layer having moisture retention and hydraulic conductivity properties within established ranges provides percolation reduction equivalent to prescriptive standards.

Modeling was performed to evaluate cover performance for high-precipitation conditions. An evapotranspiration cover is more vulnerable to failure (i.e., water percolation through the cover) from a steady and extended precipitation as opposed to a short-duration, high-volume storm event. The saturated hydraulic conductivity of the cover soil, in conjunction with the pressure head from ponded water (infiltration rate), is the constraining factor for infiltration flux. The soil will not accept water beyond this rate and additional precipitation will run off of the sloped cover.

As such, DBS&A used the precipitation dataset from 1988 through 1992 (due to completeness of climatic records), doubled the precipitation of each storm event, and applied this extreme 5-year record consecutively over a 30-year period. Over the period of record from 1933 to 1998, 1985 had the greatest average annual precipitation, at slightly over 12 inches. By doubling the 1988 to 1992 records, DBS&A generated a maximum precipitation for 1990 of slightly over 12 inches, matching the wettest year on record. This 5-year extreme precipitation was repeated 6 times, for a 30-year total, meaning that the greatest annual average precipitation was applied to the cover 6 times over a 30-year period. The performance was therefore conservatively modeled as a series of repeated critical events.

2.2.3 Test Pad Performance

ET covers were constructed in 2000 over Trenches 10 and 11 at USEI Site B. At that time, an ET cover test pad was also constructed for the purpose of monitoring performance for site-specific conditions. The monitoring test pad measures moisture conditions in the cover soil

profile using heat dissipation probes installed in two profile nests at seven different depths each. Five years of monitoring, completed in 2005, showed that percolation of moisture was not reaching the lower portion of the cover soil profile (DBS&A, 2006). The cover is effectively storing water that infiltrates the surface until it is released to the atmosphere through ET.

2.2.4 Soil Testing

The ET cover design for Cells 14 and 15 is based on site-specific soil testing that has been completed for soil samples collected from potential on-site borrow sources. Laboratory testing results are discussed in Section 4 of this report. The soil testing program showed that selected silt loam soil available on-site falls within the range of properties shown by modeling to provide satisfactory performance. The silt loam soils available on-site provide sufficient soil moisture storage capacity for an ET cover. The ET covers for Cells 14 and 15 require a minimum thickness of 5 feet, with thicker cover soil over many areas. Soil containing a high percentage of gravel and rock is also available on-site, providing material for the upper erosion protection layer of the ET cover. The erosion protection layer will minimize both wind and water erosion and maximize cover longevity.

2.2.5 Cover Soil Freeze-Thaw

Freeze-thaw does not adversely affect loosely packed soil used for ET covers in semiarid regions. The frost depth at USEI is approximately 2 feet (USACE, 1992), while the minimum cover thickness is 5 feet. Therefore, the majority of the cover will not be affected. The freeze-thaw action of the top portion of the ET cover is not a detriment to the design or performance. The freeze-thaw action keeps the top portion of the cover in a low-density condition, which benefits root penetration and storage capacity of water.

2.2.6 Burrowing Animal Control

The potential for burrowing animal damage to the ET covers will be addressed by inspection and repair to correct animal burrows and macropores. Inspections will look for evidence of animal intrusion, burrows, cracks, or other macropores. Inspections will be performed initially

on a monthly basis; over time, inspection frequency may be adjusted to quarterly or semiannually based on performance of the cover. Repairs will be made as needed to restore and revegetate the cover soil.

The design basis for the ET covers is described in more detail in the following sections of this permit modification. Soil testing is discussed Section 4. Section 5 provides information on cover slopes and thickness. Slope stability is discussed in Section 6, and erosion protection is discussed in Section 7. Section 8 provides information on the vegetation plan. Engineering design drawings of the final covers are provided as Appendix A. A construction quality assurance (CQA) plan is provided in Appendix B. The CQA plan ensures the selection of proper soils for cover construction and the soil placement methods required for ET cover construction. Construction specifications are provided as Appendix C. Engineering calculations of slope stability, wind and water erosion, and critical density of soils are included in Appendix D. Complete soil laboratory test results for the soil samples tested in 2008 are provided in Appendix E (Volume 2).

3. Regulatory Basis for Cover Equivalency

This section describes the regulatory basis for using ET covers as final landfill covers for existing Cells 14 and 15 at USEI Site B. Documentation is provided to demonstrate ET cover compliance with RCRA as it pertains to performance standards and equivalency to the standard RCRA design. The proposed ET cover limits infiltration of precipitation to levels equivalent to prescriptive standards that use low-permeability geomembrane and clay components to limit infiltration. The USEI Site B permit currently includes a high-density polyethylene (HDPE) geomembrane overlying a geosynthetic clay liner (GCL). The following sections provide the RCRA citations that are pertinent to this determination.

3.1 40 CFR §264.111

Section 264.111 of Title 40 of the Code of Federal Regulations (40 CFR §264.111) describes the closure performance standard. The following general closure performance standard applies to closure of RCRA units:

> The owner or operator must close the facility in a manner that:
>
> (a) Minimizes the need for further maintenance; and
>
> (b) Controls, minimizes or eliminates, to the extent necessary to protect human health and the environment, post-closure escape of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the ground or surface waters or to the atmosphere; and
>
> (c) Complies with the closure requirements of this subpart, including, but not limited to the requirements of §§264.178, 264.197, 264.228, 264.258, 264.280, 264.310, 264.351, 264.601 through 264.603, and 264.1102.

The performance of an ET cover at the USEI site will meet this standard. The ET cover minimizes the need for further maintenance because of the materials used in its construction and the natural vegetative layer established on its surface. A monolithic soil layer topped with selected gravels is naturally resistant to subsidence, slippage, and erosion. The natural vegetative layer requires no further maintenance once it is established, and any unanticipated

cap repairs can be easily made without the need for specialized expertise or materials. Existing ET covers at USEI Site B (Trenches 10 and 11) have been evaluated for long-term stability and found to be stable.

An ET cover effectively protects human health and the environment by forming a barrier that bars direct contact with waste materials or hazardous constituents and that isolates disposed wastes beneath the cover. This prevents release of waste and constituents beyond the boundaries of the cover and ensures that the surface remains uncontaminated and incapable of releasing waste constituents to the ground, to surface water, or to the atmosphere. The nature of the waste within the USEI landfill is consistent with the performance of the ET cover. These wastes were all disposed of following the adoption of EPA's land ban regulations (1984 Hazardous and Solid Waste Amendments). Wastes are treated prior to disposal to meet land ban standards (40 CFR §268 Subpart D Treatment Standards). They are treated to remove free liquids and to ensure limited leachability. Organic waste constituents are minimized through treatment and no putrescible wastes are accepted at the site. These actions minimize the possibility of gas formation and release to the atmosphere.

The landfill closure standards of 40 CFR §264.310 are the only standards cited above that are relevant to a discussion of an ET cover. Compliance with this standard is discussed in detail in the next section.

3.2 40 CFR §264.310

As part of 40 CFR §264.111, RCRA cell closure must comply with Section 264.310. 40 CFR §264.310 states that:

> (a) . . . the owner or operator must cover the landfill or cell with a final cover designed and constructed to:
>
> (1) Provide long-term minimization of migration of liquids through the closed landfill;
>
> (2) Function with minimum maintenance;
>
> (3) Promote drainage and minimize erosion or abrasion of the cover;

(4) Accommodate settling and subsidence so that the cover's integrity is maintained; and

(5) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

The ET cover is constructed primarily of lightly compacted silts and fine sands that have a hydraulic conductivity (K) on the order of 1×10^{-4} to 1×10^{-5} centimeters per second (cm/s). Rather than inhibit flow into underlying materials by the standard design using impermeable barriers, the ET cover system promotes evaporation and transpiration of any water that infiltrates the cover surface. The results of 5 years of long-term monitoring at the ET cover test pad constructed at the site show that no changes in moisture were noted at a depth of 5 feet below ground surface (DBS&A, 2006). This is not a measure of K, but is an indication that percolation to the base of the cover is not occurring, and thus demonstrates performance equivalency. The absence of percolation indicates that the ET cover effectively returns all moisture to the atmosphere to prevent moisture movement past the base of the cover. The testing completed at USEI Site B demonstrates that the ET cover provides performance equivalent to a conventional cover system with low-permeability components. As such, DBS&A believes that the ET cover meets the requirements set forth in 40 CFR §264.310(a)(1).

ET covers offer performance that exceeds conventional cover performance with regard to the items in 40 CFR §264.310(a)(1 through 4) pertaining to (1) longevity, (2) maintenance, (3) erosion resistance, and (4) accommodation of subsidence, as follows:

- ET covers are constructed of natural soil materials that are not subject to degradation as are the materials used under prescriptive standards. The geosynthetic materials in the prescriptive standards are subject to degradation and have limited longevity. Even the compacted clay layer in a prescriptive cover is subject to desiccation, cracking, root penetration, and loss of compaction. Such desiccation and cracking are of particular concern in an extremely dry climate like that of the USEI Site B facility. Therefore, ET covers will provide the best long-term stewardship and post-closure longevity.

- The ET cover surface consists of a gravel amended soil that is stabilized by vegetation. Maintenance is reduced for an ET cover as compared to prescriptive standards due to

improved erosion resistance and accommodation of settlement. Reduced maintenance increases long-term performance of the ET cover.

- As designed, the USEI Site B ET cover includes a 6-inch-thick gravel amended (25 to 40 percent gravel by weight) protection layer at the surface. The erosion protection layer effectively armors the cover surface to minimize wind and water erosion. In arid climates such as Grand View, Idaho, wind erosion is a key design consideration, which is minimized by the coarse soil and gravel. Well-established vegetation on the ET cover helps to minimize erosion by stormwater. Two factors aid in cover vegetation on ET covers, thereby minimizing erosion: (1) the soil profile and rooting depth is greater than in a standard RCRA cover, and (2) the permeable surface soil allows surface infiltration of precipitation, reducing runoff and making the soil moisture available at the plant roots.

- Because the soils within the ET cover are lightly compacted granular material, the ET cover can tolerate significant subsidence that could potentially damage geosynthetic cover components. In the event that maintenance is needed due to unexpected subsidence that would affect positive surface drainage, ET cover repairs can be addressed with limited equipment to regrade and revegetate surface soils, allowing for ease in maintenance (required under 40 CFR §264.310(a)(2)) while also enabling any subsidence issues to be easily addressed, as required under 40 CFR §264.310(a)(4) pertaining to the overall maintenance of the cover.

40 CFR §264.310(a)(1) and (5) require that the final cover minimize infiltration of moisture into the landfill in order to prevent accumulation of liquid on the liner, a condition referred to as the "bathtub effect" (U.S. EPA, 1989). The USEI Site B ET cover will meet this standard by minimizing percolation of moisture through the final cover to a level less than 1 millimeter per year (0.04 in/yr). This limit was established by modeling the ET cover performance using site-specific conditions for the USEI site and conservative assumptions for the water balance modeling (DBS&A, 1998). Most importantly, the ET cover performance has been field verified by the test pad constructed at the USEI site. ET cover test pad monitoring for more than five years has shown zero percolation (DBS&A, 2006).

EPA's 2003 guidance document on ET landfill cover systems (U.S. EPA, 2003) provides a summary of the research that has been performed to demonstrate ET cover performance. EPA recognizes that ET cover performance can be demonstrated to minimize percolation of moisture to levels equivalent to conventional cover designs that use low hydraulic conductivity barriers. The guidance states:

> Alternative final cover systems, such as evapotranspiration (ET) cover systems, are increasingly being considered for use at waste disposal sites, including municipal solid waste (MSW) and hazardous waste landfills when equivalent performance to conventional final cover systems can be demonstrated. Unlike conventional cover system designs that use materials with low hydraulic permeability (barrier layers) to minimize the downward migration of water from the cover to the waste (percolation), ET cover systems use water balance components to minimize percolation.

EPA is currently tracking more than 60 ET cover projects, including demonstrations and full-scale applications of ET landfill covers (U.S. EPA, 2009).

Experience gained from research sponsored by EPA and others, along with the USEI test pad performance data, provide confidence that the ET cover will provide the necessary performance to minimize moisture percolation. In summary, the proposed ET cover design for Cells 14 and 15 at USEI Site B will meet the performance standards set forth in 40 CFR §264.111, as well as the specific requirements listed in 40 CFR §264.310.

4. Soil Testing and Analysis

4.1 Introduction

In 2008, DBS&A tested soils from the USEI Site B Facility to determine their adequacy as a borrow source for construction of an ET cover over USEI Cells 14 and 15. Adequacy was determined by comparing the results of the recent soils testing to the results of earlier testing and numerical modeling of soils from the same site in 1998. In 1998, DBS&A tested borrow source soils and performed numerical modeling using the programs HELP and UNSAT-H to determine the adequacy of the soils as an infiltration barrier over Trenches 10 and 11 (DBS&A, 1998). The 1998 modeling showed that soils typical of those on-site would be adequate. The 2008 soil testing was conducted to identify acceptable borrow sources for construction of the Cell 14 and 15 ET covers, and determined which soils have characteristics indicative of performing as well or better than those modeled in 1998.

ET covers have been shown to perform well as infiltration barriers in regions where evaporation exceeds precipitation. The covers are designed to accept and store infiltration from precipitation events, which is later removed by evaporation and/or transpiration before water can infiltrate the thickness of the cover. The variables of interest for performance of an ET cover are the storage capacity and the hydraulic conductivity for a wetted soil. This evaluation focuses on the soil properties needed for the primary soil rooting medium layer to provide moisture storage and release for the required ET cover performance. Other ET cover soil components such as the upper erosion protection layer will require other properties.

4.2 Soil Sampling and Testing

Soil samples were collected from potential soil borrow source areas located on USEI property, but outside of the current USEI operating area. Samples were collected from the area planned for future Cell 16 to the west, an existing soil stockpile located adjacent to Cell 15, and the USEI property to the east, known as the Steiner property. Previous soil borings on the Steiner property indicated that these soils are predominantly fine-grained silty soils, which were expected to provide favorable characteristics for an ET cover. Soil from the Cell 15 stockpile

and Cell 16 contains less fines than the Steiner soil, but was tested to determine its suitability. Soil was also sampled from the soil dikes that have been constructed to form the side slopes of Cell 14. These samples were tested to determine whether this existing soil could be considered as a component of the ET cover for Cell 14. After initial testing, the Cell 14 dike soils were found to contain a low fraction of fine-grained particles, making these soils appear less favorable for consideration as a component of the ET cover. As a result, the dike soils were combined into a smaller number of composite samples for the additional hydraulic testing. The soil testing results are summarized in Table 1. Complete laboratory results are provided as Volume 2.

Cover soil properties must provide sufficient moisture retention capacity to minimize infiltration and support vegetative growth. Critical soil properties include particle size distribution, saturated hydraulic conductivity (K_{sat}), and moisture retention characteristics. Laboratory testing was performed for the following hydrologic and geotechnical parameters:

- Soil classification (ASTM D2488)
- Atterberg limits (ASTM D4318)
- Grain-size distribution (ASTM D422)
- Porosity (percent by volume)
- Dry bulk density (grams per cubic centimeter [g/cm^3]) (ASTM D4531;ASTM D6836)
- Moisture content (ASTM D2216)
- Standard Proctor compaction (ASTM D698)
- Saturated hydraulic conductivity (K_{sat}, cm/s) (ASTM D5084)
- Moisture retention characteristic curve and van Genuchten parameters (ASTM D6836; Klute, 1986; ASTM D2325; Karathanasis and Hajek, 1982):
  - alpha (α)
  - N
  - residual moisture content (θ_r)
  - saturated moisture content (θ_s)

Table 1. Soils and Selected Testing Results from 2008

Sample	USCS Classification	Water Holding Capacity (cm^3/cm^3)	Saturated Hydraulic Conductivity (K_{sat}) (cm/s)
USE1- DBSA Cell 14 Dike TP-1, 2, 5, 6, 7 (Composite) (80%)	(GP-GM)s	0.08	1.6×10^{-3}
USE1- DBSA Cell 14 Dike TP-1, 2, 5, 6, 7 (Composite) (92%)		0.04	1.6×10^{-3}
USE1- DBSA Cell 14 Dike TP-3, 4, 8 (Composite) (80%)	(GM)s	0.10	3.8×10^{-3}
USE1- DBSA Cell 14 Dike TP-3, 4, 8 (Composite) (92%)		0.09	5.0×10^{-4}
USE1- DBSA Cell 14 Dike TP-9 (80%)	SM	0.01	3.0×10^{-3}
USE1- DBSA Cell 14 Dike TP-9 (92%)		0.08	2.1×10^{-3}
USE1- DBSA Cell 15 Stockpile TP-12 (80%)	s(ML)	0.05	1.2×10^{-3}
USE1- DBSA Cell 15 Stockpile TP-12 (92%)		0.18	3.3×10^{-4}
USE1- DBSA Cell 16 TP-10, 11 (Composite) (80%)	(SM)g	0.14	1.6×10^{-3}
USE1- DBSA Cell 16 TP-10, 11 (Composite) (92%)		0.14	5.0×10^{-5}
USE1- DBSA Steiner TP-13 (80%)	SM	0.15	2.2×10^{-4}
USE1- DBSA Steiner TP-13 (92%)		0.15	7.8×10^{-6}
USE1- DBSA Steiner TP-14 (80%)	(ML)s	0.24	4.2×10^{-5}
USE1- DBSA Steiner TP-14 (92%)		0.23	1.1×10^{-5}
USE1- DBSA Steiner TP-15 (80%)	(ML)s	0.21	2.5×10^{-4}
USE1- DBSA Steiner TP-15 (92%)		0.21	5.4×10^{-5}

USCS = Unified Soil Classification System
cm^3/cm^3 = Cubic centimeters per cubic centimeter
cm/s = Centimeters per second

Soil density is a key parameter that affects a soil's hydrologic characteristics and the ability for vegetation to be established. Initial laboratory testing was performed on all samples for soil classification, grain size, and compaction. After these results were available, 16 soil samples were selected for additional soil testing of saturated hydraulic conductivity and moisture retention characteristics. These samples were compacted in the laboratory to 80 percent and 92 percent of the maximum dry density as determined according to ASTM D698 (standard Proctor compaction). This range represents the target minimum and maximum compaction rates for the ET cover soil, which are expected when the soil is placed during construction without any additional compaction effort.

For the Steiner soils tested, relative compaction values of 80 to 92 percent of the standard maximum dry density equate to the following ranges:

- Steiner TP-13: 87.4 to 100.5 pounds of force per cubic foot (lbf/ft^3)
- Steiner TP-14: 78.9 to 90.7 lbf/ft^3
- Steiner TP-15: 78.4 to 90.2 lbf/ft^3

Goldsmith et al. (2001) discuss the growth limiting bulk density (GLBD) for different soil types. They reference a GLBD textural triangle that was modified from Daddow and Warrington (1983) (see Appendix D3). Plotting the Steiner soils on the GLBD textural triangle allowed a GLBD to be determined for Steiner TP-13, Steiner TP-14, and Steiner TP-15. Data used to plot the soils were obtained from the DBS&A laboratory report particle size analysis plots (Appendix E).

The soils yielded the following values of GLBD:

- Steiner TP-13: 104.3 lbf/ft^3
- Steiner TP-14: 93.6 lbf/ft^3
- Steiner TP-15: 95.5 lbf/ft^3

The maximum densities for each soil sample, representing 92 percent of the standard maximum dry density, are all less than the corresponding GLBD values, indicating that the cover soils will not limit root growth.

The soil test results in Table 1 provide the water holding capacity and saturated hydraulic conductivity for soils compacted to 80 and 92 percent of maximum dry density, to provide the range or results for the allowable densities.

During a previous soil sampling program in November 1998, soil samples were collected for laboratory testing from 14 test pits dug on-site with a backhoe. Table 2 lists the sample ID, the soil type, the water holding capacity, and the saturated hydraulic conductivity value for each soil sample.

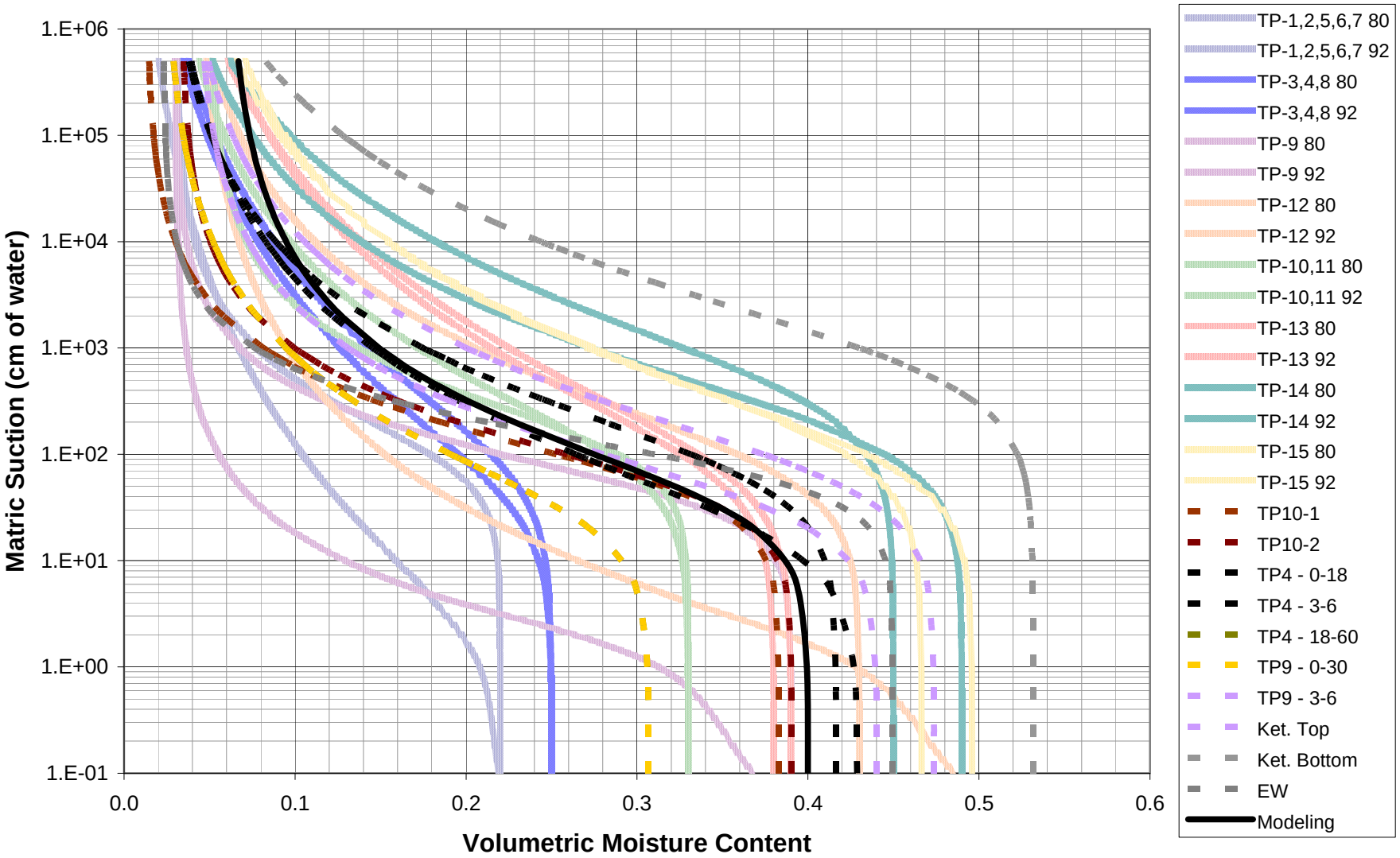
Table 2. Soils and Selected Testing Results from 1998

Sample	USCS Classification	Water Holding Capacity (cm^3/cm^3)	Saturated Hydraulic Conductivity (K_{sat}) (cm/s)
T10-1	GP-GM	0.12	3.5×10^{-3}
T10-2	GM	0.11	1.7×10^{-3}
TP4 0-18	ML	0.16	6.2×10^{-5}
TP4 3-6	ML	0.12	1.9×10^{-4}
TP4 18-60	GM	0.08	4.2×10^{-2}
TP9 0-30	ML	0.08	1.2×10^{-5}
TP9 3-6	ML	0.12	5.6×10^{-4}
Ketterling Top	ML	0.18	5.2×10^{-5}
Ketterling Bottom	CL	0.28	7.4×10^{-7}
EW	SP-SM	0.12	4.2×10^{-3}
Modeled		0.11	2.06×10^{-4}

USCS = Unified Soil Classification System
cm^3/cm^3 = Cubic centimeters per cubic centimeter
cm/s = Centimeters per second

Water holding capacity represents the water that is readily available to uptake by plant roots, which is the difference between the field capacity (defined as soil moisture content at -333 centimeters [cm] of water pressure head) and the permanent wilting point (defined as soil moisture content at –15,000 cm of water pressure head). The “Modeled” row provides the values that were used in 1998 for numerical modeling (DBS&A, 1998). The modeled values represent the silty soils (ML) selected as the most appropriate soil rooting medium from TP4 0-18, TP4 3-6, TP9 0-30, and TP9 3-6.

To compare the soil samples from 2008 to those from 1998, moisture characteristic curves (MCCs) were developed for all samples (Figure 2). In Figure 2, the solid colored lines represent soils tested in 2008 and the dashed lines represent soils tested in 1998. The black solid line (“Modeling”) is the MCC used for numerical modeling of the cover for Trenches 10 and 11. Figure 3 provides a bar graph of the water holding capacities determined from the MCCs. The blue bars represent samples from 2008 and the orange bars represent samples from 1998.



US ECOLOGY IDAHO

Moisture Characteristic Curves for All Soil Samples

Figure 2

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10/25/10

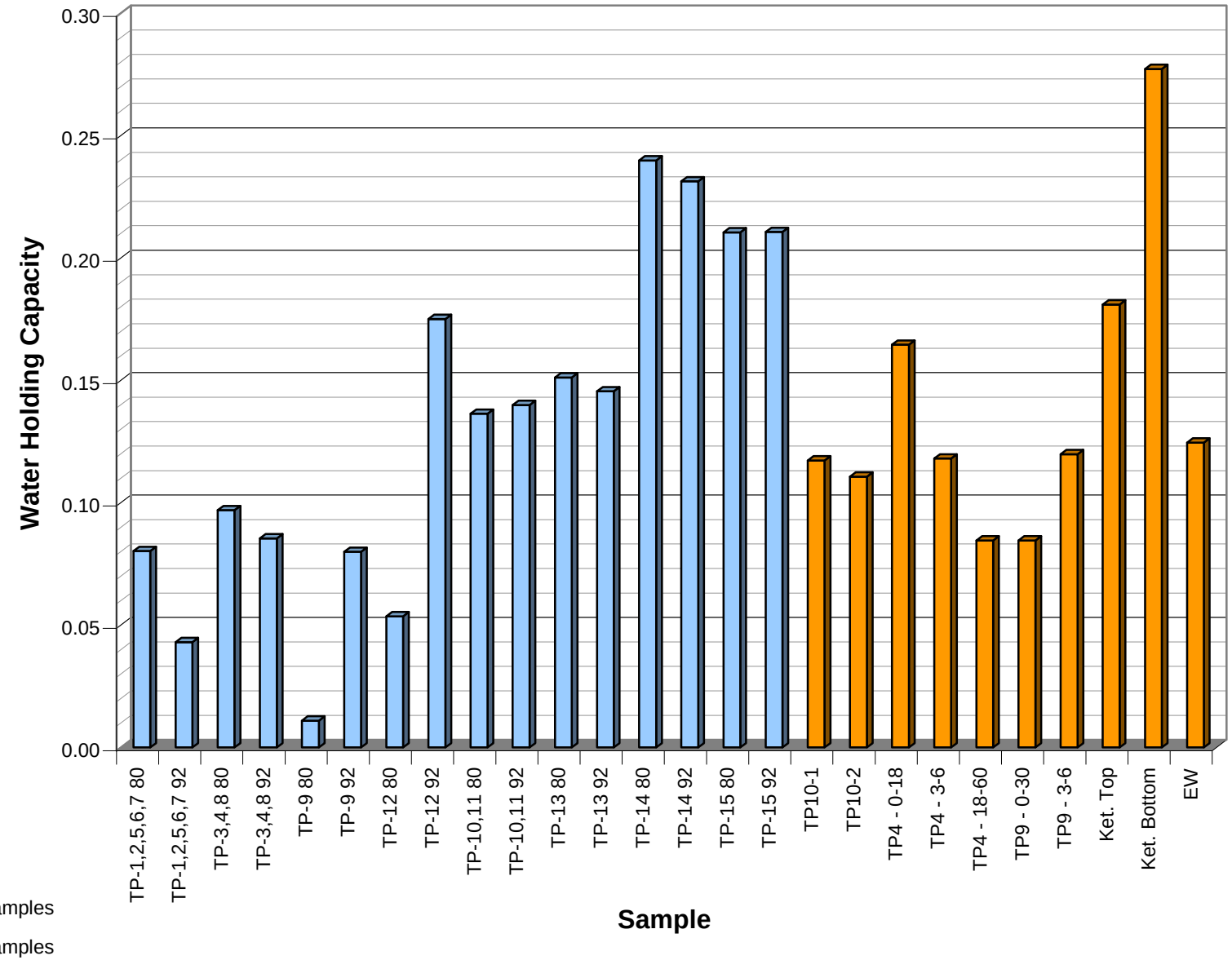

Figure 3

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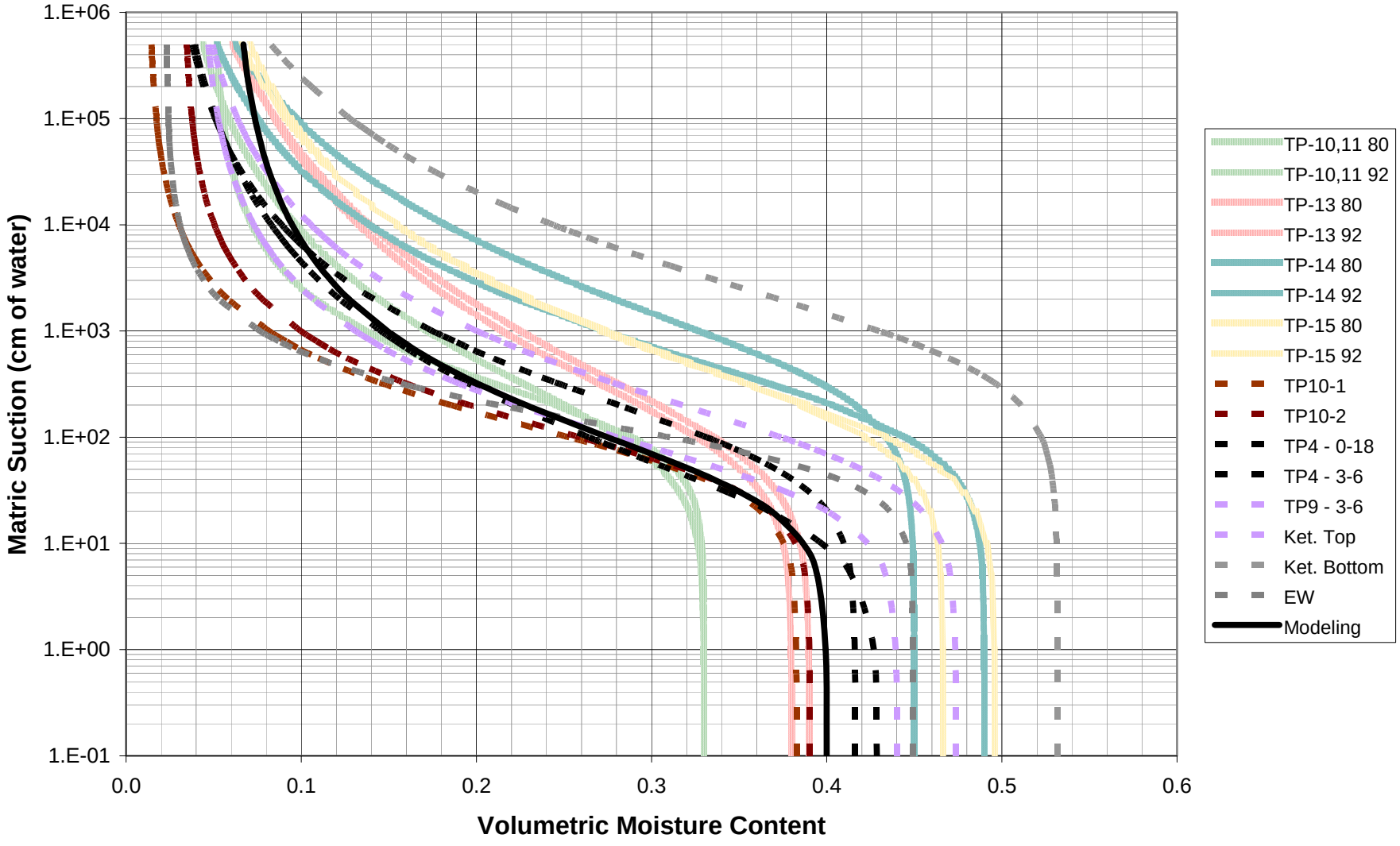
Water Holding Capacities

DBS&A used a water holding capacity value of 0.11 for the idealized cover soil used in numerical modeling of Trenches 10 and 11. The modeling showed the adequacy of the idealized soil as a soil rooting medium layer in the ET cover. Therefore, current soils that were determined to have a water holding capacity less than 0.11 were discarded from consideration as acceptable cover material. Figure 4 shows the MCCs of soils with a water holding capacity equal to or greater than 0.11.

The hydraulic conductivity values of the soils (Figure 5) were determined from the van Genuchten parameters. The “Modeling” curve represents the idealized soil used in the 1998 numerical modeling. The idealized soil modeled in 1998 was determined to be acceptable to construct the ET cover for Trenches 10 and 11. That is, the hydraulic conductivity of the soil cover after an infiltration event was small enough that the water could not penetrate a depth past the point where it could be removed by evaporation and/or transpiration. The hydraulic conductivity values of the recently tested soils in the near saturation range (~100 cm of water matric suction or smaller), less than or equal to the “modeling” hydraulic conductivity curve in Figure 5, were considered acceptable. Figure 6 provides hydraulic conductivity curves for the soils that pass this criterion.

Table 3 indicates which 2008 soil samples were determined to have acceptable qualities for use as cover material based on comparison to the idealized soil used for numerical modeling in 1998. As indicated in Table 3, TP-13, TP-14, and TP-15 represent acceptable borrow sources for construction of the ET cover for Cells 14 and 15 without further numerical modeling. These soils are the Steiner silty sands and low plasticity silts. The soils may be placed from 80 to 92 percent relative compaction, as a percentage of the maximum dry density determined from ASTM D698 (Standard Proctor). Other soils may be acceptable, but would require additional numerical modeling to confirm acceptability.



US ECOLOGY IDAHO

Moisture Characteristic Curves for Soils with Acceptable Water Holding Capacity

Figure 4

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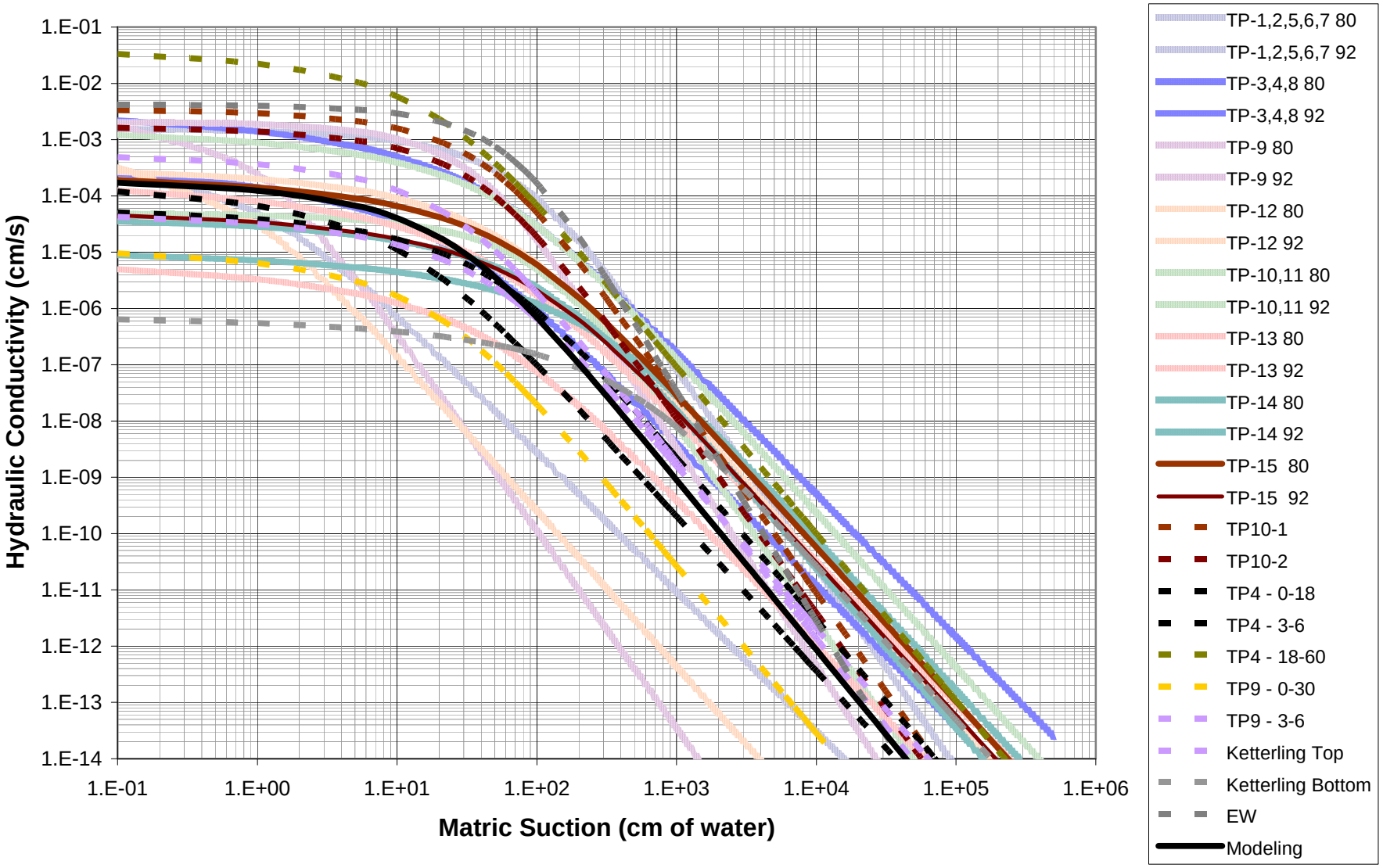
10/25/10



US ECOLOGY IDAHO

Hydraulic Conductivity Curves for All Soil Samples

Figure 5

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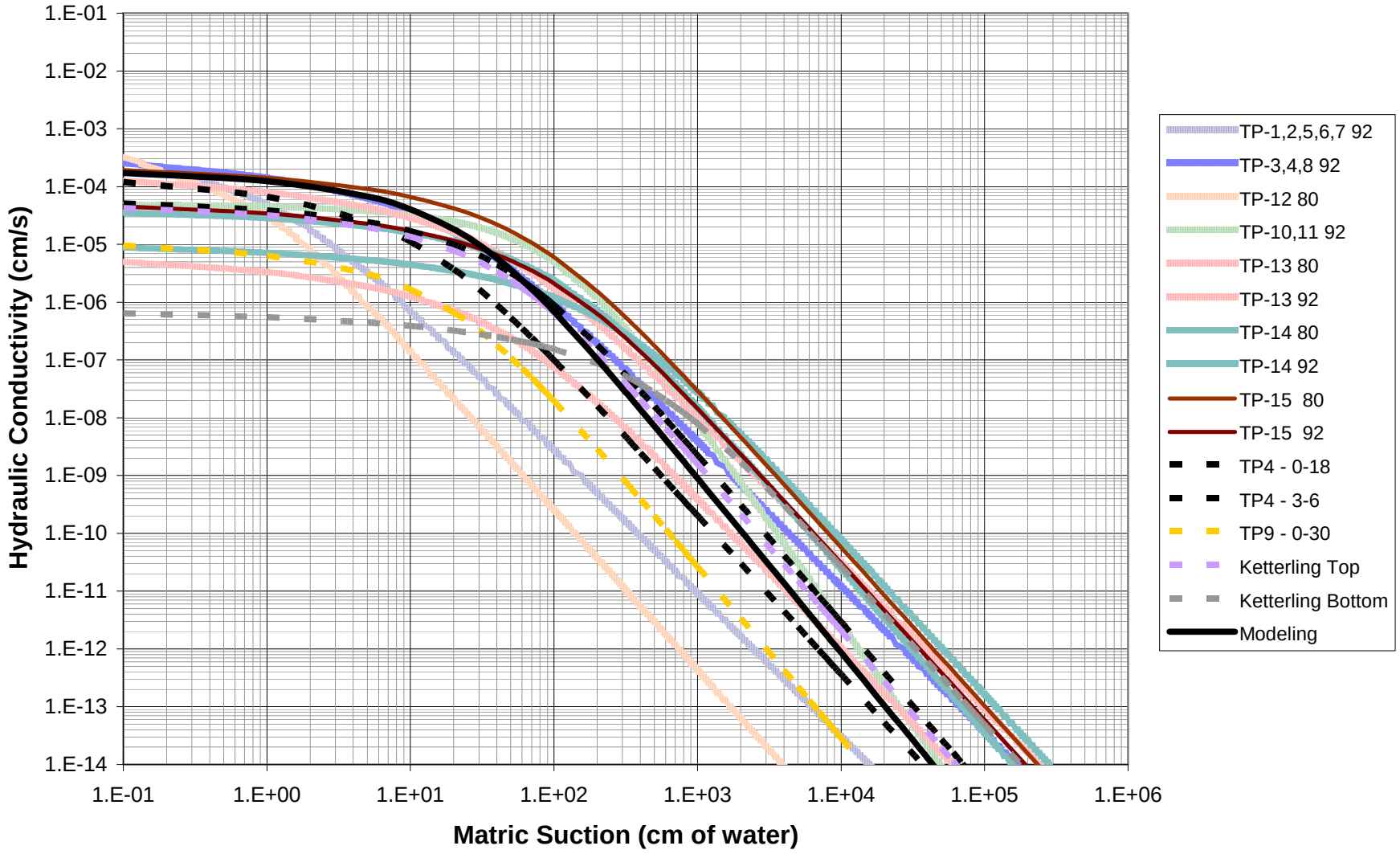
10/24/10



US ECOLOGY IDAHO

Hydraulic Conductivity Curves for Soils with Acceptable Hydraulic Conductivity Values

Figure 6

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10/24/10

Table 3. Acceptability for Cover Material Use of Soils Sampled in 2008

Sample	Acceptable Water Holding Capacity?	Acceptable Hydraulic Conductivity?	Acceptable?
USE1- DBSA Cell 14 Dike TP-1, 2, 5, 6, 7 (Composite) (80%)	No	No	No
USE1- DBSA Cell 14 Dike TP-1, 2, 5, 6, 7 (Composite) (92%)	No	**Yes**	No
USE1- DBSA Cell 14 Dike TP-3, 4, 8 (Composite) (80%)	No	No	No
USE1- DBSA Cell 14 Dike TP-3, 4, 8 (Composite) (92%)	No	**Yes**	No
USE1- DBSA Cell 14 Dike TP-9 (80%)	No	No	No
USE1- DBSA Cell 14 Dike TP-9 (92%)	No	No	No
USE1- DBSA Cell 15 Stockpile TP-12 (80%)	No	**Yes**	No
USE1- DBSA Cell 15 Stockpile TP-12 (92%)	No	No	No
USE1- DBSA Cell 16 TP-10, 11 (Composite) (80%)	**Yes**	No	No
USE1- DBSA Cell 16 TP-10, 11 (Composite) (92%)	**Yes**	**Yes**	**Yes**
USE1- DBSA Steiner TP-13 (80%)	**Yes**	**Yes**	**Yes**
USE1- DBSA Steiner TP-13 (92%)	**Yes**	**Yes**	**Yes**
USE1- DBSA Steiner TP-14 (80%)	**Yes**	**Yes**	**Yes**
USE1- DBSA Steiner TP-14 (92%)	**Yes**	**Yes**	**Yes**
USE1- DBSA Steiner TP-15 (80%)	**Yes**	**Yes**	**Yes**
USE1- DBSA Steiner TP-15 (92%)	**Yes**	**Yes**	**Yes**

5. Cover Thickness and Slopes

The cover thickness and slopes are variable on Cells 14 and 15 due to several design constraints. The covers must meet minimum thicknesses for ET cover performance and additional regulatory and performance-based criteria. The cover layouts must also address differences in the waste placement configuration in Cells 14 and 15. This section describes the design basis for the final cover thickness and slopes. Citations in this section are from the permit documents and engineering drawings for the USEI Site B facility.

Engineering design drawings for the Cell 14 and 15 covers are provided in Appendix A. The drawings include details of the cover thickness and slopes, cover grading plan, and cross sections. The cover grading plans meet the minimum cover thickness requirements at key points that control the cover design. The covers are thicker than the minimum over many areas, in order to meet the thickness requirement at the control points and provide a relatively uniform and constructible configuration.

5.1 Cell 14 Final Cover Configuration

Drawing Sheet 8 (Appendix A, Cell 14) provides a typical final cover cross section for Cell 14. Consistent with the ET cover design and performance modeling for Cells 10 and 11 (Drawing PRMI-L04), a final cover thickness of 5 feet of soil is needed to provide ET cover performance. Cover slopes on benches and the top deck are a minimum of 5 percent. Cover slopes are a maximum of 33 percent (3:1).

Soil dikes constructed on the side slopes of Cell 14 were considered as the lower component of the ET final cover. However, the laboratory testing of soil from the dikes for hydrologic and geotechnical properties showed that the dike soil is poorly graded sand and gravel with few fines, which does not provide the moisture retention characteristics to provide adequate soil moisture storage and support vegetative growth on the cover. Based on the dike soil testing, the dikes are not included as a component of the ET cover, but will provide the foundation layer underlying a soil cover constructed above. The ET cover will be a minimum of 5 feet thick over all soil dikes.

In two limited areas on the north slope of Cell 14, the final cover grading plan provides less than the minimum thickness of 5 feet above the existing surveyed grades. These areas are along access ramps consisting of soil that extends above the side slope soil dikes. To ensure that the cover meets the minimum thickness of 5 feet in all areas, soil will be removed from the access ramps where needed prior to cover construction in order to provide for placement of a sufficient thickness of suitable soil for the ET cover. Regrading the ramp will not disturb the underlying dikes or waste.

The cover must be of a minimum thickness to serve as a radon barrier over waste from the Formerly Utilized Sites Remedial Action Program (FUSRAP waste). The thickness of cover or select non-FUSRAP waste over the FUSRAP waste has been established at 3.6 meters (11.81 feet) (Exempt Radiological Procedure Manual [ERPM], USEI, April 2005, Permit Attachment 23). Dike as-built drawings for Dikes C through I show that the dikes and/or non-FUSRAP waste are always maintained at a minimum thickness of 8.31 feet. Therefore, a minimum cover thickness of 3.5 feet must be added to provide the radon barrier on the side slopes where dikes are constructed. The 5-foot minimum cover thickness included in the design satisfies this criterion.

The cover thickness is also a minimum of 5 feet on the top deck. The cover design for the top deck of Cell 14 will meet the ERPM requirement by placement of only select RCRA non-FUSRAP waste in the upper 11.81 feet or more. The minimum thickness of non-FUSRAP waste needed on the top deck is 7 feet, providing a total thickness of 12 feet including the 5-foot ET cover. Placement of FUSRAP waste has already ceased within Cell 14, while filling is occurring behind Dike I (Bailey, 2008a and 2008b). Three additional dikes will be constructed before waste reaches final height (Thurgood, 2008).

The top deck of the final cover will be graded to drain at a slope of 5 percent. The final lift of waste will also be placed on a slope of 5 percent, serving as the subgrade for the final cover. The final waste placement elevation will be 2,657 feet above mean sea level (msl), 17 feet higher than the current elevation of 2,640 feet msl at the top of Dike I. The final cover elevation will be 2,662 feet msl, matching the permitted design.

On the top deck of Cell 14, Drawing PRMI-L28 Detail 8 shows a 1-foot-thick intermediate soil cover. This intermediate cover provides a protective layer over the waste until final cover construction commences and provides a working surface for construction equipment. The intermediate cover is included as the upper component of the non-FUSRAP waste, with the intermediate cover soil included in the designed top-of-waste elevations.

Dike drawings C2 (July 2002) and D2 (January 2003) state in notes that the dike toe is to match or go beyond the primary anchor trench. Drawing PRMI-L28 Detail 9, which was used at the time of Cell 14 liner and dike construction, shows the dike matching the secondary anchor trench. The ET cover toe in the current design (as shown on Sheet 8 [Appendix A, Cell 14]) is drawn based on the dike matching the primary anchor trench. With a 5-foot cover thickness on a 3:1 slope, this design places the cover toe at 15 feet outside the primary anchor trench. This approach is conservative in placing a thicker soil cover if the dike toe is closer to the secondary anchor trench.

The cover is designed to extend beyond the primary liner anchor trench, which has been constructed at variable distances beyond the limit of the Cell 14 liner during various construction phases. Drawing PRMI-L25 shows the limit of the lined disposal cell at the upper slope break of the liner. Drawing PRMI-L22 and details on PRMI-L24 and PRMI-L25 show variable dimensions for the width of anchor trench outside the cell limit. Eastern cells that are part of Phase 1 show the primary anchor trench 4.5 feet from the cell limit (PRMI-L24 B-B and C-C). The anchor trench extension shown in Drawing PRMI-L24 C-C is not considered to change the dike location over the primary anchor trench. Western cells that are part of Phase 2 show the primary anchor trench 7.5 feet from cell limit, except for 25 feet before and after the north radius, where the primary anchor trench increases to 8.5 feet from the cell limit (L25 D-D).

5.2 Cell 15 Final Cover Configuration

Drawing Sheet 7 (Appendix A, Cell 15) provides a typical final cover cross section for Cell 15. Consistent with the ET cover design and performance modeling for Cells 10 and 11 (Drawing PRMI-L04), a final cover thickness of 5 feet of soil is needed to provide ET cover

performance. As described below, the 5-foot minimum thickness will be met on the top deck of the landfill and will be exceeded on the side slopes.

The top deck of the final cover will be graded to drain at a slope of 5 percent. The final lift of waste will also be placed on a slope of 5 percent, serving as the subgrade for the final cover. Cover side slopes are a maximum of 31 percent (3.2:1).

The cover must be of a minimum thickness to serve as a radon barrier over FUSRAP waste. The thickness of cover or select non-FUSRAP waste over the FUSRAP waste has been established at 3.6 meters (11.81 feet) (ERPM, USEI, April 2005, Permit Attachment 23). To meet the minimum thickness on side slopes, the cover is designed to be 12 feet thick, exceeding the 11.81-foot minimum. The cover design for the top deck of Cell 15 will meet the ERPM requirement by placement of only select non-FUSRAP waste in the upper 11.81 feet or more. At the final stage of filling Cell 15, all FUSRAP waste will be disposed of in Cell 16, which is planned to be open at the time Cell 15 is nearing completion of fill operations (Bailey, 2008a and 2008b). The cover thickness will be a minimum of 5 feet on the top deck and 9 feet on the upper part of the eastern side slope. Along with the 5-foot ET cover soil, a minimum of 7 feet of non-FUSRAP waste is necessary on the top deck and 3 feet on the eastern side slope to meet the ERPM 11.81-foot standard. The design drawings show the 7-foot thickness on the top deck for consistency with requirements.

Drawings 52-01-03 and 15-08-02 show that the waste limit, projected to the geomembrane liner, is set back 9 feet from the liner crest. These two drawings reference Drawings 52-01-01 and 15-08-01, respectively, which provide the coordinates of the liner crest. The liner crest serves as the reference point for the location of the cover toe.

Based on the 12-foot minimum cover thickness overlying the waste limit on the side slope, the cover will extend beyond the liner side slope crest. A minimum thickness of 5 feet of ET cover soil must be maintained at the liner side slope crest. This thickness has been verified where the cover slope extends over the perimeter channel, which is 9 feet inside the liner crest as shown on Drawing 52-01-03 Sections B and E. The perimeter bench around Cell 15 is 67 feet wide

measured from the liner crest. As designed, the cover extension distance onto the perimeter bench is 31 feet, maintaining a 36-foot-wide perimeter access road.

6. Cover Slope Stability

Slope stability analysis (Appendix D1) was performed on profiles of Cells 14 and 15 at locations representing the maximum height of the closed units. Slope stability analyses were performed using SLOPE/W 2007©, GeoStudio Version 7.13 (Geoslope International, Ltd., Calgary, Alberta, Canada).

Based on review comments from the DEQ, DBS&A performed additional analyses to include block failure (Appendix D1-4). The seismic analyses used a conservative horizontal acceleration value of 0.20 g, which represented the worst-case surface acceleration at the site. This resulted in factor of safety values greater than 1.0, but less than 1.1. A sensitivity analysis was performed on all of the slope stability analyses to better understand the effect of seismic acceleration coefficient on the factor of safety values.

The analyses considered the geometry of the liner system. Strength parameters of the various liner materials are presented in Table 4.

Table 4. Material Characteristics Used in Slope Stability Analysis

Material	Friction Angle (degrees)	Cohesion (lb/ft^2)	Unit Weight (lb/ft^3)
ET cover	27	0	101.6
Natural subgrade	36	800	115
Waste	30	125	115
Compacted clay liner	22	60	94
Common fill	31	1,000	124.8
Textured GM to GC	26	60	NA
GM to sand	17	0	NA
GM to CL soil	15	292.4	NA

lb/ft^2 = Pounds per square foot
lb/ft^3 = Pounds per cubic foot
NA = Not applicable

Cell 14 was constructed with a double liner system. The liner was represented in the analysis as a weak layer with an interface friction angle of 15 degrees. The weak liner layer was placed

on natural subgrade and covered with waste. The waste is capped with ET cover soil. Cell 15 consists of a compacted clay liner on soil subgrade, textured geomembrane, geocomposite, and liner protective soil layer (referred to as common fill in this analysis). The waste is located on the liner system and capped with ET cover soil.

The slopes of the ET covers were obtained from a profile from the design drawings. The analyses used a Mohr-Coulomb failure criterion.

Static and seismic (pseudo-static) analyses were performed to evaluate stability. The peak ground acceleration (PGA) for the site was 0.11 g (obtained from the USGS National Seismic Hazard Maps [2008]), based on a 2 percent probability of exceedance in 50 years. This value was amplified to 0.2 g to account for propagation from the bedrock to ground surface. The site contains approximately 2,250 feet of hard to very hard silty and gravelly sands, silty sands, sandy silts, and silts, overlying the Banbury Formation bedrock. An expected intermediate ground acceleration of 0.15 g was also analyzed.

The slope stability analysis was used to check against deeper circular slip surfaces and cover veneer failure. Three different approaches were used:

- Circular failure planes
- Automatic search of the failure plane, by Slope/W, with the waste treated as an impenetrable layer
- Block failure analysis with optimization of the failure surface

Automatic search is an option in Slope/W that estimates the entry and exit areas along the ground surface, based on the geometry of the problem. Slope/W evaluates trial slip surfaces and determines an approximate solution. The factor of safety is determined by optimizing the approximated critical slip surface. Optimization in Slope/W is a technique that incrementally alters segments of the approximated critical slip surface to find the shape with the lowest factor of safety. By treating the waste as an impenetrable layer, Slope/W forces the failure plane into or along the interface of the ET cover material.

Block failure analysis is performed in Slope/W by evaluating a failure surface with three planes: a bottom failure plane and two planes projecting to the ground surface. The user proposes the locations for the left and right blocks of potential intersections of the bottom and projected plane surfaces. The block surface was then optimized for the lowest factor of safety.

Automatic search of the failure plane, by Slope/W, with the waste treated as an impenetrable layer and block failure analysis with optimization of the failure surface was evaluated for static and seismic (pseudo-static) conditions for USEI Cells 14 and 15. The factors of safety determined from the analyses are presented in Table 5.

Table 5. Analytical Method Factors of Safety

	Factors of Safety					
	Cell 14			Cell 15		
Acceleration [a]	0.11 g	0.15 g	0.2 g	0.11 g	0.15 g	0.2 g
Circular Failure Plane Analysis						
Morgenstern-Price	1.888	1.702	1.56	2.116	1.937	1.76
Ordinary	1.870	1.741	1.62	1.863	1.701	1.54
Bishop	2.208	2.012	1.85	2.136	1.954	1.78
Janbu	1.755	1.604	1.46	1.817	1.656	1.50
Auto Search with Impenetrable Layers and Optimization [b]						
Morgenstern-Price	1.287	1.178	1.072	1.211	1.114	1.017
Ordinary	1.292	1.185	1.079	1.211	1.114	1.017
Bishop	1.303	1.194	1.088	1.212	1.114	1.017
Janbu	1.287	1.179	1.073	1.211	1.114	1.017
Block Analysis with Optimization [b]						
Morgenstern-Price	1.288	1.179	1.073	1.220	1.121	1.023
Ordinary	1.294	1.188	1.083	1.231	1.131	1.036
Bishop	1.317	1.206	1.100	1.279	1.177	1.078
Janbu	1.287	1.179	1.073	1.216	1.188	1.021

[a] Morgernstern-Price, Ordinary, Bishop, and Janbu refer to some of the standard solutions proposed for limit equilibrium analysis. They differ in the equations of statics that are satisfied. Ordinary and Bishop satisfy moment equilibrium. Janbu satisfies force equilibrium. Morgernstern-Price satisfies both moment and force equilibrium. For a thorough description, see Geo-Slope International Ltd. (2007).

[b] Surface raveling failure

The slope stability calculations determined that ET soil cover with slopes not exceeding 3:1 will maintain proper stability for Cells 14 and 15.

7. Erosion and Stormwater Protection

Erosion rates due to wind and stormwater were calculated for conditions prior to and after the establishment of vegetation. Calculations are provided in Appendix D2. By not considering cover vegetation, the calculations are conservative. The calculation results show that the gravel amended erosion protection layer provides a high degree of resistance to wind and water erosion.

7.1 Erosion Due to Stormwater

The calculation of soil erosion due to stormwater runoff (Appendix D2-1) used the revised universal soil loss equation. It was determined that under the assumed conditions, the maximum post-construction soil loss due to water erosion would be 0.34 ton per acre per year on the top of cover and 2.56 tons per year on the side slopes with application of 4 tons per acre of mulch, and 0.07 ton per acre per year on the top of cover and 0.51 ton per acre per year post construction with native vegetation established. Input values used in the calculation are provided in Table 6.

Table 6. Values Used in Calculation of Erosion Due to Stormwater

Variables	Value
Rainfall erosivity factor, R_e	31
Vegetative cover and management factor, native vegetation, undisturbed, C	0.01
Vegetative cover and management factor, 4 tons/acre, tacked down, C	0.05
Cover subfactor 25% gravel amended soil, C_f	0.5
Conservation support practice factor - not used, P_c	1
Organic matter, OM	0.01
Slope steepness and length factor, LS	1.04
Slope steepness and length factor, LS_2	7.94
Soil erodibility factor, K_{s1}	0.31
Soil erodibility factor, $K_{s1water}$	0.0142
Soil erodibility factor, K_{s15}	0.47
Mean soil erodibility factor, K	0.417

7.2 Critical Distance of Gully Formation

The calculation of critical distance of gully formation (Appendix D2-2) was completed to determine the critical distance before gully formation begins on the slopes of the final ET cover. The calculation was performed for cover soil amended with gravel and for unamended soil. In order to provide a substantial factor of safety in the design, a 100-year 24-hour storm event with a maximum rainfall intensity of 1 hour was considered in this equation. For the purpose of acceptance, the gully formation calculation was compared to a slope length of 300 feet for a 3:1 side slope, exceeding the maximum slope length for the cover design for Cells 14 and 15. Table 7 provides input values used in this calculation.

Table 7. Values Used in Calculation of Critical Distance of Gully Formation

Variables	Value
Runoff intensity (q_s)	1.07 inches/hour
Effective diameter, gravel amended soil (D_{75})	0.5 inch
Shear stress, gravel amended soil (t_a)	0.2 lbf/ft^2
Shear stress, on-site soil (t_s)	0.02 lbf/ft^2
Roughness factor, on-site soil (n)	0.018 (dimensionless)
Roughness factor, amended soil (n)	0.025 (dimensionless)
Slope of the top of the cover system (x_t)	2.9° (5 percent)
Slope of sides of cover system (x_S)	18.4° (33 percent)

lbf/ft^2 = Pounds of force per square foot

The critical distance for gully formation on the side slopes of the cover system is 655 feet for the gravel amended soil and 19.6 feet for the unamended soil. The critical distance for the top of the cover system was determined to be 5,405 feet for the gravel amended soil and 162 feet for the unamended soil.

The calculation results show the substantial improvement in resistance to gully formation by stormwater flow that is provided by amending the cover soil with gravel. Therefore, the cover design uses a 6-inch-thick upper erosion protection layer that will be amended with a minimum of 25 percent gravel. The cover design using gravel amended soil allows for dispersed sheet

flow of stormwater off of the covers. This design approach avoids focused flow in channels, which increases the potential for erosion. The gravel amended soil provides the necessary erosion protection to prevent rilling and gully formation, even for conditions of a large storm event occurring prior to the establishment of vegetation.

7.3 Wind Erosion

The wind erosion equation (Chepil and Woodruff, 1963) was used to determine soil loss due to wind erosion. This equation is solved using tabular and graphical analysis. Copies of the determined variables and resulting soil loss are provided in Appendix D2-3.

The wind erosion equation is expressed as follows:

$$E = f\,(IKCLV)$$

where E = estimated average annual soil loss (tons per acre per year)
f = a function of
I = soil erodibility index
K = soil surface roughness factor
C = climatic factor
L = the unsheltered distance
V = the vegetative cover factor

In determining the potential amounts of soil loss from the final cover due to wind erosion, three different scenarios were considered:

1. Vegetation and crusting had not developed on the final cover.
2. Vegetation, but not crusting, had developed.
3. Crust and vegetation were fully developed.

Annual soil loss due to wind erosion for these three scenarios was determined to be 20.6 tons per acre per year, 1.4 tons per acre per year, and 0.3 ton per acre per year, respectively. The

third value is expected to be the steady-state soil loss from the final cover and is attributed to the establishment of vegetation and crust of non-erodible materials (desert pavement) forming on the crust.

8. Vegetation Plan

Vegetation is critical to the success of an ET cover system. It provides for long-term stability of the cover surface, minimizes erosion, and removes moisture from the cover soil. Vegetation will be established on the final cover by seeding with a mix of plant varieties that are suited to the local soils and climatic conditions. Over a period of years, additional native plant varieties will spread on the ET covers, as observed on the ET covers constructed over USEI Trenches 10 and 11.

The final ET cover will be seeded with grasses, mulched, and fertilized to provide permanent erosion protection for the cover. The roots of the vegetation remove water from the cover through the process of transpiration, and are thus a critical component of the ET cover system.

A mixture of warm and cool season plants will be used for effective ET cover infiltration reduction performance. In general, cool season grasses have a more fibrous root system, while warm season vegetation is more deeply rooted. The key vegetation design requirement is that available soil-water is fully used by the plant community during the growing season. 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, when precipitation rates are highest. Native prairies always have a mixture of both warm and cool season vegetation, and the cover revegetation will simulate these natural conditions for well-adapted, sustainable vegetation.

Time of planting is a critical factor in successful establishment of plants from seeds. Seed will be planted at the appropriate time for successful germination and growth based on soil temperature and precipitation, to be determined each year at the time of planting. Mulch will be applied as needed to control erosion and enhance vegetation establishment.

The seed mix to be used at USEI Cells 14 and 15 shall consist of the following:

- Crested wheatgrass: 15 pounds per acre (lb/acre)
- Siberian wheatgrass: 18 lb/acre

- Streambed wheatgrass: 18 lb/acre

Seed will be applied by hydroseeding as an effective method to cover all of the side slopes and the contoured surface of the final cover with a uniform seed application. Hydroseeding involves spraying the seed onto the soil surface with a matrix of straw or wood fiber mulch, along with a cellulose-based tackifier that keeps the mulch adhered to the soil until the seed germinates. A timed-release fertilizer can also be applied with the hydromulch. Typical application rates are 8,000 pounds per acre mulch, 50 pounds per acre tackifier, and 400 pounds per acre fertilizer. The final products and application rates used will be determined in consultation with the hydroseeding contractor at the time that seeding occurs.

The seed and mulch will be stabilized on the cover side slopes using a spray-on bonded fiber matrix (BFM). The BFM is a hydroseeding erosion control product containing a continuous layer of elongated fiber strands held together by a bonding agent. The BFM is intended to eliminate direct raindrop impact on soil. It adheres to the final cover surface, eliminating the potential for rill erosion and downcutting. The BFM stabilizes the seed mixture to promote germination and plant growth. It retains moisture and will biodegrade completely into materials beneficial to plant growth.

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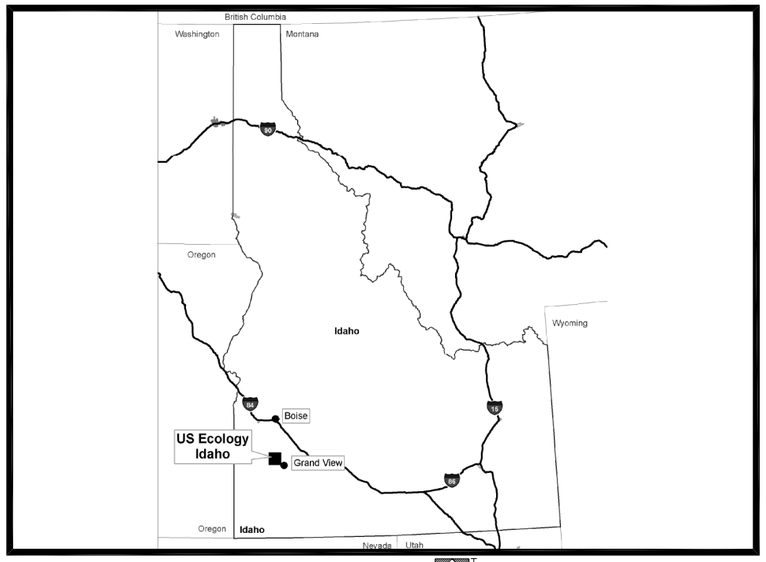
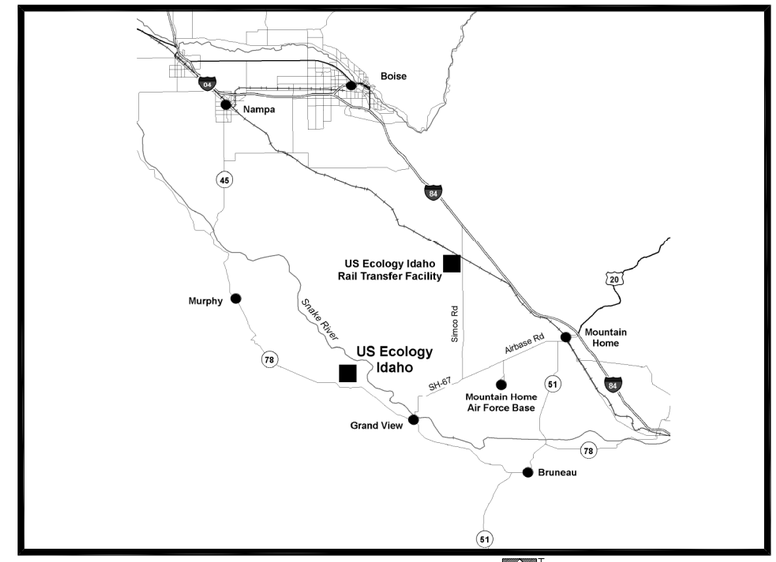
Appendix A

Drawings

Cell 14



VICINITY MAP
NTS
NORTH



SITE MAP
NTS
NORTH

CELL 14
FINAL COVER DESIGN
HAZARDOUS WASTE FACILITY

US ECOLOGY IDAHO
GRAND VIEW, IDAHO

PREPARED FOR US ECOLOGY IDAHO

INDEX OF DRAWINGS

NUMBER	TITLE
1	TITLE SHEET AND DRAWING INDEX
2	GENERAL NOTES AND LEGEND
3	CONSTRUCTION LOGISTICS
4	EXISTING WASTE GRADING PLAN
5	FINAL COVER GRADING PLAN
6	TYPICAL CROSS SECTIONS
7	TYPICAL CROSS SECTIONS
8	TYPICAL FINAL COVER SECTION AND DETAILS
9	TYPICAL DETAILS

NOT FOR CONSTRUCTION

PROFESSIONAL ENGINEER REGISTERED 12139 STATE OF IDAHO R. ERIC PEASE
Ronald Eric Pease 10/25/2010

REV.	BY / DATE	CHK'D / DATE	DESCRIPTION	PROJ ENGR / DATE	SUPV ENGR / DATE

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an American Ecology company

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ENVIRONMENTAL SCIENTISTS & ENGINEERS
6020 ACADEMY NE, SUITE 100, ALBUQUERQUE, NM 87109, (505) 822-9400

SITE B
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
TITLE SHEET AND DRAWING INDEX

DRAWN BY: DATE	SCALE:	FILE CODE PRMIL28A	REV. NO.
KDB 10/25/10	N.T.S.	DWG. NO. SHEET 1 OF 9	3
CHECKED DATE	ENGINEER DATE		
M. Miller 10/25/10	R.E.Pease 10/25/10		
PROJ. MGR. DATE	APPROVED DATE	PROJ. NO. PRMI	
J. Kelsey 10/25/10			

CONSTRUCTION NOTES

GENERAL

CONTRACTOR IS RESPONSIBLE FOR OBTAINING ALL REQUIRED PERMITS PRIOR TO START OF CONSTRUCTION.

ALL WORK ON THIS PROJECT SHALL BE PERFORMED IN ACCORDANCE WITH APPLICABLE FEDERAL, STATE AND LOCAL LAWS, RULES AND REGULATIONS CONCERNING CONSTRUCTION SAFETY AND HEALTH. ALL WORK, INCLUDING WORK WITHIN TRENCHES, SHALL BE IN COMPLIANCE WITH THE OCCUPATIONAL SAFETY AND HEALTH ACT (OSHA).

THE CONTRACTOR SHALL NOT INSTALL ITEMS AS SHOWN ON THE PLANS WHEN IT IS OBVIOUS THAT FIELD CONDITIONS ARE DIFFERENT THAN SHOWN IN THE DESIGN. SUCH CONDITIONS SHOULD BE BROUGHT TO THE ATTENTION OF THE ENGINEER. IN THE EVENT THE CONTRACTOR DOES NOT NOTIFY THE ENGINEER, THE CONTRACTOR ASSUMES FULL RESPONSIBILITY AND EXPENSE FOR ANY REVISIONS NECESSARY.

EXISTING SITE IMPROVEMENTS WHICH ARE DAMAGED OR DISPLACED BY THE CONTRACTOR SHALL BE REMOVED AND REPLACED BY THE CONTRACTOR AT THE CONTRACTOR'S OWN EXPENSE. REPAIRS SHALL BE APPROVED BY THE OWNER PRIOR TO CONSTRUCTION OF THE REPAIRS. REPAIRS SHALL BE ACCEPTED BY THE OWNER PRIOR TO FINAL PAYMENT.

EXISTING FENCING THAT IS NOT DESIGNATED FOR REMOVAL SHALL NOT BE DISTURBED. ANY FENCING THAT IS DISTURBED OR ALTERED BY THE CONTRACTOR SHALL BE RESTORED TO ITS ORIGINAL CONDITION AT THE CONTRACTOR'S EXPENSE. IF THE CONTRACTOR WOULD LIKE TO REMOVE FENCING TO FACILITATE CONSTRUCTION OPERATIONS, THIS MAY BE DONE WITH THE OWNER'S PERMISSION, AND THE CONTRACTOR SHALL RESTORE THE FENCE TO ITS ORIGINAL CONDITION PRIOR TO THE CLOSE OF THE PROJECT. CONTRACTOR IS RESPONSIBLE FOR SECURITY OF THE SITE UNTIL THE FENCE IS REPLACED. FENCE MATERIAL SHALL BE APPROVED BY THE OWNER.

THE CONTRACTOR SHALL USE THE DESIGNATED STAGING AREA FOR STORAGE OF EQUIPMENT AND MATERIAL. NO MATERIAL OR EQUIPMENT MAY BE STORED OR LEFT ON SITE AT ANY OTHER LOCATION. THE OWNER ASSUMES NO LIABILITY FOR CONTRACTOR'S EQUIPMENT OR MATERIAL IN THE STAGING AREA. SECURITY SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR.

AT THE END OF EACH WORK DAY, THE CONTRACTOR SHALL CLEAN AND PICK UP THE WORK AREA. AT NO TIME SHALL THE WORK BE LEFT IN A MANNER THAT COULD ENDANGER WORKERS OR THE PUBLIC.

ALL MATERIALS AND WORKMANSHIP SHALL CONFORM TO PROJECT SPECIFICATIONS AND PLANS, AS AMENDED AND REVISED BY THE ENGINEER. ALL INSTALLATION DETAILS ARE TYPICAL AND MAY BE CHANGED TO BETTER FIT EXISTING LOCAL CONDITIONS UPON THE DIRECTION OF THE ENGINEER.

ESTIMATED QUANTITIES SHOWN HEREIN ARE FOR INFORMATION ONLY; FINAL QUANTITIES WILL BE DETERMINED BASED ON ACTUAL WORK ACCOMPLISHED, UPON COMPLETION OF PROJECT AND ON FINAL MEASUREMENTS.

THE CONTRACTOR SHALL TAKE ALL NECESSARY MEASURES TO ENSURE THAT ALL EXISTING MONITOR WELLS AND SURVEY MONUMENTS ARE NOT DAMAGED DURING THE WORK. THE CONTRACTOR SHALL BEAR THE RESPONSIBILITY OF PROTECTING THE WELLS AND MONUMENTS DURING CONSTRUCTION, AND SHALL BEAR ALL COSTS IN THE REPAIR OR REPLACEMENT OF DAMAGED WELLS AND MONUMENTS.

THE CONTRACTOR SHALL COMPLY WITH ALL APPLICABLE REGULATIONS CONCERNING CONSTRUCTION NOISE AND HOURS OF OPERATIONS.

SOILS

UNLESS OTHERWISE SPECIFIED, MATERIALS SHALL BE COMPACTED TO THE FOLLOWING PERCENTAGES OF THE ASTM D 698 MAXIMUM STANDARD PROCTOR DENSITY.

MATERIAL	PERCENT COMPACTION
COVER SOIL	80–92
COMPACTED COMMON FILL	90

UTILITIES

IF ANY UTILITY LINES, PIPELINES, OR UNDERGROUND UTILITY LINES ARE SHOWN ON THESE DRAWINGS, THEY ARE SHOWN IN AN APPROXIMATE MANNER ONLY, AND SUCH LINES MAY EXIST WHERE NONE ARE SHOWN. IF ANY SUCH EXISTING LINES ARE SHOWN, THE LOCATION IS BASED UPON INFORMATION PROVIDED TO THE ENGINEER BY OTHERS, AND THE INFORMATION MAY BE INCOMPLETE, OR MAY BE OBSOLETE BY THE TIME CONSTRUCTION COMMENCES. THE CONTRACTOR SHALL VERIFY THE LOCATION OF ANY UTILITY LINE, PIPELINE OR UNDERGROUND UTILITY LINE IN OR NEAR THE AREA OF THE WORK.

PRIOR TO CONSTRUCTION, THE CONTRACTOR SHALL EXCAVATE AND VERIFY THE HORIZONTAL AND VERTICAL LOCATIONS OF PERTINENT UTILITIES. SHOULD A CONFLICT EXIST, THE CONTRACTOR SHALL NOTIFY THE ENGINEER SO THAT THE CONFLICT CAN BE RESOLVED WITH A MINIMUM AMOUNT OF DELAY. CONTRACTOR IS TO EXERCISE DUE CARE TO AVOID DISTURBING ANY EXISTING UNDERGROUND UTILITIES. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO COORDINATE ANY POTENTIAL DISRUPTIONS IN UTILITY SERVICE WITH THE UTILITY COMPANIES AFFECTED AT LEAST 24 HOURS PRIOR TO THE DISRUPTION.

THE CONTRACTOR SHALL SECURE AND PAY FOR ALL NECESSARY PERMITS.

EROSION CONTROL, ENVIRONMENTAL PROTECTION, AND STORMWATER POLLUTION PREVENTION PLAN

THE CONTRACTOR SHALL CONFORM TO ALL CITY, COUNTY, STATE, AND FEDERAL DUST AND EROSION CONTROL REGULATIONS. THE CONTRACTOR SHALL PREPARE AND OBTAIN ANY NECESSARY DUST OR EROSION CONTROL PERMITS FROM REGULATORY AGENCIES.

THE CONTRACTOR SHALL BE RESPONSIBLE FOR TEMPORARY EROSION AND SEDIMENT CONTROL MEASURES IN ACCORDANCE WITH THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES).

THE CONTRACTOR SHALL ENSURE THAT NO SOIL ERODES FROM THE SITE ONTO OTHER PROPERTY BY CONSTRUCTING TEMPORARY EROSION CONTROL BERMS OR INSTALLING SILT FENCES AT THE PROPERTY LINES AND WETTING THE SOIL TO KEEP IT FROM BLOWING.

CONSTRUCTION AREAS SHALL BE WATERED FOR DUST CONTROL IN COMPLIANCE WITH GOVERNMENT ORDINANCES. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING WATER ON SITE WITH THE OWNER'S DIRECTION.

ALL WASTE PRODUCTS FROM THE CONSTRUCTION SITE, INCLUDING ITEMS DESIGNED FOR REMOVAL, CONSTRUCTION WASTE, CONSTRUCTION EQUIPMENT WASTE PRODUCTS (OIL, GAS, TIRES, ETC.), GARBAGE, GRUBBING, EXCESS CUT MATERIAL, VEGETATIVE DEBRIS, ETC. SHALL BE REMOVED FROM THE SITE WITH THE APPROVAL OF THE OWNER AT NO ADDITIONAL COST TO THE OWNER. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO OBTAIN ANY PERMITS REQUIRED FOR HAUL OR DISPOSAL OF WASTE PRODUCTS. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO ENSURE THAT THE WASTE DISPOSAL SITE COMPLIES WITH GOVERNMENT REGULATIONS REGARDING THE ENVIRONMENT, ENDANGERED SPECIES, AND ARCHAEOLOGICAL RESOURCES.

THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE CLEAN–UP AND REPORTING OF SPILLS OF HAZARDOUS MATERIALS ASSOCIATED WITH THE CONSTRUCTION SITE. HAZARDOUS MATERIALS INCLUDE GASOLINE, DIESEL FUEL, MOTOR OIL, SOLVENTS, CHEMICALS, PAINT, ETC. WHICH MAY BE A THREAT TO THE ENVIRONMENT. UNDER NO CIRCUMSTANCES SHALL THE CONTRACTOR DISPOSE OF HAZARDOUS MATERIALS ON–SITE. ALL HAZARDOUS WASTE MONITORING, TESTING, HANDLING, TRANSPORTATION AND DISPOSAL SHALL BE DONE IN ACCORDANCE WITH US ECOLOGY IDAHO.

THE CONTRACTOR SHALL COMPLY WITH ALL APPLICABLE REGULATIONS CONCERNING SURFACE AND UNDERGROUND WATER. CONTACT WITH SURFACE WATER BY CONSTRUCTION EQUIPMENT AND PERSONNEL SHALL BE MINIMIZED. EQUIPMENT MAINTENANCE AND REFUELING OPERATIONS SHALL BE PERFORMED IN AN ENVIRONMENTALLY SAFE MANNER IN COMPLIANCE WITH GOVERNMENT REGULATIONS.

ABBREVIATIONS

A = AIR
A.B.I. = ADDITIVE BID ITEM
AD = AREA DRAIN
A.D. = ALGEBRAIC DIFFERENCE IN SLOPES
AIP = ABANDONED IN PLACE
AP = ANALYSIS POINT
BLDG = BUILDING
BM = BENCHMARK
BW = BASE OF WALL
CATV = CABLE TV LINE
CB = CATCH BASIN
CIP = CAST IRON PIPE
CR = CURB RETURN
CMP = CORRUGATED METAL PIPE
CMPA = CORRUGATED METAL PIPE ARCH
CMU = CONCRETE MASONRY UNITS
CO = CLEANOUT
CONC = CONCRETE
CL = CHAIN LINK
DIA = DIAMETER
DI = DROP INLET
DIP = DUCTILE IRON PIPE
DW = DOMESTIC WATER
E = ELECTRIC
ELEV = ELEVATION
ESMT = EASEMENT
EXIST = EXISTING
EB = ELECTRIC BOX
FF = FINISHED FLOOR
FG = FINISHED GRADE
FH = FIRE HYDRANT
FL = FLOW LINE
FM = FORCE MAIN
FP = FIRE PROTECTION
FP = FINISHED PAD (DIRT)
G = GAS
GM = GAS METER
GV = GATE VALVE
H = HORIZONTAL
HC = HANDICAP
HIPT = HIGH POINT
INV = INVERT ELEVATION
IP = IRON PIPE
IW = INDUSTRIAL WASTE
L = LENGTH
LF = LINEAR FEET
LP = LIGHT POLE
L/S = LANDSCAPING
LT = LEFT
MH = MANHOLE
MIN = MINIMUM
NG = NATURAL GRADE
NTS = NOT TO SCALE
O.C. = ON CENTER
PB = PULL BOX
PL = PROPERTY LINE
PCC = PORTLAND CEMENT CONCRETE
PP = POWER POLE
PCP = POLYVINYL CHLORIDE PIPE
R = RADIUS
RCP = REINFORCED CONCRETE PIPE
ROW = RIGHT OF WAY
RT = RIGHT
SL = SLOPE
SAS = SANITARY SEWER LINE
SD = STORM DRAIN
SIM = SIMILAR
SP = STEEL PIPE
STA = STATION
STD = STANDARD
T = TELEPHONE LINE
TA = TOP OF ASPHALT
TC = TOP OF CONCRETE
TG = TOP OF GRATE
T/P = TOP OF PIPE
TW = TOP OF WALL
TYP = TYPICAL
TB = TELEPHONE BOX
TR = TELEPHONE RISER
TS = TRAFFIC SIGN
TYP = TYPICAL
UE = UNDERGROUND ELECTRICAL LINE
UT = UNDERGROUND TELEPHONE LINE
UN = UNKNOWN
V = VERTICAL
VP = VENT PIPE
W = WATER
WM = WATER METER
WV = WATER VALVE
WW = WASH WATER

LEGEND

DISPOSAL TRENCH LIMITS
BUILDING
FENCE
MONITOR WELL — MW-#
WATER VALVE
DOMESTIC WASTE SYSTEM — DW
WASH WASTE SYSTEM — WW
POTABLE WATER — W
FIRE PROTECTION WATER — FP
GAS — G
OVERHEAD LINE — OHL
EXISTING UTILITY LINE — U
EXISTING ASPHALT
POWER POLE
LIGHT POLE
SLOPE (HORIZONTAL: VERTICAL) — 3:1
COMPACTED EXISTING MATERIAL
COMPACTED COMMON FILL
IN SITU SOIL
CONCRETE

NOT FOR CONSTRUCTION

REV.	BY / DATE	CHK'D / DATE	DESCRIPTION	PROJ ENGR / DATE	SUPV ENGR / DATE

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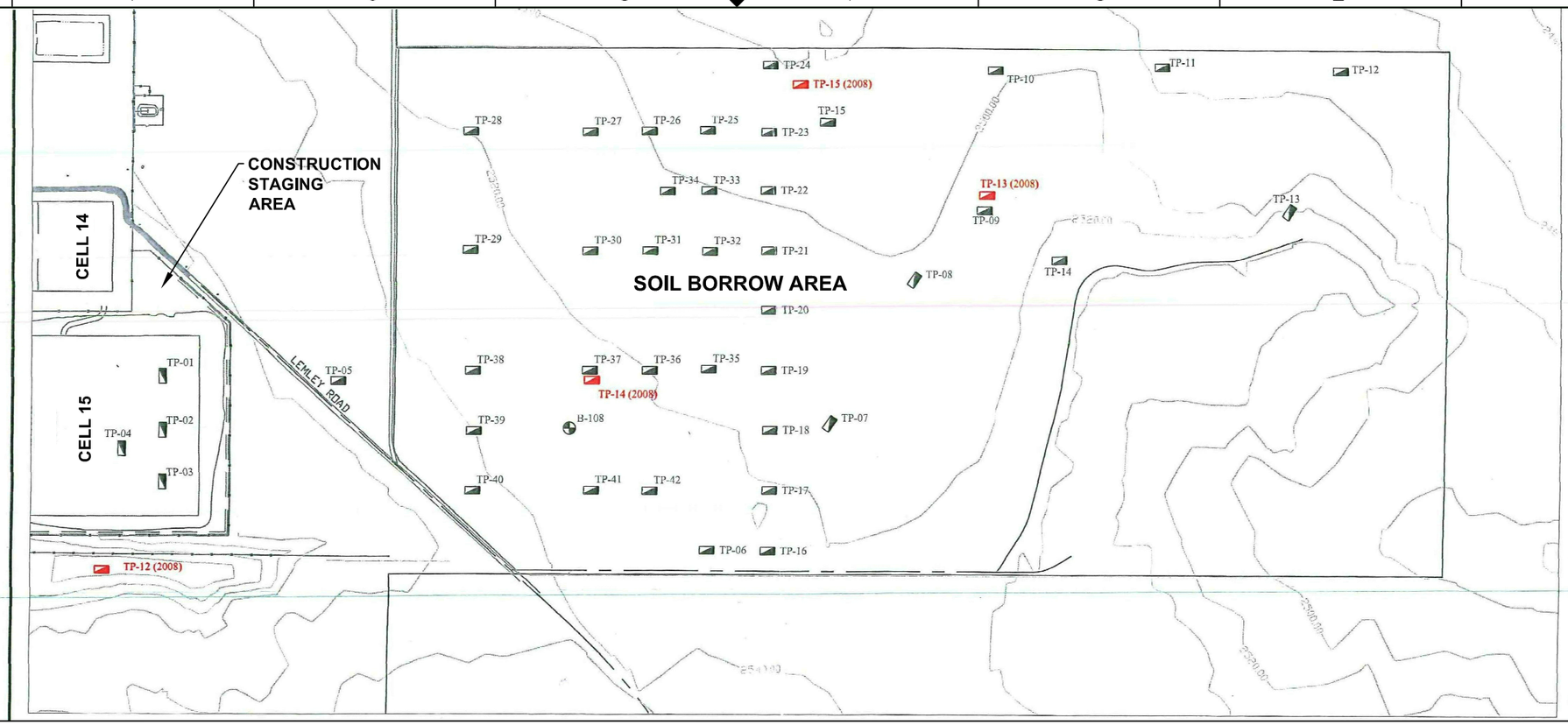
SITE B
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

PROFESSIONAL ENGINEER REGISTERED 12739 STATE OF IDAHO R. ERIC PEASE
Randall Eric Pease 10/25/2010

TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
GENERAL NOTES AND LEGEND

DRAWN BY:	DATE	SCALE:	FILE CODE PRMIL28A	REV. NO.
KDB	10/25/10	N.T.S.	DWG. NO. SHEET 2 OF 9	3
CHECKED M. Miller	DATE 10/25/10	ENGINEER R.E. Pease	DATE 10/25/10	
PROJ. MGR. J. Kelsey	DATE 10/25/10	APPROVED	DATE	PROJ. NO. PRMI



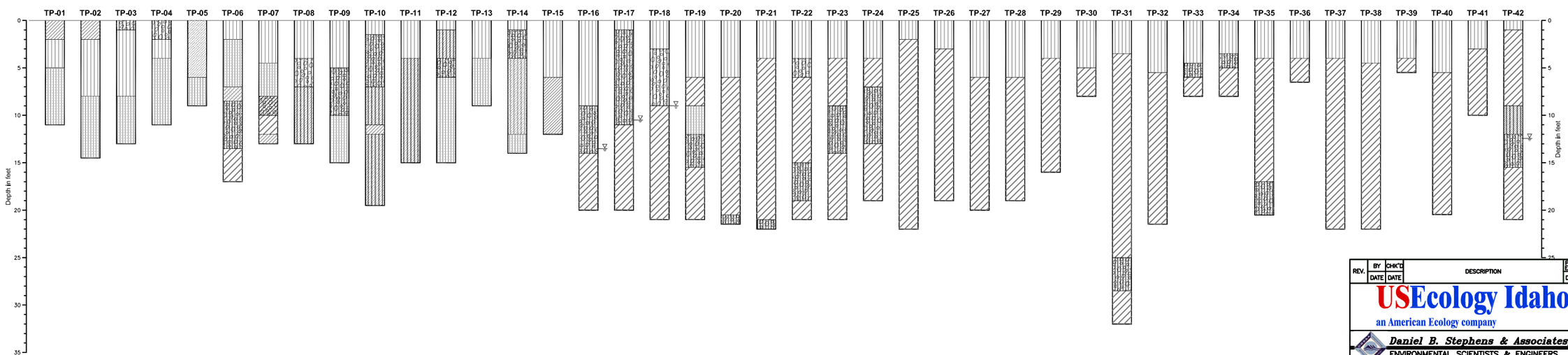
Note: Contractor shall provide traffic control on Lemley Road and all other affected roads to ensure safety during soil transport and construction.

NORTH

0 300 FT

Explanation

Test pit locations (year)



Soil Boring Geologic Logs from Soil Borrow Area

- Silt
- Silty sand
- Poorly graded sand
- Poorly graded sand with silt
- Silty gravel
- Poorly graded gravel with silt
- Poorly graded gravel with clay
- Clayey sand
- Lean clay
- Fat clay

NOT FOR CONSTRUCTION

REV.	BY / DATE	CHK'D / DATE	DESCRIPTION	PROJ ENGR / DATE	SUPV ENGR / DATE

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SITE B
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
CONSTRUCTION LOGISTICS

PROFESSIONAL ENGINEER REGISTERED STATE OF IDAHO R. ERIC PEASE 12139
Ronald Eric Pease 10/25/2010

DRAWN BY: DATE	SCALE:	FILE CODE	REV. NO.
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M. Miller 10/25/10 / R.E.Pease 10/25/10		SHEET 3 of 9	3
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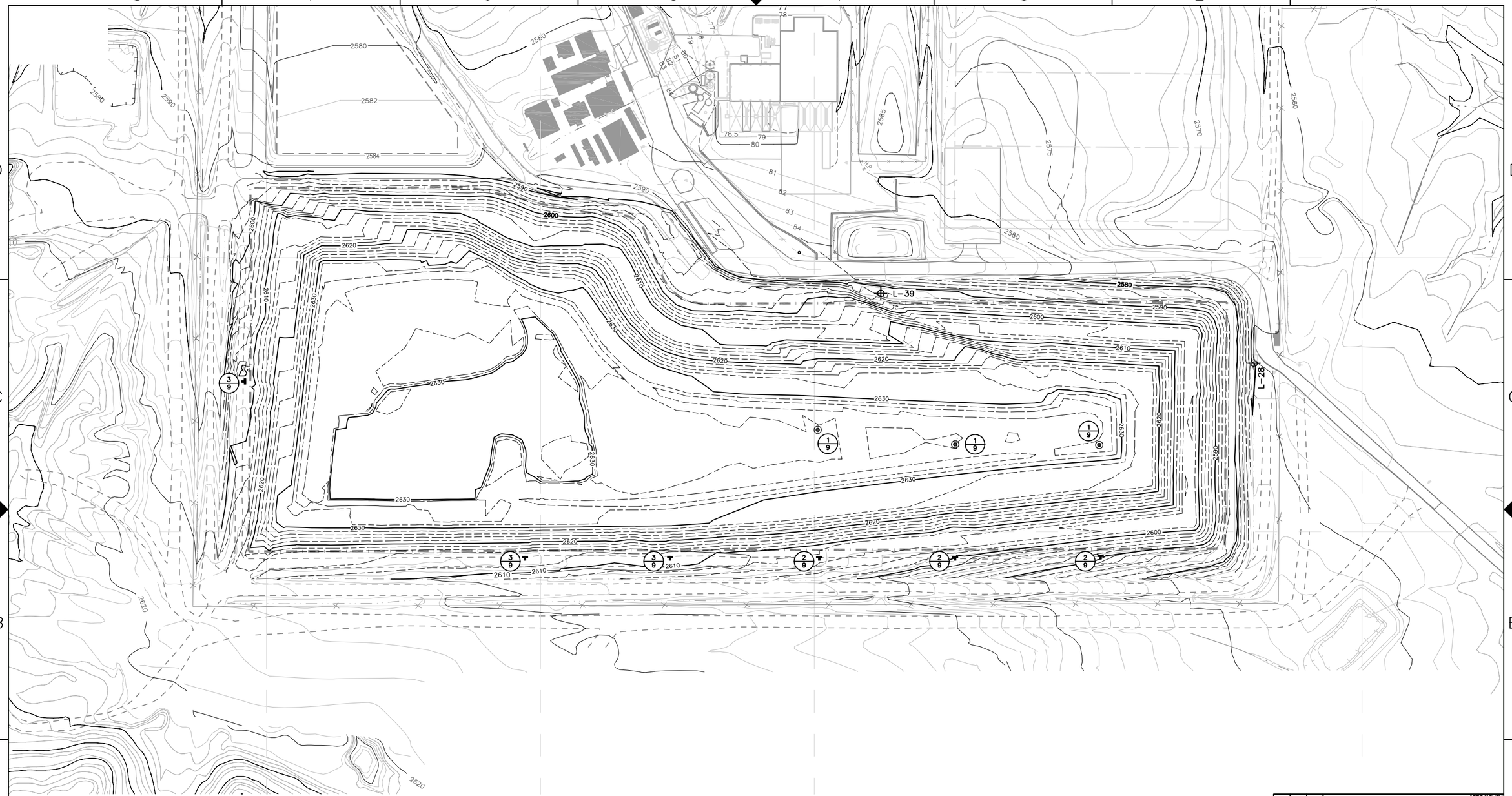

SOURCE: SURVEY COMPLETED MAY 2009 BY ARROW LAND SURVEYING, INC.

NOTES: CONTOUR INTERVAL 2-FEET

CONTOURS ARE FEET ABOVE MEAN SEA LEVEL

LIMITS OF LINED CELL

NORTH

0 80 FT

Explanation

Leachate riser and piping

Leachate riser manhole

NOT FOR CONSTRUCTION

REV.	BY / DATE	CHK'D / DATE	DESCRIPTION	PROJ. ENGR / DATE	SUPV. ENGR / DATE

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GRAND VIEW, IDAHO

US EPA ID NO. IDD 073 114 654

TITLE:

CIVIL

CELL 14 – FINAL CLOSURE

EXISTING WASTE GRADING PLAN

PROFESSIONAL ENGINEER REGISTERED 15139 STATE OF IDAHO R. ERIC PEASE

Randall Eric Pease 10/25/2010

DRAWN BY:	DATE	SCALE:	FILE CODE	REV. NO.
KDB	10/25/10	AS NOTED	ES07_0130_07B	3
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M. Miller	10/25/10	R.E.Pease	10/25/10	SHEET 4 of 9
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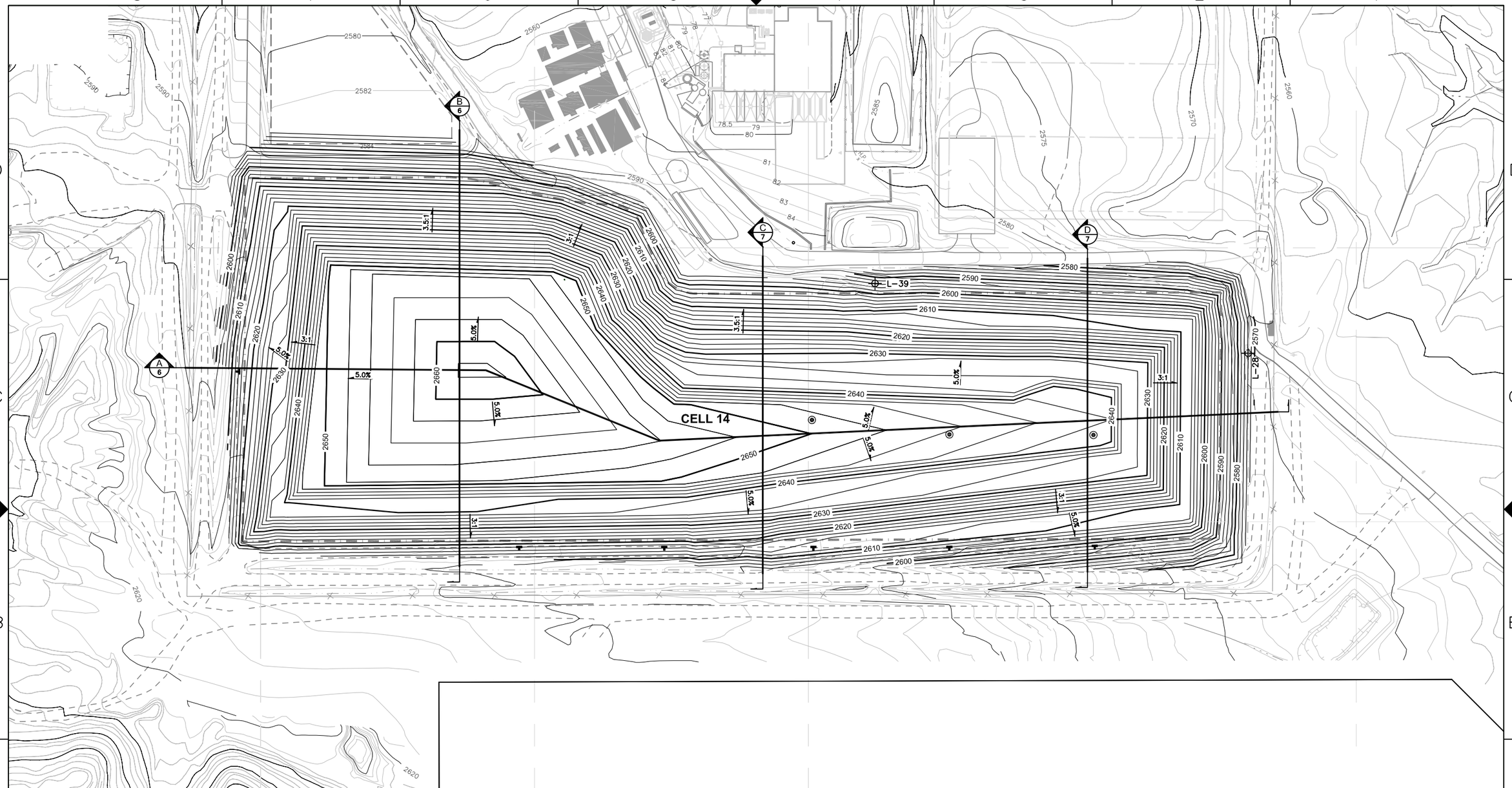
J. Kelsey	10/25/10			ES07.0130



NORTH

0 80 FT

NOTES: CONTOUR INTERVAL 2-FEET

CONTOURS ARE FEET ABOVE MEAN SEA LEVEL

LIMITS OF LINED CELL

Explanation

Leachate riser and piping

Leachate riser manhole

NOT FOR CONSTRUCTION

REV.	BY / DATE	CHK'D / DATE	DESCRIPTION	PROJ ENGR / DATE	SUPV ENGR / DATE

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SITE B

GRAND VIEW, IDAHO

US EPA ID NO. IDD 073 114 654

PROFESSIONAL ENGINEER REGISTERED STATE OF IDAHO R. ERIC PEASE 12391

Ronald Eric Pease 10/25/2010

TITLE:

CIVIL

CELL 14 – FINAL CLOSURE

FINAL COVER GRADING PLAN

DRAWN BY: KDB	DATE 10/25/10	SCALE: AS NOTED	FILE CODE ES07_0130_07B	REV. NO.
CHECKED M. Miller	DATE 10/25/10	ENGINEER R.E.Pease	DATE 10/25/10	DWG. NO. SHEET 5 of 9
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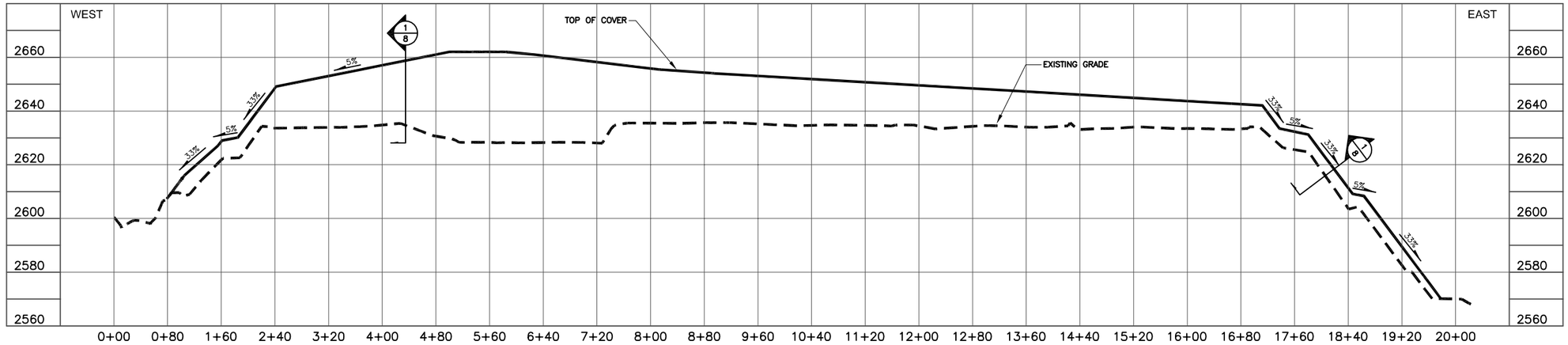
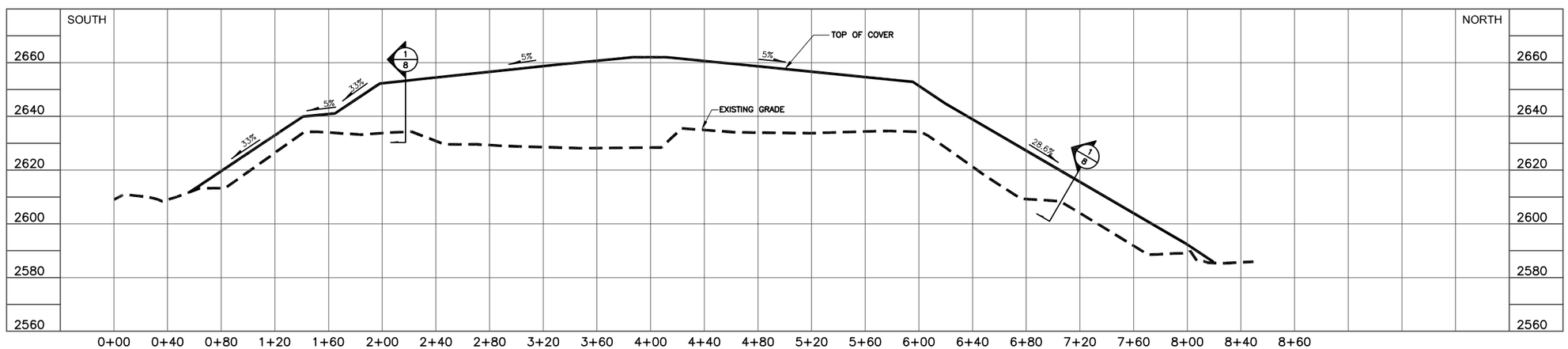
3



NOTE: VERTICAL EXAGGERATION x4

CROSS SECTION A/5

HORIZONTAL SCALE: 1"=80'
VERTICAL SCALE: 1"=20'



NOTE: VERTICAL EXAGGERATION x2

CROSS SECTION B/5

HORIZONTAL SCALE: 1"=40'
VERTICAL SCALE: 1"=20'

REV.	BY / DATE	CHK'D / DATE	DESCRIPTION	PROJ ENGR / DATE	SUPV ENGR / DATE

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SITE B
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
TYPICAL CROSS SECTIONS

PROFESSIONAL ENGINEER REGISTERED 12739 STATE OF IDAHO R. ERIC PEASE
Ronald Eric Pease 10/25/2010

DRAWN BY: KDB	DATE 10/25/10	SCALE: AS NOTED	FILE CODE ES07_0130_07B	REV. NO.
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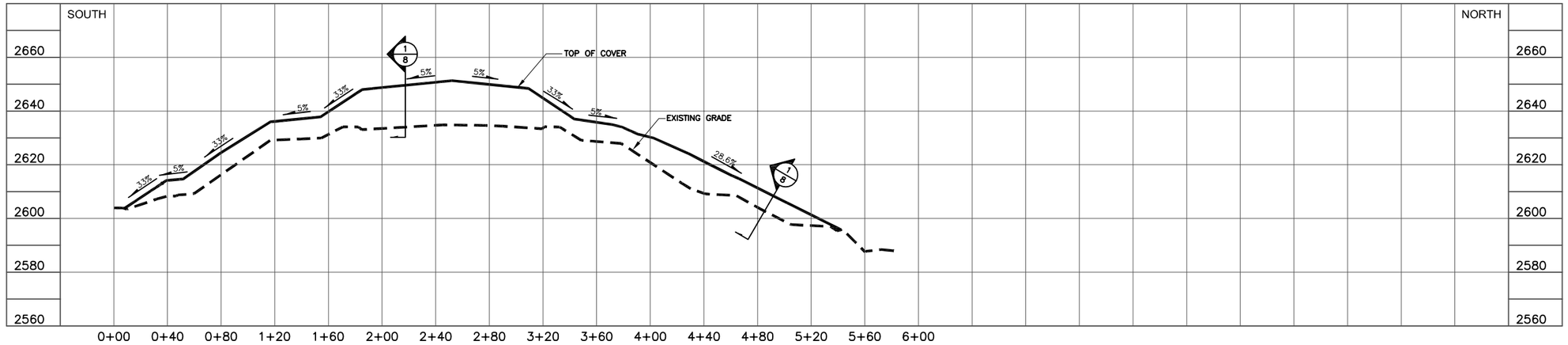
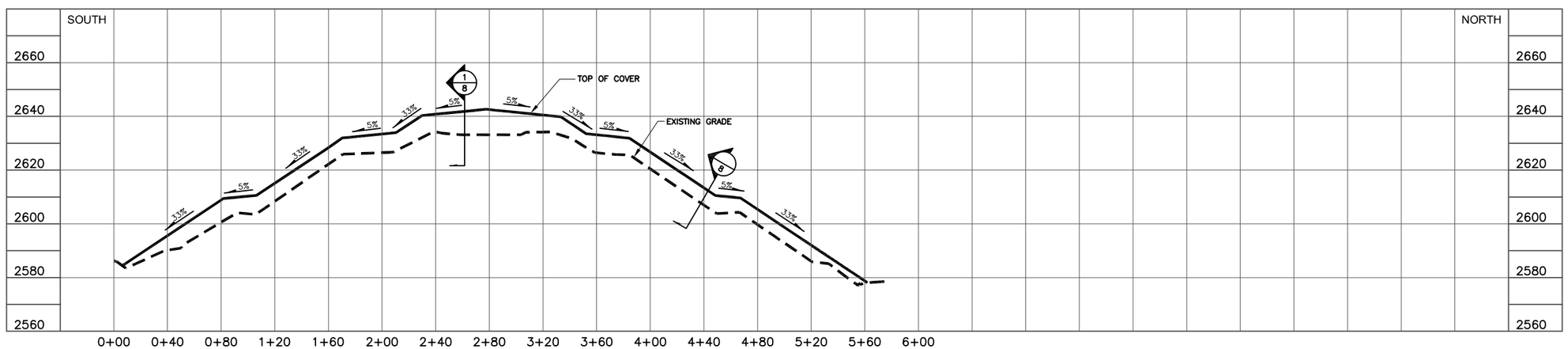
PROJ. MGR. J. Kelsey	DATE 10/25/10	APPROVED	DATE	PROJ. NO: ES07.0130

NOT FOR CONSTRUCTION



NOTE: VERTICAL EXAGGERATION x2

CROSS SECTION C/5
HORIZONTAL SCALE: 1"=40'
VERTICAL SCALE: 1"=20'



NOTE: VERTICAL EXAGGERATION x2

CROSS SECTION D/5
HORIZONTAL SCALE: 1"=40'
VERTICAL SCALE: 1"=20'

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6020 ACADEMY NE, SUITE 100, ALBUQUERQUE, NM 87109, (505) 822-9400

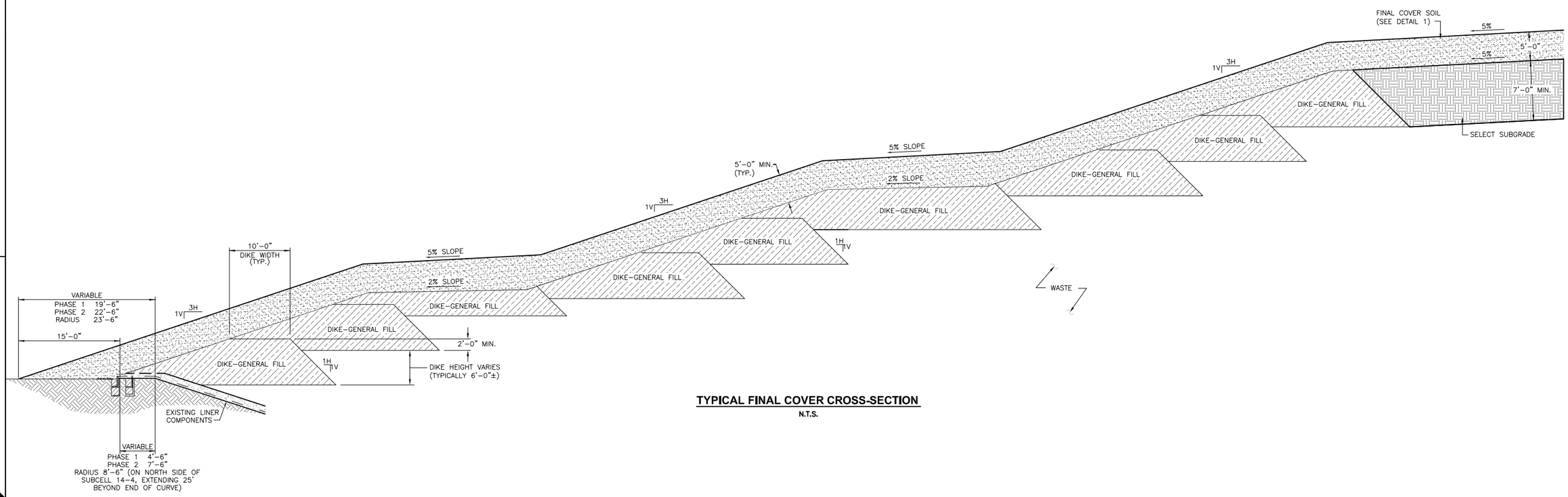
SITE B
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
TYPICAL CROSS SECTIONS

PROFESSIONAL ENGINEER REGISTERED 12739 STATE OF IDAHO R. ERIC PEASE
Ronald Eric Pease 10/25/2010

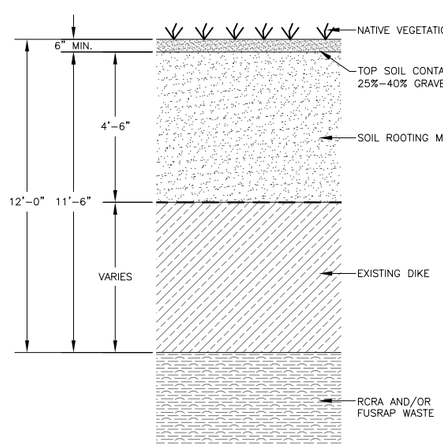
DRAWN BY: KDB	DATE 10/25/10	SCALE: AS NOTED	FILE CODE ES07_0130_07B	REV. NO.
CHECKED M. Miller	DATE 10/25/10	ENGINEER R.E.Pease	DATE 10/25/10	DWG. NO. SHEET 7 of 9
PROJ. MGR. J. Kelsey	DATE 10/25/10	APPROVED	DATE	PROJ. NO: ES07.0130

NOT FOR CONSTRUCTION



TYPICAL FINAL COVER CROSS-SECTION

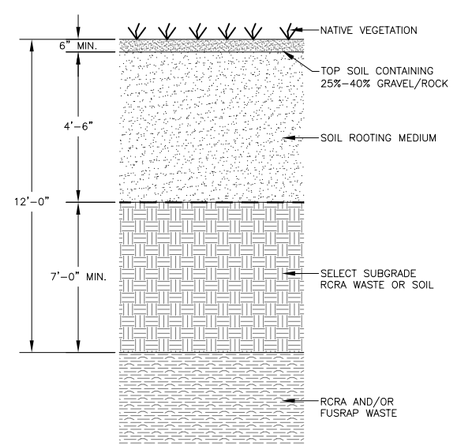
N.T.S.



SIDE SLOPE

NOTES:

1. BONDED FIBER MATRIX OR EROSION CONTROL BLANKET APPLIED TO SURFACE FOR TEMPORARY (1-YEAR) STABILIZATION TO PROMOTE ESTABLISHING VEGETATION.
2. SIDE SLOPE: EXISTING DIKES AND NON-FUSRAP WASTE ARE PLACED WITH MINIMUM 8.31-FOOT THICKNESS. MINIMUM SOIL COVER THICKNESS OF 3.5 FEET NEEDED TO MEET 11.81-FOOT (3.6 METER) RADON BARRIER REQUIREMENT.
3. TOP DECK: SELECT RCRA NON-FUSRAP WASTE OR SOIL TO BE PLACED WITH MINIMUM 7.0-FOOT THICKNESS. MINIMUM SOIL COVER THICKNESS OF 5.0 FEET NEEDED TO MEET 11.81-FOOT (3.6 METER) RADON BARRIER REQUIREMENT AND EVAPOTRANSPIRATION COVER PERFORMANCE.



TOP DECK

CELL 14 EVAPOTRANSPIRATION FINAL COVER SCHEMATIC (1 / 6,7)

N.T.S.

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SITE B
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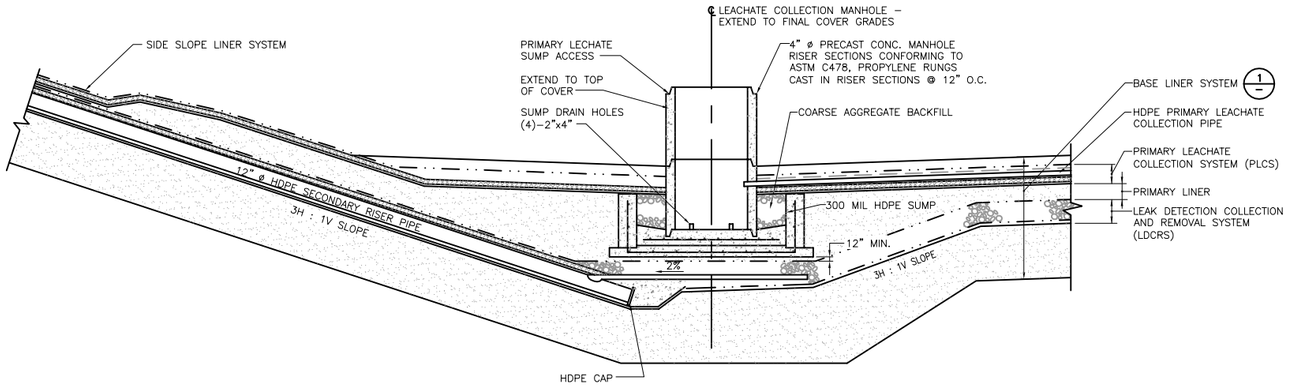
PROFESSIONAL ENGINEER REGISTERED 12139 STATE OF IDAHO R. ERIC PEASE
Ronald Eric Pease 10/25/2010

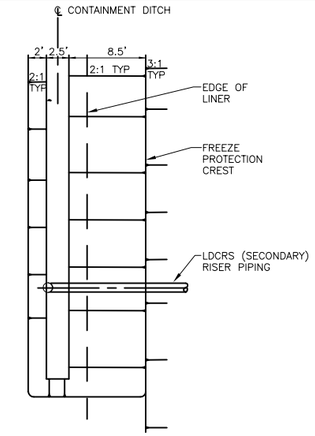
TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
TYPICAL FINAL COVER SECTION AND DETAILS

DRAWN BY: KDB DATE 10/25/10	SCALE: AS NOTED	FILE CODE ES07_0130_07B	REV. NO.
CHECKED M. Miller DATE 10/25/10	ENGINEER R.E.Pease DATE 10/25/10	DWG. NO. SHEET 8 of 9	3
PROJ. MGR. J. Kelsey DATE 10/25/10	APPROVED DATE	PROJ. NO. ES07.0130	



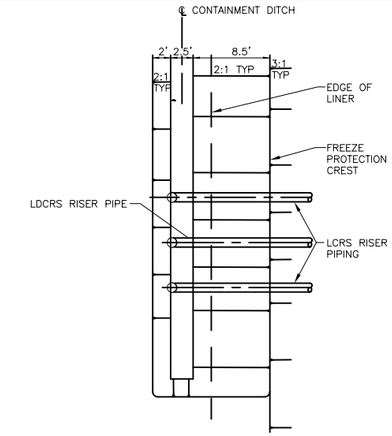
LEACHATE COLLECTION MANHOLE EXTENSION PHASES 1, 2, AND 3 TYPICAL SECTION THROUGH SUMP (1/4)

SCALE: N.T.S.



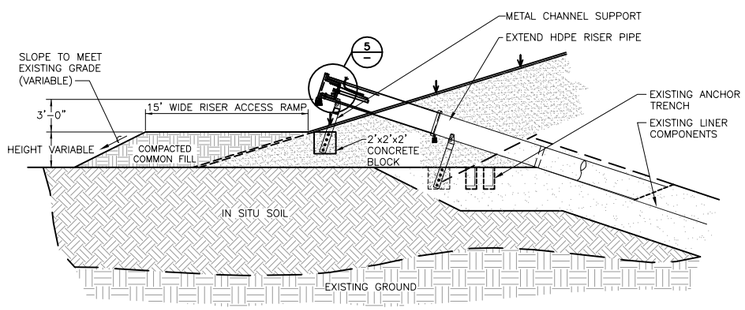
EXISTING PHASES 1, 2 AND 3 SECONDARY LEACHATE PIPING (2/4)

SCALE: N.T.S.



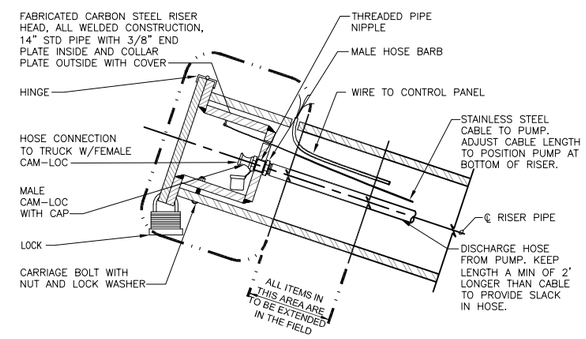
EXISTING PHASES 4, 5 AND 6 PRIMARY AND SECONDARY LEACHATE PIPING (3/4)

SCALE: N.T.S.



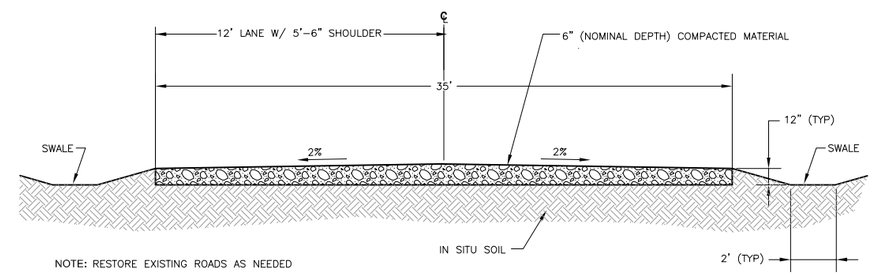
FINAL COVER TYPICAL LEACHATE/RISER PIPE DETAIL (4/-)

SCALE: N.T.S.



TYPICAL RISER PIPE HOOKUP DETAIL (5/-)

SCALE: N.T.S.



ACCESS ROAD DETAIL (6/-)

SCALE: 1"=4'

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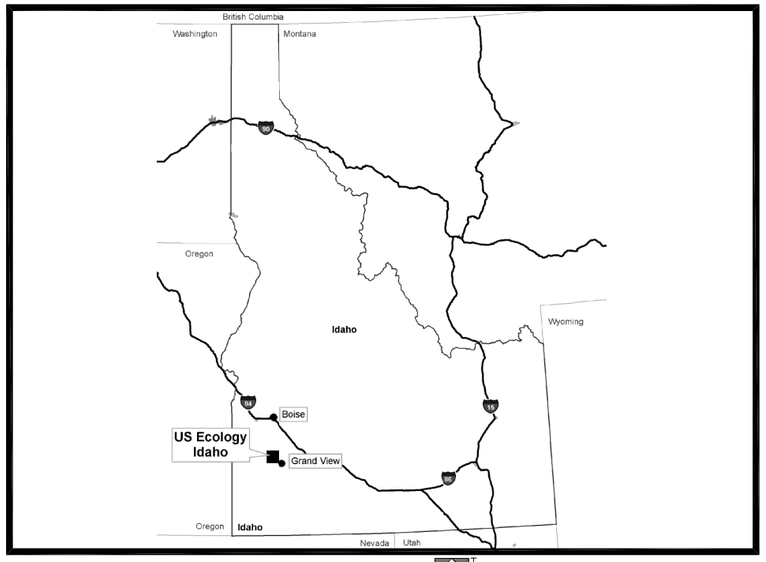
PROFESSIONAL ENGINEER REGISTERED STATE OF IDAHO R. ERIC PEASE 12139
Randall Eric Pease 10/25/2010

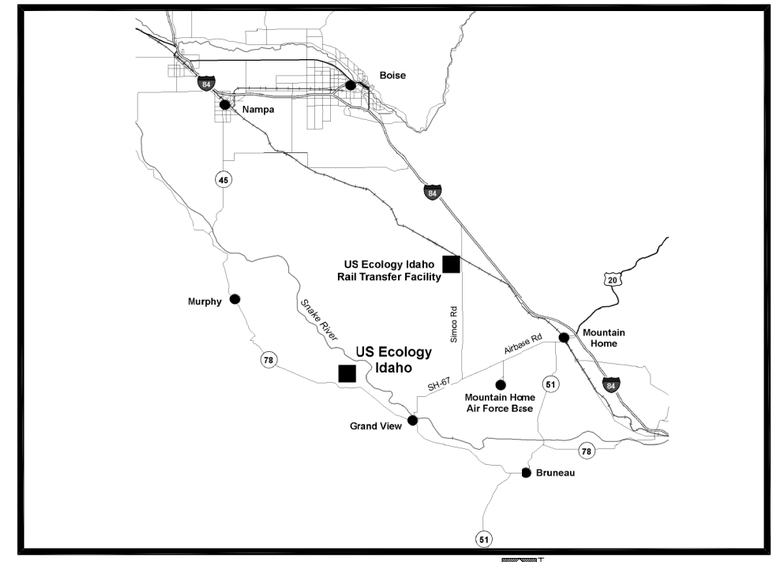
TITLE:
CIVIL
CELL 14 – FINAL CLOSURE
TYPICAL DETAILS

DRAWN BY: DATE	SCALE:	FILE CODE PRMIL28A	REV. NO.
KDB 10/25/10	N.T.S.	DWG. NO. SHEET 9 OF 9	3
CHECKED DATE M. Miller 10/25/10	ENGINEER DATE R.E. Pease10/25/10		
PROJ. MGR. DATE J. Kelsey10/25/10	APPROVED DATE	PROJ. NO. PRMI	

Cell 15



VICINITY MAP
NTS
NORTH



SITE MAP
NTS
NORTH

CELL 15
FINAL COVER DESIGN
HAZARDOUS WASTE FACILITY

US ECOLOGY IDAHO
GRAND VIEW, IDAHO

PREPARED FOR US ECOLOGY IDAHO

INDEX OF DRAWINGS

NUMBER	TITLE
1	TITLE SHEET AND DRAWING INDEX
2	GENERAL NOTES AND LEGEND
3	CONSTRUCTION LOGISTICS
4	FINAL WASTE GRADING PLAN
5	FINAL COVER GRADING PLAN
6	TYPICAL CROSS SECTIONS
7	TYPICAL FINAL COVER SECTION AND DETAILS
8	TYPICAL DETAILS

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Ronald Eric Pease 10/25/2010

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CELL 15 – FINAL CLOSURE
TITLE SHEET AND DRAWING INDEX

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CHECKED	DATE	ENGINEER	DATE	PROJ. NO. PRMI
M. Miller	10/25/10	R.E.Pease	10/25/10	
PROJ. MGR.	DATE	APPROVED	DATE	
J. Kelsey	10/25/10			

CONSTRUCTION NOTES

GENERAL

CONTRACTOR IS RESPONSIBLE FOR OBTAINING ALL REQUIRED PERMITS PRIOR TO START OF CONSTRUCTION.

ALL WORK ON THIS PROJECT SHALL BE PERFORMED IN ACCORDANCE WITH APPLICABLE FEDERAL, STATE AND LOCAL LAWS, RULES AND REGULATIONS CONCERNING CONSTRUCTION SAFETY AND HEALTH. ALL WORK, INCLUDING WORK WITHIN TRENCHES, SHALL BE IN COMPLIANCE WITH THE OCCUPATIONAL SAFETY AND HEALTH ACT (OSHA).

THE CONTRACTOR SHALL NOT INSTALL ITEMS AS SHOWN ON THE PLANS WHEN IT IS OBVIOUS THAT FIELD CONDITIONS ARE DIFFERENT THAN SHOWN IN THE DESIGN. SUCH CONDITIONS SHOULD BE BROUGHT TO THE ATTENTION OF THE ENGINEER. IN THE EVENT THE CONTRACTOR DOES NOT NOTIFY THE ENGINEER, THE CONTRACTOR ASSUMES FULL RESPONSIBILITY AND EXPENSE FOR ANY REVISIONS NECESSARY.

EXISTING SITE IMPROVEMENTS WHICH ARE DAMAGED OR DISPLACED BY THE CONTRACTOR SHALL BE REMOVED AND REPLACED BY THE CONTRACTOR AT THE CONTRACTOR'S OWN EXPENSE. REPAIRS SHALL BE APPROVED BY THE OWNER PRIOR TO CONSTRUCTION OF THE REPAIRS. REPAIRS SHALL BE ACCEPTED BY THE OWNER PRIOR TO FINAL PAYMENT.

EXISTING FENCING THAT IS NOT DESIGNATED FOR REMOVAL SHALL NOT BE DISTURBED. ANY FENCING THAT IS DISTURBED OR ALTERED BY THE CONTRACTOR SHALL BE RESTORED TO ITS ORIGINAL CONDITION AT THE CONTRACTOR'S EXPENSE. IF THE CONTRACTOR WOULD LIKE TO REMOVE FENCING TO FACILITATE CONSTRUCTION OPERATIONS, THIS MAY BE DONE WITH THE OWNER'S PERMISSION, AND THE CONTRACTOR SHALL RESTORE THE FENCE TO ITS ORIGINAL CONDITION PRIOR TO THE CLOSE OF THE PROJECT. CONTRACTOR IS RESPONSIBLE FOR SECURITY OF THE SITE UNTIL THE FENCE IS REPLACED. FENCE MATERIAL SHALL BE APPROVED BY THE OWNER.

THE CONTRACTOR SHALL USE THE DESIGNATED STAGING AREA FOR STORAGE OF EQUIPMENT AND MATERIAL. NO MATERIAL OR EQUIPMENT MAY BE STORED OR LEFT ON SITE AT ANY OTHER LOCATION. THE OWNER ASSUMES NO LIABILITY FOR CONTRACTOR'S EQUIPMENT OR MATERIAL IN THE STAGING AREA. SECURITY SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR.

AT THE END OF EACH WORK DAY, THE CONTRACTOR SHALL CLEAN AND PICK UP THE WORK AREA. AT NO TIME SHALL THE WORK BE LEFT IN A MANNER THAT COULD ENDANGER WORKERS OR THE PUBLIC.

ALL MATERIALS AND WORKMANSHIP SHALL CONFORM TO PROJECT SPECIFICATIONS AND PLANS, AS AMENDED AND REVISED BY THE ENGINEER. ALL INSTALLATION DETAILS ARE TYPICAL AND MAY BE CHANGED TO BETTER FIT EXISTING LOCAL CONDITIONS UPON THE DIRECTION OF THE ENGINEER.

ESTIMATED QUANTITIES SHOWN HEREIN ARE FOR INFORMATION ONLY; FINAL QUANTITIES WILL BE DETERMINED BASED ON ACTUAL WORK ACCOMPLISHED, UPON COMPLETION OF PROJECT AND ON FINAL MEASUREMENTS.

THE CONTRACTOR SHALL TAKE ALL NECESSARY MEASURES TO ENSURE THAT ALL EXISTING MONITOR WELLS AND SURVEY MONUMENTS ARE NOT DAMAGED DURING THE WORK. THE CONTRACTOR SHALL BEAR THE RESPONSIBILITY OF PROTECTING THE WELLS AND MONUMENTS DURING CONSTRUCTION, AND SHALL BEAR ALL COSTS IN THE REPAIR OR REPLACEMENT OF DAMAGED WELLS AND MONUMENTS.

THE CONTRACTOR SHALL COMPLY WITH ALL APPLICABLE REGULATIONS CONCERNING CONSTRUCTION NOISE AND HOURS OF OPERATIONS.

SOILS

UNLESS OTHERWISE SPECIFIED, MATERIALS SHALL BE COMPACTED TO THE FOLLOWING PERCENTAGES OF THE ASTM D 698 MAXIMUM STANDARD PROCTOR DENSITY.

MATERIAL	PERCENT COMPACTION
COVER SOIL	80–92
COMPACTED COMMON MATERIAL	90
BEDDING MATERIAL	90

UTILITIES

IF ANY UTILITY LINES, PIPELINES, OR UNDERGROUND UTILITY LINES ARE SHOWN ON THESE DRAWINGS, THEY ARE SHOWN IN AN APPROXIMATE MANNER ONLY, AND SUCH LINES MAY EXIST WHERE NONE ARE SHOWN. IF ANY SUCH EXISTING LINES ARE SHOWN, THE LOCATION IS BASED UPON INFORMATION PROVIDED TO THE ENGINEER BY OTHERS, AND THE INFORMATION MAY BE INCOMPLETE, OR MAY BE OBSOLETE BY THE TIME CONSTRUCTION COMMENCES. THE CONTRACTOR SHALL VERIFY THE LOCATION OF ANY UTILITY LINE, PIPELINE OR UNDERGROUND UTILITY LINE IN OR NEAR THE AREA OF THE WORK.

PRIOR TO CONSTRUCTION, THE CONTRACTOR SHALL EXCAVATE AND VERIFY THE HORIZONTAL AND VERTICAL LOCATIONS OF PERTINENT UTILITIES. SHOULD A CONFLICT EXIST, THE CONTRACTOR SHALL NOTIFY THE ENGINEER SO THAT THE CONFLICT CAN BE RESOLVED WITH A MINIMUM AMOUNT OF DELAY. CONTRACTOR IS TO EXERCISE DUE CARE TO AVOID DISTURBING ANY EXISTING UNDERGROUND UTILITIES. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO COORDINATE ANY POTENTIAL DISRUPTIONS IN UTILITY SERVICE WITH THE UTILITY COMPANIES AFFECTED AT LEAST 24 HOURS PRIOR TO THE DISRUPTION.

THE CONTRACTOR SHALL SECURE AND PAY FOR ALL NECESSARY PERMITS.

EROSION CONTROL, ENVIRONMENTAL PROTECTION, AND STORMWATER POLLUTION PREVENTION PLAN

THE CONTRACTOR SHALL CONFORM TO ALL CITY, COUNTY, STATE, AND FEDERAL DUST AND EROSION CONTROL REGULATIONS. THE CONTRACTOR SHALL PREPARE AND OBTAIN ANY NECESSARY DUST OR EROSION CONTROL PERMITS FROM REGULATORY AGENCIES.

THE CONTRACTOR SHALL BE RESPONSIBLE FOR TEMPORARY EROSION AND SEDIMENT CONTROL MEASURES IN ACCORDANCE WITH THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES).

THE CONTRACTOR SHALL ENSURE THAT NO SOIL ERODES FROM THE SITE ONTO OTHER PROPERTY BY CONSTRUCTING TEMPORARY EROSION CONTROL BERMS OR INSTALLING SILT FENCES AT THE PROPERTY LINES AND WETTING THE SOIL TO KEEP IT FROM BLOWING.

CONSTRUCTION AREAS SHALL BE WATERED FOR DUST CONTROL IN COMPLIANCE WITH GOVERNMENT ORDINANCES. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING WATER ON SITE WITH THE OWNER'S DIRECTION.

ALL WASTE PRODUCTS FROM THE CONSTRUCTION SITE, INCLUDING ITEMS DESIGNED FOR REMOVAL, CONSTRUCTION WASTE, CONSTRUCTION EQUIPMENT WASTE PRODUCTS (OIL, GAS, TIRES, ETC.), GARBAGE, GRUBBING, EXCESS CUT MATERIAL, VEGETATIVE DEBRIS, ETC. SHALL BE REMOVED FROM THE SITE WITH THE APPROVAL OF THE OWNER AT NO ADDITIONAL COST TO THE OWNER. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO OBTAIN ANY PERMITS REQUIRED FOR HAUL OR DISPOSAL OF WASTE PRODUCTS. IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO ENSURE THAT THE WASTE DISPOSAL SITE COMPLIES WITH GOVERNMENT REGULATIONS REGARDING THE ENVIRONMENT, ENDANGERED SPECIES, AND ARCHAEOLOGICAL RESOURCES.

THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE CLEAN–UP AND REPORTING OF SPILLS OF HAZARDOUS MATERIALS ASSOCIATED WITH THE CONSTRUCTION SITE. HAZARDOUS MATERIALS INCLUDE GASOLINE, DIESEL FUEL, MOTOR OIL, SOLVENTS, CHEMICALS, PAINT, ETC. WHICH MAY BE A THREAT TO THE ENVIRONMENT. UNDER NO CIRCUMSTANCES SHALL THE CONTRACTOR DISPOSE OF HAZARDOUS MATERIALS ON–SITE. ALL HAZARDOUS WASTE MONITORING, TESTING, HANDLING, TRANSPORTATION AND DISPOSAL SHALL BE DONE IN ACCORDANCE WITH US ECOLOGY IDAHO.

THE CONTRACTOR SHALL COMPLY WITH ALL APPLICABLE REGULATIONS CONCERNING SURFACE AND UNDERGROUND WATER. CONTACT WITH SURFACE WATER BY CONSTRUCTION EQUIPMENT AND PERSONNEL SHALL BE MINIMIZED. EQUIPMENT MAINTENANCE AND REFUELING OPERATIONS SHALL BE PERFORMED IN AN ENVIRONMENTALLY SAFE MANNER IN COMPLIANCE WITH GOVERNMENT REGULATIONS.

ABBREVIATIONS

A = AIR
A.B.I. = ADDITIVE BID ITEM
AD = AREA DRAIN
A.D. = ALGEBRAIC DIFFERENCE IN SLOPES
AIP = ABANDONED IN PLACE
AP = ANALYSIS POINT
BLDG = BUILDING
BM = BENCHMARK
BW = BASE OF WALL
CATV = CABLE TV LINE
CB = CATCH BASIN
CIP = CAST IRON PIPE
CR = CURB RETURN
CMP = CORRUGATED METAL PIPE
CMPA = CORRUGATED METAL PIPE ARCH
CMU = CONCRETE MASONRY UNITS
CO = CLEANOUT
CONC = CONCRETE
CL = CHAIN LINK
DIA = DIAMETER
DI = DROP INLET
DIP = DUCTILE IRON PIPE
DW = DOMESTIC WATER
E = ELECTRIC
ELEV = ELEVATION
ESMT = EASEMENT
EXIST = EXISTING
EB = ELECTRIC BOX
FF = FINISHED FLOOR
FG = FINISHED GRADE
FH = FIRE HYDRANT
FL = FLOW LINE
FM = FORCE MAIN
FP = FIRE PROTECTION
FP = FINISHED PAD (DIRT)
G = GAS
GM = GAS METER
GV = GATE VALVE
H = HORIZONTAL
HC = HANDICAP
HIPT = HIGH POINT
ID = INNER DIAMETER
INV = INVERT ELEVATION
IP = IRON PIPE
IW = INDUSTRIAL WASTE
L = LENGTH
LF = LINEAR FEET
LP = LIGHT POLE
L/S = LANDSCAPING
LT = LEFT
MH = MANHOLE
MIN. = MINIMUM
NG = NATURAL GRADE
NTS = NOT TO SCALE
OD = OUTER DIAMETER
PB = PULL BOX
PL = PROPERTY LINE
PCC = PORTLAND CEMENT CONCRETE
PP = POWER POLE
PCP = POLYVINYL CHLORIDE PIPE
R = RADIUS
RCP = REINFORCED CONCRETE PIPE
ROW = RIGHT OF WAY
RT = RIGHT
SAS = SANITARY SEWER LINE
SD = STORM DRAIN
SIM = SIMILAR
SL = SLOPE
SP = STEEL PIPE
SS = STAINLESS STEEL
STA = STATION
STD = STANDARD
T = TELEPHONE LINE
TA = TOP OF ASPHALT
TC = TOP OF CONCRETE
TG = TOP OF GRATE
T/P = TOP OF PIPE
TW = TOP OF WALL
TYP = TYPICAL
TB = TELEPHONE BOX
TR = TELEPHONE RISER
TS = TRAFFIC SIGN
TYP. = TYPICAL
UE = UNDERGROUND ELECTRICAL LINE
UT = UNDERGROUND TELEPHONE LINE
UN = UNKNOWN
V = VERTICAL
VP = VENT PIPE
W = WATER
WM = WATER METER
WV = WATER VALVE
WW = WASH WATER

LEGEND

DISPOSAL TRENCH LIMITS
BUILDING
FENCE
MONITOR WELL — MW-#
WATER VALVE
DOMESTIC WASTE SYSTEM — DW
WASH WASTE SYSTEM — WW
POTABLE WATER — W
FIRE PROTECTION WATER — FP
GAS — G
OVERHEAD LINE — OHL
EXISTING UTILITY LINE — U
EXISTING ASPHALT
POWER POLE
LIGHT POLE
SLOPE (HORIZONTAL: VERTICAL) — 3:1
COMPACTED EXISTING MATERIAL
COMPACTED COMMON FILL
IN SITU SOIL
BEDDING MATERIAL
CONCRETE

NOT FOR CONSTRUCTION

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Ronald Eric Pease 10/25/2010

TITLE:
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CELL 15 – FINAL CLOSURE
GENERAL NOTES AND LEGEND

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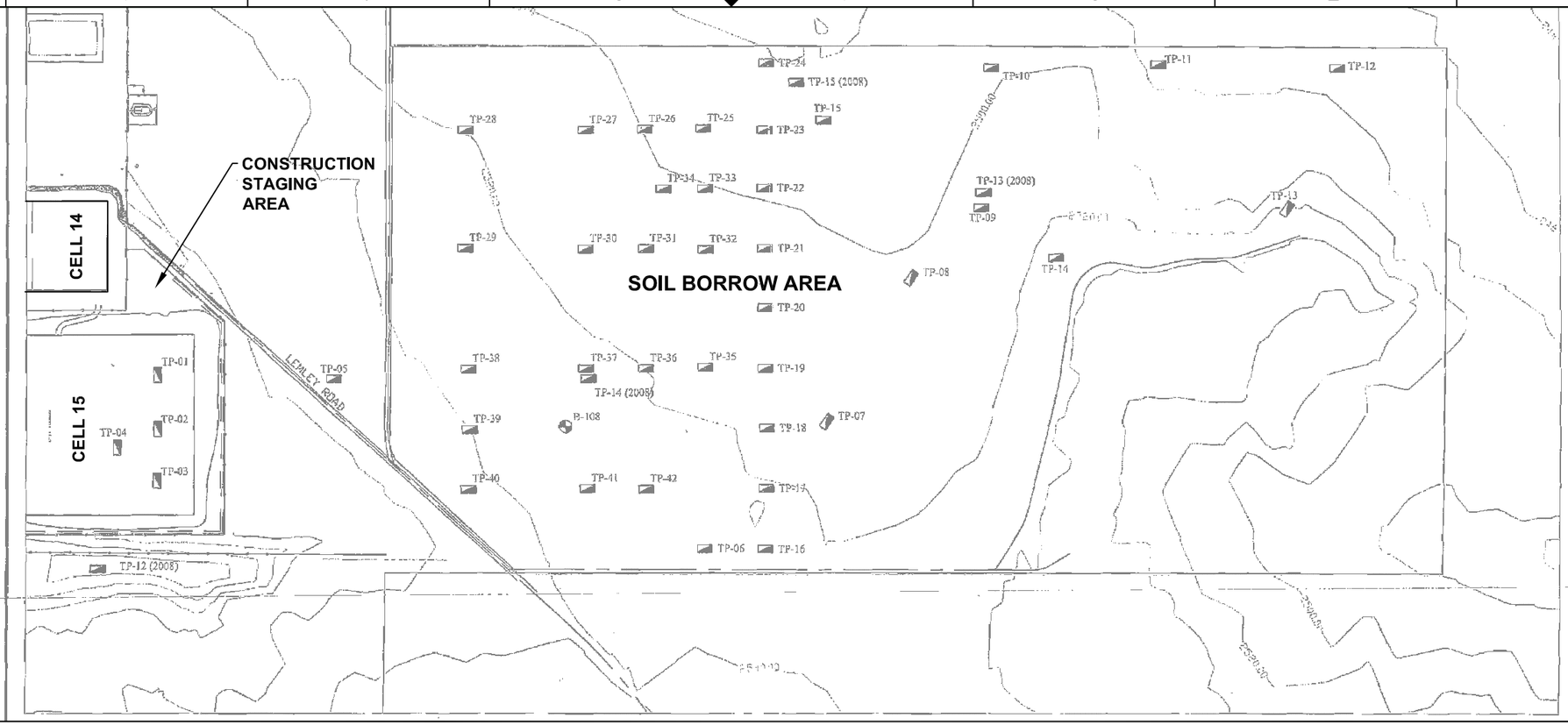


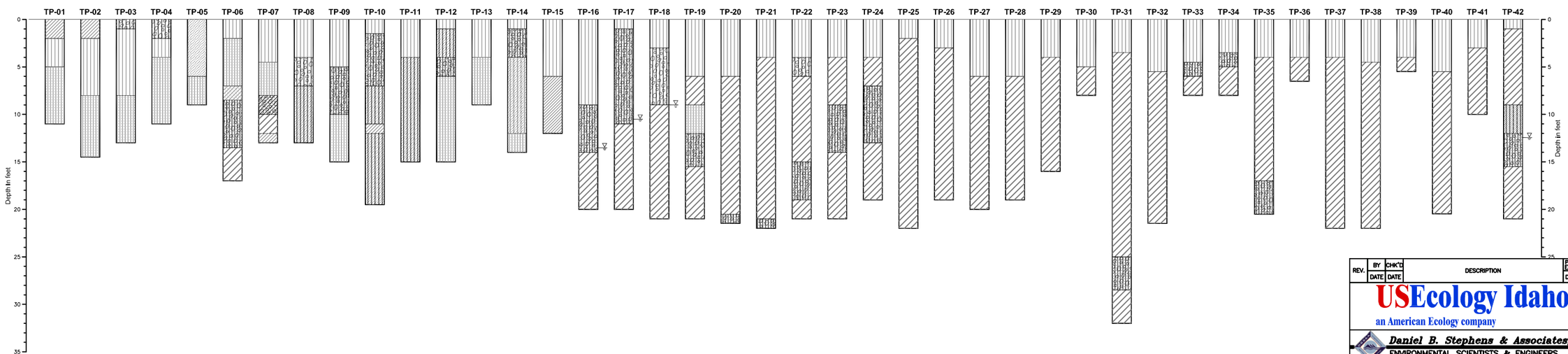
Note: Contractor shall provide traffic control on Lemley Road and all other affected roads to ensure safety during soil transport and construction.

NORTH

0 300 FT

Explanation

Test pit locations (year)



Soil Boring Geologic Logs from Soil Borrow Area

- Silt
- Silty sand
- Poorly graded sand
- Poorly graded sand with silt
- Silty gravel
- Poorly graded gravel with silt
- Poorly graded gravel with clay
- Clayey sand
- Lean clay
- Fat clay

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Ronald Eric Pease 10/25/2010

TITLE:
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CELL 15 – FINAL CLOSURE
CONSTRUCTION LOGISTICS

DRAWN BY: KOB	DATE 10/25/10	SCALE: N.T.S.	FILE CODE ES07_0130_07B	REV. NO.
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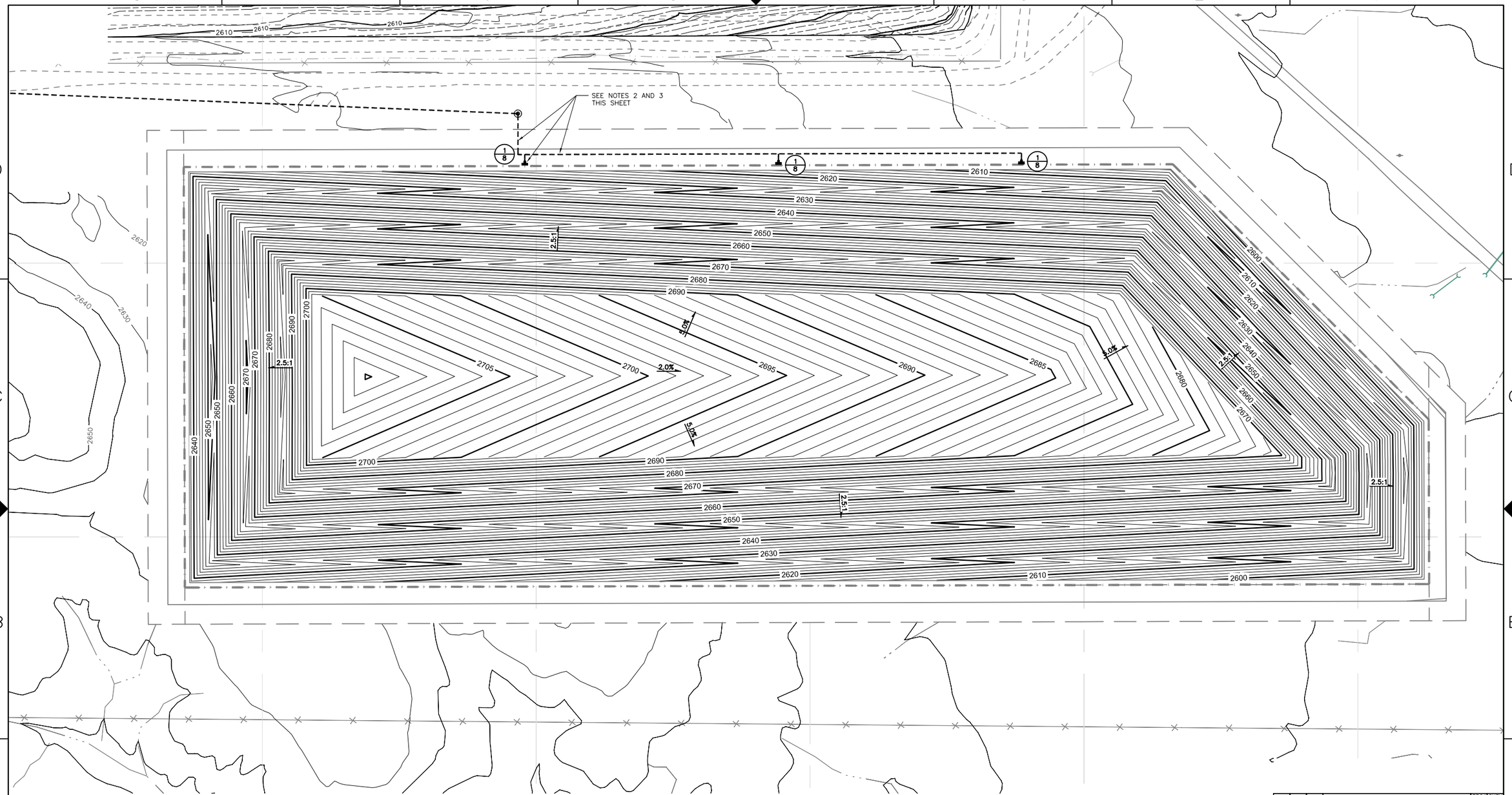

NOTES:
1. CONTOUR INTERVAL 2-FEET ON SIDE SLOPES AND 1-FOOT ON TOP DECK. CONTOURS ARE FEET ABOVE MEAN SEA LEVEL.
2. REMOVE 4-INCH SINGLE WALL LEACHATE PIPES PRIOR TO COVER INSTALLATION.
3. RE-INSTALL 2-INCH STAINLESS STEEL PIPE AND 4"x8" HDPE DOUBLE WALL PIPE AT NEW LOCATION UPON CONSTRUCTION OF THE COVER – SEE DETAIL 1 SHEET 8.

Explanation

- Limits of lined cell
- Existing leachate riser and piping
- Existing leachate line manhole
- Existing leachate pipe 4-inch single wall HDPE

NORTH

0 80 FT

NOT FOR CONSTRUCTION

PROFESSIONAL ENGINEER REGISTERED 11139 STATE OF IDAHO R. ERIC PEASE

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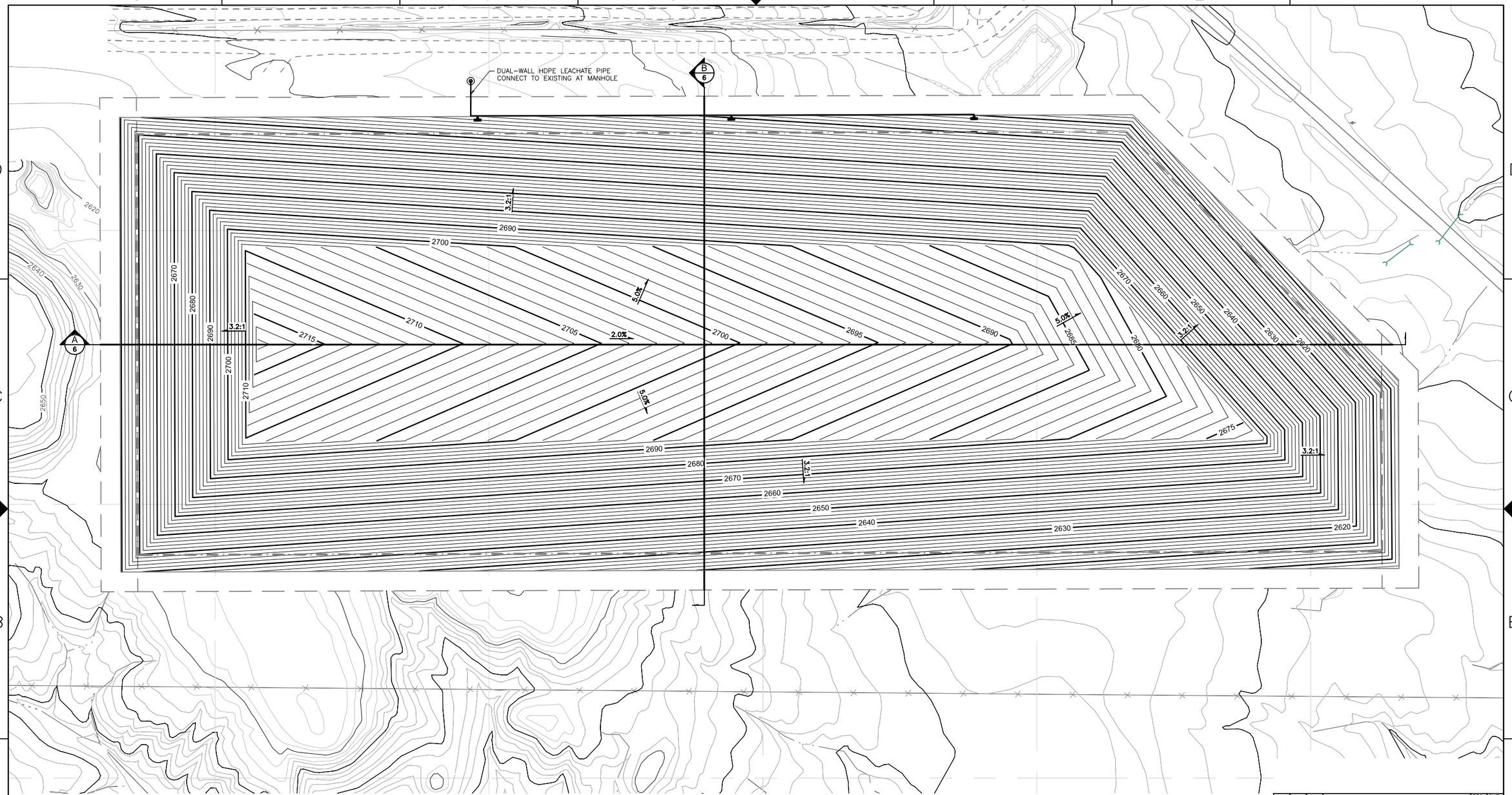
6020 ACADEMY NE, SUITE 100, ALBUQUERQUE, NM 87109, (505) 822-9400

SITE B
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

TITLE:
CIVIL
CELL 15 – FINAL CLOSURE
FINAL WASTE GRADING PLAN

DRAWN BY:	DATE	SCALE:	FILE CODE ES07_0130_07B	REV. NO.
KDB	10/25/10	N.T.S.	DWG. NO. SHEET 4 of 8	3
CHECKED M. Miller	DATE 10/25/10	ENGINEER R.E.Pease	DATE 10/25/10	
PROJ. MGR. J. Kelsey	DATE 10/25/10	APPROVED	DATE	PROJ. NO. ES07.0130



NOTES:
1. CONTOUR INTERVAL 2-FEET ON SIDE SLOPES AND 1-FOOT ON TOP DECK. CONTOURS ARE FEET ABOVE MEAN SEA LEVEL.
2. REMOVE 4-INCH SINGLE WALL LEACHATE PIPES PRIOR TO COVER INSTALLATION.
3. RE-INSTALL 2-INCH STAINLESS STEEL PIPE AND 4"x8" HDPE DOUBLE WALL PIPE AT NEW LOCATION UPON CONSTRUCTION OF THE COVER – SEE DETAIL 1 SHEET 8.

Explanation

- Limits of lined cell
- Leachate riser manhole
- Existing leachate pipe 4-inch single wall HDPE
- New leachate pipe
- New leachate riser and piping

NORTH

0 80 FT

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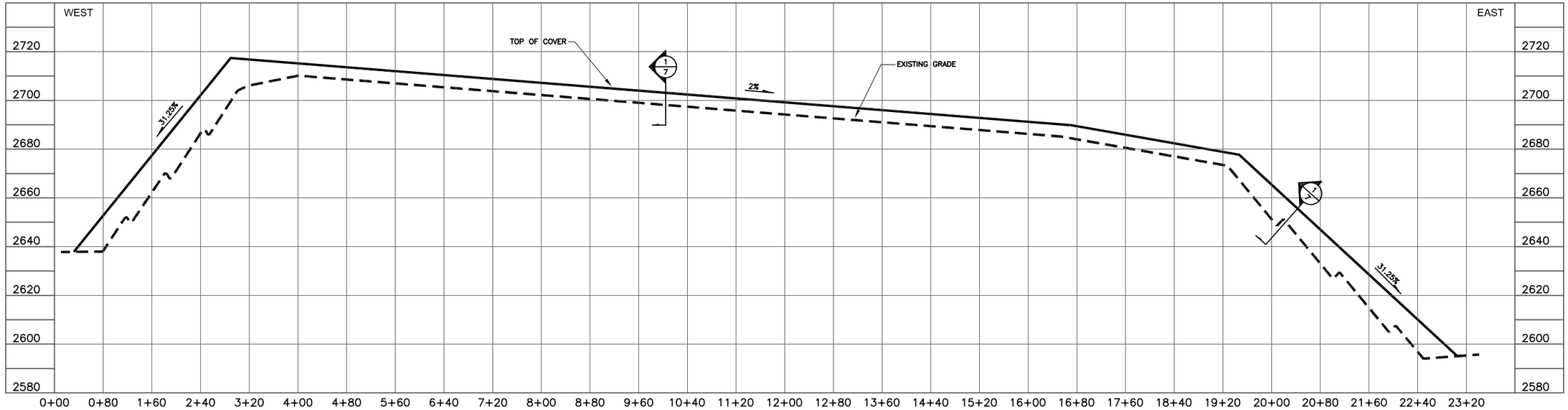
GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

PROFESSIONAL ENGINEER REGISTERED 15139 STATE OF IDAHO R. ERIC PEASE
Robert Eric Pease 10/25/2010

TITLE:
CIVIL
CELL 15 – FINAL CLOSURE
FINAL COVER GRADING PLAN

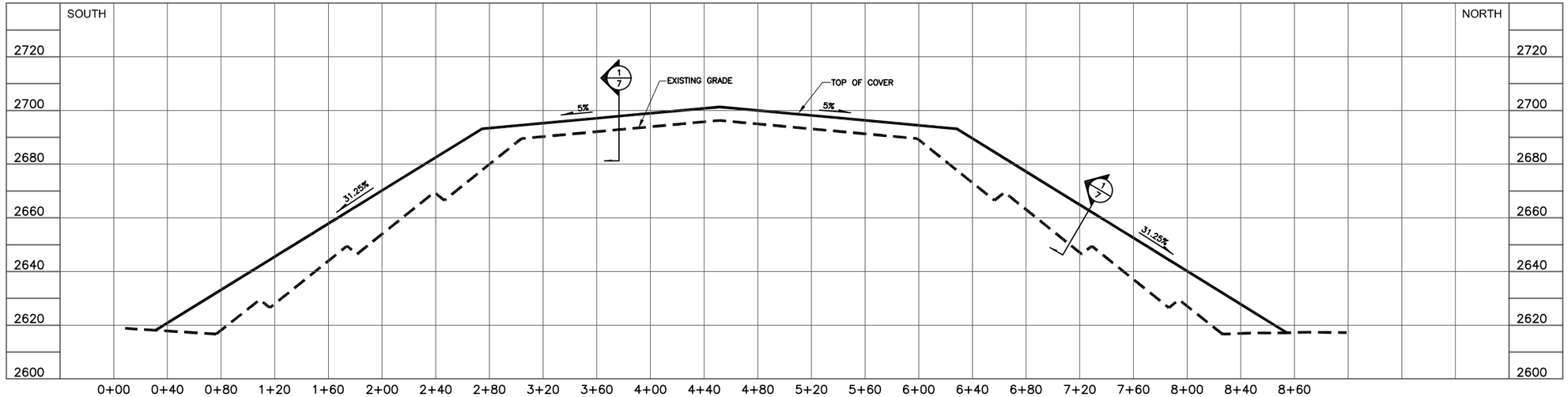
DRAWN BY:	DATE	SCALE:	FILE CODE ES07_0130_07B	REV. NO.
KDB	10/25/10	AS NOTED	DWG. NO. SHEET 5 of 8	3
CHECKED: M. Miller	DATE 10/25/10	ENGINEER: R.E.Pease	DATE 10/25/10	
PROJ. MGR.: J. Kelsey	DATE 10/25/10	APPROVED	DATE	PROJ. NO. ES07.0130



NOTE: VERTICAL EXAGGERATION x4

CROSS SECTION A/5

HORIZONTAL SCALE: 1"=80'
VERTICAL SCALE: 1"=20'



NOTE: VERTICAL EXAGGERATION x2

CROSS SECTION B/5

HORIZONTAL SCALE: 1"=40'
VERTICAL SCALE: 1"=20'

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GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

TITLE:
CIVIL
CELL 15 – FINAL CLOSURE
TYPICAL CROSS SECTIONS

PROFESSIONAL ENGINEER REGISTERED 12139 STATE OF IDAHO R. ERIC PEASE
Robert Eric Pease 10/25/2010

DRAWN BY:	DATE	SCALE:	FILE CODE ES07_0130_07B	REV. NO.
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PROJ. MGR. J. Kelsey	DATE 10/25/10	APPROVED	DATE	PROJ. NO. ES07.0130

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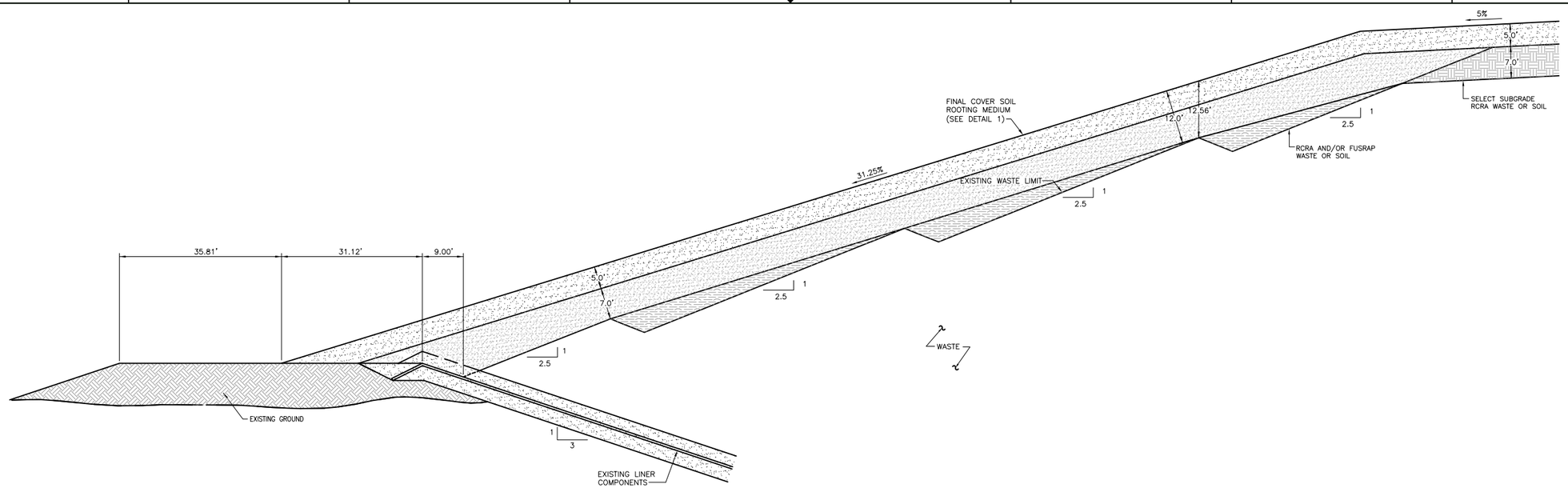
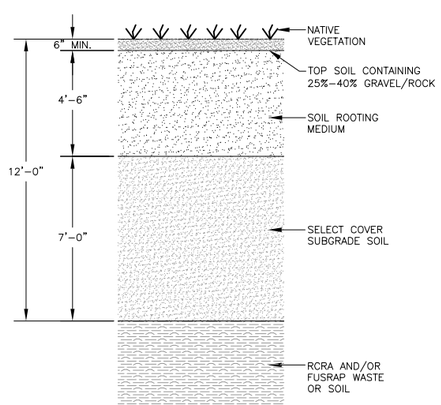


TYPICAL FINAL COVER CROSS-SECTION

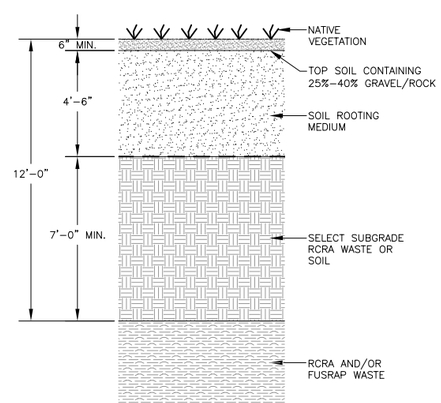
N.T.S.



SIDE SLOPE

NOTES:

1. BONDED FIBER MATRIX OR EROSION CONTROL BLANKET APPLIED TO SURFACE FOR TEMPORARY (1-YEAR) STABILIZATION TO PROMOTE ESTABLISHING VEGETATION.
2. SIDE SLOPE: MINIMUM SOIL THICKNESS COVER OF 11.81-FOOT (3.6 METER) NEEDED TO MEET RADON BARRIER REQUIREMENT.
3. TOP DECK: SELECT RCRA WASTE OR SOIL TO BE PLACED AT MINIMUM 7.0-FOOT THICKNESS OVER FUSRAP WASTE. MINIMUM SOIL COVER THICKNESS OF 4.81 FEET NEEDED TO MEET 11.81-FOOT (3.6 METER) RADON BARRIER REQUIREMENT AND 5.0 FEET FOR EVAPOTRANSPIRATION COVER PERFORMANCE.



TOP DECK

CELL 15 EVAPOTRANSPIRATION FINAL COVER SCHEMATIC

N.T.S.

1
-

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GRAND VIEW, IDAHO
US EPA ID NO. IDD 073 114 654

PROFESSIONAL ENGINEER REGISTERED 12739 STATE OF IDAHO R. ERIC PEASE

Randall Eric Pease 10/25/2010

TITLE:

CIVIL
CELL 15 – FINAL CLOSURE
TYPICAL FINAL COVER SECTION AND DETAILS

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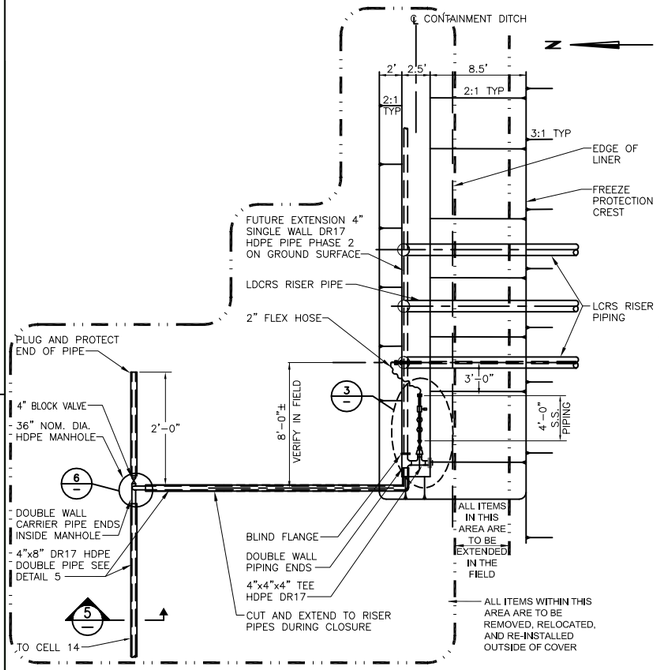
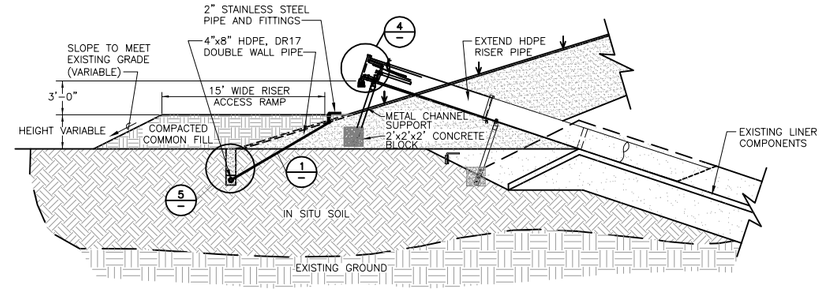
PROJ. MGR. DATE	APPROVED DATE	PROJ. NO. PRMI	
J. Kelsey 10/25/10			



EXISTING PHASES 1, 2 AND 3 PRIMARY AND SECONDARY LEACHATE PIPING (1 / -)
SCALE: N.T.S.



FINAL COVER TYPICAL LEACHATE/RISER PIPE DETAIL (2 / -)
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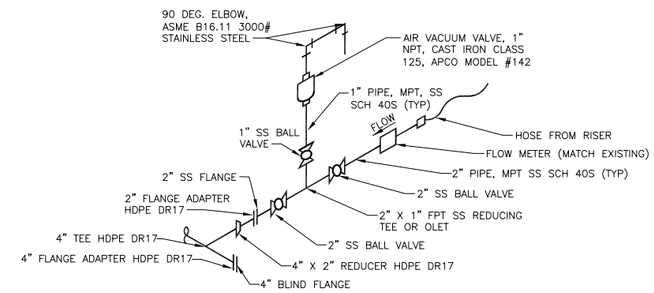

LEACHATE PIPING SCHEMATIC (3 / -)
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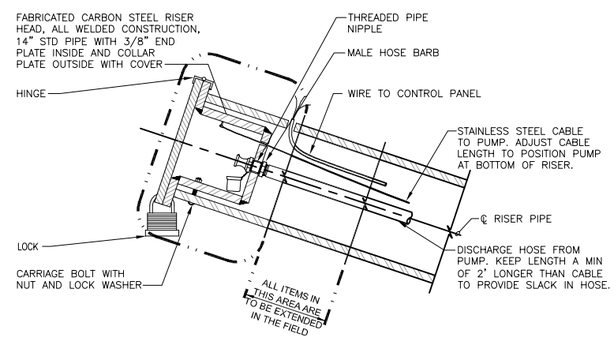

TYPICAL RISER PIPE HOOKUP DETAIL (4 / -)
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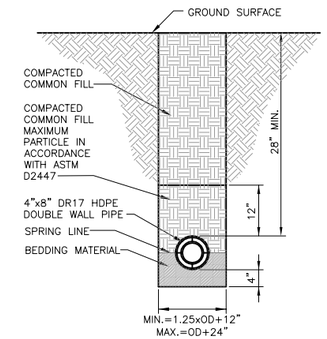

TYPICAL BURIED PIPE TRENCH (5 / -)
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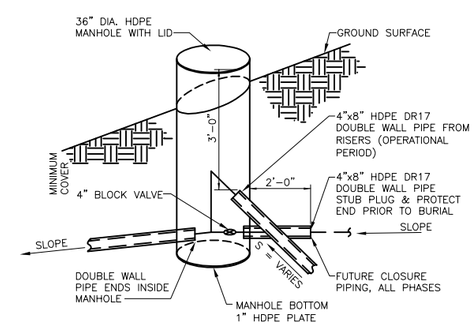
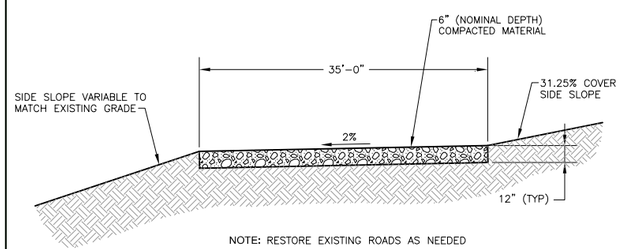
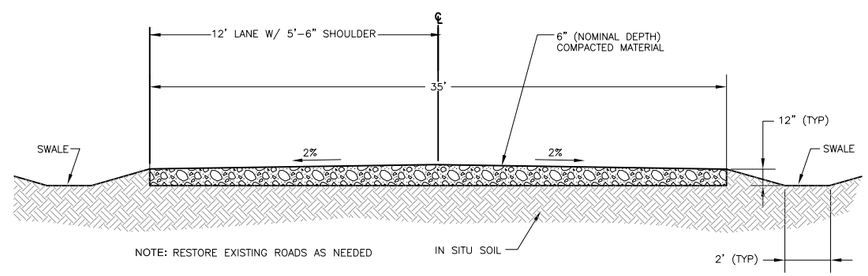


EXISTING MANHOLE DETAIL (6 / -)
SCALE: N.T.S.



UNPAVED COVER PERIMETER ROAD DETAIL (7 / -)
SCALE: 1"=4'



ACCESS ROAD DETAIL (8 / -)
SCALE: 1"=4'

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Ronald Eric Pease 10/25/2010

TITLE:
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CELL 15 – FINAL CLOSURE
TYPICAL DETAILS

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Appendix B

CQA Plan

Construction Quality Assurance Plan
US Ecology Idaho
Final Cover Design for Cells 14 and 15

October 25, 2010

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Attachment

1 Soil Rooting Medium Sampling and Analysis Plan

1. Scope

This Construction Quality Assurance Plan (CQA Plan) is intended for use during construction of the final cover systems for Cells 14 and 15 at the US Ecology Idaho (USEI) facility in Grand View, Idaho (USEI Site B). Quality assurance (QA) is a planned system of activities that provides confidence to the owner/operator (Owner) and permitting agency that the facility was constructed as required under US Ecology's Resource Conservation and Recovery Act (RCRA) operation permit (EPA ID No. IDD073114654). The CQA Plan is prepared to meet the minimum suggested standards set by the U.S. Environmental Protection Agency (EPA) (see Document Number EPA600R-93 182, *Quality Assurance and Quality Control for Waste Containment Facilities).* The CQA Plan will be followed for installation of all cover components.

The CQA Plan outlines the responsibilities for the technical documentation showing that environmental control systems have been installed in accordance with approved design, drawings, and specifications. Following cover installation, construction must be certified by a professional engineer registered in the state of Idaho. A certification report consisting of specific technical information will be submitted to USEI and the Idaho Department of Environmental Quality (DEQ). The report will include the following:

- Installation of the cover soil layer, including gravel amended topsoil
- Verification of properly constructed material depths and slopes
- Proper extension of well risers and leachate collection system components
- Revegetation
- QA/quality control (QC) testing and inspection

The final cover design for Cells 14 and 15 provides an evapotranspiration (ET) alternative cover consisting of a select soil subgrade, a thick soil rooting medium layer, and an upper topsoil erosion protection layer. Specific construction elements that are addressed in this plan include the following:

- Excavation, placement, and grading of cover subgrade soil

- Excavation, placement, and grading of the soil rooting medium
- Excavation, placement, and grading of the upper erosion protection layer (processing may be needed to incorporate gravel amendment)
- Seeding and fertilizing to establish vegetation
- Leachate collection riser extensions and piping modification
- Monitor well riser extensions (L-28 and L-39)
- Ancillary installations as needed to complete the above

In this plan, QC testing/certification is provided by the manufacturers, suppliers, contractors, and installers of the various design components. "Owner" refers to USEI. QA refers to means and actions employed by the Owner to ensure conformance of the various components, production, and installation to the contractual and regulatory requirements. The Owner will retain an Engineer to perform QA activities on the Owner's behalf. In this CQA Plan, QA Engineer refers to the Certifying Engineer or their designated representative. QC testing and documentation are the responsibility of the Contractor. QA testing and documentation are the responsibility of the QA Engineer on behalf of the Owner. QA testing is required at a minimum frequency of 5 percent of the QC testing, unless otherwise designated by the QA Engineer. Project drawings and specifications referenced in this document refer to engineering design drawings for construction of the USEI final covers. For all CQA issues, this plan takes precedence over previous documents.

The following sections describe the cover system design and CQA Plan to be used by the QA Engineer and Contractor for construction and certification. As appropriate during various construction activities, the QA Engineer will determine whether continuous or periodic inspection will occur to provide complete inspection and testing of all cover materials.

2. Cover System Description

Specifications applicable to the final cover system include Section 31 32 00 - Cover System Components. The USEI final covers will consist of soil installed over waste disposal Cells 14 and 15. The cover system profile will include the following (from the bottom up):

- Existing subgrade consisting of the following:
  - Waste
  - Intermediate cover
  - Side slope soil dikes (Cell 14 only)
  - Other existing soil
- Select cover subgrade soil (0 to approximately 10 feet thick)
- ET cover soil rooting medium 4.5 feet thick
- Topsoil layer amended with 25 to 40 percent gravel (by weight) 0.5 foot thick

The term “cover soil” refers collectively to the selected cover subgrade soil, soil rooting medium, and gravel amended top soil layers. The term “final cover” refers to the upper 5-foot-thick layer consisting of the soil rooting medium and gravel amended topsoil.

3. CQA Plan

Specifications applicable to CQA include Section 01 40 00 - Quality Requirements and Section 01 33 00 - Submittals. CQA is the planned system of activities that provides assurance that the cover system was constructed and the materials used were manufactured as specified in the accepted documents and control drawings. A copy of the site-specific drawings and specifications, CQA Plan, and QA/QC documentation reports shall be retained at the facility by the QC Representative. The drawings, specifications, and QA/QC documents are the primary means for the Owner to demonstrate to the regulatory agency that QA/QC objectives for the project have been met.

The CQA Plan shall include a detailed description of all QA/QC activities to be used during materials inspection and construction to manage the installed quality of the covers and associated facilities.

At a minimum, documentation will include the following:

- Laboratory testing results
  - All laboratory testing performed
  - Origin of all test samples
  - Certification by a professional engineer for all laboratory test results
  - Documentation showing that specified test types and frequencies were performed
  - Documentation showing that test results were within specified ranges

- Soil cover placement
  - Soil suitability per specifications
  - Thickness of placed soil
  - Compaction density
  - Line and grade control

- Vegetation
  - Seeding
  - Nutrients/amendments

- Leachate and monitor well riser extensions
  - Riser Modification Construction and Materials Plan
  - Pipe test records

3.1 Personnel Qualifications

An important factor in assessing the quality of a cover system installation is the degree to which key personnel involved in the process are qualified to perform their required tasks. QA/QC personnel must be familiar with:

- Engineering design, drawings, and specifications
- Project layout
- Materials to be used
- Drainage control features
- Soil and rock borrow materials
- Construction procedures, schedule, and necessary equipment
- Material placement techniques and requirements

Specifically, the key individuals involved in QA/QC during the construction of the final cover systems at the USEI Site B facility and their minimum recommended qualifications are listed in Table 1.

3.2 Documentation

In addition to ensuring correct installation of the cover system, QA provides documentation of the construction process.

Table 1. Minimum Personnel Qualifications

Personnel	Qualifications
Design Engineer(s)	Professional Engineer registered in the state of Idaho with job-specific experience.
QA Personnel/Inspector(s) – US Ecology or QA Engineer designated representative(s)	The individual(s) designated by the Owner, the QA Engineer, or the QA Certifying Engineer, with adequate training and experience in testing procedures and knowledge of the project and its drawings, specifications, and QA documents. The QA Personnel/Inspector(s) shall be an independent, third-party employee of an independent firm, hired by the Owner.
QA Engineer – US Ecology or QA Certifying Engineer designated representative	The individual designated by the Owner or the QA Certifying Engineer, in charge of the daily QA process. Must show a minimum of two years experience and technical knowledge of cover/liner system design and earthwork construction process and requirements. The QA Engineer shall be a qualified, independent, third-party employee of an independent firm, hired by the Owner.
QA Certifying Engineer – An independent, third party US Ecology representative. Responsible for all QA activities. May assume the role of the other QA personnel.	An independent, third party, individual designated by Owner with intimate knowledge of the project, drawings, specifications, and QA documents. Must show a minimum of two years experience and technical knowledge of cover/liner system design and earthwork construction process and requirements. Responsible for all QA activities, including the actions of the QA Engineer and QA Personnel. Responsible to stamp the Final Certification Report as a Professional Engineer registered with the state of Idaho.
QC Personnel – Contractor or subcontractor	Employed by the general Contractor's QC Representative, installation Contractor, or earthwork Contractor involved in the cover construction; appropriately trained.
QC Representative – Contractor or subcontractor representative. Responsible for all QC activities. May assume the role of the other QC personnel.	The individual specifically designated by the general Contractor, manufacturer, or fabricator in charge of quality control activities. The QC Representative shall not report to the Construction Site Superintendent.

3.2.1 Daily Reports

Daily reporting and documentation are required. The QC Representative shall prepare daily written reports that are to be included in the final QA/QC documentation. The QC

Representative shall submit daily reports to the QA Engineer on a weekly basis or more frequently as required by the QA Engineer. These reports provide a chronological framework for identifying and recording all activities/tasks that were completed. At a minimum, the daily reports shall include the following:

- Date, project name, location, waste containment unit under construction, on-site personnel and equipment, and other relevant identification information
- Description of weather conditions, including temperature, cloud cover, wind speeds, and precipitation
- Summaries of meetings and actions recommended or taken
- Specific work and locations of construction
- Equipment and personnel working on each task, including subcontractors
- Identification of areas or units of work being inspected
- Description of off-site materials received, including QC data provided by the supplier
- Calibrations or recalibrations of test equipment
- Methods used to backfill testing holes
- Decisions made regarding approval or disapproval of units of material and/or work; corrective actions to be taken in instances of substandard or suspect quality (including data and/or reporting used to substantiate substandard QC decisions)
- Signature of the QC Representative
- Any other pertinent information

3.2.2 Inspection and Testing Reports

All observations, field tests, and laboratory tests performed on- or off-site shall be recorded on a data sheet. Recorded observations and test results can take the form of notes, charts, sketches, photographs, or a combination of these. At a minimum, the inspection data sheets shall include the following information:

- Description or title of the inspection activity
- Location of the inspection or obtained sample
- Type of inspection and procedure used (reference to standard method when appropriate or specific method described in the CQA Plan)
- Recorded observation or test data
- Results of inspections (pass/fail); comparison with specification requirements
- In addition to the individual preparing the data sheet, identification of all personnel involved in the inspection
- Signature of the QA inspector and review signature by the QA Engineer

3.2.3 Problem Identification and Corrective Measure Reports

A problem is defined as material or workmanship that does not meet the requirements of the drawings, specifications, or CQA Plan, or any obvious defect (even if there is conformance with drawings, specifications, and the CQA Plan). At a minimum, problem identification and corrective measure reports shall contain the following information:

- Location of the problem
- Description in sufficient detail (with supporting sketches or photographic information where appropriate) to adequately describe the problem
- Probable cause for the problem
- How and when the problem was identified (reference to inspection data sheet or daily summary report by inspector)
- Where relevant, estimation of how long the problem existed
- Any disagreement between the Inspector and Contractor about the problem
- Suggested corrective measure(s)

- Documentation of corrective action, if taken and completed prior to finalization of the problem, and completed corrective measures report (reference to inspection data sheet, where applicable)
- Where applicable, outline of suggested methods to prevent similar problems in the future
- Signature of the QC Representative and review signature of QA Engineer

3.2.4 Drawings of Record

Drawings of record ("as-built" drawings) shall be prepared to document the actual lines, grades, and conditions of each completed component of the construction. For the cover soil components, the record drawings shall include survey data that identifies lower and upper elevations of a particular component (layer), the plan dimensions of the component, and locations of all destructive and nondestructive test sampling sites. For the leachate and monitor well riser components, the record drawings shall include all piping, electrical, and control details and dimensions. The as-built drawings shall note all changes to the original set of construction drawings. The as-built drawings shall include, but are not limited to, each layer/component of the cover soil layer and modifications to the leachate collection system and monitor wells.

3.2.5 Final Documentation and Certification

Upon completion of the project, the QA Certifying Engineer shall prepare a final documentation and certification report. The report shall certify that the hazardous waste unit has been closed in accordance with the specifications and design of the approved closure plan, and shall meet the standards set by the EPA for RCRA closure certification in 40 CFR 264.115. This report shall include the following:

- Inspection reports
- QA/QC summary reports
- Inspection data sheets
- Problem identification and corrective measures reports
- QC data provided by manufacturers or fabricators

- Laboratory test results (including pre-construction testing)
- Field testing results (including pre-construction testing)
- Photographs
- As-built drawings
- Internal QA/QC memoranda
- Minutes of pre-construction and weekly meetings
- Data interpretation and analyses
- Submittals and QA Engineer's authorization of change orders and equivalent substitutes
- Design changes made by the Design Engineer during construction

The document shall be certified to be correct by the QA Certifying Engineer. The final documentation and certification prepared by the QA Certifying Engineer shall be submitted by the Owner to DEQ for approval.

3.2.6 Document Control

The QA/QC documents shall be maintained under a document control procedure. Any modifications to the documents shall be reported to and agreed upon by all parties involved. An indexing procedure shall be developed for conveniently replacing pages in the CQA Plan when modifications become necessary; the replacement pages will detail the revision status.

3.2.7 Storage of Records

During construction, the QC Representative shall be responsible for all QC documents, including copies of the design criteria, specifications, plan revisions, and originals of all data sheets and reports. Duplicate records shall be kept at a separate location.

3.3 Meetings

A pre-bid meeting shall be held prior to bidding of the contract. A pre-construction meeting shall be held prior to the start of construction activities.

3.3.1 Pre-Bid Meeting

The intent of this meeting is to discuss the design drawings, specifications, bid requirements, contract terms, and CQA Plan to clarify requirements and resolve differences of opinion among the concerned parties before the project is let for bidding. Holding the pre-bid meeting before formal construction bids are prepared can allow the companies bidding on the construction to better understand the level of QC required on the project. Also, if the bidders identify problems with the CQA Plan, USEI has the opportunity to correct those problems early in the process.

3.3.2 Pre-Construction Meeting

The objectives of the pre-construction meeting are to establish lines of communication, review construction drawings and specifications, emphasize the critical aspects of the project planning and coordination of tasks, and identify potential factors that could cause difficulties or delays in construction. At the pre-construction meeting, details of the CQA Plan shall be reviewed to ensure that the responsibility and authority of each individual is clearly understood, to reach agreement on the established procedures to resolve construction problems, and to establish a foundation of cooperation in quality management. The pre-construction meeting shall be scheduled after the general construction contracts have been awarded and the major subcontractors and material suppliers have been established.

The meeting shall be attended by appropriate USEI personnel, the project's Design Engineer, Contractor's representatives, the QC Representative, major subcontractors, the QA Engineer, and the QA Certifying Engineer.

The pre-construction meeting shall cover the following activities:

- An individual shall be assigned to take minutes.
- Individuals shall be introduced to one another.
- Each organization's responsibility, authority, and lines of communication shall be discussed.

- Copies of the project drawings and specifications shall be made available for group discussion.
- The drawings and specifications shall be described, along with unique design features, potential construction problems, and answers to questions from any of the parties concerning the construction.
- Reporting procedures, distribution of documents, the schedule for routine project meetings, and resolution of construction problems shall be discussed.
- Site requirements and logistics, including safety procedures, shall be reviewed.
- The project design shall be reviewed, and the most critical construction aspects will be discussed, as will scheduling and sequencing issues.
- The CQA Plan shall be reviewed and discussed, with the QA Engineer and QA Certifying Engineer outlining their expectations and identifying the most critical components of their project participation.
- QC procedures for materials to be employed by the suppliers contracted to the Contractor shall be discussed.
- Construction QC procedures to be employed by the Installer or Contractor shall be discussed.
- A list of action items requiring resolution shall be compiled and responsibilities for these items shall be assigned.
- Corrective actions to resolve potential construction problems shall be discussed.
- Procedures for documentation and distribution of documents shall be discussed.
- Suggested modifications to the CQA Plan that would improve quality management on the project shall be solicited.
- Climatic variables (e.g., precipitation, wind, temperature) that might affect the construction schedule shall be discussed.

Familiarizing all project participants with inspection and testing procedures and the criteria for pass/fail decisions (including the resolution of test data outliers) is a key objective of this

meeting. Additionally, it is imperative that all parties understand any key problems QA personnel have identified and that each party fully understands their roles and responsibilities and the procedures regarding problem resolution.

3.3.3 Progress Meetings

Weekly progress meetings shall be held at the job site or at the discretion of the Design Engineer, QA Engineer, or Contractor. The QC Representative and QA Engineer or his/her designated representative shall be present at all meetings.

3.4 Sample Custody

All samples shall be documented with origin, date, and intent. Whenever a sample is transferred to another individual or laboratory, records of the transfer shall be established with a chain of custody.

3.5 Weather

Specifications shall make clear restrictions for certain construction activities due to weather. The Contractor is responsible for ensuring that these weather restrictions are observed during construction.

3.6 Work Stoppages

Unexpected work stoppages can result from a variety of causes. The QC Representative shall be careful during any work stoppages to determine (1) whether in-place materials were covered and protected from damage, (2) whether partially covered materials were adequately protected, and (3) whether manufactured materials were properly stored and properly or adequately protected from the elements. The cessation of construction during work stoppages does not mean that QA inspection and documentation cease.

4. Site Preparation

4.1 General

Specifications applicable to site preparation include Section 31 10 00 - Site Clearing and Section 01 71 23 - Field Engineering. The following work will be included in site preparation and grading:

- Field check existing landfill infrastructure and utility locations, as appropriate.
- Mark all survey hub markers, permanent benchmarks, monitor wells, etc.
- Strip or remove all brush, vegetation, surface debris, and similar materials from the soil borrow source surface by grading the soil to a depth of approximately 1 to 2 inches. Relocate soil and vegetation to a designated area on the site.
- Existing vegetation on the Cell 14 sideslope soil dikes shall not be removed prior to cover soil placement. This sparse, low vegetation will not cause a detriment to the construction or CQA.
- The existing surfaces shall be checked and improved as needed to provide stable conditions of the existing surface and provide a trafficable, reasonably smooth working surface for construction equipment.

4.2 Survey Coordinate System

All areas to be affected by cover construction, including Cells 14 and 15, shall be surveyed and integrated into a grid system so that locations of sample and testing points determined during construction can be readily discernible by the QA/QC personnel. This grid system should consist of equidistant parallel lines, 100 feet on center, projecting north to south and east to west within the limits of the landfill. This grid system shall be coincident with the existing site coordinate system for future reference. Other areas that are part of the construction project, such as soil borrow sources, shall be surveyed in a manner that is approved by the QA

Engineer. The project limits will be staked out by the Owner or his representative based on record drawings.

4.3 Existing Subgrade

Specifications applicable to the subgrade include Section 31 00 00 - Earthwork. Cover soil placement will be directly on the existing subgrade. Excavation of waste or soil dikes is not allowed unless approved by the QA Engineer. The subgrade will be protected and approved in accordance with the following procedures:

- The existing subgrade shall be protected from erosion and damage of any kind.
- The subgrade shall be kept free of all trash and debris.
- The condition of the subgrade shall be approved by the QA Engineer prior to cover soil placement.

5. Cover Soil

QA of the cover soil shall accomplish these objectives:

- Ensure that material quality meets specifications
- Ensure that materials were properly placed
- Ensure that minimum thicknesses of material layers have been achieved

The covers for Cells 14 and 15 will be ET covers with an adequate depth of quality cover soil. The objective of the cover soil is to install a uniform layer that provides for water storage capacity while encouraging the establishment of an adequate rooting medium to allow for successful plant establishment.

5.1 Cover Soil Layer

Specifications applicable to the cover soil include Section 31 00 00 - Earthwork, Section 31 38 01 - Surface Rock Durability Requirements, and Section 31 32 00, Cover System Components. Cover thickness shall be measured perpendicular to the final cover slope. Select cover subgrade soil shall be placed on the existing subgrade to meet the lines and grades needed for placement of the final cover soil.

5.1.1 Contractor Requirements

The Contractor shall be responsible for locating, testing, excavating, hauling, preparing (mixing), spreading, compacting, and grading the cover soil. The Owner has completed limited testing of soil from two prospective borrow sources on the Owner's property. Testing shows that limited soil quantities with suitable properties are available. The Owner will provide the available soil testing data to the Contractor. The Contractor shall be responsible for all soil selection and testing necessary to complete construction.

Borrow source soils shall be tested and determined satisfactory prior to construction of the covers (see Attachment 1). Depths and lateral extents of borrow sources will be determined

from borehole drilling or test pit excavation, soil sample extraction, and laboratory testing. Soils used in the cover soil shall be only those from borrow source(s) approved by the QA Engineer.

Areas of the cover that may become overcompacted, such as haul roads, shall be tested for soil density and as needed, shall be ripped to loosen the soil and retested to verify soil conformance.

The Contractor shall be responsible for testing in-place (field) density and moisture content of representative cover soil samples. Soil density testing shall be used by the Contractor as a QC measure to verify acceptable soil density.

The Contractor shall prepare survey documentation that shows that the ET cover soil conforms to the design grades.

5.1.2 Engineer Requirements

The QA Engineer shall approve suitable soils and placement with respect to construction criteria. The QA Engineer shall inspect the select cover subgrade soil, soil rooting medium, and topsoil, and grant approval prior to the Contractor proceeding with construction of the next component.

5.2 Test Pads

Test pads are not required for cover soil that will be placed in lifts of 12 inches or less in thickness. For soil lifts greater than 12-inch loose lifts, the Contractor shall construct test pads prior to cover construction to demonstrate that the soil lift placement and compaction methods provide acceptable compaction throughout the soil lift thickness. A test pad shall be constructed for each soil type used in the cover. Significant changes in soil type that require a separate test pad shall be determined by the QA Engineer.

Soil to be used in test pad construction shall be sampled from the borrow source and tested. Testing shall be in accordance with all requirements of the soil type being tested.

Test pads shall be constructed at locations within the project area selected by the Contractor. The test pads shall have minimum dimensions of 50 feet by 100 feet. The lift thickness shall match the lifts to be used during cover construction. Test pad construction methods must be consistent with procedures to be used for cover construction in the field during construction, including soil type, lift thickness, equipment, and equipment operating speeds.

The Contractor shall be responsible for testing in-place (field) density and moisture content of representative test pad soil samples. Density shall be tested at a minimum of 10 locations representative of equal areas on the test pad. At each of the 10 testing locations, in-place density shall be measured at 6-inch depth intervals in a profile through the full test pad thickness. The Contractor shall place the test pad soil in a manner that meets the acceptable range specified. Acceptable soil density must be between 80 and 92 percent of maximum dry density determined from the Standard Proctor test (ASTM D698).

Density testing shall use cone penetrometer testing (ASTM D6951), nuclear densiometer tests (ASTM D6938), and sand cone tests (ASTM D1556). Cone penetrometer testing provides a method of testing soil density in a profile through the entire lift thickness up to 3 feet. Nuclear densiometer testing provides a method to check the cone penetrometer tests for the test pad soils. As a check on the nuclear densiometer results, one sand cone test (ASTM D1556) and one oven-dried moisture determination (ASTM D2216) test shall be performed for every 10 field nuclear density tests. Holes caused by any of the density test methods shall be backfilled with the same constructed materials and tamped to a similar density as the adjacent material.

The Contractor shall submit all test pad methods and results to the QA Engineer for approval. Cover construction shall proceed only when approval has been granted by the QA Engineer.

5.3 Development of a Density Correlation for Thick Lifts

The Contractor may place soils in lifts greater than 12 inches and verify density with a mechanical cone penetrometer (ASTM D6951) if an acceptable correlation between in-place density measured by nuclear densiometer testing (ASTM D6938) and penetrometer resistance is developed. The Contractor shall develop this correlation during test pad construction. The

Contractor shall construct a soil lift using the same thickness (3-foot maximum), procedures, equipment, and equipment speeds as will be used in the field during construction. At a minimum of 10 locations, the Contractor will develop a profile of cone penetrometer resistance versus depth for the entire thickness of the lift.

The 10 locations chosen on the test pad shall be tested using the cone penetrometer (ASTM D6951). Following the cone penetrometer testing, each of the 10 locations shall be carefully excavated in 6-inch lifts and tested in accordance with ASTM D6938, direct transmission method, for the full depth of the excavated lift. The ASTM D6938 density tests shall be performed in close proximity to where the cone penetrometer testing (ASTM D6951) was performed, but it shall be separated by enough distance to ensure that independent and accurate density test results are obtained for both tests at each of the 10 locations on the test pad. The cone penetrometer will provide a number of blows per lift. The number of blows per lift will correspond to an average wet density for the lift as determined by ASTM D6938, direct transmission method. Thus, a correlation of number of blows will be equivalent to a wet density. The final data set will show that x number of blows corresponds to a density y on one lift, density y+i on another lift, density y+j on a third lift, etc. The final data reduction should show that y, y+i, y+j,...,n are within ±2 lbf/ft^3 of the average density for that number of samples corresponding to that number of blows. The moisture contents obtained from ASTM D6938 will allow the wet densities to be converted to dry density values. The dry densities may be compared to the specifications for acceptance.

The test pad correlation must be performed in the presence of the QA Engineer. The density correlation method must be accepted by the QA Engineer and the Idaho DEQ. If the Contractor can prove this correlation to the QA Engineer, the Contractor shall be allowed to place soil in lifts not to exceed 3 feet and shall verify the density of full thickness of placed material using cone penetrometer testing.

5.4 Select Cover Subgrade Soil

Select cover subgrade soil shall be placed over the existing subgrade to the thickness necessary to meet the grades that will provide suitable subgrade for placement of the 5-foot-

thick final cover layer. The select cover subgrade soil requires placement of soil that is suitable for plant roots and compatible with the overlying final cover soil.

The select cover subgrade soil shall meet the following criteria:

- All select cover subgrade soil shall be sampled from the borrow source and tested.
- The soil must satisfy the requirements for select cover subgrade soil as defined in Section 31 00 00 - Earthwork.
- Soil tests shall include Classification (ASTM D2487), Grain-Size Distribution (ASTM D422), Atterberg Limits (ASTM D4318), Standard Proctor (ASTM D698), and salinity testing.
- All cover subgrade soil material shall be approved by the QA Engineer.

The Contractor shall provide a survey to the QA Engineer to certify that the completed cover subgrade soil layer meets the grades needed for completion of the final cover soil layer. The final cover soil layer must meet minimum thickness requirements, but may be thicker, as long as the final cover grades are met when construction is completed. Thickness of the cover soil layer shall be measured perpendicular to the final cover surface grades. The Contractor shall obtain approval of the survey of the select cover subgrade soil layer from the QA Engineer prior to placing final cover soil. The thickness of the cover subgrade soil layer shall be determined by the difference between the cover subgrade soil topography and the pre-construction existing subgrade topography.

5.5 Soil Rooting Medium and Gravel Amended Topsoil Layers

Specifications applicable to the soil rooting medium and gravel amended topsoil layers include Section 31 00 00 - Earthwork, Section 31 38 01 - Surface Rock Durability Requirements, and Section 31 32 00 Cover System Components. Testing of soil rooting medium borrow source material shall comply with the soil rooting medium sampling and analysis plan provided in

Attachment 1, and shall be approved by the QA Engineer prior to excavation for cover construction.

5.5.1 Soil Rooting Medium

The soil rooting medium shall meet the following criteria:

- Shall be sampled from the borrow source and tested at frequencies specified in Section 31 00 00 - Earthwork (see Attachment 1).

- Soil rooting medium shall meet specifications designated in Section 31 00 00 - Earthwork. Additional soil classifications may be approved by the QA Engineer if soil test results show that all other criteria are met and approval is granted by Idaho DEQ.

- Percent relative compaction, saturated hydraulic conductivity, and water holding capacity shall meet specifications designated in Section 31 00 00 - Earthwork.

- Uniform density is critical for this entire cover soil layer. Any higher-density areas caused by truck traffic or other activity are to be loosened to meet the compaction standard.

- Laboratory soil testing shall include USCS Classification (ASTM D2487), Grain-Size Distribution (ASTM D422), Atterberg Limits (ASTM D4318), Standard Proctor (ASTM D698), Saturated Hydraulic Conductivity (ASTM D2434 or ASTM D5084), and Retention Curve Determination at Two Points (ASTM D6836). Moisture retention tests shall determine the moisture content at -333 cm water pressure head (⅓ bar) and -15,000 cm water pressure head (15 bar). Testing for saturated hydraulic conductivity (ASTM D2434 or ASTM D5084) and moisture retention (ASTM D6836) shall be performed on laboratory-prepared remolded samples at a relative compaction of 85 ± 2 percent of the maximum standard dry density, with a final measured density meeting the required 80 to 92 percent of standard maximum dry density. The saturated hydraulic conductivity and moisture retention samples shall be remolded using the same

criterion as the Standard Proctor (ASTM D698) method used for compaction. The largest particle size shall be determined by grain size distribution of the sample.

- Field testing shall include in-place density and moisture content by nuclear methods (ASTM D6938), sand cone density testing (ASTM 1556), and mechanical cone penetrometer testing (ASTM D6951). Agronomic properties testing shall meet specifications designated in Section 31 00 00 - Earthwork. These tests are to ensure that the select cover subgrade soil will support native vegetation.

  - Salinity Limits: Soil rooting medium shall meet salinity specifications designated in Section 31 00 00 - Earthwork. Soils that do not meet the salinity limits shall not be used in the cover.

  - Nutrient Limits: Soil rooting medium shall meet the nutrient requirements designated in Section 31 00 00 - Earthwork. Should the soil not meet these nutrient requirements, amendments will be required as appropriate. Any amendment is to be approved by the QA Engineer prior to application.

5.5.2 Gravel Amended Topsoil

The gravel amended topsoil shall meet the following criteria:

- The material must satisfy the same agronomic properties as the soil rooting medium layer (see Section 31 00 00 - Earthwork).

- The fine portion must be productive topsoil satisfying the definition for topsoil in Section 31 00 00 - Earthwork.

- Gravel in the top soil layer must be uniformly mixed within the profile to the extent that pockets of soil will not have significant disparities in water holding capacity.

- The gravel amended topsoil layer shall be placed in one uncompacted lift.

- All topsoil material shall be approved by the QA Engineer.

The Contractor shall provide a survey to the QA Engineer to certify that the completed cover soil layer has, at any point, the minimum thickness designated on the final design cover soil surface. The thickness of the cover soil layer construction shall be determined by the difference of the final cover topography and cover subgrade soil topography.

5.6 Delivery, Storage, and Handling

If cover soil/gravel admixture materials are delivered to the site prior to placement approval, materials shall be stockpiled on-site in areas as dictated by the Owner. Provision shall be implemented to minimize surface water impact on the stockpile. Removal and placement of the materials shall be done in a manner to minimize intrusion of soils adjacent to and beneath the stockpile.

5.7 Cover Soil Placement

No cover soil shall be placed, spread, or compacted during unfavorable weather conditions. At such times, work shall be suspended by the Contractor. The QA Engineer shall have authority to halt the work when material is overly wet or during unfavorable weather conditions. The cover soil layer surface must be made smooth and free from ruts or indentations at the end of any working day when significant precipitation is forecast and/or at the completion of the placement operations in an area in order to prevent saturation of the soil.

6. Leachate System and Monitor Well Extensions

6.1 General

Specifications applicable to the leachate system and monitor well extensions include Section 33 24 14 - Well Riser Modification, Section 40 14 49 - HDPE Pipe, specification used for construction of the liner and leachate collection system, US Ecology Idaho, Cell 15, Section 15062 - Piping and Mechanical, November 15, 2002, and specification used for construction of the liner and leachate collection system, US Ecology Idaho, Cell 15, Section 16050 - Electrical Work, September 30, 2002. The existing leachate collection system components in Cells 14 and 15 will require extensions and modifications as an integral component of the cover construction project. Two existing groundwater monitor wells will require wellhead extensions as part of Cell 14 cover construction. The Contractor shall be responsible for necessary extensions and modifications in accordance with the design drawings and specifications, including:

- Leachate collection riser extensions and piping modification, including the following:
  - primary leachate collection vertical manhole extensions for Phases 1, 2, and 3 of Cell 14
  - secondary leachate collection lateral extensions for Phases 1, 2, and 3 of Cell 14
  - both primary and secondary lateral extensions for Phases 4, 5, and 6 of Cell 14
  - both primary and secondary lateral extensions for Phases 1, 2, 3/4 of Cell 15
- Relocation of existing leachate pump controls
- Extension of all piping, hose, cable, and electrical components
- Installation of buried, double-wall high-density polyethylene (HDPE) leachate conveyance pipe outside the Cell 15 cover
- Extension of groundwater monitor well wellheads for wells L-28 and L-39 to extend above the Cell 14 final cover grades

6.2 Installation

The Contractor shall prepare a written plan for the construction of the leachate riser extensions and monitor well risers. The plan shall include all materials and methods to be used. The plan shall be accepted in writing by the QA Engineer and the Idaho DEQ prior to commencement of construction. All materials and methods used in the riser extensions shall be consistent with the existing materials. Existing materials and equipment shall be modified and reused to the extent practicable.

The QA Engineer shall inspect the installation of riser extensions. After completion of any section of pipe, the grades, joints, and alignment shall be true to line and grade. The pipe shall be completely free from any cracks and from protruding joint materials, deposits of sand, dirt, debris, or other materials on the inside.

6.3 Health and Safety

Health and safety monitoring is a critical aspect of the leachate system extensions. Vapor within the leachate risers is potentially toxic, explosive, or deficient in oxygen. The Contractor shall provide a site-specific health and safety plan (HASP) to the QA Engineer for approval. The HASP shall address monitoring methods, engineering controls (such as ventilation systems), and construction methods that ensure worker health and safety.

6.4 Material Properties

All materials used for extension of the existing structures shall conform to the specification used for construction of the liner and leachate collection system, US Ecology Idaho, Cell 15, Section 15062 - Piping and Mechanical, November 15, 2002, and the specification used for construction of the liner and leachate collection system, US Ecology Idaho, Cell 15, Section 16050 - Electrical Work, September 30, 2002. New piping structure materials shall adhere to Section 40 14 49, HDPE Pipe.

6.4.1 HDPE Pipe

The HDPE pipe used for the systems shall be manufactured in accordance with ASTM D714 and have the following physical characteristics:

- The pipe shall be as uniform as commercially practical in color, opacity, density, and other physical properties.
- Apart from structural voids and hollows associated with some profile wall designs, the pipe fittings shall be homogeneous throughout and free from visible cracks, holes, foreign inclusions, or other defects.

6.4.2 HDPE Pipe Fittings

End caps for the clean-out risers will be of low-pressure type HDPE, or similar. HDPE fittings shall be manufactured in accordance with the requirements of ASTM D3350.

6.5 Manufacturer Quality Control Documentation

Prior to installation of any pipe, the Contractor shall provide the following information certified by the manufacturer for the delivered pipe:

- Manufacturer's certification verifying that the quality of the raw materials used to manufacture the pipe meets the manufacturer specifications
- The following identification information for each pipe length delivered to the project site:
  - Manufacturer's name
  - Pipe size
  - Ring stiffness constant classification or SDR number
  - Production code designating plant location, machine, and date of manufacture

6.6 Delivery, Storage, and Handling

Off-loading and storage of the HDPE pipe shall be performed by the Contractor. Storage of the pipe shall not exceed 17 rows high, per manufacturer's recommendation.

The Contractor shall be responsible for moving the pipes and fittings from the storage area to the area of pipe installation. The Contractor shall be responsible for replacing any material damaged during transport or installation.

6.7 Quality Assurance

Each length of pipe produced shall be checked at the factory by production staff for the items listed below. The results of all measurements shall be recorded on production sheets that become part of the manufacturer's permanent records.

- Pipe in process shall be checked visually, inside and out, for cosmetic defects (grooves, pits, hollows, etc.).
- Pipe outside diameter shall be measured using a suitable periphery tape to ensure conformance with ASTM D1785.
- Pipe wall thickness shall be measured at 12 equally spaced locations around the circumference at both ends of the pipe to ensure conformance with the manufacturer's specifications.
- Pipe length shall be measured.
- Pipe marking shall be examined and checked for accuracy.
- Pipe ends shall be checked to ensure they are cut square and clean.

7. Seeding Quality Control

Specifications applicable to seeding include Section 32 92 19 - Vegetation and Seeding. Vegetation is critical to the success of an ET cover system; it provides for long-term stability of the cover surface, minimizes erosion, and reduces infiltration flux.

Seeds shall be applied through hydromulching with a bonded fiber matrix (BFM). The hydromulch shall be applied at a rate designated in Section 32 92 19 - Vegetation and Seeding.

Ensuring an adequate stand of vegetation begins with ensuring the quality of seed used. A variety of mechanisms can be used to control and ensure high-quality seeding operations. The seeding Contractor shall be required to develop and submit a seeding plan, detailing all seeding equipment to be used, fertilizer types, and mulch sources for inspection prior to initiation of work. Seed and fertilizer formulation certifications from the suppliers shall be submitted prior to material use. Daily quality control logs shall be maintained.

Qualified seeding Contractors and operators shall be employed. Seeding requires experience and familiarity with the various seed types to ensure proper planting. The proper equipment for seeding the specified seed mix must be used.

Seed and seed mixtures shall be delivered in sealed containers. Wet, moldy, or otherwise damaged seed or packages shall be rejected and unacceptable materials removed from the job site. All labeling required by law shall be intact and legible. After delivery to the job site, seeds shall be stored in a cool, dry, weatherproof, and rodent-proof place or container in a manner that protects the seed from deterioration and permits easy access for inspection.

All seed shall be subject to inspection and concurrence by the Contractor before the subcontractor is authorized to proceed with the seeding operation. Seed shall be tested according to the Association of Official Seed Analysts, International Seed Testing Association, and the Federal Seed Act standards. A certificate of analysis from a certified testing laboratory shall accompany seed, certifying the following individual seed tests:

- Purity and germination: Before seed is used, retest for germination all seed stored over six months from the date of the original acceptance test, and resubmit the results for inspection.

- Prohibited noxious weed seed: Seed shall not contain any federal- or state-listed prohibited noxious weed seed (an amount within the tolerance of 0 percent) as determined by a standard purity test.

- Restricted noxious weed seed: Seed shall contain no more than 40 seeds per pound of any single species, or 150 seeds per pound of all species combined, of restricted noxious weed seed.

- Weed seed: Seed shall contain no more than 1 percent by weight of weed seed of other crops and plant species as determined by standard purity tests.

Laboratory certification seed testing within six months of date of delivery includes the following:

- Name and address of laboratory

- Date of test

- Lot number of each seed type

- Results of tests, including name, percentage of purity and germination, percentages of weed content for each kind of seed furnished, hard seed content, and in case of seed mixtures, pure live seed (PLS) proportions of each kind of seed as specified

The seed vendor on each standard sealed container label can provide information regarding the seed mixture. The labels shall include the following information:

- Seed mixture name
- Lot number
- Total net weight and PLS weight of each seed type
- Percentages of purity and germination

- Seed coverage (in acres) on a PLS basis
- Percentage of maximum weed seed content clearly marked for each seed type

The vendor shall package seed such that the acre coverage of each container is equal for convenience of inventory. Prior to planting any seed, the seed labels and certification documentation shall be inspected by the QC Representative to ensure that the seed provided meets the requirements specified.

Equipment proposed for use and the methods of seeding shall be inspected for concurrence prior to the commencement of seeding operations. The equipment shall be checked for compliance to safety requirements (in the Contractor's HASP) prior to the commencement of seeding operations. Equipment calibration tests shall be conducted immediately prior to commencement of seeding operations and when the seed mix changes or different equipment is used.

Consider environmental conditions and perform seeding operations only during periods when successful results can be obtained. When drought, excessive moisture, or other unsatisfactory conditions prevail, seeding operation shall be discontinued.

8. ASTM Standards for Cover Installation

The following standards from ASTM are applicable to the installation and testing of soil and cover materials. Construction specifications prepared for the USEI cover construction will include the final testing requirements and standards.

8.1 Cover Soil

ASTM D422: Standard Test Method for Particle-Size Analysis of Soils

ASTM D698: Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort

ASTM D1556: Standard Test Method for Determining Soil Density, Sand Cone Method

ASTM D2216: Standard Test Method for Determining Water Content of Soil Aggregate Mixtures

ASTM D2434: Standard Test Method for Permeability of Granular Soils (Constant Head)

ASTM D2487: Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM D4318: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

ASTM D6836: Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge

ASTM D6938: Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

ASTM D6951 - Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

8.2 Cover Subgrade Preparation

ASTM D698: Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort

ASTM D1556: Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method

ASTM D2216: Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

ASTM D6938: Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

8.3 Plastic Pipe

ASTM D256: Test Methods for Determining the Impact Resistance of Notched Specimens of Plastics

ASTM D638: Test Method for Tensile Properties of Plastics

ASTM D746: Test Method for Brittleness Temperature of Plastics and Elastomers by Impact

ASTM D790: Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

ASTM D1238: Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer

ASTM D1248: Specification for Polyethylene Plastics Molding and Extrusion Materials

ASTM D1505: Test Method for Density of Plastics by the Density-Gradient Technique

ASTM D2774: Standard Practice for Underground Installation of Thermoplastic Pressure Piping

ASTM D2837: Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials

ASTM D2240-05: Test Method for Rubber Property-Durometer Hardness

ASTM D380: Methods of Testing Rubber Hose

ASTM D1525: Test Method for Vicat Softening Temperature of Plastics

ASTM D1603: Test Method for Carbon Black in Olefin Plastics

ASTM D1693: Test Method for Environmental Stress-Cracking of Ethylene Plastics

ASTM D696: Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C

ASTM D2513: Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings

ASTM D2657: Practice for Heat Joining of Polyolefin Pipe and Fittings

ASTM D2683: Specification for Socket-Type Polyethylene Fittings for Outside-Diameter Controlled Polyethylene Pipe and Tubing

ASTM D3350: Specification for Polyethylene Plastic Pipe and Fitting Materials

Attachment 1

Soil Rooting Medium Sampling and Analysis Plan

Soil Rooting Medium Sampling and Analysis Plan
Soil Characterization for Evapotranspiration Cover
US Ecology Idaho Cells 14 and 15

This soil rooting medium sampling and analysis plan addresses characterization of borrow soils at the US Ecology Idaho (USEI) site. All of the administrative and substantive requirements found in the main construction quality assurance (CQA) plan shall apply to this document. The purpose of this program is to collect the necessary data to delineate and approve the borrow source soils for the soil rooting medium prior to the construction of the evapotranspiration (ET) cover at Cells 14 and 15.

Section 4 of the design report identifies the soil properties necessary for acceptable cover soil material. Section 4 of the design report also identifies on-site soils that were tested to demonstrate meeting the necessary criteria. The soil rooting medium layer of the ET cover has the most stringent characterization specifications; therefore, it is proposed that soil sources meeting those criteria be identified and approved in advance of cover construction. Data obtained from the soil characterization investigation will be used to identify soil locations for the soil rooting medium and other soil materials needed for cover construction. Note that any soil that satisfies the requirements for soil rooting medium also satisfies the requirements for select soil subgrade and topsoil used in the ET cover.

1. Source Soil Testing Frequency

The soil rooting medium testing requirements are presented in Table 1. Index testing of the soil rooting medium shall be performed every 5,000 cubic yards (yd^3); therefore, test pits will be excavated to obtain soil samples meeting this frequency. Materials acceptable for soil rooting medium are classified as silty sand (SM) and/or silt (ML). Testing for saturated hydraulic conductivity, water retention capacity, salinity, and nutrients of the soil rooting medium will be performed every 10,000 yd^3. Testing must satisfy the specification criteria listed in Table 1.

Table 1. Summary of Soil Rooting Medium Testing Frequency

Test	Method	Frequency	Requirement(s)
Index Tests			
Liquid limit, plastic limit and plasticity index	ASTM D4318	1 per 5,000 yd^3	Used for classification
Particle size analysis	ASTM D422	1 per 5,000 yd^3	Used for classification
Soil classification	ASTM D2487	1 per 5,000 yd^3	Silty sand (SM) or silt (ML)
Laboratory moisture-density relations	ASTM D698	1 per 5,000 yd^3	Reference for percent compaction
Moisture Characteristics			
Saturated hydraulic conductivity	ASTM D2434 or D5084	1 per 10,000 yd^3 (may be increased to 1 per 5,000 yd^3) [a]	Less than or equal to 2.0×10^{-4} cm/s tested at a relative compaction of 85% ± 2% of the standard maximum dry density. Minimal confinement pressure shall be used in accordance with the ASTM standard.
Retention curve determination at two points	ASTM D6836	1 per 10,000 yd^3 (may be increased to 1 per 5,000 yd^3) [a]	Water holding capacity greater than or equal to 0.11 tested at a relative compaction of 85% ± 2% of the standard maximum dry density
Salinity			
Electrical conductivity (EC)	Bureau of Soils Method; USDA Handbook 60	1 per 10,000 yd^3	Less than 8 mmhos/cm
Sodium adsorption ratio (SAR)	EPA 6010B	1 per 10,000 yd^3	Less than 6
Exchangeable sodium percentage (ESP)	EPA 6010B, ASA 9	1 per 10,000 yd^3	Less than 15% (g/g)
Calcium carbonate ($CaCO_3$)	ASA 10-3	1 per 10,000 yd^3	Less than 15% (g/g)
pH	SM4500-H+B: PH	1 per 10,000 yd^3	Between 6 and 8.4
Cation exchange capacity (CEC)	EPA 6010B, USDA Handbook 60	1 per 10,000 yd^3	Greater than 15 (meq/100 g)
Nutrients			
Percent organic matter	ASTM D2974	1 per 10,000 yd^3	Greater than 2% (g/g)
Nitrogen (N)	SM 4500NorgC and EPA 300.0	1 per 10,000 yd^3	Greater than 6 parts per million (ppm)
Phosphorous (P)	EPA 6010B	1 per 10,000 yd^3	Greater than 5 ppm
Potassium (K)	EPA 6010B	1 per 10,000 yd^3	Greater than 50 ppm

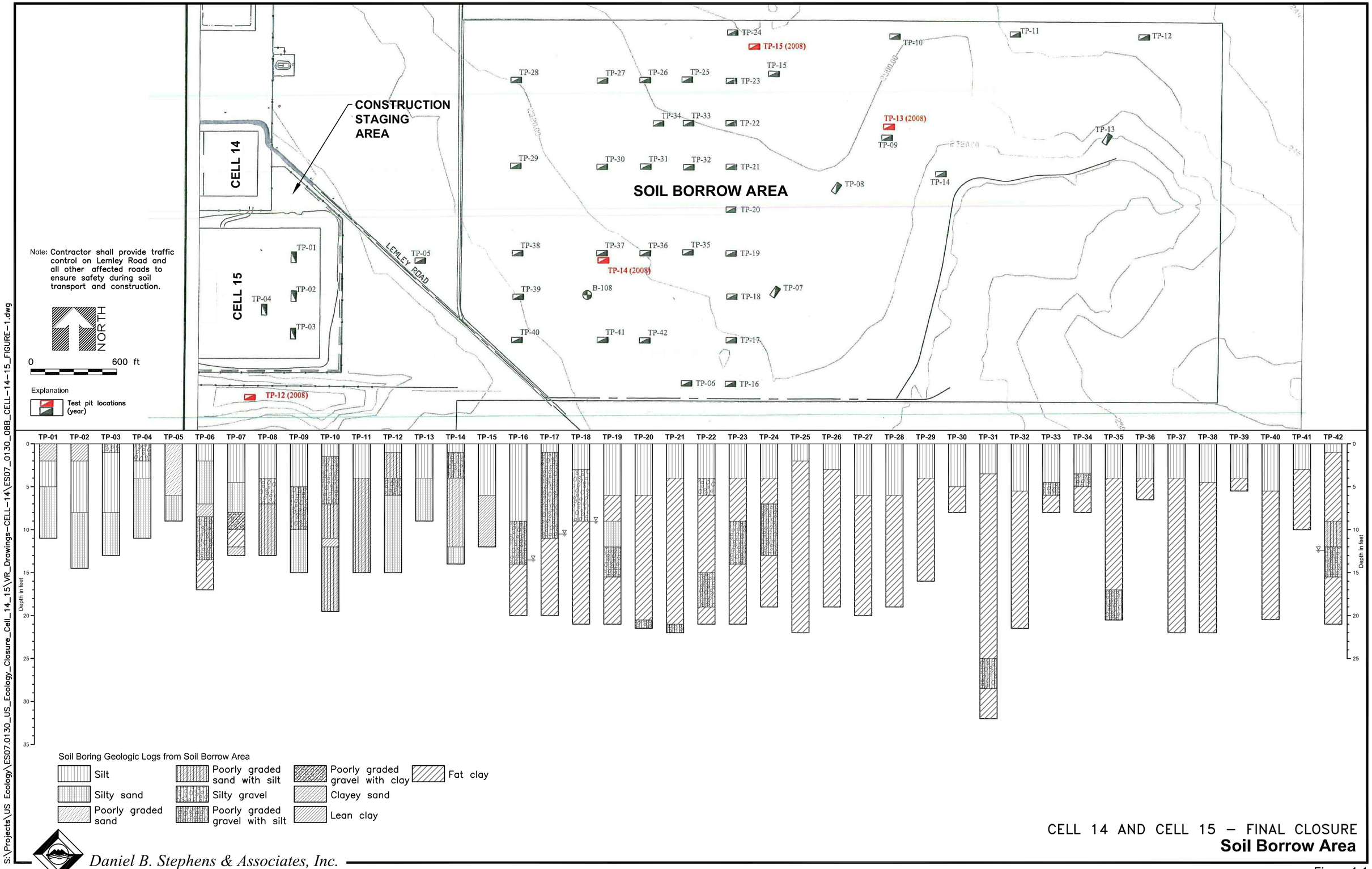
[a] Testing frequencies for saturated hydraulic conductivity and water holding capacity designated at 1 per 10,000 yd^3 are dependent on the variability of the borrow source material. If the borrow source soil shows significant variability, then the testing frequency will be increased to 1 per 5,000 yd^3. DEQ concurrence will be required to establish the final test frequency for saturated hydraulic conductivity and water holding capacity.

A total of approximately 850,000 yd^3 of soil will be required to construct covers for Cells 14 and 15. The soil rooting medium layer in the final covers requires approximately 450,000 yd^3 of the total amount of soil. Testing requirements are specific for each of the three cover soil components:

- Gravel amended topsoil
- Soil rooting medium
- Select cover subgrade soil

The soil borrow area illustrated on Figure 1-1 is approximately 318 acres. The borrow area is known as the Steiner property, which is owned by US Ecology. Based on lithologic logs from test pits completed within the soil borrow area, the silt and silty sand material needed for the soil rooting medium is generally found within the upper 10 feet of soil. The lithologic logs are shown on Figure 1-1. Assuming an average 5-foot depth of excavation, soil rooting medium samples will need to be collected from an area of approximately 60 acres, selected within the 318-acre borrow area. At a testing rate of 1 per 5,000 yd^3 of soil rooting medium, approximately 90 index tests will be required. Testing for saturated hydraulic conductivity, water holding capacity, salinity, and nutrients at a frequency of 1 per 10,000 yd^3 will initially require approximately 45 tests.

Following completion of the soil rooting medium sampling and initial testing, the QA Certifying Engineer shall submit a preliminary report on the soil testing to the DEQ for review and approval. The report shall include all test results and a recommendation on whether the testing frequency of 1 per 10,000 yd^3 for saturated hydraulic conductivity and water holding capacity is sufficient, or whether additional testing is justified. The report shall also include calculations demonstrating that the borrow source sampling locations, including vertical and horizontal spacing, satisfy the sampling frequencies specified in Table 1 of this sampling plan. The need for additional testing will be based on the degree of soil variability. DEQ concurrence, prior to soil rooting medium final placement, will be required to establish the final test frequency for saturated hydraulic conductivity and water holding capacity.



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Daniel B. Stephens & Associates, Inc.

10-25-10

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CELL 14 AND CELL 15 – FINAL CLOSURE

Soil Borrow Area

Figure 1-1

2. Soil Sampling Methods

Soil samples will be collected by excavation of test pits. Test pits will be excavated using a backhoe or excavator. Based on previous test pit excavations within the soil borrow area, a distinct transition is visually evident at the depth where the desired silty soil for the soil rooting medium transitions to a deeper clay horizon. Test pit excavations should extend at least 2 feet beyond the desired SM/ML stratum to clearly identify the contact.

Soil samples will be collected as composite samples from each test pit location. Composite samples should be representative of the entire stratum thickness proposed for use in cover construction. The sampling interval depths should be recorded and referenced to a known survey elevation for each test pit. When samples are collected, a total of approximately 15 gallons of soil (three 5-gallon buckets) will be needed for each sample.

3. Inspection of Sample Collection

Inspection of soil sample collection shall be performed under the direction of the QA Certifying Engineer. During collection of the soil rooting medium samples, full-time inspection of the test pit excavation and soil sample collection shall be performed. The QA Certifying Engineer may designate a QA Inspector who is a qualified engineer, geologist, or soil scientist with at least two years of relevant experience. The QA Inspector shall direct test pit excavation and perform inspection of soil sampling. The QA Inspector shall record soil descriptions and make note of the largest particle size evident at each testing location. The QA Inspector shall determine whether soil samples will be collected at a given location, or whether soil should not be collected when the soil does not appear to meet the characteristics required for the soil rooting medium.

4. Limits of Qualifying Area

Figure 1-1 shows the entire soil borrow area available and the location of three Steiner property soil samples that were tested to show conformance with the soil rooting medium requirements. Within the soil borrow area, the QA Inspector will direct where test pits are excavated. Contiguous areas located within the limits of test pits yielding acceptable results for soil rooting

medium are qualified for use in construction. Soil rooting medium shall not be obtained outside of the qualified areas. The depth of excavation shall be limited to the depth of soils that were previously tested to show acceptable characteristics.

The goal of soil testing will be to qualify a single, contiguous area of approximately 60 acres for excavation of the soil rooting medium. More than one area may also be selected if necessary to obtain qualifying soil. Within the area being tested, test pits will be spaced at approximately 160-foot on-center intervals, depending upon the thickness of the desired stratum. The test pits shall be spaced at representative intervals as the testing for source evaluation proceeds.

The location of each test pit shall be staked and labeled during excavation. The locations and test pit labels shall be recorded by a licensed surveyor. Accurate recording of the test pit locations is essential to establishing the limits of the qualifying area. The test pit locations shall be recorded on a map by the QA Inspector. The origins of each sample must be distinctly and uniquely identified on sample containers and laboratory chain of custody forms.

During construction, the limits of the qualifying area for the soil rooting medium shall be clearly staked and identified to the Contractor.

Appendix C

Specifications

Final Cover Design
US Ecology Idaho

Specifications

Division 1

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32 92 19	Vegetation and Seeding

Division 33

33 24 14	Leachate and Well Riser Modification

Division 40

40 14 49	HDPE Pipe

Division 1

SECTION 01 20 00

MEASUREMENT AND PAYMENT

PART 1 GENERAL

1.1 Progress Payments

A. Each progress payment shall include three (3) copies of the detailed reports (monthly reports). The Contractor's monthly reports shall contain:

1. Description of Work accomplished since submission of previous progress schedule;
2. Comparison of the actual status of the Work with Contractor's original and current project schedule;
3. Status of equipment and material deliveries. The Contractor shall enumerate all orders placed for major equipment or materials with date of order and, if possible, date of anticipated delivery;
4. The Contractor shall state the availability of all materials, work fabrications, and/or equipment specified;
5. Personnel staffing schedule;
6. Revision of schedules (if any);
7. Action proposed to restore schedule.

B. Each pay application shall also include all Daily Field Reports processed by the Contractor during the month for the associated pay application.

1.2 Schedule of Values

A. Before the first Application for Payment, the Contractor shall submit to the Owner a Schedule of Values allocated to the various portions of the Work, and supported by such data to substantiate its accuracy as the Engineer and the Owner may require. This schedule, unless objected to by the Owner shall be used only as a basis for the Contractor's Applications for Payment.

1.3 Applications for Payment

A. Per the Contract Documents, the Contractor shall meet with the Engineer and Owner and submit a completed Progress Report, in accordance with the requirements of Contract Documents, supported by such data substantiating the Contractor's right to payment as the Owner or Engineer may require. Contractor shall also certify that he has paid all due and payable amounts for which previous certificates for payment were issued and payments received from the Owner.

B. The submission and approval of the Construction Schedule and monthly updates thereof as required by the Contract Documents shall be an integral part and basic element of the Application upon which progress payment shall be made. The Contractor shall be entitled to progress payments only upon substantial compliance with all requirements for

the construction schedule. Compliance with this requirement shall be a condition precedent to the processing of Contractor's Applications.

C. The Contractor's Application for Payment shall show percentage of work completed for each application, total percentage of work completed for each application, total percentage complete-to-date and balance of work remaining for each bid item.

D. The Contractor shall promptly pay each Subcontractor (including suppliers, laborers and material men) performing labor or furnishing material for the Work upon receipt of payment from the Owner. The Contractor shall, by an appropriate agreement with each Subcontractor, also require each Subcontractor to make payments to Sub-subcontractors in similar manner.

E. The Owner may, on request and at Owner's discretion, furnish to any Subcontractor, if practicable, information regarding the percentages of completion or the amounts applied for by the Contractor and the action taken thereon by the Engineer on account of Work done by such Subcontractors.

F. Neither the Owner nor the Engineer shall have any obligation to pay or to see to the payment of any monies to any Subcontractor except as may otherwise be required by law.

G. No Certificate for a progress payment, nor any progress payment, nor any partial or entire use or occupancy of the Project by the Owner, shall constitute an acceptance of any Work which is not in accordance with the Contract Documents.

1.4 Payments Withheld

A. The Owner and Engineer may decline to certify payment and may withhold the Certificate in whole or in part, to the extent necessary to protect the Owner, if in their opinion the Contractor is unable to make correct and accurate representations to the Owner. If the Engineer is unable to make representations to the Owner and to certify payment in the amount of the Application, they shall notify the Contractor. If the Contractor and the Engineer cannot agree on a revised amount, the Engineer shall promptly issue a Certificate for Payment in the amount for which they are able to make such representations to the Owner. The Engineer may also decline to certify payment or any part thereof or, because of subsequent observations, they may nullify the whole or any part of any Certificate for Payment previously issued, to such extent as may be necessary in their opinion to protect the Owner from loss because of:

1. Defective work not remedied;
2. Third party claims filed or reasonable evidence indicating probable filing of such claims;
3. Failure of the Contractor to make payments properly to Subcontractors or for labor, materials or equipment;
4. Reasonable evidence that the Work cannot be completed for the unpaid balance of the Contract Sum;
5. Damage to the Owner or another Subcontractor;
6. Reasonable evidence that the Work will not be or has not been completed within the Contract Time or Specific Dates;
7. Failure to carry out the Work in accordance with the Contract Documents;

8. Liens or stop notices filed or reason to believe it is probable same will be filed for any portion of the Work; or
9. Failure or refusal of the Contractor to fully comply with the contract requirements.
10. Not maintaining "as-built" drawings.
11. Not submitting coordination drawings.

1.5 Stored Materials

A. At the time the schedule of values is developed the Contractor shall submit a listing of those items proposed as stored equipment and materials for which payment will be requested. Payment shall not be considered for items which are incorporated into the work on a continuing basis or for materials which are available as shelf or warehouse items. Materials shall be properly stored and protected from the elements. Receipts shall be provided substantiating that payment has been made for the materials and/or equipment. Stored materials shall be housed within 30 (thirty) miles of the project site, be accessible for review by the Engineer and/or Owner (should they desire), housed in a bonded warehouse with the Owner listed as co-insured, and separated and easily identified as specific to this project. All applicable papers shall be attached to the pay application for payment consideration.

1.6 Lien Waivers

A. For each progress payment application the Contractor shall include lien waivers signed and notarized by each Subcontractor paid for the previous month.

END OF SECTION

SECTION 01 22 00

UNIT PRICES

PART 1 GENERAL

1.1 Work Under This Contract

A. See General Conditions and Supplementary Conditions, which apply to all work. All related work not specifically affected by the unit prices shall be accomplished according to the basic specifications. See drawings, specifications, or schedules for all items and construction covered by this section.

B. Each bidder shall submit on the form(s) provided unit price proposals stating the price (additions or deletions) from the base bid for adding, deleting or substituting the materials and/or systems described hereunder.

1.2 General Provisions

A. Each Unit Price represents the aggregate lump-sum cost to the Owner, per unit of measure stated, including, but not limited to, materials, delivery, handling, on-site labor and installation, adjustments to related Work, overhead, profit and similar fees for administration/supervision, and proportionate shares of such general expenses as bond and insurance premiums, temporary construction facilities, and temporary controls.

B. Owner and Engineer shall give prompt and reasonable notice to the Contractor of proposed revisions to the scope of the work, to not unreasonably delay the construction schedule for the affected Work or the Date of Substantial Completion. Adjustments to the Contract Sum, due to the application of Unit Prices, shall be computed on a net basis (cost of work added less the cost of Work deleted) calculated for the entire Project.

C. Items and quantities of Work are estimated to vary from the Contract Documents as of the date of the Owner-Contractor Agreement by not more than, nor less than 15 percent. If the ultimate quantities substantially exceed said percentage, Unit Prices are subject to adjustment in accordance with the General Conditions.

D. Products and Execution requirements for the Work of all Unit Prices is indicated on the Drawings and specified in applicable Sections of the Specifications; either specifically for the Work of the Unit Prices or for similar Work which is otherwise required for the basic work of the contract.

E. The Final Contract Sum shall be adjusted by Change Order to reflect final quantities or adjusted costs for Unit Prices.

1.3 Payment Quantities

A. Quantities for payment to the Contractor shall be based on in-place quantities constructed in accordance with the Drawings and Specifications.

B. Earthwork quantities shall be calculated based on surveys conducted at appropriate stages of construction, before and after earthwork is conducted.

C. Earthwork quantities shall be based on in-place densities that meet the density requirements in the Drawings and Specifications. Contractor costs and requests for payment shall reflect in-place quantities and densities. Payment for in-place earthwork quantities shall be inclusive of all costs for excavation, loading, hauling, grading, compaction, and other associated work. No additional payment shall be provided based on measurement of soil excavated or loads hauled.

D. Payment quantities shall be based strictly on design requirements as shown in the Drawings and Specifications. Payment shall be based on design dimensions, which shall be met as a minimum by the Contractor. For example, payment quantities for a 6-inch compacted soil subgrade will be paid based on a uniform 6-inch in-place thickness, and although the Specifications may allow for a tolerance of greater thickness, any added material would be placed at the Contractor's convenience to facilitate construction and would not be paid in addition to the required quantity.

E. All adjustments to the quantities in the Bid Form shall be documented by the Contractor. The Contractor shall submit all requests for quantity adjustments in writing for the Engineer's review. Payment increases are subject to approval by the Owner and Engineer.

END OF SECTION

SECTION 01 25 00

SUBSTITUTION PROCEDURES

PART 1 GENERAL

1.1 Description

A. This section describes standards used in specifying products, materials and equipment and options available to Bidders and the Contractor for securing approval of proposed substitutions.

1.2 Product Options

A. Products, materials and equipment furnished under the Contract shall conform to standards of quality, function, appearance and dimension established by the Contract Documents. Reference in the Specifications to a manufacturer's name and/or model number is not meant to exclude alternative products, which meet the requirements of the Contract Documents form consideration through the Prior Approval process.

B. For products specified by reference to national standards such as ASTM, ACI, etc., and where no manufacturer and/or model number is specified, use only products meeting such standards. Referenced standards shall be those standards currently enforced by public authorities or utilities having jurisdiction. Prior Approval is not required for products specified by reference to national standards.

C. For products specified by listing one or more manufacturers and/or model numbers, select any manufacturer listed whose product conforms to the standards of quality, function, appearance and dimension established by the Contract Documents.

1.3 Substitutions – Prior to Receipt of Bid (Prior Approval)

A. During bidding the Owner shall consider written requests for substitutions, received at least seven (7) days prior to bid date; requests received after that time shall not be considered. Requests for substitutions shall be made only in writing to the Owner through the Engineer. The Engineer shall make recommendations on proposed substitutions; the Owner shall make final decisions.

B. In connection with the use of any substitute item accepted by the Owner, it shall be the Contractor's responsibility to see that such items meet all space requirements, and that any alterations to connecting items necessitated by use of the alternate items are properly made, at no increase in cost to the Owner.

C. In making request for substitution, Bidder/Contractor represents that:

1. Bidder/Contractor has investigated the proposed product or method and determined that it is equal or better in all respects to that specified and that it fully complies with all requirements of the Contract Documents.

2. Bidder/Contractor shall meet all contract obligations with regards to this substitution.
3. Bidder/Contractor shall coordinate installation of accepted substitutions into the work, making all such changes and any required schedule adjustments, at no additional cost to the Owner, as may be required for the work to be completed in all respects.
4. Bidder/Contractor waives all claims for additional costs and additional time related to substitutions, which consequently become apparent. Bidder/Contractor also agrees to hold the Owner harmless from claims for extra costs and time incurred by other subcontractors and suppliers, or additional services which may have to be performed by the Engineer, for changes or extra work that may, at some time or date, be determined to be necessary in order for the Work to function in the manner intended in the Contract Documents.
5. Bidder/Contractor shall provide the same warranty and guarantee, and perform any work required in accordance therewith, for the substitution that is applicable to the specified item for which the substitution is requested.
6. Material shall be installed, handled, stored, adjusted, tested, and operated in accordance with the manufacturers' recommendation and as specified.
7. In all cases new materials shall be used unless this provision is waived by notice from the Owner, or the Engineer, or unless otherwise specified in the Contract Documents.
8. All material and workmanship shall in every respect be in accordance with that in the opinion of the Owner, or design Engineer is in conformity with approved modern practice.
9. Contractor is to provide a statement as to the advantages to the Owner if a substitution is permitted.

1.4 Substitutions After Contract Execution

A. After the Contract has been executed, a formal request for the substitution of alternate products, not approved prior, shall be considered in place of those specified under the following conditions:
   1. Specified product cannot be delivered without project delay, or
   2. Specified product has been discontinued, or
   3. Specified product has been replaced by superior product, or
   4. Specified product cannot be guaranteed as specified, or
   5. Specified product will not fit within designated space, or
   6. Substitution otherwise determined by the Owner to be in his best interest.

B. The request shall be accompanied by complete data on the proposed substitution substantiating compliance with the Contract Documents, including: product identification and description, performance and test data, references and samples (where applicable), and an itemized comparison of the proposed substitution with the products specified or named by addenda, with data relating to contract time schedule, design and artistic effect where applicable, and its relationship to separate contract.

C. The request shall be accompanied by accurate cost data on the proposed substitution in comparison with the product specified, whether or not modification of the Contract Sum is to be a consideration.

D. Requests for substitution after the contract has been executed, as stated above, when forwarded by the Contractor to the Engineer for the Owner's review and approval, are understood to mean that the Contractor:
   1. Represents that Contractor has personally investigated the proposed substitute product and determined that it is equal or superior in all respects to that specified.
   2. Shall provide at least the same warranty for the substitution that Contractor would for that specified.
   3. Certifies that the cost data presented is complete and includes all related costs under this Contract, but excludes costs under separate contracts and the Engineer's redesign costs, and that Contractor waives all claims for additional cost related to the substitution which subsequently become apparent.
   4. Shall coordinate the installation of the accepted substitute, making such changes as may be required for the work to be completed in all respects.

E. Substitutions shall not be considered if:
   1. They are indicated or implied on shop drawing submissions without the formal request required in subparagraph under SUBSTITUTIONS above.
   2. For their implementation they require a substantial revision of the Contract Documents in order to accommodate their use.

F. Substitutions, if acceptable to the Owner, shall be incorporated into the Contract Documents by means of a Change Order.

END OF SECTION

SECTION 01 31 00

COORDINATION

PART 1 GENERAL

1.1 Division of Specifications and Drawings

A. The Contract Specifications and Drawings are divided into sections for the convenience of the Contractor. These divisions are not for the purpose of apportioning work or assigning responsibility among subcontractors, suppliers, and manufacturers, and shall not relieve the Contractor of the responsibility for fully coordinating the completion of all work as shown.

1.2 Design Clarification, Errors, and Omissions

A. Should the Contractor require clarification or interpretation of the Contract, or become aware of any claimed error or omission, Contractor shall immediately inform the Engineer in writing. The Engineer shall promptly review the circumstances and determine the appropriate corrective action, if any, and so advise the Contractor.

1.3 Manufacturers' Specifications

A. When no specification information is supplied, manufacturers' specifications and recommendations for installing materials, equipment and appurtenances as a part of this Contract shall govern the installation unless in conflict with other specified requirements or local conditions, in which case the approval of the Owner shall be obtained before proceeding.

1.4 Examination of Preparatory Work

A. Before starting a section of work, the Contractor or responsible Subcontractor shall carefully examine all preparatory work that has been executed. Contractor shall check carefully, by whatever means are required, to ensure that the work shall finish to proper contours, planes, and levels. The Subcontractor shall promptly notify the General Contractor, who shall notify the Owner in writing, of any defects or imperfections in preparatory work which in any way affect satisfactory completion of the final product. Absence of such notification shall be construed as an acceptance of preparatory work, and later claims of defects or delays therein shall not be recognized. Under no condition shall a section of work proceed prior to preparatory work having been completed, cured, dried, and otherwise made satisfactory to receive such related work. Responsibility for timely installation of all materials rests solely with the General Contractor, who shall maintain coordination control at all times.

1.5 Field Measurement and Drawing Dimensions

A. Before ordering any material or doing any work, the Contractor shall field-verify all dimensions and measurements with the Contract Documents. Any significant differences

shall be promptly reported according to DESIGN CLARIFICATION, ERRORS, AND OMISSIONS above. No claims for additional Contractor costs or time shall be recognized for any conditions not so reported.

B. Actual dimensions or drawings or notes indicating dimensions shall be used instead of measurements of the drawings by scale, and shall be strictly complied with. No scaled measurements shall be used as dimensions to work to. Figures on drawings, as well as detail drawings themselves are subject in every case to measurements of adjacent or incorporated work. All such measurements necessary shall be made before undertaking any work dependent upon such data.

1.6 Description of Work

A. These coordination requirements shall be participated in by the Contractor and each Subcontractor, even though certain items of work may be assigned to a specific contractor.

PART 2 COORDINATION AND MEETINGS

2.1 Administrative/Supervisory Personnel

A. General:
1. In addition to the General Superintendent and other administrative and supervisory personnel required for performance of the work, the Contractor shall provide specific coordinating personnel as reasonably required for interfacing with other work of the total project.
2. For the purpose of his provision, "interfacing" includes: scheduling and sequencing, sharing of access, installations, protection of each other's work, cutting and patching, tolerances, cleaning, selections for compatibility, preparation of coordination drawings, inspections, tests, and temporary facilities and services.

B. Project Coordinator: The Contractor shall provide a full-time Superintendent who is experienced in administration and supervision of earthwork and liner installation.

C. Submittal of Staff Names, Duties: At the Pre-Construction Meeting the Contractor shall submit a listing of Contractor's principal staff assignments, naming persons and listing their telephone numbers as well as a listing of his subcontractors. This listing shall include the resume of the Contractor’s proposed Superintendent. The Owner shall have seven (7) days upon receipt of the resume(s) to disapprove the staff. The Owner’s acceptance or disapproval of the staff shall not affect the bid. The staff shall have experience at a minimum of two projects of similar size and scope.

2.2 Scheduling

A. Contractor shall be responsible for his construction schedule utilizing Microsoft Project, current version, or other system proposed by the Contractor and approved by Owner and Engineer.

2.3 Limitations on Use of the Site

A. General: Limitations and requirements, the Contractor shall administer allocation of available space equitably among the separate Subcontractors and other entities needing access and space, so as to produce the best overall efficiency in performance of the total work of the project. Each Subcontractor shall schedule deliveries so as to minimize space and time requirements for storage of materials and equipment on site.

B. Site Access: The Contractor shall not enter on or occupy with personnel, tools, equipment, or material, any ground outside the construction area without approval of the Owner. Other contractors, employees, or agents of the Owner may, for business purposes, enter the work site and premises used by the Contractor.

C. Coordination with Owner's Operations: The Contractor’s use of the site is primarily restricted to the limit of construction activity as shown in the Construction Drawings. The Contractor shall not impede any work being done by others unless necessary as determined by the Engineer. Movement of the Contractor’s equipment will be required to obtain borrow soils and access the source of construction water. The Contractor shall coordinate all movement of personnel and equipment with the Owner to ensure efficient and safe operations for both the Owner and Contractor. The Contractor shall follow instructions from the Owner for designated routes of travel within the landfill to minimize interruption of landfill operations.

D. Protection of Site: Except as otherwise provided herein, the Contractor shall protect all existing fences, structures, utilities, etc. During progress of the work, the Contractor shall remove all debris and unused materials and shall, upon completion of the work, restore the site as nearly as possible to its original condition to the satisfaction of the Owner. The restoration shall include the replacement, at the Contractor's sole expense, of any facility that has been destroyed or damaged beyond restoration.

E. Safety Requirements: The Contractor shall comply with all pertinent provisions of the site-specific Health and Safety Plan (HASP). The Contractor shall inspect the site for the presence of overhead and underground utilities and shall satisfy himself in regard to their existence and locations prior to submitting his bid. Contractor shall have utilities spotted prior to beginning any subsurface work. A safe distance shall be maintained between equipment and materials and power lines. The Contractor shall provide temporary fencing, caution signs, or barricades as necessary to ensure the safety of personnel at the site and people adjacent to or passing by the site.

2.4 General Installation Provisions

A. Pre-Installation Conferences: The Contractor shall coordinate with the Engineer the scheduling and holding of pre-installation meeting(s) at the project site well before installation of each unit of work which requires coordination with other units of work. Other Subcontractors involved in the unit of work as well as the installer and representatives of manufacturers and fabricators who are involved in or affected by that unit of work and with its coordination or integration with other work that has preceded or will follow shall attend this meeting. Pre-installation meetings may coincide with regularly scheduled construction progress meetings or be scheduled at the request of the

Contractor. The Contractor shall give the Engineer seventy-two (72) hour notifications for all pre-installation meetings. The Engineer shall advise the Owner of scheduled meeting dates.

1. At each meeting review progress of other work and preparation for the particular work under consideration including specific requirements for the following:
    a. Contract Documents
    b. Options
    c. Related Change Orders
    d. Purchases
    e. Deliveries
    f. Shop Drawings, Product Data and Quality Control Samples
    g. Possible Conflicts and Compatibility Problems
    h. Time Schedules
    i. Weather Limitations
    j. Manufacturers Recommendations
    k. Compatibility of Materials
    l. Acceptability of Substances
    m. Temporary Facilities
    n. Space and Access Limitations
    o. Regulations
    p. Safety
    q. Inspection and Testing Requirements
    r. Required Performance Results
    s. Recording Requirements
    t. Protection
2. The Contractor shall record significant discussions of each conference and shall record agreements and disagreements along with the final plan of action. The Contractor shall distribute the record of the meeting promptly to everyone concerned, including the Owner and Engineer.
3. Contractor shall not proceed with the unit of work where the pre-installation conference cannot be successfully concluded. The Contractor shall initiate whatever actions are necessary to resolve impediments to performance of the work and shall reconvene pre-installation conference at the earliest feasible date.
4. Installer's Inspection of Conditions: The Contractor involved shall require the Installer of each major unit of work to inspect the substrate to receive the work and the conditions under which the work is to be performed. The Installer shall report all unsatisfactory conditions in writing to the Engineer and the Contractor. Work shall not proceed until unsatisfactory conditions have been corrected in a manner acceptable to the Installer.

B. Manufacturer's Instructions: Where installations include manufactured products, Contractor shall comply with the manufacturer's applicable instructions and recommendations for installation, to the extent that these instructions and recommendations are more explicit or more stringent than requirements indicated in the Contract Documents.

C. Inspection Prior to Installation: The Contractor shall, as applicable to his work, inspect each item of materials or equipment immediately prior to installation and reject damaged and defective items.

D. Weather: The Contractor shall install each unit of work during weather conditions and project status, which ensures the best possible results in coordination with the entire work. Isolate each unit of work from incompatible work necessary to prevent deterioration.

E. Enclosure of the Work: The Contractor shall coordinate the closing-in of the work with required inspections and tests, so as to minimize the necessity of uncovering work for that purpose.

2.5 Cleaning and Protection

A. General: During handling and installation of work at the project site, the Contractor shall clean and protect work in progress and adjoining work on the basis of continuous maintenance; and shall apply protective covering on installed work where it is required to endure freedom from damage or deterioration at the time of substantial completion.
1. The Contractor shall clean and perform maintenance on installed work as frequently as necessary through the remainder of the construction period.
2. The Contractor shall remove rubbish and waste material resulting from his work on a daily basis and as directed by the Owner and Engineer.

B. Limiting Exposure of Work: To the extent possible through reasonable control and protection methods, the Contractor shall supervise performance of the work in such a manner and by such means which ensures that none of the work, whether completed or in progress, is subjected to harmful, dangerous, damaging or otherwise deleterious exposure during the construction period. Such exposure includes, where applicable, but not by way of limitation, the following:
1. Excessive static or dynamic loading
2. Excessive internal or external pressures
3. Excessively high or low temperatures
4. Water or ice
5. Solvents
6. Chemicals
7. Puncture
8. Abrasion
9. Heavy traffic
10. Soiling
11. Bacteria
12. Insect infestation
13. Combustion
14. Electrical current
15. Incompatible interface
16. Destructive testing
17. Misalignment
18. Excessive weathering
19. Unprotected storage

20. Improper shipping or handling
21. Theft
22. Vandalism

2.6 Conservation and Salvage

A. It is a requirement for Contractor's supervision and administration of the work that construction operations be carried out with the maximum possible consideration given to conservation of energy, water and materials. In addition, maximum consideration shall be given to salvaging materials and equipment involved in performance of the work, but not incorporated therein.

END OF SECTION

SECTION 01 33 00

SUBMITTALS

PART 1 GENERAL

1.1 Description of Work

A. This section includes administrative and procedural requirements for submittals required for performance of the work, including:
   1. Type A - Shop Drawings
   2. Type B - Catalog Data
   3. Type C - Installation Instructions
   4. Type D - Operating Manual, Maintenance Instructions and Parts List
   5. Type E - Internal Wiring Diagrams
   6. Type S - Special

1.2 Purpose of Submittal Review

A. Contractor Responsibility: The Contractor's responsibility with respect to submittals shall be to review, stamp, and submit all submittals in the proper format and in a timely manner. The General Contractor shall be responsible for the following items and shall not submit a request for approval of said items but shall be ultimately and solely responsible for them:
   1. Field verification and confirmation of all dimensions for proper fit of all materials. Sub-contractors' requests for field verification of dimensions shall be addressed by the General Contractor prior to submitting shop drawings to the Engineer.
   2. Field verification and confirmation of quantities of materials.
   3. Fabrication processes and techniques of construction.

B. Engineer: Submittals shall be reviewed by the Engineer for the sole purpose of checking general conformance with the design concepts of the project and general compliance with the contract documents. Any action shown is subject to the requirements of the contract documents including plans and specifications and does not relieve the Contractor from compliance with all provisions and requirements therein. Approval of a submittal does not relieve the Contractor of his responsibility for correcting any errors which may exist in the submittal or for meeting the requirements of the contract documents.

1.3 When Submittals are Required and Not Required

A. General: The submittals required by the Specifications are those which the Engineer shall review. The Contractor may, at the Contractor's discretion, require additional submittals from Subcontractors and suppliers as may be necessary to construct the project.

B. Product Data Not Required: If the Contractor is furnishing the specified item, unless specifically requested.

C. Product Data Required: If specifically requested by the Contract Documents, or if the product being furnished is:

1. By another "Acceptable Manufacturer" listed in the Specification; or
2. A Prior Approval Substitution; or
3. Other approved substitution.

D. Shop Drawings Not Required: If the Contractor is furnishing the specified item, which is of "standard manufacture" and not "custom fabricated" for the particular project, unless specifically requested.

E. Shop Drawings Required: If specifically requested by the Contract Documents, or if the product being furnished is:
1. "Custom fabricated" for the Project; or
2. By another "Acceptable Manufacturer" listed in the Specification; or
3. A Prior Approval Substitution; or
4. Other approved substitution.

F. Samples Not Required: If the Contractor is furnishing the specified item which is of "standard manufacture" for which color, texture, or other aesthetic required is included in the specification. If current product color samples are on file in Engineer's office, submittals for color selection are not required. Contractor shall verify that these samples are on file and that they are current samples.

G. Samples Required: If specifically requested by the Contract Documents, or if the product being furnished is:
1. "Custom fabricated" for the project; or
2. Field finished; or
3. By another "Acceptable Manufacturer" listed in the specification; or
4. A prior approval substitution; or
5. Other approved substitution; or
6. Pattern, color or texture selection is to be made and current sample is not on file in Engineer's office.

1.4 Manufacturers' Detailed Instructions

A. For various materials specified by reference to standard or reference to type specifications, prepare and submit a list of such materials stating manufacturers' names and identifications to the extent requested by the Engineer or the Owner.

1.5 Certificates

A. Each certificate required by the Contract Documents shall be signed by an officer, agent, or individual lawfully authorized to execute the certificate, and such authority shall be cited in the certificate by description, title, or other acceptable evidence. Certificates shall be sworn and notarized as to correctness and validity of the contents, and copies shall be notarized to be true copies.

PART 2 MATERIALS

2.1 Descriptive Submittal Lists

A. Reference Numbers: Reference numbers are to be assigned to each submittal.

B. Submittal Types: The descriptive submittal types are used to identify the type of information being requested. They are defined below and are marked on the "Descriptive Submittals" review form.

1. Type A - Shop Drawings: Detailed drawings prepared specifically for the project and used for fabrication and/or assembly of material or equipment.
   a. Prepare each complete submittal including dimensions, design criteria, materials, connections, anchors, and the like, and further including such technical and performance data as are necessary to confirm the information in the Shop Drawings.
   b. Shop drawings shall be prepared accurately and to scale. Encircle deviations from the contract documents.
   c. Shop drawings shall include dimensions, identification of products and materials, notation of special coordination requirements, notation of dimensions established by field measurements and shall indicate compliance with specified standards.
   d. Shop drawings shall be submitted on sheets at least 8.5 x 11 inches but no larger than 24 x 36 inches.
   e. Each Shop Drawing shall have an adequate title block giving: (1) Name and address of work; (2) Name and address of each Subcontractor, manufacturer, or supplier, as applicable; (3) Name and address of the Engineer; (4) Date, scale of drawings, and identification number; and (5) Contractor's review and approval stamp, dated and signed.
   f. Copies of the Contract Drawings marked to show Shop Drawing information are not acceptable.
   g. Initial and Re-submittals: Submit Shop Drawings as necessary for submittal approval.
   h. Review of Shop Drawings: Engineer shall mark notations, corrections, and exceptions, on submitted reproducible for return to the Contractor. Contractor shall resubmit in the same manner if Shop Drawings are not accepted as submitted.
   i. Final Distribution: Contractor shall furnish and distribute prints of the approved Shop Drawings as required for performance of the work.
2. Type B - Catalog Data: Manufacturer's published literature describing the salient features of the product (e.g. size, weight, performance, code conformance, capacity, physical size, pictures, ratings, and construction features). Clearly highlight specified items and optional features such that there is no misunderstanding as to what precisely is being proposed.
3. Type C - Installation Instructions: Manufacturer's information explaining the preparation and installation of material and equipment, including:
   a. Outline drawings showing major components and dimensional service connection points.
   b. Service connection requirements such as electrical fuse or circuit breaker size and type, pipe size and type, and special precautions.
   c. Adjustment requirements that must precede operation, including initial alignment procedures, leveling, purging, charging, and lubrication.
4. Type D - Operating Manual, Maintenance Instructions, and Parts List: Complete calibration procedures and operating instructions including all necessary pre-start up checks and safety precautions.

a. Provide instructions for step-by-step preventive maintenance and minor field repairs that will ensure optimum dependable performance, longevity, and life cycle cost.
b. Provide manufacturer's compiled parts list for maintenance and repair.
c. Provide a symptom, diagnostic, and corrective action schedule.

5. Type E - Internal Wiring Diagrams: Internal wiring and elementary (ladder) diagram for factory pre-wired equipment.
   a. Include control diagrams that show the relative position of each component as a system diagram.
   b. Include any additional information requested in the Mechanical and Electrical specifications for a particular product.
6. Type S - Special: Special information, tests, samples, and others as indicated.
   a. Include laboratory test results for materials proposed from the Owners property and other purchased materials.
   b. Include actual color, texture, and pattern when submitting samples.
   c. Indicate product sources and availability as well as manufacturer's name.

C. List of Submittal Items:

Table 1. Items to be Submitted

Item	A	B	C	D	E	S
Cover soil (including density correlation)		•	•			Soil properties, maximum dry density, optimum moisture content; placement technique to be employed
Soil compaction techniques			•			Describe methods and equipment to be used with applicable ASTM Standards
Soil/gravel mixing method			•			Describe methods and equipment to be used with applicable ASTM Standards
Soil nutrient amendments		•	•			Chemical composition, certification that it is free of weeds, source of material
Soil nutrient amendment mixing/application method		•	•			Application rate and method
Seed		•	•			Purity and germination, prohibited weed seed percentage, restricted noxious weed seed count, restricted weed seed count, weed seed percentage
Rock for amended topsoil layer		•				Durability requirements (i.e., unit weight , absorption, sulfate soundness, abrasion), maximum and minimum particle size, and source
Leachate riser extensions	•	•	•		•	Describe methods and equipment to be used with applicable ASTM Standards
Leachate conveyance HDPE piping	•	•	•			Meeting specifications
Topographical Surveys					•	Surveys required for acceptance of cover soil layers
Health and safety plan					•	Required for all construction
Borrow soil sampling and analysis plan					•	Required for borrow approval
Dust control plan					•	Required prior to construction

2.2 Samples

A. Provide the following sample sizes unless otherwise specified:
   1. Flat or sheet products: Minimum 6" square, maximum 12"x12".
   2. Linear products: Minimum 6" maximum, 12" long.
   3. Bulk products: Minimum one pint, maximum one gallon.

PART 3 EXECUTION

3.1 Submittal Procedures

A. Coordination: Coordinate preparation and processing of submittals with performance of construction activities. Transmit each submittal in advance of performance of related construction activities.
   1. Coordinate each submittal with fabrications, purchasing, testing, delivery, other submittals and related activities that require sequential activity.
   2. Coordinate transmittal of different types of submittals for related materials so processing will not be delayed by the need to review related submittals concurrently. The Engineer reserves the right to withhold action on a submittal requiring review of related submittals until the related submittal information is received.

B. Review Time: The Engineer may take two weeks for initial review. The Engineer may also take additional time if processing must be delayed to permit review of related subsequent submittals. Allow additional time for processing of re-submittals.

C. These submittals shall include complete lists of materials, catalog data and brochures, performance and technical data including characteristics, service history, and similar information to fully describe the products covered by the submittal.

D. Submittal Preparation: Bind each submittal copy with sturdy labeled cover and include typed index listing the contents. Loose unbound submittals shall be returned unreviewed. For each item listed, include the manufacturer's name and address, trade or brand name, all conditions of the manufacturer's guarantee and warranty, information to fully describe each item, and supplementary information as may be required for approval. Mark cuts, brochures, and data to indicate the items proposed and intended use as required for transmittal.

E. Submittal Packaging: Bindable submittals for each discipline shall be three-hole punched and bound into a cardstock binder with flexible metal clips:
   1. The submittal binder shall be stamped on the lower right hand corner of the cover with an approximately 4 inches x 4 inches identification stamp as described below:
      a. Contract Number
      b. Descriptive Submittal Reference Number
      c. General Contractor Information
      d. Company Name
      e. Company Phone Number
      f. General Contractor Reviewer Signature

g. General Contractor Reviewer Printed Name

2. The Contractor shall submit descriptive submittals to the Engineer only after Contractor review. The Contractor's Reviewer shall sign his name on the identification stamp on the cover of the binder indicating Contractor's approval of the submittal and acknowledgment as to the appropriateness of the material or information submitted for use in construction. Unstamped, unsigned, or otherwise incomplete submittals shall not be accepted by the Engineer.

3. Submittals shall be grouped together with related products of the same discipline when possible. The requested submittal types for a particular item should always be complete and submitted together. Do not submit one type of submittal apart from other types of submittals for the same product. Each submittal shall be legible and grouped together in the following order for each product requested:

   a. Submittal Type A - Shop Drawings. Fold shop drawings down to 8.5 x 11 inches and insert into submittal package.
   b. Submittal Type B - Catalog Data
   c. Submittal Type C - Installation Instructions
   d. Submittal Type D - Operating Manual, Maintenance Instructions and Parts List
   e. Submittal Type E - Internal Wiring Diagrams
   f. Submittal Type S - Special: (Only bindable special submittals including laboratory reports and manufacturer data) Unbindable special submittals shall be submitted under separate cover and per product specification.

F. Submittal Delivery: For all types of submittals except samples, transmit the number of submittals needed for the Contractor's purposes plus two (2) copies to be retained by the Engineer. Submittals received from sources other than the Contractor shall not be accepted. Incomplete, improperly packaged and/or submittals which have not been stamped by the Contractor shall be returned without action. When submitting samples, submit two (2) sets of samples for review unless otherwise requested.

1. Deliver descriptive submittals to the Engineer within 15 calendar days after the Notice to Proceed, except:

   a. as may be stipulated elsewhere in this Contract;
   b. "original drawing(s)" prepared by the General Contractor for specialty systems, which shall be delivered within 30 calendar days after the Notice to Proceed.

2. Material and/or equipment shall not be installed until requested submittals pertaining to said material and/or equipment have been approved.

G. Unless otherwise specified, each Sample submittal shall include not less than three (3) complete sets of Samples. One set of approved Samples and all disapproved Samples will be available for return to the Contractor. Any Samples of value retained by the Engineer will be available for return to Contractor at completion of the work if Contractor's first transmittal for the Sample requests its return. Approval Samples returned to the Contractor may be installed in the work if location is recorded and samples bear temporary identification as such.

H. Unless otherwise specified, Shop Drawings shall consist of four bound copies; one copy shall be returned to the Contractor marked to show required corrections or other actions.

If corrections or changes are required, final submittal shall include four bound corrected or revised copies.

I. The Contractor shall submit shop drawings and details sufficiently in advance of the work, and in accordance with a prearranged schedule, to afford ample time for checking, correcting and rechecking, if necessary. The Engineer shall review the Submittal Schedule prepared by the Contractor for review/modification/approval within 15 calendar days of the notice to proceed date. Submittals and the review/approval process shall be in accordance with the approved Submittals Schedule. Items not included on the submittal log but included in the contract in no way relieve the contractor from fulfilling his obligations.

J. Submittal Review: Submittals will be reviewed and stamped with a self-explanatory action stamp. The stamp will be appropriately marked, as follows, to indicate the action taken:

1. Final Unrestricted Release: When submittals are marked "Approved," that part of the work covered by the submittal may proceed provided it complies with requirements of the contract documents; final acceptance will depend upon that compliance. The term "Approved" shall only indicate that there are no exceptions taken to the submittal.
2. Final But Restricted Release: When submittals are marked "Approved Except as Noted," that part of the work covered by the submittal may proceed provided it complies with notations or corrections on the submittal and requirements of the contract documents; final acceptance will depend upon that compliance.
3. Returned for Resubmittal: When submittal is marked "Not Approved, Revise and Resubmit," do not proceed with that part of the work covered by the submittal or prepare a new submittal in accordance with the notations and resubmit without delay. Repeat as necessary to obtain a different action mark.

END OF SECTION

SECTION 01 33 23

SHOP DRAWINGS, PRODUCT DATA, AND SAMPLES

PART 1 GENERAL

1.1 Submittal Schedule

A. The Contractor shall submit shop drawings and details sufficiently in advance of the Work, and in accordance with a prearranged schedule, to afford ample time for checking, correcting and rechecking, if necessary. The Engineer shall review the Submittal Schedule prepared by the Contractor for review/modification/approval within 10 calendar days of the notice to proceed date. Submittals and the review/approval process shall be in accordance with the approved Submittals Schedule. Items not included on the submittal log but included in the contract in no way relieve the Contractor from fulfilling his obligations.

1.2 Shop Drawings

A. Preparation: Prepare each submittal complete including dimensions, design criteria, materials, connections, anchors, and the like, and further including such technical and performance data as is necessary to confirm the information in the Shop Drawings. Prepare Shop Drawings of same size as the Drawings or an 8½" by 11”, 3-hole punched sheets suitable for photocopy reproduction. Copies of the Contract Drawings marked to show Shop Drawing information are not acceptable. Each Shop Drawing shall have an adequate title block giving: (1) Name and address of work; (2) Name and address of each Subcontractor, manufacturer, or supplier, as applicable; (3) Name and address of the Engineer; (4) Date, scale of drawings, and identification number; and (5) Contractor's review and approval stamp, dated and signed.

B. Initial and Resubmittals: Submit Shop Drawings as necessary for submittal approval.

C. Review of Shop Drawings: Engineer shall mark notations, corrections, and exceptions, on submitted reproducibles for return to the Contractor. Contractor shall resubmit in the same manner if Shop Drawings are not accepted as submitted.

D. Final Distribution: Contractor shall furnish and distribute prints of the approved Shop Drawings as required for performance of the work.

1.3 Samples

A. Unless otherwise specified, each Sample submittal shall include not less than three (3) complete sets of Samples. One set of approved Samples and all disapproved Samples will be available for return to the contractor. Any Samples of value retained by the Engineer will be available for return to Contractor at completion of the work if Contractor's first transmittal for the Sample requests its return. Approval Samples returned to the Contractor may be installed in the work if location is recorded and Samples bear temporary identification as such.

1.4 Sizes

A. Provide the following sample sizes unless otherwise specified:
   1. Flat or sheet products: Minimum 6" square, maximum 12"x12".
   2. Linear products: Minimum 6" maximum, 12" long.
   3. Bulk products: Minimum one pint, maximum one gallon.

1.5 Product Data Submittals

A. These submittals shall include complete lists of materials, catalog data and brochures, performance and technical data including characteristics, service history, and similar information to fully describe the products covered by the submittal.

B. Submittal Preparation: Bind each submittal copy with sturdy labeled cover and include typed index listing the contents. Loose unbound submittals shall be returned unreviewed. For each item listed, include the manufacturer's name and address, trade or brand name, all conditions of the manufacturer's guarantee and warranty, information to fully describe each item, and supplementary information as may be required for approval. Mark cuts, brochures, and data to indicate the items proposed and intended use as required for transmittal.

C. Submittal Procedure: Unless otherwise specified, submittals shall consist of four bound copies; one copy shall be returned to the Contractor marked to show required corrections or other actions. If corrections or changes are required, final submittal shall include four bound corrected or revised copies.

END OF SECTION

SECTION 01 40 00

QUALITY REQUIREMENTS

PART 1 GENERAL

1.1 Section Includes

A. Quality control and control of installation.

B. Tolerances.

C. References.

D. Labeling.

E. Mock-up requirements.

F. Testing and inspection services.

G. Manufacturers' field services.

H. Examination.

I. Preparation.

1.2 Quality Control of Installation

A. References:
1. See the approved Construction Quality Assurance Plan.

B. Monitor quality control over suppliers, manufacturers, products, services, site conditions, and workmanship, to produce Work of specified quality.

C. Where applicable, comply with manufacturers' instructions, including each step in sequence.

D. When manufacturers' instructions conflict with Contract Documents, request clarification from Engineer before proceeding.

E. Comply with specified standards as minimum quality for the Work except where more stringent tolerances, codes, or specified requirements indicate higher standards or more precise workmanship.

F. Perform Work by persons qualified to produce required and specified quality.

G. Verify field measurements.

1.3 Tolerances

A. Monitor installation tolerance to produce acceptable Work. Do not permit tolerances to accumulate.

1.4 References

A. For products or workmanship specified by association, trade, or other consensus standards, comply with requirements of standard, except when more rigid requirements are specified or are required by applicable codes.

B. Conform to reference standard by date of issue current on date of Contract Documents, except where specific date is established by code.

C. Obtain copies of standards where required by specification sections.

D. When specified reference standards conflict with Contract Documents, request clarification from Engineer before proceeding.

E. Neither contractual relationships, duties, nor responsibilities of parties in Contract nor those of Engineer shall be altered from Contract Documents by mention or inference otherwise in reference documents.

1.5 Testing and Inspection Services

A. Employ and pay for services of an independent testing agency or laboratory acceptable to Owner to perform specified testing.

B. Prior to start of Work, submit testing laboratory name, address, and telephone number, and names of full time specialist and responsible officer.

C. Submit copy of report of laboratory facilities inspection made by Materials Reference Laboratory of National Bureau of Standards during most recent inspection, with memorandum of remedies of deficiencies reported by inspection.

D. The independent firm will perform tests, inspections and other services specified in individual specification sections and as required by Engineer.
   1. Laboratory: Authorized to operate at Project location.
   2. Laboratory Staff: Maintain full time specialist on staff to review services.
   3. Testing Equipment: Calibrated at reasonable intervals with devices of accuracy traceable to National Bureau of Standards or accepted values of natural physical constants.

E. Testing, inspections and source quality control may occur on or off project site. Perform off-site testing as required by Engineer or Owner.

F. Reports will be submitted by independent firm to Engineer, Contractor, and authority having jurisdiction, in duplicate, indicating observations and results of tests and indicating compliance or non-compliance with Contract Documents.

1. Submit final report indicating correction of Work previously reported as non-compliant.

G. Cooperate with independent firm; furnish samples of materials, design mix, equipment, tools, storage, safe access, and assistance by incidental labor as requested.
   1. Notify Engineer and independent firm 24 hours prior to expected time for operations requiring services.
   2. Make arrangements with independent firm and pay for additional samples and tests required for Contractor's use.

H. Testing and employment of testing agency or laboratory shall not relieve Contractor of obligation to perform Work in accordance with requirements of Contract Documents.

I. Retesting or reinspection required because of non-conformance to specified requirements shall be performed by same independent firm on instructions by Engineer. Payment for re-testing or re-inspection will be charged to Contractor by deducting testing charges from Contract Sum/Price.

J. Agency/Laboratory Responsibilities:
   1. Test samples of mixes submitted by Contractor.
   2. Provide qualified personnel at site. Cooperate with Engineer and Contractor in performance of services.
   3. Perform specified sampling and testing of products in accordance with specified standards.
   4. Ascertain compliance of materials and mixes with requirements of Contract Documents.
   5. Promptly notify Engineer and Contractor of observed irregularities or non-conformance of Work or products.
   6. Perform additional tests required by Engineer.
   7. Attend preconstruction meetings and progress meetings.

K. Agency/Laboratory Reports: After each test, promptly submit two copies of report to Engineer, Contractor, and authority having jurisdiction. When requested by Engineer, provide interpretation of test results. Include the following:
   1. Date issued.
   2. Project title and number.
   3. Name of inspector.
   4. Date and time of sampling or inspection.
   5. Identification of product and specifications section.
   6. Location in Project.
   7. Type of inspection or test.
   8. Date of test.
   9. Results of tests.
   10. Conformance with Contract Documents.

L. Limits On Testing Authority:
   1. Agency or laboratory may not release, revoke, alter, or enlarge on requirements of Contract Documents.
   2. Agency or laboratory may not approve or accept any portion of the Work.

3. Agency or laboratory may not assume duties of Contractor.
4. Agency or laboratory has no authority to stop the Work.

1.6 Manufacturers' Field Services

A. When specified in individual specification sections, require material or product suppliers or manufacturers to provide qualified staff personnel to observe site conditions, conditions of surfaces and installation, quality of workmanship, as applicable, and to initiate instructions when necessary.

B. Submit qualifications of observer to Engineer 30 days in advance of required observations. The observer is subject to the approval of the Engineer.

C. Report observations and site decisions or instructions given to applicators or installers that are supplemental or contrary to manufacturers' written instructions.

D. Refer to Section 01 33 00 - Submittals.

PART 2 PRODUCTS

Not used.

PART 3 EXECUTION

3.1 Examination

A. Verify existing site conditions and substrate surfaces are acceptable for subsequent Work. Beginning new Work means acceptance of existing conditions.

B. Verify existing substrate is capable of structural support or attachment of new Work.

C. Examine and verify specific conditions described in individual specification sections.

D. Verify utility services are available, of correct characteristics, and in correct locations.

END OF SECTION

SECTION 01 42 13

ABBREVIATIONS, SYMBOLS, AND ACRONYMS

PART 1 GENERAL

1.1 Specification Language

A. Abbreviated Language: These Specifications are of abbreviated, simplified, and streamlined type and include incomplete sentences.
   1. Omissions of words or phrases such as "the Contractor shall", "in conformity therewith", "shall be", "as noted on the Drawings", "a", "the", are intentional.
   2. Supply omitted words or phrases by inference in same manner as they are.
   3. Supply words "shall be" or "shall" by inference when colon is used within sentences or phrases.
   4. Supply words "on the drawings" by inference when "as indicated" is used with sentences or phrases.

B. Definitions: Following words shall have following meanings:
   1. Furnish or Supply: Supply complete with all parts and accessories; does not include installation.
   2. Install: Establish in place, condition, or status, complete and ready for use or service; does not include furnishing.
   3. Provide: Furnish and install.
   4. Concealed and Concealed Space: Embedded within construction, in trenches, in crawl space.
   5. Unfinished Space: Space not indicated or scheduled to be finished and spaces ordinarily only accessible to maintenance personnel.
   6. Finished Space: Space indicated or scheduled to be finished.
   7. Exposed: Not installed underground or "concealed" as above.

1.2 Association Acronyms

A. Reference in Contract Documents to trade associations, technical societies, recognized authorities and other institutions include following organizations which are sometimes referred to only by corresponding abbreviations:
   1. AASHTO American Association of State Highway and Transportation Officials
   2. ASTM American Society for Testing and Materials
   3. AWS American Welding Society
   4. AWWA American Water Works Association
   5. CFR Code of Federal Regulations
   6. DEQ Idaho Department of Environmental Quality
   7. NSF National Sanitation Foundation
   8. OSHA Occupational Safety and Health Administration
   9. PS Product Standard (See NBS)
   10. UL Underwriters' Laboratories, Inc.
   11. USEPA United States Environmental Protection Agency

1.3 Abbreviations

A. Specifications: Following abbreviations are used in specification:

1.	Alternating current	AC
2.	Afternoon	PM
3.	Ampere	AMP
4.	Ampere (with number 30A)	A
5.	Before noon	AM
6.	Brake horsepower	BHP
7.	British thermal unit	BTU
8.	Critical path method	CPM
9.	Cubic feet per day	CU FT/DAY
10.	Cubic feet per hour	CU FT/HR
11.	Cubic feet per minute	CFM
12.	Cubic feet per second	CU FT/SEC
13.	Cubic foot (feet)	CU FT
14.	Cubic inch (inches)	CU IN
15.	Cubic yard	CU YD
16.	Decibels	DB
17.	Direct current	DC
18.	Dry bulb (temperature)	DB
19.	Fahrenheit	F
20.	Feet per day	FT/DAY
21.	Feet per hour	FT/Hr
22.	Feet per minute	FPM
23.	Feet per second	FPS
24.	Foot	FT
25.	Foot-candle	FC
26.	Gallons per day	GPD
27.	Gallons per minute	GPM
28.	Carbon dioxide	CO_2
29.	Gallons per second	GPS
30.	Heat transfer coefficient	U
31.	Hertz	HZ
32.	High density polyethylene	HDPE
33.	Horsepower	HP
34.	Inch	IN
35.	Inches per second	IN/SEC
36.	Inside diameter	ID
37.	Kilovolt	KV
38.	Kilovolt-ampere	KVA
39.	Kilowatt	KWA
40.	Kips	Ki
41.	Kips per square inch	KSI
42.	Lineal foot (feet)	LF
43.	Miles per hour	MPH
44.	Noise reduction coefficient	NRC
45.	Number	NO.

46.	Numbers	NOS.
47.	On center	OC
48.	Ounces per square foot	OZ/SQ FT
49.	Outside screw and yoke	OS&Y
50.	Polyvinyl chloride	PVC
51.	Post meridian (afternoon)	PM
52.	Pounds per cubic foot	PCF
53.	Pounds per lineal foot	PLF
54.	Pounds per square foot	PSF
55.	Pounds per square inch	PSI
56.	Pounds per square inch (gauge)	PSIG
57.	Relative humidity	RH
58.	Revolutions per minute	RPM
59.	Revolutions per second	RPS
60.	Sound transmission class	STC
61.	Square foot (feet)	SQ FT
62.	Square inch (inches)	SQ IN
63.	Square yard (yards)	SQ
64.	Thermal conductivity	K
65.	Thermal resistance	R
66.	Tongue and groove	T&G
67.	U factor (coefficient of heat transfer)	U
68.	United States	US
69.	United States Steel (gauge)	USS
70.	Volts (with number 120V)	V
71.	Wet bulb	Wb

1.4 Symbols

A. Specifications: Following symbols are used in specifications:

1. ± for "plus or minus" (± 2 percent)
2. x for "by" (2x4)
3. / for "per" (6 OZ/SQ FT)
4. $ for "dollars" ($5.00)
5. ' for "feet", and
6. " for "inches" when used in combination (6'-9")

END OF SECTION

SECTION 01 42 16

DEFINITIONS AND STANDARDS

PART 1 GENERAL

1.1 Definitions

A. When the following terms are used in the plans, specifications, contract documents and correspondence, the intent and meaning shall be interpreted as follows:

1. Addendum. A change in the plans of specifications issued after the advertisement but prior to the Bid opening.
2. Advertisement. (Also called Invitation for Bids.) A public announcement inviting bids for work to be performed or materials to be furnished.
3. Award. The written acceptance by the Owner of a Bid.
4. Basis of payment. The terms under which "work" is paid, as a designated "pay item" in accordance with the quantity measured and the "pay unit."
5. Bid. The offer of a Bidder, on the prescribed form, to perform the work and to furnish the labor and materials at the prices quoted.
6. Bidder. An individual, partnership, firm, corporation, joint venture or their authorized representative submitting a bid.
7. Bid form. The approved form on which the Owner requires bids to be prepared and submitted for the work.
8. Bid guarantee. The security furnished with a bid to guarantee that the Bidder shall enter into the contract if the bid is accepted.
9. Calendar day. Each and every day shown on the calendar, beginning and ending at midnight.
10. Change order. A written order to the Contractor for extra work and for changes in the plans or quantities, or both, and establishing the basis of payment and time adjustments, if any, for the work ordered. The change order can consist of either a supplemental agreement or field sheet.
11. Commercial material source. A material source that has been utilized by any private producer in a commercial operation from which substantial material has been sold within the last twenty-four (24) months prior to the date of the letting.
12. Contract. The written agreement between the Owner and the Contractor setting forth the obligations of the parties there under, including, but not limited to, the performance of the work, the furnishing of labor and materials, and the basis of payment. The contract includes the advertisement, proposals, contract form and contract bond, contract clauses, standard specifications, supplemental specifications, special provisions, addenda, general and detailed plans, standard drawing serials and notice to proceed, also any change orders and agreements that are required to complete the construction of the work in an acceptable manner, including authorized extensions thereof, all of which constitute one instrument.
13. Contract bond. The approved form of bond, executed by the Contractor and the Contractor's surety or sureties, guaranteeing complete execution of the contract and all change orders pertaining thereto and the payment of all debts pertaining to the construction of the project.

14. Contract clauses. The contract clauses contained in the solicitation package, including general contract requirements, addenda, construction contract requirements and socioeconomic program requirements.
15. Contract item (pay item). A specifically described unit of work for which a price is provided in the contract.
16. Contract time. The time specified in the invitation for bids for completion of the contract. This time may be defined either as a specified fixed date, a given number of work days or a given number of calendar days. The contract time may be amended by mutual written agreement to include authorized extensions of time as the performance of the contract requires.
17. Contractor. The individual, partnership, firm, corporation or joint venture contracting with the Owner for performance of prescribed work.
18. Contractor furnished material source. A source of material that is acquired by the Contractor.
19. Cost reduction proposals. Alternates provided by the Contractor to the work methods or materials specified in the contract that establish a better or approved equal product or result without affecting the functional purpose of the work being revised and that produce a net savings to the Owner.
20. Cost savings suggestions. Revisions provided by the Contractor to the work methods, plans or the specifications that do not adversely affect the quality of the work and that provide a cost savings to the Owner.
21. Debar. To disqualify or suspend a Bidder or Contractor from bidding or performing construction work pursuant to Owner regulations.
22. Detour. A temporary route for traffic around a closed portion of a road.
23. Engineer. The individual designated by the Owner to work on their behalf, who is a registered professional engineer in the State of Idaho, and shall serve as the quality assurance (QA) Certifying Engineer to oversee and certify the construction of the project. The QA Certifying Engineer may serve as, or designate a representative to serve as, the QA engineer performing construction inspection. Daniel B. Stephens & Associates, Inc. is the Design Engineer working on the Owner's behalf. The QA Certifying Engineer shall obtain direction and clarification from the Design Engineer if questions on the design are encountered. Only one Engineer shall have official responsibility for the project at a given time.
24. Equipment. All machinery, tools, and equipment, together with the necessary supplies for upkeep and maintenance, necessary for the construction and completion of the contract.
25. Federal agencies. Whenever in these specifications reference is made to federal agency or officer, such reference shall be deemed made to any agency or officer succeeding in accordance with law to powers, duties, jurisdiction, and authority of the agency or officer mentioned.
26. Field sheet. A document used to change the quantity of construction within the scope of the contract; constitutes an order to the Contractor requiring performance without negotiation.
27. Inspector. The Owner's authorized representative assigned to make detailed inspections of contract performance.
28. Invitation for bids. See advertisement.

29. Laboratory. An approved testing laboratory qualified and/or certified to perform specified tests.
30. Listed material source. A local source of material that is listed and described in the plans and in the contract for possible use on a project.
31. Materials. Any substances specified for use in the construction of the project and its appurtenances.
32. Method of measurements. The method in which a "pay item" is measured to conform with the "pay unit."
33. Noncommercial material source. A material source not meeting the definition of a commercial material source.
34. Notice to proceed. (Work Order) Written notice to the Contractor to proceed with the contract work including, when applicable, the beginning date of contract time.
35. Owner. The contracting agent, US Ecology Idaho.
36. Plans. The approved contract drawings showing profiles, typical cross sections, working drawings and standard drawings serials, or exact reproductions which show the location, character, dimensions and details of the work to be done.
37. Project. The site location on which construction is to be performed as described in the contract.
38. Project engineer. A project manager who is registered professional engineer.
39. Project manager. The Owner's representative who is delegated the responsibility for administration of the project.
40. Roadway. A general term denoting the traveled way and the shoulders.
41. Special provisions. Additions and revisions to the standard and supplemental specifications covering conditions peculiar to an individual project.
42. Specifications. A general term applied to all provisions and requirements pertaining to performance of the work.
43. Standard drawing serials. Detailed drawings for specific items of work approved for repetitive use and considered as part of the plans.
44. State. The State of Idaho acting through the authorized representative. Whenever in these specifications reference is made to a State agency or officer, such reference shall be deemed made to any agency or officer succeeding in accordance with law to powers, duties, jurisdiction, and authority of the agency or officer mentioned.
45. Structures. Bridges, culverts, catch basins, drop inlets, retaining walls, cribbing, manholes, endwalls, buildings, sewers, service pipes, underdrains, foundation drains, and other such features which may be encountered in the work.
46. Subcontractor. An individual, partnership, firm, corporation, or joint venture to whom the Contractor subcontracts part of the contract.
47. Subgrade. The portion of the project prepared as a foundation for other elements in the project.
48. Substantial completion. The date as certified by engineer when the construction of the project or a specified part thereof is sufficiently completed, in accordance with contract documents, so that the project or specified part can be utilized for the purposes for which it was intended.
49. Superintendent. The Contractor's representative authorized in writing to be in responsible charge of the project.

50. Supplemental agreement. A negotiated, written agreement between the Contractor and the Owner constituting a modification of the originally executed contract and covering the performance of work within the intended scope of the original contract or work which is beyond the scope of the original contract.
51. Supplemental specifications. Approved additions and revisions to the Standard Specifications.
52. Surety. The corporation, partnership, or individual, other than the Contractor, executing a bond furnished by the Contractor.
53. Titles (or Headings). The titles or headings of the sections and subsections herein are intended for convenience of reference and shall not be considered as having a bearing on their interpretation.
54. Town, city or district. A subdivision of the State used to designate or identify the location of the proposed work.
55. Unbalanced bid. When a unit bid price for a contract item deviates by more than 100% from (1) the average unit bid prices submitted at the contract letting for the same item and (2) the average unit bid price for the same item submitted during the previous twelve (12) months.
56. Unlisted material source. When a possible source of material is not listed in the plans and the Contractor is required to furnish the material source.
57. Work. The furnishing of all labor, materials, equipment and other incidentals necessary for the successful completion of the project, the successful completion of pay items, and the carrying out of all duties and obligations imposed by the contract.
58. Work order. See Notice to Proceed.
59. Work permit. An agreement with the property owner which allows specific work to be accomplished on private property which is necessary in conjunction with a construction project which will benefit the property owner.

1.2 Standards

A. The references in the contract documents to established construction industry standards, either by name or by abbreviation, include those by government agencies, trade associations, technical societies, and other recognized authorities and institutions.

B. Each standard used in the contract document shall be referenced by basic designation. Abbreviations and names of agencies, associations, societies and other recognized authorities and instructions publishing standards are identified as follows:

1. AASHTO American Association of State Highway and Transportation Officials, 341 National Press Building, Washington, DC 20004; (202)628-2438
2. ANSI American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018; (212)354-3300
3. ASTM American Society for Testing & Materials, 1916 Race Street, Philadelphia, PA 19103; (215)299-5400
4. CE Corps of Engineers (US Dept. of Army) Washington, DC 20315
5. FS Federal Specification (General Services Administration) Building 197, Washington Navy Yard S.E., Washington, DC 20407

6. MIL Military Standardization Documents (US Dept. of Defense) Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120

C. Reference within these specifications to the above publications is either by Name or Abbreviation. The latest standard or publication at the time of bid opening shall apply to this project.

PART 2 PRODUCTS

2.1 General

A. Throughout these specifications, types of material may be specified by manufacturer's name and catalogue number in order to establish standards of quality and performance and not for the purpose of limiting competition. Unless specifically stated otherwise the Bidder shall assume the phrase "or approved equal", except that the burden is upon the bidder to prove such equality.

PART 3 EXECUTION

Not used.

PART 4 MEASUREMENT AND PAYMENT

4.1 General

A. Work covered by this section is considered incidental to the completion of the Contract. No separate measurement and payment for this section is provided.

END OF SECTION

SECTION 01 50 00

TEMPORARY FACILITIES

PART 1 GENERAL

1.1 Related Documents

A. Drawings and contract clauses apply to work of this section.

B. Refer to the Contractor's Site-Specific Health and Safety Plan for temporary facilities necessary for worker health and safety in accordance with Occupational Safety and Health Administration (OSHA) requirements.

1.2 Description of Requirements

A. Definitions: Specific administrative and procedural minimum actions are specified in this section, as extensions of provisions in the Contract Documents. These requirements have been included for special purposes as indicated.

1.3 Job Conditions

A. General: Establish and initiate use of the temporary facility at time first reasonably required for proper performance of the work. Terminate use and remove facility at earliest reasonable time, when no longer needed.

B. Conditions of Use: Install, operate, maintain and protect temporary facilities in a manner and at locations which shall be safe, nonhazardous, sanitary and protective of persons and property and free of deleterious effects.

PART 2 PRODUCTS

Not used.

PART 3 EXECUTION

3.1 Temporary Support Facilities

A. The types of temporary support facilities required include, but not necessarily limited to field offices, sanitary facilities, and similar miscellaneous general services, all as may be reasonably required for proficient performance of the work and accommodation of personnel at the site. Discontinue and remove temporary support facilities and make incidental similar use of permanent work of the project, only when and in manner authorized by the Contract Administrator and, if not otherwise indicated, immediately before time of substantial completion. Locate temporary support facilities for convenience of users and for minimum interference with construction activities.

B. Contractor's Field Office: Provide adequate office space for field office personnel.

C. Sanitary Facilities: Provide self-contained toilet units of type acceptable to the Contract Administrator, adequate (at all stages of construction) for use of personnel at project site.

D. Water Fill Stand: Water for construction activities will be available on site for the Contractor. The Contractor shall be responsible for setting up a fill stand, in coordination with US Ecology Idaho.

PART 4 MEASUREMENT AND PAYMENT

4.1 General

A. Work covered by this section is considered incidental to the completion of the Contract. No separate measurement and payment for this section is provided.

END OF SECTION

SECTION 01 60 00

PRODUCT REQUIREMENTS

PART 1 GENERAL

1.1 Work Specified Herein

A. This Section outlines the requirements for delivery and storage of materials for the Project work.

1.2 PROCUREMENT

A. The Contractor, immediately upon Award of the Contract (or where shop drawings, samples, etc., are required, immediately upon receipt of approval thereof), shall place orders for all materials, work, fabrication and/or equipment to be employed by him in that portion of the work contracted for. Contractor is responsible for timely and coordinated procurement of materials required for completion of the Work. Execute purchase orders and subcontracts in proper sequence for efficient installation and in accordance with dates required by the Progress Schedule. No extensions of time or substitutions of material shall be allowed because of ill-timed procurement procedures, unless approved in writing.

1.3 Transportation and Handling

A. Shipping: Provide undamaged products, materials, and equipment; pack and crate all items while transporting to the site and during shipment from the plant of manufacture to the site; no damaged, scratched, bent, dented, chipped, marred, defaced, or discolored items shall be accepted. Protect all items from adverse environmental conditions, which might detrimentally affect their performance, quality, or intended purpose in the Work. Special protection requirements are specified in the appropriate technical specification.

B. Delivery: Deliver proprietary materials in original containers or packages with manufacturer's name and brand label or identifying quality marks thereon. Do not open containers or remove labels until ready for installation.

C. Deliver fabrications in as large assemblies as practicable, and where specified to be shop primed or shop finished, they shall be packaged or crated as required to preserve such priming or finish intact and free from abrasion.

1.4 Storage and Protection

A. Storage: Provide weatherproof, secure storage for all material and equipment until installation in the Work; do not mark in manner which will remain visible after installation or which will affect performance after installation or which will affect performance or appearance of the product. Organize and arrange storage of products to furnish accessibility for inspection and for efficient and timely installation sequence.

1. Store material at locations approved by the Owner so as to cause no obstructions. The Contractor shall be responsible for protecting all material and equipment furnished under the Contract.
2. Location of storage space shall be subject to approval of the Engineer.

B. Protection: The Contractor is responsible for the protection of all materials, products, and equipment from harm. Requirements specified herein set standards for the protection of all materials and products to be incorporated in the Work and are to be applied where appropriate to the material, product, or piece of equipment. Store, support, stack, separate, cover, keep dry and warm, ventilate, protect from contamination and intrusion of foreign matter, from deterioration, deformation, defacement, discoloration, and damage of any kind.

C. Additional requirements for storage and protection of materials and equipment are identified under the individual Specification Sections. All materials are to be stored at the job site.

1.5 Reference or Manufacturer's Standards and "Industry Practice"

A. Nationally and regionally recognized Reference Standards are used throughout this Project Manual as requirements for materials and workmanship.
1. Reference Standards are incorporated into the Project Manual by reference to number, title or other designation in the Specification Sections. Provisions of Standards so referenced become a part of the Project Manual as though included in their entirety.
2. The date of the Standard shall be that which is in effect as of the Bid date.

B. The requirements of the Contract take precedence over requirements of Reference Standards, Manufacturer's Standards, or local "Industry Practice", when the contract documents call for more stringent or greater requirements. No provision of Reference Standard specifications, manuals or codes, or manufacturer acceptance of work not meeting contract documents or his own standards, shall be effective to change the duties and responsibilities of the Contractor or Engineer, or any of their agents, Engineer, or employees from those set forth in the Contract Documents.

C. Clarification is to be received from the Engineer prior to material purchase, fabrication or installation when Referenced Standards conflict with information specified or indicated on Drawings. When there is a conflict or discrepancy between a Standard and the Contract Documents or with another Referenced Standard, the more stringent requirements shall apply.

1.6 Underwriters' Laboratories and Factory Mutual Label

A. Where applicable, all such materials and equipment for which Underwriters' Laboratories, Inc., and Factory Mutual standards have been established and their label services available shall bear the appropriate UL or FM label.

END OF SECTION

SECTION 01 71 23

FIELD ENGINEERING

PART 1 GENERAL

1.1 General

A. Contractor, as required for the execution of his work, shall engage a Registered Land Surveyor or Professional Engineer experienced and authorized to practice in land survey work, registered with the State of Idaho, to perform the services specified in this article. Contractor shall submit registration of Land Surveyor to the Engineer.

1. Working from lines and levels established by the drawings, the Surveyor shall establish and maintain benchmarks and other dependable markers. These bench marks and markers are established to set lines and levels as needed to properly locate each element of the project. Contractor shall calculate and measure required dimensions as shown, within recognized tolerances. Drawings shall not be scaled to determine dimension. Advise entities performing work, of marked lines and levels provided for their use.

1.2 Survey and Location

A. The Contractor shall immediately upon entering the project site for purposes of beginning work, locate all survey reference points and take such action as is necessary to prevent their destruction; lay out the work and be responsible for all lines, elevations, and measurements of liner, earthwork, site work, and other work executed under the contract. Contractor shall exercise proper precaution to verify figures shown on drawings before laying out work and shall be held responsible for any error resulting from his failure to exercise such precaution. Contractor shall employ the services of a registered surveyor satisfactory to the Engineer to set grade levels and line stakes in accordance with the drawings. Any survey data found to be in conflict with that shown on the contract documents shall be immediately forwarded to the Engineer for clarification.

1.3 Survey Procedures

A. Before proceeding with the layout of actual work, Contractor shall verify the layout information shown on the drawings, in relation to the existing benchmarks. As the work proceeds, the Surveyor shall check every major element for line, level and plumb. Maintain a surveyor's log or record book of such checks. Make this log or record book available for the Owner's or Engineer's reference. The Surveyor shall record deviations from required lines and levels, and shall, upon detection, promptly advise the Engineer of deviations exceeding indicated or recognized tolerances. Contractor shall record deviations, which are accepted, not corrected, on record drawings.

1.4 Field Adjustments

A. All field adjustments shall be documented on one set of Record Drawings retained by the Contractor. Field adjustments shall have the authorization of the QA Certifying Engineer

and the Design Engineer. The Contractor shall be responsible to document all proposed, accepted/rejected, and implemented field changes. Field Order and Change Order requests shall be documented on forms provided in the Contract Documents. Each form shall be assigned a unique number and the Contractor shall maintain, in a safe place, a comprehensive and chronological log of all Field Order requests, Change Order requests, Drawings, Specifications, Addenda, Work Change Directives, and written interpretations and clarifications in good order and annotated to show changes made during construction. These record documents together with all approved Samples and a counterpart of all approved Shop Drawings will be available to Engineer for reference. Upon completion of the Work, these record documents, Samples, and Shop Drawings will be delivered to Engineer for Owner.

1.5 Final Property Survey

A. Before substantial completion, Contractor shall have a Surveyor prepare a final property survey showing significant features (real property) that have resulted from construction of the project. On the survey shall be certification, signed by the Surveyor, to the effect that principal lines and levels of the project are accurately positioned as shown on the drawings.

END OF SECTION

SECTION 01 77 00

PROJECT CLOSEOUT

PART 1 GENERAL

1.1 Work Specified Herein

A. This section outlines requirements and procedures for submittal of pertinent data relating to closing out the Project upon completion of the Work. Receipt and approval of all items specified in this Section is a prerequisite for Final Payment. Detailed instructions elsewhere in these Specifications require that certain items listed herein be submitted prior to Substantial Completion of the Project.

1.2 Substantial Completion

A. Sequence of events: Prepare and submit a comprehensive list of items to be completed or corrected for substantial completion (Punch List). Within a reasonable time after receipt of the list, the Owner/Engineer shall inspect to determine status of completion. Should the Owner/Engineer determine that the Work is not substantially completed, the Contractor shall remedy the deficiencies and notify the Owner/Construction Manager/Engineer when the Work is ready for re-inspection. The Owner/Engineer shall then re-inspect the Work. When the Owner/Engineer concur that the Work is substantially complete, the Engineer shall prepare a “Certificate of Substantial Completion” on EJCDC Form Number C-625, accompanied by the Contractor’s list of items to be completed or corrected, as verified by the Owner/Engineer. The Engineer shall submit the Certificate to the Owner and to the Contractor for their written acceptance of the responsibilities assigned to them in the Certificate.

B. Result of Work not being substantially complete: If the Owner/Engineer determines during the inspection that the Project is not substantially complete, and announces this determination to the Contractor, any additional time requested by the Contractor and spent by the Owner and Engineer during this particular inspection shall be paid for by the Contractor at the prevailing hourly rates of the respective offices.

C. Termination of inspection: If the Contractor does not wish to pay for the additional services on this particular inspection as described above, then the Owner/Engineer shall not proceed with the inspection and shall wait for the Contractor to request another inspection at such time as the work is substantially complete.

1.3 Final Completion

A. General: Prepare and submit the notice for final completion. Verify that the Work is complete including, but not necessarily limited to, the “Punch List”.

B. The Contractor shall provide "As-Built Drawings" of the project. The "As-Built Drawings" shall include all the design drawings (Cell 14 Sheets 1 though 9 and/or Cell 15 Sheets 1 through 8) and shall be submitted with all changes noted and as-built surveys of

all as-built components. The "As-Built Drawings" of the final cover shall include a detailed survey of the plan dimensions and elevations of existing waste and soil subgrade surface, select cover subgrade soil, soil rooting medium, and gravel amended topsoil.

C. Certification: Contractor to Certify in writing that:
1. Contract Documents have been reviewed;
2. Work has been inspected for compliance with the Contract Documents;
3. Work has been completed in accordance with the Contract Documents;
4. Equipment and systems have been tested as required, and are operational; and
5. Work is completed and ready for final inspection.

D. Inspection: Upon receipt of certification above, the Owner/Engineer shall make an inspection to verify status of completion. Should the Owner/Engineer determine that the Work is incomplete or defective, the Owner/Engineer shall promptly notify the Contractor, in writing, listing the incomplete or defective Work. The Contractor shall remedy the deficiencies promptly, and notify the Owner/Engineer when ready for re-inspection. When the Owner/Engineer determines the Work is acceptable under the Contract Documents, Owner/Engineer shall request the Contractor to make closeout submittals.

1.4 Closeout Submittals

A. General: Submit remainder of project submittals in preparation for final payment. Closeout submittals include, but not necessarily limited to the following.

B. Guarantees: Submit written guarantees, warranties and certificates required. In addition, provide written guarantees or certificates required in pertinent other Sections of these Specifications.

C. Spare parts and maintenance materials: Deliver to the Owner the spare parts and maintenance materials required in pertinent other Sections of these Specifications. Neatly package and identify materials. Submit Owner’s signed receipt for these materials.

1.5 Evidence of Payment and Release of Liens

A. The Contractor shall submit to the Engineer the following documentation on standard EJCDC Forms to be provided by the Engineer:

B. Contractor's Affidavit of Payment of Debt and Claims.

C. Contractor's Affidavit of Release of Liens, including the following:
1. Consent of Contractor's Surety to Final Payment.
2. Contractor's Release or Waiver of Liens.
3. Separate releases or Waivers of Lien for each Subcontractor, supplier, and others with lien rights against Owner's property, together with list of those parties.

D. Duly sign and execute all submittals, before delivery to the Engineer.

1.6 Final Adjustment of Accounts

A. Submit final statement of accounting to the Engineer, including the following:
   1. Original Contract Sum.
   2. Additions and deduction resulting from:
      a. Previous Change Orders.
      b. Deductions for uncompleted Work (if any).
      c. Deductions for Liquidated Damages (if any).
      d. Deductions for Re-inspection Payments (if any).
   3. Total Contract Sum, as adjusted.
   4. Previous Payments.
   5. Sum remaining due.

B. The Engineer shall prepare and issue a final Change Order reflecting approved adjustment to Contract Sum not previously made by Change Orders, if necessary.

1.7 Final Application for Payment

A. Follow procedures specified in the General and Supplementary General Conditions.

END OF SECTION

Division 31

SECTION 31 00 00

EARTHWORK

PART 1 GENERAL

1.1 Summary

A. This section includes all labor, materials, equipment, and incidentals necessary to perform excavation, backfill, fill, grading, compaction, and soil amendment required for completion of the work shown on the Drawings and specified herein. The work shall include, but not be limited to:

1. Site preparation
2. Excavation
3. Placement of cover soil material
4. Final grading
5. Slope surface protection through soil amendment
6. Trench excavation
7. Disposal of waste and surplus materials
8. All related work

B. Related Work

1. Section 01 42 16 - Definitions
2. Section 31 10 00 - Site Clearing
3. Section 31 32 00 - Cover System Components
4. Section 31 38 01 - Surface Rock Durability Requirements
5. Section 32 92 19 - Vegetation and Seeding
6. Section 33 24 14 - Leachate and Well Riser Modification
7. Section 40 14 49 - HDPE Pipe

1.2 References

A. American Society for Testing and Materials (ASTM)

1. ASTM C136 - Standard Method for Sieve Analysis of Fine and Coarse Aggregates
2. ASTM D75 - Standard Practice for Sampling Aggregates
3. ASTM D422 - Standard Test Method for Particle-Size Analysis of Soils
4. ASTM D698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3))
5. ASTM D1140 - Standard Test Methods for Amount of Material in Soils Finer than the No. 200 (75-µm) Sieve
6. ASTM D1556 - Standard Test Method for Density and Unit Weight of Soil in Place by the Sand Cone Method
7. ASTM D2216 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
8. ASTM D2434 - Standard Test Method for Permeability of Granular Soils (Constant Head)

9. ASTM D2487 - Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)
10. ASTM D2774 - Standard Practice for Underground Installation of Thermoplastic Pressure Piping
11. ASTM D4253 - Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
12. ASTM D4254 - Standard Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
13. ASTM D4318 - Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
14. ASTM D4643 - Standard Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
15. ASTM D5084 - Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
16. ASTM D6836 - Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge
17. ASTM D6938 - Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
18. ASTM D6951 - Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

B. Occupational Health and Safety Administration (OSHA)
1. Title 29 Labor, Part 1518, "Safety and Health Regulations for Construction" and detailed requirements of Subpart P, "Excavations, Trenching and Shoring."

1.3 Submittals

A. All submittals shall be made in accordance with the requirements of Section 01 33 00 - Submittals. All submittals are subject to approval by the Engineer. The following submittals are required:
1. Proposed methods of construction, including excavation, filling, and compaction for the various portions of the work. Review shall be for method only.
2. All soil and material testing results.
3. Proposed mixing method for gravel amended topsoil.
4. Nutrient amendments proposed for soils deficient in the required nutrients.
5. Dust Control Plan
6. Certified test results from accredited independent testing agency.
7. Topographical surveys of:
   a. existing waste and soil subgrade surface
   b. top of the select cover subgrade soil
   c. top of the cover soil rooting medium before topsoil placement
   d. top of the gravel amended topsoil

B. Borrow soils shall have been approved prior to construction. The Contractor shall receive areas and depths approved for excavation.

1.4 Quality Assurance

A. Refer to the Construction Quality Assurance (CQA) plan and specific sections for quality assurance requirements.

B. The Contractor shall appoint a registered professional civil engineer to certify inspections and test results. These certifications shall state that the tests and observations were performed by or under the direct supervision of the Engineer and that the results are representative of the materials or conditions being certified by the tests.

PART 2 PRODUCTS

2.1 Unsatisfactory Materials

A. Unsatisfactory materials shall not be used as construction materials. Unsatisfactory materials include man-made fills; trash; refuse; backfills from previous construction; and soil that contains excessive roots, debris left from vegetation, or other excess organic matter or frozen material. Contractor shall notify the Engineer when encountering any contaminated materials.

2.2 Topsoil

A. Material suitable for topsoil is natural, friable soil representative of productive, well-drained soils in the area. Topsoil is the upper component of the cover soil. Topsoil shall be free of stumps, rocks larger than 2-inch diameter, brush, weeds, toxic substances, and other material detrimental to plant growth. All topsoil material shall be submitted to the Engineer for approval.

B. The topsoil shall meet the salt content requirements listed in Table 1.

Table 1. Requirements to Limit Excess Salts

Test	Limit
Electrical conductivity (EC)	Less than 8 mmhos/cm
Sodium adsorption ratio (SAR)	Less than 6
Exchangeable sodium percentage (ESP)	Less than 15% (g/g)
Calcium carbonate ($CaCO_3$)	Less than 15% (g/g)
pH	Between 6 and 8.4

C. The topsoil shall meet the nutrient requirements listed in Table 2.

Table 2. Nutrient Requirements

Test	Limit
Cation exchange capacity (CEC)	Greater than 15 (meq/100 g)
Percent organic matter	Greater than 2% (g/g)
Nitrogen (N)	Greater than 6 parts per million (ppm)
Phosphorous (P)	Greater than 5 ppm
Potassium (K)	Greater than 50 ppm

2.3 Common Fill

A. Common fill shall have a soil classification of GW, GP, GM, GC, SW, SP, SM, or SC with a maximum liquid limit of 35, a maximum plasticity index of 12, and a maximum of 25 percent by weight passing (ASTM D 1140 or ASTM D422) passing the No. 200 sieve (75 micrometers). Common fill shall contain less than 20 percent gravel, with a maximum particle size of 4 inches in the greatest dimension. Common fill shall be free from roots, debris left from vegetation or other excess organic matter, trash, debris, and frozen materials. All common fill material shall be submitted to the Engineer for approval.

2.4 Gravel

A. Gravel shall conform to Section 31 38 0 - Rock Durability.

B. Gravel is required for topsoil amendment.

2.5 Bedding Material

A. Bedding material is required under and adjacent to backfilled pipe. Bedding material shall consist of well graded sand, gravel, or crushed stone. Maximum particle size of bedding material shall not exceed recommendations in Paragraph 9.6 of ASTM D2774. (¾-inch for an 8-inch-outside-diameter pipe).

2.6 Cover Soil

A. Cover soil refers to the components comprising a minimum 5-foot layer of earthen material placed over the waste or existing soil within the waste cells. The cover soil will have a minimum 6-inch top layer of gravel amended topsoil overlying a minimum 54-inch layer of soil rooting medium. Portions of the cover exceeding 5 feet thick include select cover subgrade soil placed below the soil rooting medium. The cover soil shall be placed above the existing subgrade consisting of either waste, soil dikes, and/or other soil.

2.7 Gravel Amended Topsoil

A. The upper 6 inches of the cover soil shall be composed of gravel amended topsoil, containing natural gravel or, with the Engineer's approval, mixed with gravel. The gravel to soil mix shall be a minimum of 25% gravel to 75% soil by weight and a maximum of 40% gravel to 60% soil by weight. Screened gravel shall be nominally ½-inch diameter (minimum) to 2-inch diameter (maximum). The method and mixing location shall be approved by the Engineer.

2.8 Soil Rooting Medium

A. A minimum of 54 inches of soil rooting medium shall be required below the gravel amended topsoil and above the select subgrade surface. The soil rooting medium shall be suitable to support native vegetation and meet the following criteria:

1. USCS soil classification of silty sand (SM) or silt (ML).
2. Saturated hydraulic conductivity less than or equal to 2.0×10^{-4} cm/sec at a relative compaction of 85% ± 2% of the standard maximum dry density determined by ASTM D698.
3. Water holding capacity greater than or equal to 0.11. Water holding capacity is defined as the difference in the volumetric moisture contents equivalent to the field capacity of the soil (–333 cm of water pressure head) and the permanent wilting point (–15,000 cm of water pressure head) of the soil tested at a relative compaction of 85% ± 2% of the standard maximum dry density as determined by ASTM D698.
4. Soil rooting medium shall have a maximum particle size of 4 inches in the greatest dimension.
5. The soil rooting medium shall meet the salt content requirements listed in Table 1.
6. The soil rooting medium shall meet the nutrient requirements listed in Table 2.

2.9 Select Cover Subgrade Soil

A. Select cover subgrade soil shall be placed by the Contractor to the lines and grades necessary to support placement of the 5-foot-thick (minimum) cover soil. Select subgrade soil shall have a USCS soil classification of silty gravel (GM), clayey gravel (GC), silty sand (SM), clayey sand (SC), lean clay (CL), or silt (ML). Select cover subgrade soil shall have a maximum particle size of 4 inches in the greatest dimension. Select cover subgrade soil shall satisfy the salinity requirements of Table 1.

PART 3 EXECUTION

3.1 Delivery, Storage, and Handling of Materials

A. Temporary Stockpiling

1. Contractor may temporarily stockpile materials at a staging location identified by the drawings or approved by the Engineer. Stockpiles shall not obstruct roads or Owner’s operations. Stockpiles should maintain clearance from existing permanent monitoring wells and fence limits as shown on the Drawings.

2. All stockpiles shall be kept neat and orderly. The Contractor shall take necessary precautions to maintain existing erosion and dust control measures and prevent off-site sediment and dust releases. When work is completed, the stockpile area shall be graded to drain surface water runoff to appropriate collection and discharge points.

3.2 Clearing and Grubbing

A. Clearing and grubbing shall be performed in accordance with Section 31 10 00 - Site Clearing.

3.3 Excavation

A. General

1. The Contractor shall execute all earth excavation related to specified tasks required under this contract. Excavation for the convenience of the Contractor shall conform to the limits approved by the Engineer and shall be at no additional expense to Owner.
2. The Contractor shall perform required excavation within the soil borrow area indicated on the Drawings. The Contractor may propose excavation of suitable materials in various areas of the site in order to obtain materials meeting specifications for various components of the work. Excavated material may be stockpiled for later use. All excavation and stockpile locations shall be approved by the Engineer.
3. During construction, the Contractor shall perform excavation in a manner and sequence that will provide proper drainage at all times. The Contractor shall provide and maintain proper equipment and facilities to remove all water entering excavations as necessary so as to obtain a satisfactory material meeting the required specifications.
4. Neither extracted soil, soil stockpiles, equipment, nor vehicles shall be allowed within 2 feet of an open excavation.

B. Trench Excavation

1. Excavate trenches as recommended by the Manufacturer of the pipe to be installed.
2. Slope trench walls below the top of the pipe, or make vertical, and of such width as recommended in the Manufacturer's printed installation manual. Provide vertical trench walls where no Manufacturer's printed installation manual is available.
3. Shore trench walls more than 4 feet high, cut back to a stable slope, or provide with equivalent means of protection for employees who may be exposed to moving ground or cave in.
4. Excavate trench walls which are cut back to at least the angle of repose of the soil. Give special attention to slopes which may be adversely affected by weather or moisture content.
5. Grade the bottoms of trenches accurately to provide uniform bearing and support for the bottom quadrant of each section of the pipe. Excavate bell holes to the necessary size at each joint or coupling to eliminate point bearing. Remove

stones of 3 inches or greater in any dimension, or as recommended by the pipe Manufacturer, whichever is smaller, to avoid point bearing.

6. Where overdepth is not indicated and unyielding material is encountered in the bottom of the trench, remove such material 6 inches below the required grade and replace with suitable materials.
7. Where unstable material is encountered in the bottom of the trench, remove such material to the depth directed and replace it to the proper grade with select granular material. When removal of unstable material is required due to the Contractor's fault or neglect in performing the work, the Contractor is responsible for excavating the resulting material and replacing it without additional cost to the Owner.

3.4 Imported Material and Borrow Source Areas

A. Suitability of Materials: The suitability of all cover materials will be approved by the Engineer. Fill soil will be approved material from the designated borrow source(s). All source material shall meet the testing requirements of Table 3 and follow the CQA Plan - Attachment 1 - Soil Rooting Medium Sampling and Analysis Plan, Soil Characterization for Evapotranspiration Cover, US Ecology Idaho Cells 14 And 15.

B. The Engineer may direct the Contractor to cut inspection trenches or test pits into the designated borrow area(s) prior to this soil’s removal to determine that the Specifications have been met. Such trenches or pits will be of limited depth and size, and shall be backfilled with the material excavated therefrom, or other fill material approved by the Engineer. Inspection trenches or test pits, and the refilling of the same, shall be at the Contractor's expense.

3.5 Subgrade Preparation

A. Cover soil placement shall be directly on the existing subgrade.

B. Excavation of waste or soil dikes is not allowed unless approved by the Engineer.

C. The subgrade shall be protected in accordance with the following procedures:
1. The existing subgrade shall be protected from erosion and damage of any kind.
2. The subgrade shall be kept free of all trash and debris.

D. Waste excavation shall not be allowed except as approved by the Engineer. The placement of common fill at the start of the project as directed by the Engineer shall be subject to compensation in accordance with the unit costs established in Section 01 20 00 - Price and Payment Procedures.

E. The condition of the subgrade shall be approved by the Engineer prior to cover soil placement.

3.6 Material Placement

A. General

1. Fill materials shall be placed and compacted to the lines and grades shown on the Drawings. The cover layer thicknesses and slopes, as designated in these specifications and plans, shall be measured on final grade for each layer.
2. The Contractor shall place material to maintain a positive drainage off of the cover systems throughout construction to preclude the ponding of water. No fill shall be placed on any area where ponding has been allowed to occur. Where ponding has occurred and the fill material is required to be placed, the water shall be removed and the material replaced.
3. Materials shall not be placed on frozen subgrade or embankment material foundations, nor shall frozen material be used as fill.
4. Place and spread fill materials in continuous, horizontal lifts (or lifts parallel to final slope) of uniform thickness, in a manner that avoids segregation and compact each lift to specified densities prior to placing succeeding lifts. Slope lifts where necessary to conform to final grades or as necessary to keep placement surfaces drained of water.
5. Fill materials shall be placed as dry as possible with a maximum water content not to exceed their optimum moisture content as determined per ASTM D698.
6. All lift surfaces must maintain a uniform slope.

B. Cover Soil (Topsoil, Soil Rooting Medium, and Select Cover Subgrade Soil) Placement

1. Any areas of placed cover soil damaged by traffic, erosion, settlement, or other cause, shall be repaired and the grades shown on the drawings shall be reestablished. Any exposed cover soil that exhibits desiccation cracking shall be wetted, compacted, and regraded prior to placement of any cover soil.
2. Loose lift thickness for soil rooting medium and select cover subgrade cover soil shall be a standard 12 inches and a maximum of 36 inches. Use of lifts less than 12 inches shall be minimized and used only as needed to meet required grades and thicknesses.
3. Keep placement surfaces free of water, debris, and foreign material during placement and compaction of fill materials.
4. During placement, the moisture content of cover soil shall be maintained dry of the optimum moisture content (ASTM D698).
5. Gravel amended topsoil shall be placed in one minimum 6-inch lift, uncompacted.

3.7 Material Compaction

A. General

1. If any of the material does not meet the specified requirements, the Contractor shall remove such material and replace it with fill materials meeting the specification at no additional cost. Finish compaction shall be done by steel-wheeled rollers, vibratory compactors, or other approved equipment.
2. Soil compaction of lifts not exceeding 12 inches thick shall be tested by nuclear densiometer testing (ASTM D6938).
3. For every 10 nuclear density tests (ASTM D6938), one test shall be performed by the sand cone density test method (ASTM D1556) and the oven-dried moisture test method (ASTM D2216).
4. Soil compaction of lifts exceeding 12 inches thick, but not greater than 36 inches thick, may be tested by cone penetrometer testing (ASTM D6951), when a test

pad density correlation has been completed by the Contractor and approved by the Engineer and the Idaho DEQ.

5. Fill placed at densities outside of the specified allowable density range or at moisture contents outside the specified acceptable range of moisture content shall be reworked to meet the density and moisture requirements or removed and replaced by acceptable fill compacted to meet these requirements.
6. Hand compact common fill adjacent to any and all types of structures, and compact to at least 90% of the maximum dry density as determined by ASTM D698 to prevent wedging action or eccentric loading upon or against the structure. Compact material within 12 inches of the structure.
7. No compaction shall be performed when the material exceeds the optimum moisture content for compaction, either from rain or from excess application of water. At such times, work shall be suspended by the Contractor until the previously placed and new materials have dried sufficiently to permit proper compaction. The Engineer shall have authority to halt the work when material is overly wet or due to adverse weather conditions.

B. Subgrade Compaction

1. Existing subgrade materials consisting of waste, soil dikes, or other soil shall not be compacted prior to placement of cover soil.

C. Common Fill

1. Each layer of common fill shall be compacted to a minimum of 90% of maximum dry density as determined by ASTM D698.

D. Select Cover Subgrade Soil

1. Select cover subgrade soil shall be compacted to a minimum of 80% and a maximum of 92% of the maximum dry density as determined by ASTM D698.

E. Soil Rooting Medium and Topsoil Compaction

1. Soil Rooting Medium shall be placed with a compacted density from 80% to 92% of the maximum dry density as determined by ASTM D698.
2. The Contractor is responsible for documenting the constructed density for the entire thickness of the lift placed. Uniform density is critical for this soil; consequently, any higher-density areas in this layer due to truck traffic or other are to be loosened to match the adjacent soil layer.
3. The top 6-inch layer is the gravel amended topsoil, which shall be placed in a single uncompacted lift with uniform density.
4. Cover soil that exceeds the maximum specified relative compaction shall be removed or ripped and recompacted to the specified density.
5. Finish compaction shall be done by steel-wheeled rollers, vibratory compactors, or other approved equipment.

3.8 Test Pad Density Correlation

A. The Contractor may place soils with a lift thickness exceeding 12 inches after demonstrating by use of a test pad that proper compaction can be achieved and tested. Placement of lifts with a maximum thickness of 3 feet must be approved by the Engineer

and the Idaho DEQ based on a test pad density correlation demonstrated by the Contractor.

B. During test pad construction, the Contractor shall develop a correlation between mechanical cone penetrometer testing (ASTM D6951) and in-place density testing by nuclear methods (ASTM D6938).

C. The Contractor shall construct a maximum 3-foot-thick loose soil lift using the same procedures as will be used in the field during construction. The minimum test pad dimensions shall be 50 feet by 100 feet. Test pad construction methods shall match procedures to be used for cover construction, including soil type, lift thickness, equipment, and equipment operating speeds.

D. At a minimum of 10 locations on the test pad, the Contractor shall develop a profile of cone penetrometer resistance (blows per lift) versus depth for the entire thickness of the lift. Tests shall be spatially distributed to represent the entire test pad. The 10 locations chosen on the test pad shall be tested using the cone penetrometer (ASTM D6951). Following the cone penetrometer testing, each of the 10 locations shall be carefully excavated in 6-inch lifts and tested in accordance with ASTM D6938, direct transmission method, for the full depth of the excavated lift. The ASTM D6938 density tests shall be performed in close proximity to where the cone penetrometer testing (ASTM D6951) was performed, but it shall be separated by enough distance to ensure that independent and accurate density test results are obtained for both tests at each of the 10 locations on the test pad. The cone penetrometer will provide a number of blows per lift. The number of blows per lift will correspond to an average wet density for the lift as determined by ASTM D6938, direct transmission method. Thus, a correlation of number of blows will be equivalent to a wet density. The final data set will show that x number of blows corresponds to a density y on one lift, density y+i on another lift, density y+j on a third lift, etc. The final data reduction should show that y, y+i, y+j,...,n are within ±2 lbf/ft^3 of the average density for that number of samples corresponding to that number of blows. The moisture contents obtained from ASTM D6938 will allow the wet densities to be converted to dry density values. The dry densities may be compared to the specifications for acceptance. The test pad correlation must be performed in the presence of the QA Engineer. The density correlation method must be accepted by the QA Engineer and the Idaho DEQ.

E. If the Contractor can prove this correlation to the Engineer and the Idaho DEQ, the Contractor shall be allowed to place soil in lifts not to exceed 3 feet and verify the density of placed material using the cone penetrometer testing at a minimum frequency of 4 tests per acre.

F. The Contractor shall construct a test pad for each soil type used in cover construction, subject to approval by the Engineer, before placing cover soil in lifts exceeding 12 inches.

3.9 Trench Backfill Compaction

A. Trench width shall be in accordance with ASTM D2774 and shall be sufficient to ensure working room to properly and safely place and compact haunching and other backfill materials. Minimum trench width shall not be less than 1.25 times the pipe outside

diameter plus 12 inches, (1.25 x O.D. + 12”). Maximum trench width shall not exceed the outside pipe diameter plus 24 inches.

B. Provide bedding material to the thicknesses shown on the Drawings and in accordance with ASTM D2774. Only hand tampers shall be used to compact backfill around the pipe. Care shall be taken not to damage or misalign the pipe during compaction. The pipe haunch zone shall be backfilled with bedding material so that no voids exist.

C. Place initial backfill material (compacted common fill with maximum particle size in accordance with ASTM D2774) with approved tampers to a height of at least 1 foot above the pipe or conduit. Bring up the remaining backfill (compacted common fill) evenly on both sides of the pipe for the full length of the pipe.

3.10 Final Grading/Tolerance

A. The Engineer shall certify that the completed cover soil, at any point, has the minimum thickness designated by the plans, this shall include a minimum of 6 inches of gravel amended topsoil in the top of the cover soil. The Engineer shall identify the locations where the soil thicknesses are less than required, and the Contractor shall be responsible for correcting any deficiencies in thickness.

3.11 Grading Classifications

A. Operations in areas designated for grading shall comply with the following classifications:
   1. Rough Grading, when specified, shall produce reasonably uniform surface, free of major ruts, windrows, and undulations. Rough grades shall match plan grades or contours within 0.5 foot.
   2. Fine Grading, when specified, shall produce a uniform ground surface, free of ruts, windrows, and undulations. Finish grades shall closely match plan grades or contours within a tolerance of 0.1 foot, except as otherwise indicated on the Drawings or Specifications, or otherwise indicated by the Engineer.

3.12 Tolerances

A. The Contractor shall meet the following tolerances for thickness and grade. Tolerances will be verified by survey.
   1. Thickness: Variable thickness shall be minimum thickness shown on the Drawings, plus 6.0 inches, minus zero.
   2. Grade: Slope as shown on the Drawings; plus or minus 0.25 percent.

B. If at the time of grading it is not possible to place any material in its proper location, it shall be stockpiled in approved areas for later use. No extra payment shall be made for the stockpiling or double handling of the excavated material.

C. The Engineer reserves the right to make minor adjustments or revisions in lines or grades as necessary during the progress of the work.

PART 4 QUALITY CONTROL AND QUALITY ASSURANCE

4.1 General

A. The Contractor shall perform and pay for all Quality Control (QC) soil testing, including testing for off-site soils proposed for use in the work.

B. The Engineer will perform and the Owner will pay for all Quality Assurance (QA) testing during construction to ascertain that the work is performed in compliance with these Specifications. Samples may be taken at the place of excavation, stockpiles, or on placed fill. The QA Engineer will verify QC laboratory results by performing duplicate testing, using the same locations and/or split soil samples, and methods as the Contractor. The number of tests performed by the QA Engineer shall equal, at a minimum, 5% of the total QC testing for the project. The Contractor shall remove surface material and render assistance as necessary to enable sampling and testing.

4.2 Material Testing

A. General
1. Material acceptance is subject to approval by the Engineer.
2. The Contractor shall pay for all costs associated with corrective work and retesting resulting from failing tests.
3. The Contractor shall give a minimum 24-hour advance notice to Engineer when ready for material testing and inspection.
4. Testing shall be performed by a valid commercial testing laboratory. If the Contractor elects to establish testing facilities, work requiring testing will not be permitted until the Contractor's facilities have been inspected and approved by the Engineer.

B. Source Soils
1. All tests necessary for the Contractor to locate an acceptable source of borrow material shall be made by the Contractor. Certification that the material conforms to the Specification requirements, along with copies of the test results from a qualified independent testing laboratory, shall be submitted to the Engineer for approval at least 20 days before the material is required for use. All material samples shall be furnished by the Contractor at the Contractor's sole expense. Samples shall be representative and clearly marked to show the source of the material and the intended use on the project. Sampling of the material source shall be done by the Contractor in accordance with ASTM D75. The Contractor shall notify the Engineer at least 24 hours prior to sampling. The Engineer shall observe the sampling procedures. Tentative acceptance of the material source shall be based on an inspection of the source by the Engineer and/or the certified test results submitted by the Contractor to the Engineer, at the Engineer’s discretion. No imported materials shall be delivered to the site until accepted in writing by the Engineer.
2. Test results shall be forwarded to the Engineer within 48 hours after test completion. If tests conducted by the Contractor or the Engineer indicate that the material does not meet Specification requirements, material placement will be terminated until corrective measures are taken.

3. Material that does not conform to the Specification requirements and is placed in the work shall be removed and replaced at the Contractor's sole expense.

C. Common Fill and Select Cover Subgrade Soil

1. Samples of the borrow sources for common fill and select cover subgrade soil shall be tested for particle size analysis, Atterberg Limits (Liquid Limit, Plastic Limit and Plasticity Index), Unified Soil Classification, and standard moisture-density. One of each of these tests shall be performed for each 10,000 yd^3 of loose material. The testing frequency may be increased by the Engineer, if variation in gradation is occurring, or if the material appears to depart from the Specifications.
2. Samples of the borrow sources for select cover subgrade soil shall be tested for salt content. These tests shall include pH, electrical conductivity (EC), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), and calcium carbonate equivalent ($CaCO_3$). Table 1 summarizes the appropriate salt levels with their acceptable range. One of each of these tests shall be performed for each 10,000 yd^3 of loose material.

D. Soil Rooting Medium and Topsoil

1. Samples of the borrow sources for soil rooting medium shall be tested for particle size analysis, Atterberg Limits (Liquid Limit, Plastic Limit and Plasticity Index), Unified Soil Classification, and standard moisture-density. One of each of these tests shall be performed for each 5,000 yd^3 of loose material. The testing frequency may be increased by the Engineer, if variation in gradation is occurring, or if the material appears to depart from the Specifications.
2. Samples of the borrow sources for soil rooting medium shall be tested for saturated hydraulic conductivity and two points of the soil water retention curve corresponding to the field capacity (–333 cm water pressure head) and the permanent wilting point (–15,000 cm water pressure head). Samples tested for saturated hydraulic conductivity and soil water retention shall be prepared by laboratory compaction of samples to 85% ± 2% of the standard maximum dry density as determined by ASTM D698. One of each of these tests shall be performed for each 10,000 yd^3 of loose material. Testing frequency may be increased by the Engineer if borrow source soils are too variable. The saturated hydraulic conductivity and moisture retention samples shall be remolded using the same criterion as the standard Proctor (ASTM D698) method used for compaction. Thus, the largest particle size shall be determined by grain size distribution of the sample.
3. Samples of the borrow sources for soil rooting medium and topsoil shall be tested for salt content. These tests shall include pH, electrical conductivity (EC), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), and calcium carbonate equivalent ($CaCO_3$). Table 1 summarizes the appropriate salt levels with their acceptable range. One of each of these tests shall be performed for each 10,000 yd^3 of loose material.
4. Samples of the borrow sources for soil rooting medium and topsoil shall be tested for soil nutrient requirements. These tests shall include cation exchange capacity (CEC), percent organic matter, nitrogen (N), phosphorus (P), and potassium (K). One of each of these tests shall be performed for each 10,000 yd^3 of loose material. Table 2 summarizes the appropriate nutrients levels with their

acceptable range. Should the soil not meet these nutrient requirements, amendments will be required as appropriate. Any amendment is to be approved by the Engineer prior to application.

E. Placed Soils

1. When ASTM D6938 is used to determine in-place density and moisture content, the probe must be checked against the calibration curves and adjusted using only the sand cone method as described in ASTM D1556. ASTM D6938 results in a wet unit weight and a moisture content of the soil when using this method. Check the calibration curves furnished with the moisture gauges along with density calibration checks as described in ASTM D 6938. Check the calibration of both the density and moisture gauges at the beginning of a job, on each different type of material encountered, and at intervals as directed by the Engineer.
2. If ASTM D 6938 is used, check in-place densities by ASTM D1556 as follows: One check test per lift for each 10 densities determined by ASTM D6938, or fraction thereof, of each lift of fill compacted by other than hand-operated machines.
3. When test results indicate, as determined by the Engineer, that compaction is not as specified, corrective action shall be taken. Upon the Engineer's judgment, corrective action may include, but is not limited to, recompaction, removal, and replacement. The Contractor shall perform tests on recompacted areas to determine conformance with specification requirements.
4. Holes caused by any of the density test methods shall be backfilled with the same constructed materials and tamped to a similar density as the adjacent material.

F. Common Fill and Select Soil Subgrade Compaction

1. Field compaction testing shall be performed in accordance with ASTM D6938 or ASTM D6951 (if approved) at a minimum of four tests per acre per loose lift.

G. Soil Rooting Medium and Topsoil Compaction

1. Field compaction testing for soil rooting medium shall be performed in accordance with ASTM D6938 or ASTM D6951 (if approved) at a minimum of four tests per acre per loose lift
2. The topsoil shall be placed in one minimum 6-inch lift, uncompacted.

Table 3. Summary of Soil Testing Frequency

Test	Method	Frequency [a]	Requirement(s)
Select Cover Subgrade Soil Source			
Liquid limit, plastic limit, and plasticity index	ASTM D4318	1 per 10,000 yd^3	Used for classification
Particle size analysis	ASTM D422	1 per 10,000 yd^3	Used for classification Maximum particle size of 4 inches in the greatest dimension
Soil classification	ASTM D2487	1 per 10,000 yd^3	GM, GC, SM, SC, CL, ML
Laboratory moisture-density relations	ASTM D698	1 per 10,000 yd^3	Reference for percent compaction

Table 3 (continued)

Test	Method	Frequency [a]	Requirement(s)
Select Cover Subgrade Soil Source (cont.)			
Electrical conductivity (EC)	Bureau of Soils Method; USDA Handbook 60	1 per 10,000 yd^3	Less than 8 mmhos/cm
Sodium adsorption ratio (SAR)	EPA 6010B	1 per 10,000 yd^3	Less than 6
Exchangeable sodium percentage (ESP)	EPA 6010B, ASA 9	1 per 10,000 yd^3	Less than 15% (g/g)
Calcium carbonate ($CaCO_3$)	ASA 10-3	1 per 10,000 yd^3	Less than 15% (g/g)
pH	SM4500-H+B: PH	1 per 10,000 yd^3	Between 6 and 8.4
Common Fill Source			
Liquid limit, plastic limit, and plasticity index	ASTM D4318	1 per 10,000 yd^3	Maximum liquid limit of 35 Maximum plasticity index of 12
Particle size analysis	ASTM D422	1 per 10,000 yd^3	Maximum of 25 percent by weight passing the No. 200 sieve Less than 20 percent gravel Maximum particle size of 4 inches in the greatest dimension
Soil classification	ASTM D2487	1 per 10,000 yd^3	GW, GP, GM, GC, SW, SP, SM, or SC
Laboratory moisture-density relations	ASTM D698	1 per 10,000 yd^3	Reference for percent compaction
Gravel Amended Topsoil Source			
Particle size analysis	ASTM D422	1 per 10,000 yd^3	Minimum 25 percent and maximum 40 percent gravel by weight Modified ASTM sieved on 2-inch and 0.5-inch sieves Maximum particle size of 2 inches in the greatest dimension
Soil Rooting Medium Source in Accordance with CQA Plan Attachment 1			
Liquid limit, plastic limit and plasticity index	ASTM D4318	1 per 5,000 yd^3	Used for classification
Particle size analysis	ASTM D422	1 per 5,000 yd^3	Used for classification
Soil classification	ASTM D2487	1 per 5,000 yd^3	Silty sand (SM) or silt (ML)
Laboratory moisture-density relations	ASTM D698	1 per 5,000 yd^3	Reference for percent compaction
Saturated hydraulic conductivity	ASTM D2434 or D5084	1 per 10,000 yd^3 (may be increased to 1 per 5,000 yd^3) [a]	Less than or equal to 2.0×10^{-4} cm/sec tested at a relative compaction of 85% ± 2% of the standard maximum dry density. Minimal confinement pressure shall be used in accordance with the ASTM standard.
Retention curve determination at two points	ASTM D6836	1 per 10,000 yd^3 (may be increased to 1 per 5,000 yd^3) [a]	Water holding capacity greater than or equal to 0.11 tested at a relative compaction of 85% ± 2% of the standard maximum dry density
Bedding Material Source			
Particle size analysis	ASTM D422	1 per 5,000 yd^3	Used for classification Maximum particle size in accordance with ASTM D2447
Soil classification	ASTM D2487	1 per 5,000 yd^3	SW, GW
Laboratory moisture-density relations	ASTM D698	1 per 5,000 yd^3	Reference for percent compaction

Table 3 (continued)

Soil Rooting Medium and Topsoil Source			
Electrical conductivity (EC)	Bureau of Soils Method; USDA Handbook 60	1 per 10,000 yd^3	Less than 8 mmhos/cm
Sodium adsorption ratio (SAR)	EPA 6010B	1 per 10,000 yd^3	Less than 6
Exchangeable sodium percentage (ESP)	EPA 6010B, ASA 9	1 per 10,000 yd^3	Less than 15% (g/g)
Calcium carbonate ($CaCO_3$)	ASA 10-3	1 per 10,000 yd^3	Less than 15% (g/g)
pH	SM4500-H+B: PH	1 per 10,000 yd^3	Between 6 and 8.4
Cation exchange capacity (CEC)	EPA 6010B, USDA Handbook 60	1 per 10,000 yd^3	Greater than 15 (meq/100 g)
Percent organic matter	ASTM D2974	1 per 10,000 yd^3	Greater than 2% (g/g)
Nitrogen (N)	SM 4500NorgC and EPA 300.0	1 per 10,000 yd^3	Greater than 6 parts per million (ppm)
Phosphorous (P)	EPA 6010B	1 per 10,000 yd^3	Greater than 5 ppm
Potassium (K)	EPA 6010B	1 per 10,000 yd^3	Greater than 50 ppm
Placed Select Cover Subgrade Soil			
In-place density and moisture	ASTM D6938 or ASTM D6951	4 tests per acre per loose lift for ASTM D6938 or a minimum of 4 tests per acre per 3-foot (maximum) lift for ASTM D6951	80–92% of maximum dry density Dry of optimum moisture content If used, ASTM D6951 to include testing the full lift thickness. Tests shall be spatially distributed to represent the entire site.
In-place density (sand cone)	ASTM D1556	1 test per 10 ASTM D6938 tests	Confirmation of nuclear probe calibration
Compacted Common Fill			
In-place density and moisture	ASTM D6938 or ASTM D6951	4 tests per acre per loose lift for ASTM D6938 or a minimum of 4 tests per acre per 3-foot (maximum) lift for ASTM D6951	Minimum of 90% of maximum dry density Dry of optimum moisture content If used, ASTM D6951 to include testing the full lift thickness. Tests shall be spatially distributed to represent the entire site.
In-place density (sand cone)	ASTM D1556	1 test per 10 ASTM D6938 tests	Confirmation of nuclear probe calibration
Placed Soil Rooting Medium			
In-place density and moisture	ASTM D6938 or D6951	A minimum of 4 tests per acre per loose lift for ASTM D6938 or a minimum of 4 tests per acre per 3-foot (maximum) lift for ASTM D6951	80% to 92% of the maximum dry density Dry of optimum moisture content If used, ASTM D6951 to include testing the full lift thickness. Tests shall be spatially distributed to represent the entire site.
In-place density (sand cone)	ASTM D1556	1 test per 10 ASTM D6938 tests	Confirmation of nuclear probe calibration
Placed Bedding Material			
In-place density and moisture	ASTM D6938	A minimum of 1 test per 200 ft.	Greater than or equal to 90% of the maximum dry density
In-place density (sand cone)	ASTM D1556	1 test per 10 ASTM D6938 tests	Confirmation of nuclear probe calibration

Table 3 (continued)

Placed Gravel Amended Topsoil
One 6-inch, uncompacted lift - 25% to 40% by weight gravel, 75% to 60% by weight topsoil

[a] Testing frequencies for saturated hydraulic conductivity and water holding capacity designated at 1 per 10,000 yd^3 are dependent on the variability of the borrow source material. If the borrow source soil shows significant variability, then the testing frequency will be increased to 1 per 5,000 yd^3. DEQ concurrence will be required to establish the final test frequency for saturated hydraulic conductivity and water holding capacity.

PART 5 ADDITIONAL REQUIREMENTS

5.1 Settlement

A. The Contractor shall correct and repair any subsequent damage to structures, pavements, curbs, slabs, piping, and other facilities caused by settlement of fill or backfill material.

5.2 Dust Control

A. Dust control shall consist of furnishing water supply, required equipment, additives, accessories, and incidentals, and applying water during the completion of the Contract, as required by the Engineer. Special care must be taken so as not to apply excessive water. Prior to any earthwork activities on the project areas (including borrow area) such as site preparation and borrow area excavation. The Contractor shall submit a Dust Control Plan for approval. The plan shall identify methods and equipment to minimize/control dust generation during all earthwork operations and include the following minimum requirements:

1. Continuous control of dust generation during borrow area excavation and fill placement, etc.
2. Continuous control of wind-generated dust, including disturbed areas that are not being actively worked.
3. Keeping unpaved haul roads watered or using tackifier to control dust.
4. Application of water or other approved dust suppressants to keep visible dust to a minimum during execution of Work. See restrictions on moisture addition for fill.
5. Appropriate hand-held hose lines, sprinklers, and other equipment as needed to access and control dust at areas difficult to access by vehicles, such as borrow and stockpile side slopes.

5.3 Protection

A. The Contractor shall maintain and protect native vegetation where possible, through minimization of site disturbance.

B. The Contractor shall limit access road development to the minimum necessary to execute work.

C. The Contractor shall provide stabilization of inactive disturbed work areas by longer-term methods such as matting, tack and mulch, or crusting agents.

D. The Contractor shall provide implementation of permanent stabilization on a regular basis when sufficient area exists for application. The Contractor shall protect existing surface and subsurface features on site and adjacent to site as necessary, in accordance with, but not limited to, the following guidelines:

1. Provide barricades, coverings or other types of protection necessary to prevent damage to existing items indicated to remain in place.
2. Protect and maintain benchmarks, monuments, or other established reference points and property corners. If disturbed or destroyed, replace at the Contractor's expense to full satisfaction of Owner and controlling authority.
3. Maintain stockpiles and excavations in such a manner to avoid inconvenience or damage to structures on site or adjoining property, and avoid blocking access roads to or within the site.

E. The Contractor may remove and replace existing items indicated to remain in place, at his option, at no additional loss to Owner. Replacement items must be approved by Owner.

F. The Contractor shall take all necessary precautions to preclude the accidental discharge of fuel, oil, etc. in order to prevent adverse effects on water quality.

G. The Contractor is responsible for stormwater damage resulting from storms exceeding the 25-year, 24-hour storm event and shall carry All-Risk Builders Insurance to cover such damage. Owner is not responsible for stormwater damage or delays.

H. Contractor shall be responsible for all costs associated with repair and/or replacement of the ground surface utilities and appurtenant facilities damaged by the Contractor to the satisfaction of the Owner. Any damage resulting from unauthorized intrusion upon or use of off-site areas shall be completely and immediately repaired, solely at the expense of the Contractor.

5.4 Safety

A. The Contractor shall ensure full compliance with applicable requirements of OSHA. Special attention is directed to Title 29 Labor, Part 1518, "Safety and Health Regulations for Construction" and detailed requirements of Subpart P "Excavations, Trenching and Shoring."

B. The Contractor shall comply with local and specific requirements of the State of Idaho.

5.5 Water Supply

A. Water supply for earthwork, compaction, and dust control will be provided by the Owner from an on-site storage pond. The Contractor shall have access to the water storage pond, and tank-trucks may be filled from the pond or a Contractor supplied storage tank. The Contractor shall supply pumps necessary to provide the flow rates needed. Use of the water shall be coordinated between the Owner and the Contractor. The Contractor shall be responsible for obtaining the water necessary for construction activities, including dust control and fire protection.

B. For water connections during the freezing temperatures, coordinate all connections with the Owner. Contractor shall take all necessary measures to prevent freezing and/or damage to the raw water system.

C. The Contractor shall conserve water to the extent practicable.

5.6 Sequencing and Scheduling

A. Fill activities shall commence only after Dust Control Plan has been approved.

5.7 Disposal of Surplus Material

A. No excavated materials shall be removed from the site or disposed of by the Contractor except as directed by the Engineer. Materials shall be neatly piled so as to minimize inconveniencing operations.

B. Suitable excavated material shall be used for fill embankments or backfill for different parts of the work as required.

C. Items and materials of salvage value as determined by the Engineer, unless incorporated in the new work, shall remain the property of the Owner and shall be delivered to storage areas as directed by the Engineer. Such items and materials shall be carefully removed and delivered in such a manner as to permit reuse.

5.8 Cleanup and Disposal

A. Garbage, refuse, debris, oil, and any waste material that is generated by the Contractor and is harmful to the environment or offensive to the area shall be removed from the job site and disposed of off-site in a manner approved by the authority having jurisdiction over the disposal site.

B. The Contractor shall dispose of all vegetative materials on-site, as directed by the Engineer or Owner.

C. Burning of cleared and grubbed materials shall not be permitted.

5.9 Waste

A. Excavation shall cease if any waste (refuse) is encountered during excavation. The Contractor shall immediately notify the Engineer of the occurrence of unexpected waste.

END OF SECTION

SECTION 31 10 00

SITE CLEARING

PART 1 GENERAL

1.1 Work Included

A. The work covered by this section consists of furnishing all labor and equipment in performing all stripping and clearing operations in accordance with the plans and specifications. Clearing shall consist of removing natural and artificial objectionable material from the construction areas and proper disposal.

1.2 Related Work

A. Section 31 00 00 - Earthwork

PART 2 PRODUCTS

Not used.

PART 3 EXECUTION

3.1 Coordination

A. Strip and stockpile suitable soil which may be reused.

3.2 Clearing and Grubbing

A. General: Clear and grub all areas shown on the contract drawings to be excavated.

B. Borrow Excavation Areas:

1. Clearing and grubbing shall consist of removal and disposal of trees and other vegetation as well as down timber, snags, brush, existing foundations, slabs, and rubbish within the areas to be cleared. Clearing shall be performed by grading the soil to a depth of approximately 1 to 2 inches. Strip vegetation and surface soil and any other material deemed unsuitable by the QC Representative.
2. Stripped soil and vegetation shall be stockpiled at a location designated by the Owner or Engineer.

C. Cover Construction Area: Grass, roots, and incidental vegetation within the areas of cover construction shall be left in place to prevent disturbance of the existing subgrade or waste.

3.3 Salvageable Items

A. Carefully remove items indicated to be salvaged and store as indicated on the Drawings or as directed by Owner.

3.4 Preservation of Property

A. The Contractor shall be responsible for compliance with National Pollutant Discharge Elimination System (NPDES) requirements using best management practices and following an approved Storm Water Pollution Prevention Plan.

B. Provide temporary fences, barricades, coverings, or other protection to preserve existing items indicated to remain and to prevent injury or damage to persons or property. Apply protection to adjacent properties as required.

C. Restore damaged work to condition existing prior to start of work, unless otherwise directed.

3.5 Existing Utilities

A. The Contractor shall verify the location of any utility lines, pipelines, or underground utility lines in or near the area of the work in advance of and during clearing work. The Contractor is fully responsible for any and all damage caused by failure to locate, identify, and preserve any and all existing utilities, pipelines, and underground utility lines. Repair damaged utilities to the satisfaction of the utility owner at no expense to the Owner.

B. Should uncharted or incorrectly charted piping or other utilities be encountered during clearing, Contractor shall contact the Engineer immediately for directions as to procedures.

C. Contractor shall cooperate with the Owner and public or private utility companies in keeping service and facilities in operation.

3.6 Waste

A. Dispose of all pre-existing waste material encountered within the area of clearing and grubbing, other than vegetation, on-site at a location specified by the Owner.

B. Burning of waste shall not be permitted.

PART 4 MEASUREMENT AND PAYMENT

4.1 General

A. A description of measurement and payment for work covered by this section is provided in Section 01 20 00 - Measurement and Payment, included in these Contract Documents.

B. Any clearing of the Contractor's staging area to remove unwanted vegetation is at the Contractor's discretion to facilitate work and is considered incidental to completion of the project. No separate measurement and payment for incidental clearing is provided.

END OF SECTION

SECTION 31 32 00

COVER SYSTEM COMPONENTS

PART 1 GENERAL

1.1 Summary

A. Section includes construction and installation sequence of various components of the landfill cover system.

B. Related Sections
1. Section 31 00 00 - Earthwork
2. Section 32 92 19 - Vegetation and Seeding

1.2 Submittals

A. All submittals shall be made in accordance with the requirements of Section 01 33 00 - Submittals.

B. Required Submittals
1. As-Built Drawings
2. Detailed survey including the waste and soil subgrade prior to construction, select cover subgrade soil, soil rooting medium, and topsoil shall be submitted.

1.3 Quality Assurance

A. Refer to the Construction Quality Assurance (CQA) plan and specific sections for quality assurance requirements.

PART 2 PRODUCTS

2.1 Cover System Components

A. The cover system shall consist of the following components (from bottom to top) as shown on the Drawings.
1. Cover Soil - The cover soil shall have a minimum thickness of 5 feet, as shown on the Drawings. The cover soil shall consist of:
   a. Select Cover Subgrade Soil - The select cover subgrade soil, where required, shall be suitable soil or soil rooting medium of variable thickness in accordance with Section 31 00 00 - Earthwork.
   b. Soil Rooting Medium - The soil rooting medium shall have a minimum thickness of 54 inches in accordance with Section 31 00 00 - Earthwork.
   c. Gravel Amended Topsoil - The gravel amended topsoil consists of the upper 6-inch layer of the soil rooting medium, containing natural gravel or mixed with gravel, in accordance with Section 31 00 00 - Earthwork.

2. Vegetation and Seeding - Vegetation and seeding includes application of seed, fertilizer, and mulch in accordance with Section 32 92 19 - Vegetation and Seeding.

B. Existing Subgrade

1. The existing subgrade may be composed of existing soil dikes, waste, or other subgrade soil. The Contractor shall place cover soil over the existing subgrade without excessive alteration of the subgrade. Where required, subgrade shall be augmented with compacted common fill and prepared in accordance with Section 31 00 00 - Earthwork. Excavation of existing waste shall not be allowed, except as approved by the Engineer.

PART 3 EXECUTION

3.1 Installation

A. Refer to specification sections corresponding to individual components of the cover system for the installation and construction procedures for the waste disposal cell.

PART 4 MEASUREMENT AND PAYMENT

4.1 General

A. A description of measurement and payment for work covered by this section is provided in Section 01 20 00 - Measurement and Payment, included in these Contract Documents.

END OF SECTION

SECTION 31 38 01

SURFACE ROCK DURABILITY REQUIREMENTS

PART 1 GENERAL

1.1 Summary

A. This section covers all labor, equipment, appurtenances, materials, and performing all operations, including, but not limited to, hauling, placing, spreading, watering, processing, compacting, and shaping rock required on this project. Rock includes gravel for topsoil admix.

B. Related Sections:
1. Section 31 10 00 - Site Clearing
2. Section 31 20 00 - Earthwork

1.2 References

A. American Society for Testing and Materials (ASTM)
1. ASTM C33 - Standard Specification for Concrete Aggregates.
2. ASTM C88 - Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
3. ASTM C127 - Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate.
4. ASTM C136 - Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
5. ASTM C295 - Standard Guide for Petrographic Examination of Aggregates for Concrete.
6. ASTM C535 - Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.
7. ASTM D5240 - Standard Test Method for Testing Rock Slabs to Evaluate Soundness of Riprap by Use of Sodium Sulfate or Magnesium Sulfate.
8. ASTM D5312 - Standard Test Method for Evaluation of Durability of Rock for Erosion Control Under Freezing and Thawing Conditions.
9. ASTM D5313 - Standard Test Method for Evaluation of Durability of Rock for Erosion Control Under Wetting and Drying Conditions.
10. ASTM D6473 - Standard Test Method for Specific Gravity and Absorption of Rock For Erosion Control.

1.3 Unit Price - Measurement and Payment

A. A description of measurement and payment for work covered by this section is provided in Section 01 20 00 - Measurement and Payment of the Supplemental Provisions, included in these Contract Documents.

1.4 Submittals

A. Section 01 33 00 - Submittals.

B. A certificate or affidavit signed by a legally authorized official of the supplier of the stone fill and the supplier of the natural filter material that it meets the quality required and gradation limits specified.

1.5 Quality Assurance

A. Furnish each aggregate material from a single source throughout the Work.

B. A certificate or affidavit shall be provided by the Contractor, signed by a legally authorized official of the supplier of the stone fill and the supplier of the natural filter material that it meets the quality required and gradation limits specified.

1.6 Certification

A. The Contractor shall provide acceptable documentation that the rock proposed for the project meets the requirements of this Specification. The Engineer may waive the need for certification of the rock upon inspection of the source.

1.7 Testing and Inspection

A. The Contractor shall provide all testing, retesting, and inspection services. The Testing Laboratory that will perform testing and inspection service is subject to prior approval by the Engineer.

1.8 Quality Assurance

A. The Contractor is responsible for meeting all requirements set forth in the contract documents. The Engineer will perform Quality Assurance (QA) testing, at their discretion, during construction activities. Samples may be taken at the place of excavation, stockpiles, or from the placed materials. The Contractor shall conduct laboratory testing as frequently as the Engineer considers necessary. The Contractor shall remove surface material and render assistance as necessary to enable sampling and testing.

B. Suitability of Materials: The suitability of all rock will be approved by the Engineer.

PART 2 PRODUCTS

2.1 Materials

A. All material shall be clean, free of roots, trash, debris, and lumps.

B. Rock Durability: The suitability of the rock to be used is based on its physical properties including size and durability. This specification section addresses the durability requirements to be met.

C. Gravel for Admix: Gravel for Admix shall be non-calcareous material that satisfies the requirements of Table 1.

Table 1. Gravel for Admix Requirements

Description	Requirement	Reference
Maximum particle size (D_{100})	2 inches	ASTM C136
Minimum particle size (D_0)	½ inch	ASTM C136
Unit weight	160 lbf/ft^3 or greater	ASTM C127
Absorption	Less than 1.0 percent	ASTM D6473
Sulfate soundness	Less than 5 percent loss	ASTM D5240
Abrasion	Less than 20 percent loss for 500 revolutions	ASTM C535

PART 3 EXECUTION

3.1 Delivery, Handling, and Storage

A. Rock shall be excavated and screened on-site. The Bruneau Formation is present west of the project area on the USEI property where future Cell 16 will be excavated, as shown on the Plans. The Contractor shall investigate this and/or other locations on the USEI property and propose a borrow source for the gravel material. The sources from which the Contractor obtains the material shall be selected well in advance of the time when the material will be required in the work. The inclusion of any sand, silt, clay, and rock fines in gravel for the top soil gravel admix shall be consistent with the final soil type and test criteria for the soil rooting medium as per Section 31 00 00 - Earthwork.

B. Gravel shall be handled, loaded, transported, stockpiled, and placed in a manner that avoids segregation and degradation.

3.2 Waste

A. Dispose of all surplus material as per Section 31 00 00 - Earthwork.

B. Excavation shall cease if any waste (refuse) is encountered during excavation. The Contractor shall immediately notify the Engineer of the occurrence of unexpected waste.

3.3 Air Pollution

A. Use water sprinkling, temporary enclosures, and other suitable methods to limit dust and dirt air pollution. Comply with governing regulations pertaining to environmental protection.

END OF SECTION

Division 32

SECTION 32 92 19

VEGETATION AND SEEDING

PART 1 GENERAL

1.1 Work Included

A. This section covers the Work necessary to seed and fertilize the cover surface and areas around the cover that are disturbed as a result of construction activities.

B. Related Sections
1. Section 31 00 00 - Earthwork
2. Section 31 32 00 - Cover System Components

1.2 Work Limits

A. Areas required to be planted and maintained include the entire cover surface soil area.

1.3 Submittals

A. Section 01 33 00 - Submittals.

B. Plant material source and seed mix guarantee.

C. Fertilizer analysis guarantee and material safety data sheet (MSDS).

D. Certified weed-free straw guarantee.

E. Hydromulch products, application rates, and methods.

1.4 Quality Control

A. Work covered under this specification section shall be the work of a single firm experienced in dryland revegetation work. Submit statement of qualifications to the Engineer for approval.

B. Source Quality Control:
1. General: Do not ship any materials until approval of submittals have been obtained from the Engineer. Ship materials with certificates of inspection required by governing authorities. Comply with State regulations applicable to revegetation material.
2. Do not make substitutions. If specified materials are not obtainable, submit proof of non-availability to the Engineer, together with proposal for use of equivalent material.
3. Analysis and Standards: Package standard products with manufacturer’s certified analysis.

1.5 Delivery, Storage, and Handling

A. Fertilizer and seed shall be protected from wind and moisture during transport and storage before use. Fertilizer or seed that has become wet, moldy, or otherwise damaged in transit or storage will not be accepted.

B. Notify the Engineer's Field Representative at least 3 days in advance of each delivery and planting.

1.6 Traffic Control

A. The only vehicle allowed to be driven across the cover surface and sideslopes will be a low ground pressure vehicle used to hydroseed and fertilize. While performing those operations, traffic shall be minimized and shall not be allowed following heavy rain events to prevent rutting and compaction of barrier soils.

1.7 Scheduling and Sequencing

A. Within 14 days of the Engineer acceptance of cover final grading, the cover surface and side slopes shall be seeded and mulched. The seeding contractor shall provide a recommendation to the Engineer for approval regarding the appropriate seed mix related to the season in which seeding will occur.

PART 2 PRODUCTS

2.1 Seed Materials

A. The seed mixes shall meet the following requirements.
1. Seed shall be 80% pure live seed or greater.
2. Seed shall not contain any federal- or state-listed prohibited noxious weed seed as determined by a standard purity test.
3. Seed shall not contain more than 40 seeds per pound of any single restricted noxious weed or more than 150 seeds per pound of all species combined of restricted noxious weed seed.
4. Seed shall not contain more than 1 percent by weight of weed seed or other crops and plant species as determined by a standard purity test.
5. The Contractor shall supply certified seed or, if not available, submit proof of non-availability along with the proposed substitute.
6. Seed certification from a laboratory for seed testing shall include but is not limited to the following:
a. Name and address of testing laboratory.
b. Date of testing.
c. Lot number for each seed type.
d. Results of tests, including name, percentage of purity and germination, percentages of weed content for each kind of seed furnished, hard seed content, and in the case of seed mixtures, pure live seed proportions of each kind of seed as specified. All seed shall be subject to inspection and concurrence by the Contractor before the subcontractor is authorized

to proceed with the seeding operation. Seed shall be tested according to the Association of Official Seed Analysts, International Seed Testing Association, and the Federal Seed Act standards. A certificate of analysis from a certified testing laboratory shall accompany all seed.

7. Species Substitutions: Due to potential availability problems, alternative species meeting the requirements above may be substituted for species listed below with the approval of the Engineer. Substitutions must be submitted to the Engineer for approval at least 30 days prior to ordering. Substitutions shall be allowed only with approval from Idaho DEQ.
8. Permanent Seeding Plant List:
   a. Total seed mixture application shall be 51.0 pounds live seed (PLS) per acre of the following species:

Table 1. Permanent Seed Mix

Common Name	Scientific Name	PLS/acre
Crested wheatgrass	*Agropyron cristatum*	15.0
Siberian wheatgrass	Agropyron sibericum	18.0
Streambed wheatgrass	Elymus lanceolatus lanceolatus	18.0
	Total PLS/acre	51.0

B. Seed Delivery: Unopened containers or bags shall be delivered with the following information clearly marked.
   1. Certified or non-certified name of seed as specified.
   2. Lot number.
   3. Net weight.
   4. Percentage purity.
   5. Percentage germination.
   6. Seed coverage (in acres) on a PLS basis
   7. Percentage of weed seed content and inert material clearly marked for each kind of seed in accordance with applicable state and federal laws.

2.2 Fertilizer

A. The seeding contractor shall provide a submittal for the proposed fertilizer products, application rates, and methods. Materials and methods shall be based on soil nutrient test results in accordance with Section 31 00 00 - Earthwork.

B. Fertilizer shall be furnished in standard, unopened bags with weight, nutrient content, and manufacturer's analysis marked.

PART 3 EXECUTION

3.1 Preparation

A. The cover surface shall be prepared for seeding by placement of gravel amended topsoil in accordance with Section 31 00 00 - Earthwork.

3.2 Seeding

A. The seeds shall be applied through a hydromulch. The hydromulch shall be applied to the landfill surface at a minimum of 8,000 lbs/acre.
   1. Bonded fiber matrix shall be co-applied with the hydromulch.
   2. Granular fertilizer shall be co-applied during seeding.

B. The seed mix shall be evenly applied throughout the planting area.

C. The hydromulch products, application rates, and methods shall be submitted by the Contractor for approval by the Engineer.

END OF SECTION

Division 33

SECTION 33 24 14

LEACHATE AND WELL RISER MODIFICATION

PART 1 GENERAL

1.1 Summary

A. This section includes the work and materials required for modification of leachate risers and monitor well risers.
   1. Leachate risers include:
      a. HDPE side slope riser pipes extending on an angle from the liner side slope through the final cover. Side slope risers include all existing leachate pump controls and piping.
      b. Concrete manhole risers extending vertically from liner sumps through the final cover.
   2. Monitor well risers include:
      a. 4-inch-diameter polyvinyl chloride (PVC) well casing.
      b. Protective steel shroud with locking cap.
      c. Concrete pad.

B. The Contractor shall familiarize himself with site conditions at the project site, including locations and conditions of all leachate and well risers. Failure to do so shall in no way relieve Contractor of the responsibility for performing any of the work or operations required as a part of this contract.

C. The Contractor shall provide to the Engineer for his or her approval a detailed Riser Modification Construction and Materials Plan to modify and extend the existing risers. All materials and methods used in the riser extensions shall be consistent with the existing materials. Existing materials and equipment shall be modified and reused to the extent practicable. Work shall not begin without the Engineer's expressed approval of the Contractor's proposed plan for extension and modification.

D. Section Includes
   1. Parts, materials, and installation of riser extensions.

E. Related Sections:
   1. Section 31 00 00 - Earthwork
   2. Section 40 14 49 - HDPE Pipe
   3. Specification used for construction of the system. US Ecology Idaho, Cell 15, Section 15062 - Piping and Mechanical, November 15, 2002.
   4. Specification used for construction of the system. US Ecology Idaho, Cell 15, Section 16050 - Electrical Work, September 30, 2002

1.2 General Provisions

A. Warranties: Contractor shall warrant against defects, all materials provided and work performed under this contract for a period of 1 year from the date of Final Completion, as

determined by the Engineer in accordance with the Standard General Conditions of the Construction Contract and amendments thereto. The Contractor shall replace promptly, at the Contractor's own expense, any materials and workmanship that fail during this warranty period as determined by the Owner or Engineer.

B. Protection: The original risers and completed extensions shall be flagged so as to be highly visible by equipment operators and protected from damage.

C. Health and safety: Health and safety monitoring is a critical aspect of the leachate system extensions. Vapor within the leachate risers is potentially toxic, explosive, or deficient in oxygen. The Contractor shall provide a site-specific health and safety plan (HASP) to the Engineer for approval.

D. The Contractor shall be held responsible, and payment will be withheld for damages to the riser due to any act of omission, error, or faulty operation by the Contractor or his employees or agents. Resulting repairs shall be completed by the Contractor to the satisfaction of the Owner/Engineer at no additional cost to the Owner and without claim against the Owner, Engineer, or agents.

1.3 Submittals

A. Submittals shall be in accordance with Section 01 33 00 - Submittals.

B. Riser Modification Construction and Materials Plan: The Contractor shall submit to the Engineer a detailed plan of proposed riser construction methods and materials to be used. The Contractor shall not perform any work on the riser construction until the plan has been approved in writing by the Idaho Department of Environmental Quality and by the Engineer.

C. Site-Specific Health and Safety Plan (HASP): The Contractor shall submit to the Engineer a site-specific HASP for approval. The HASP shall address monitoring methods, engineering controls (such as ventilation systems), and construction methods that ensure worker health and safety.

PART 2 PRODUCTS

2.1 Contractor’s Equipment and Methods

A. General Requirements:

1. The modifications shall be constructed using conventional methods consistent with existing riser materials and equipment. The Contractor is directed to the specification sections used for construction of the Leachate Collection and Removal System (LCRS) and the Leachate Detection, Collection, and Removal System (LDCRS).
2. Specification used for construction of the system. US Ecology Idaho, Cell 15, Section 15062 - Piping and Mechanical, November 15, 2002. Applicable sections will include but not be limited to: 1.4 Submittals, 1.5 Quality Assurance, 1.6 Delivery, Storage, and Handling of Materials, 2.3 Pipe and Fittings,

2.4 Cell 15 Leachate Pipe to Cell 14 Tie-In, Part 3 Execution, and Part 4 Field Quality Control.

3. Specification used for construction of the system. US Ecology Idaho, Cell 15, Section 16050 - Electrical Work, September 30, 2002. Applicable sections will include but not be limited to: 1.1 Scope, 1.4 Jobsite Conditions, 1.5 Applicable Publications, 1.6 Quality Assurance, 1.7 Coordination, 1.10 Record Documents, 1.13 Interruption of Existing Electrical and Other Necessary Services, 1.14 Protection During Construction, 2.5 Wire and Cable, 2.6 Miscellaneous Materials and Hardware, 3.2 Wires and Cable, 3.3 Conduits, 3.4 Grounding.

4. The Contractor shall supply capable and experienced personnel and suitable equipment to perform the work, as specified herein. The Contractor shall employ only competent workers for the execution of the work, which shall be directly supervised by an experienced superintendent who shall be deemed satisfactory by the Owner/Engineer. The individual responsible for welding shall be a certified welder. The individual responsible for electrical work shall be a certified electrician.

B. Materials and Equipment: All riser materials and equipment shall be compatible with the leachate riser or monitor well's continued function and use by using only materials that are consistent with existing materials and free of any contaminants that could impact leachate collection operations or monitoring results.

C. The premises, materials, tools, and equipment shall be maintained so as to minimize the potential for contaminant impacts to the risers during modification or extension.

PART 3 EXECUTION

3.1 Construction

A. Construction shall be executed in accordance with the Riser Modification Construction and Materials Plan submitted by the Contractor and approved by the Engineer.

B. Surface Protection: During construction, the open risers shall be protected from entry of unwanted material at all times. No materials or liquids, including surface water runoff, shall be allowed to enter the risers during construction activities. Whenever work ceases on the risers, the risers shall be capped for protection until the permanent extension is completed.

C. Material Tallies: An accurate record of all materials on the location shall be maintained at all times.

D. Cleanup: After the work is completed, the Contractor shall remove all debris, tools, equipment, supplies, and excess material from the site and shall restore the site to its original condition, as approved by the Owner/Engineer.

PART 4 MEASUREMENT AND PAYMENT

4.1 Installation

A. A description of measurement and payment for work covered by this Section is provided in Section 01 20 00 - Measurement and Payment, included in these Contract Documents.

END OF SECTION

Division 40

SECTION 40 14 49

HDPE PIPE

PART 1 GENERAL

1.1 Summary

A. Section Includes
1. High-Density Polyethylene (HDPE) Pipe used in the project including, but not limited to:
   a. Leachate riser extension and modification.

B. Related Sections
1. 33 24 14 - Leachate and Well Riser Modification
2. 31 00 00 - Earthwork

1.2 References

A. American Society for Testing and Materials (ASTM)
1. ASTM D256 - Standard Test Method for Determining the Impact Resistance of Notched Specimens of Plastics.
2. ASTM D380 - Standard Methods of Testing Rubber Hose.
3. ASTM D638 - Standard Test Method for Tensile Properties of Plastics.
4. ASTM D696 - Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between 30°C and 30°C.
5. ASTM D746 - Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact.
6. ASTM D790 - Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.
7. ASTM D1238 - Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.
8. ASTM D1248 - Standard Specification for Polyethylene Molding and Extrusion Materials.
9. ASTM D1505 - Standard Test Method for Density of Plastics by the Density-Gradient Technique.
10. ASTM D1525 - Standard Test Method for Vicat Softening Temperature of Plastics.
11. ASTM D1603 - Standard Test Method for Carbon Black in Olefin Plastics.
12. ASTM D1693 - Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics.
13. ASTM D2122 - Standard Test Determining Dimensions of Thermoplastic Pipe and Fittings.
14. ASTM D2239 - Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameters.
15. ASTM D2240 - Standard Test Method for Rubber Property-Durometer Hardness.
16. ASTM D2241 - Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter.

17. ASTM D2447 - Standard Specification for Polyethylene (PE) Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter.
18. ASTM D2513 - Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings.
19. ASTM D2609 - Standard Specification for Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe.
20. ASTM D2657 - Standard Practice for Heat-Joining Polyolefin Pipe and Fittings.
21. ASTM D2683 - Standard Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing.
22. ASTM D2774 - Standard Practice for Underground Installation of Thermoplastic Pressure Piping
23. ASTM D3035 - Standard Specification for Polyethylene (PE) Plastic Pipe (DR PR) Based on Controlled Outside Diameter.
24. ASTM D3261 - 03 Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
25. ASTM D3350 - Standard Specification for Polyethylene Plastics Pipe and Fitting Materials.
26. ASTM F412 - Standard Terminology Relating to Plastic Piping System.
27. ASTM F714 - Standard Specification for 3 to 63 in. (SDR-PR) Polyethylene Pipe

B. Code of Federal Regulations (CFR)
1. 49 CFR 192.285 - Plastic pipe; qualifying persons to make joints.

C. American Water Works Association
1. AWWA C901 - AWWA Standard for Polyethylene (PE) Pressure Pipe and Tubing, ½ In. (13 mm) through 3 In. (76 mm), for Water Service

1.3 Submittals

A. Section 01 33 00 - Submittals

B. Product Data: Submit data on pipe sizes, materials and fittings. Submit manufacturers catalog information.

C. Submittals shall be furnished in accordance with Section 01 33 00 - Submittals.
1. Fabrication drawings for piping system. Drawings shall include materials list; piping layout; joining methods; fittings; type, size, and spacing of perforations/screen size.
2. Certificates for pipe manufacturer's quality control tests, and for calibration of acceptance testing equipment.
3. Records demonstrating personnel qualifications.
4. Documentation including test records and as-built drawings.
5. Samples of field-fabricated pipes shall be submitted to the Engineer for approval prior to installation.

1.4 Qualifications

A. Manufacturer: Company specializing in manufacturing Products specified with minimum 5 years documented experience.

B. Installer: Company specializing in performing work of this Section with minimum 5 years documented experience.

1.5 Delivery, Storage, and Handling

A. All necessary precautions shall be taken to prevent damage or contamination to pipe and other materials during shipment and delivery.

B. All materials shall be securely fastened to truck or rail car to prevent movement or damage during shipment.

C. The Contractor shall examine all materials before loading.

D. Section 01 60 00 - Product Requirements: Requirements for transporting, handling, storing, and protecting products.

E. Furnish temporary end caps and closures on piping and fittings. Maintain in place until installation.

F. Protect piping from entry of foreign materials by temporary covers, completing sections of the Work, and isolating parts of completed system.

G. All pipe materials shall be handled in such a manner as to prevent damage. HDPE pipe shall not be dropped, rolled or pushed off from any height during delivery, storage or installation.

H. All pipe materials shall be stored off the ground in a dry location.

I. All pipe materials shall be stored in such a manner as to prevent sagging or bending.

PART 2 PRODUCTS

2.1 High Density Polyethylene Pipes

A. Polyethylene Pipe: Pipe shall be provided in diameters, pressure classes, and dimension ratios (DR) as shown on the plans and in accordance with ASTM D3035. Also:
1. HDPE pipe shall be manufactured from extra high molecular weight polyethylene pipe materials meeting the requirements of cell classification PE345434C Standard PE Code Designation PE3408 as defined by ASTM D3350.
2. Fittings: AWWA C901, molded.
3. Joints: Butt fusion by a qualified technician, trained by an approved manufacturer's representative, and in accordance with the manufacturer's recommended procedures.

B. Typical Material Physical Properties: All pipe and fitting materials shall meet these typical physical properties:
1. The HDPE pipes shall be able to withstand a live load of 80,000 pounds generated by a dual axle vehicle driven directly over the buried pipe with a minimum soil cover thickness of 1.5 feet.

2. Specific Gravity - 0.94 minimum as determined by ASTM D1505.
3. Carbon Black Content - 2 percent minimum as determined by ASTM D1603.
4. Melt Index - 0.1 to 1.1 g per 10 min as determined by ASTM D1238 Condition 190.2.16.
5. All HDPE pipes shall have Standard Diameter Ratio (SDR) of 11.
6. All HDPE pipes shall demonstrate adequate physical and chemical resistance to typical vapors generated in municipal solid waste landfills.
7. HDPE pipe shall be manufactured from first quality polyethylene resin containing no more than 2 percent recycled polymer by weight. Resin shall be Type III, Category 5, Class C, Grade 34 per ASTM D 1248. The cell classification shall be 345434C per ASTM D3350. Pipe shall be rated PE3408. Workmanship shall be as specified by ASTM F714.
8. HDPE vapor extraction piping beneath the cover geomembrane, and elsewhere as shown on the Drawings, shall be 0.04 inch slot perforated unless otherwise noted.

C. HDPE Pipe Quality
1. The pipe shall have uniform wall thickness and shall be uniform in color, opacity, density, and other physical properties. Pipe shall be homogeneous throughout and free of visible cracks, holes, blisters, bubbles, un-dispersed raw materials, or any contamination by foreign matter. Any pipe with nicks, scrapes, or gouges deeper than 5 percent of the nominal wall thickness shall be rejected.
2. Pipe may be supplied in a continuous extruded seamless piece or in sections.

2.2 Fittings

A. The fittings shall be manufactured from the same cell class resin and fully pressure rated to the same pressure rating as the designed piping system.

B. Shall have a controlled outside diameter and produced to the SDR/DR rating for the pressure specified by the Engineer.

C. Shall be specifically manufactured to the standardized dimensions noted on the Drawings.

D. Butt fusion fittings shall be manufactured from the same material as the extruded pipe.

E. Shall be rated for the pressure service at least equal to that of the system pipe.

F. Shall have outlets manufactured to the same DR as that of system pipe.

G. Molded fittings shall be manufactured in accordance with ASTM D3261. Socket fittings shall be manufactured in accordance with ASTM D2683.

H. Couplings
1. Couplings for socket fusion, if necessary, shall satisfy the specifications listed for HDPE pipe, except that other cell classifications are acceptable.
2. All molded fittings and reducers, flange adapters, stub ends, and transition fittings shall be fully pressure rated to match the pipe SDR pressure rating to which they are made.

2.3 Manufacturer's Quality Control Certificates

A. Prior to shipment, the HDPE pipe Manufacturer shall submit a quality control certificate for each lot/batch of HDPE pipe provided. The quality control certificate shall be signed by a responsible party employed by the HDPE pipe Manufacturer, such as the Production Manager. The quality control certificate shall include both:
1. Lot/batch numbers and identification.
2. Sampling procedures and results of quality control tests.

PART 3 EXECUTION

3.1 Examination

A. Contractor shall inspect all piping to ensure that the piping is free from defects in material and workmanship.

B. Compatibility of all pipe and fittings shall be verified.

C. Pipe, fittings and accessories that are cracked, damaged, not identified or in poor condition shall be rejected.

D. Any pipe section or fitting containing scratches, dents or marks that exceed 10 percent of the calculated wall thickness shall be deemed unusable and rejected, or the suspect section or fitting removed from service.

E. The Engineer shall have free access to all joints and test joints for determining the suitability of the joining process.

F. Where construction restrictions limit inspection of joints, the Engineer may have the person joining the pipe and or fittings perform a test joint in the presence of the Engineer.

G. The Engineer shall determine the method of testing either by visual examination or bent strap testing.

3.2 Dimensions

A. Piping dimensions shown on the Drawings are approximate. It is the Contractor's responsibility to furnish and install piping of the proper dimensions, which shall properly fit with the connecting elements, pipes, fittings, etc.

3.3 Preparation

A. Remove burrs.

B. Remove scale and dirt on inside and outside before assembly.

C. Prepare piping connections to equipment with flanges or unions.

D. Keep open ends of pipe free from scale and dirt. Protect open ends with temporary plugs or caps.

3.4 Joining

A. All joining of HDPE pipe to HDPE pipe, except as otherwise mentioned, shall be performed by thermal butt or socket fusion. Pipe shall be joined per ASTM D2657 and per Manufacturer's recommendations. Installation personnel who join HDPE pipe shall be experienced and certified in accordance with 49 CFR 192.285. The Contractor shall submit a list of proposed joining personnel and their qualifications to the Engineer for approval.

B. Bending HDPE Pipe

1. Pipe meeting the specifications delineated in Part 2 of this Section may be cold-bent to a minimum radius as recommended by the manufacturer as it is installed, instead of installing elbows for slight bends. The minimum bending radius that can be applied to the pipe without kinking it varies with the diameter and wall thickness of the pipe. If adequate space is not available for the required radius, a fitting of the desired angle may be fused into the piping system to obtain the necessary change in direction, as shown in the Drawings for pipe connections in the sumps and for the sideslope riser pipe.

3.5 Acceptance Testing

A. The Contractor shall receive approval from the Engineer prior to burying the pipe.

3.6 Contractor Quality Control

A. The Contractor shall establish and maintain a quality control system to assure compliance with Specifications and shall maintain records of quality control for all operations including but not limited to the following:

1. Conformance of materials to the requirements of this Section.
2. Installation in accordance with the requirements of this Section and Section 33 24 14 - Leachate and Well Riser Modification.
3. As-built locations of all piping.

3.7 Measurement and Payment

A. Measurement shall be based on dimensions shown on the Drawings or on authorized modifications established in writing by the Engineer. Measurement of pipe lengths includes all fittings, reducers, bends, and caps as shown on the Drawings. No additional allowance is made for perforation or fabrication of materials.

B. A description of measurement and payment for work covered by this Section is provided in Section 01 20 00 - Measurement and Payment, included in these Contract Documents.

END OF SECTION

Appendix D

Calculations

Appendix D1

Slope Stability Calculations

Appendix D1-1
Cell 14 Calculations

U.S. Ecology Idaho (USEI)
Slope Stability of Final Cover
Cell 14

Stability Calculations

Objective:

This calculation is performed to determine the stability of the final geometry of USEI cell 14 using the proposed cover design.

References:

1) Koerner, R. M. 1990. *Designing with Geosynthetics.* Second Edition. Prentice Hall, New Jersey.

2) Gundle/SLT Environmental, Inc. (GSE). 2006. GSE Technical Note 17. Direct Shear & Friction Angle Testing for GSE Membranes.

3) Geosynthetic Research Institute (GRI). 2006. Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes. GRI Test Method GM13.

4) GeoStudio 2007 (Version 7.12 Build 4250). Geoslope International, Ltd., Calgary, Alberta, Canada.

5) Washington Group International, Inc. 2002. Engineering Report for Landfill Cell 15 - Grand View Facility. Boise, Idaho.

6) USEPA, 1995. RCRA Subtitle D (258) Seismic design Guidance for Municipal Solid Waste Landfill Facilities. EPA/600/R-95/051. Washington D.C.

7) USGS National Seismic Hazard Map, 2008.

$\delta_1 := 26 \cdot deg$ friction angle between textured geomembrane and geocomposite peak value reference 2

$c_1 := 60 \cdot \frac{lbf}{ft^2}$ cohesion between textured geomembrane and geocomposite

$\delta_2 := 17 \cdot deg$ angle of shearing resistance between HDPE geomembrane and Mica Schist Sand

$c_2 := 0 \cdot \frac{lbf}{ft^2}$ reference 1 - Table 5.5 (a), Pg. 382

$\delta_3 := 15 \cdot deg$ angle of shearing resistance between HDPE and CL soil

$c_3 := 14 \frac{kN}{m^2}$ $c_3 = 292.396 \cdot \frac{lbf}{ft^2}$ reference 1 - Table 5.6, Soil No. 3, Pg. 384

$\delta_{min} := \min(\delta_1, \delta_2, \delta_3)$ $\delta_{min} = 15 \cdot deg$ weakest liner strength parameters

RCRA Subtitle C (40 CFR 264, 265) does not provide direction for seismic design. At a minimum, the landfill should satisfy the criteria for municipal waste landfills, RCRA Subtitle D, 40 CFR 258.14.

USEI cells 14 and 15 are located in a seismic impact zone. Seismic impact zones are defined as those regions having a peak bedrock acceleration exceeding 0.1 g based on a 90% probability of non-exceedance over a 250 year time period (reference 6).

$a_{max} := 0.11 \cdot g$ $a_{max} = 3.539 \cdot \frac{ft}{s^2}$ Peak Ground Acceleration (PGA) value from the USGS National Seismic Hazard Maps, 2008
2% probability of exceedance in 50 years

note: This value represents the maximum ***bedrock*** (lithified earth) acceleration in the area. Reference 5 (3.4.2) indicates that the surface of USEI is approximately 2,250 ft. to the Banbury formation, representing bedrock at the site. Soils at the site are described as (Reference 5, 3.2.3) silty and gravelly sands, silty sands, sandy silts, and silts. There are interspersed layers of clay. Soils are decribed as very hard to hard, but shear wave velocities are not available for the site.

Reference 6, Figure 4.4 and Figure 4.5 were used to relate the maximum bedrock acceleration to the landfill cover acceleration. Both figures consistently predict a surface acceleration of approximately 0.2g from a bedrock acceleration of 0.11g, for soft soils and/or municipal waste. The seismic, horizontal acceleration of 0.2g was used in this analysis.

$a_{max} := 0.2 \cdot g$ $a_{max} = 6.435 \cdot \frac{ft}{s^2}$

Slope Stability Calculations Using Slope/W (reference 4)

Static and seismic slope stability calculations were performed for the cross-section presented in Figure 1.

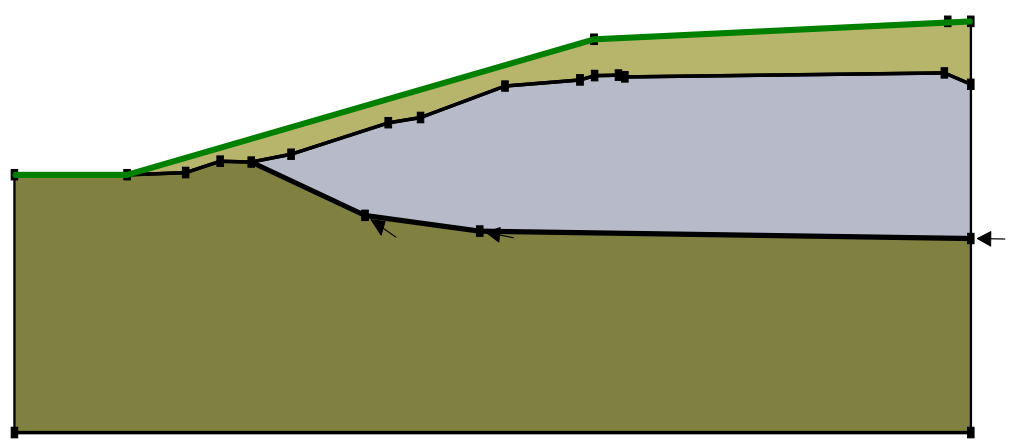

Figure 1. Profile of Cell 14 used for stability analysis.

Assumptions:

1) Saturated conditions were not considered in the analysis, due to the nature of the waste and depth to the groundwater.

2) The peak bedrock acceleration was obtained from the USGS National Seismic Hazard Maps, 2008, 2% probability of exceedance in 50 years.

3) The peak ground acceleration represents the value for bedrock in the area. The subsurface materials on top of the bedrock were considered to amplify the bedrock acceleration. The combination of waste and subgrade soils were treated as soft soil; a conservative estimate due to the lack of subgrade shear wave velocities from the site.

Summary of Minimum Factors of Safety

Method	Static FS	Seismic FS	Analysis
Morgenstern-Price	2.98	1.56	Circular
Ordinary	2.65	1.62	Circular
Bishop	2.98	1.85	Circular
Janbu	2.62	1.46	Circular
Morgenstern-Price	1.78	1.07	Auto Search
Ordinary	1.80	1.08	Auto Search
Bishop	1.80	1.09	Auto Search
Janbu	1.79	1.07	Auto Search
Morgenstern-Price	1.78	1.07	Block
Ordinary	1.78	1.08	Block
Bishop	1.81	1.10	Block
Janbu	1.78	1.07	Block

Conclusion

A 3:1 (horizontal:vertical) sloped ET soil cover will be adequately stable against typical seismic events expected at this site. Critical failure surfaces are displayed in Figures 2 through 7, for static and seismic stability, respectively. Specific report analyses are attached to this calculation.

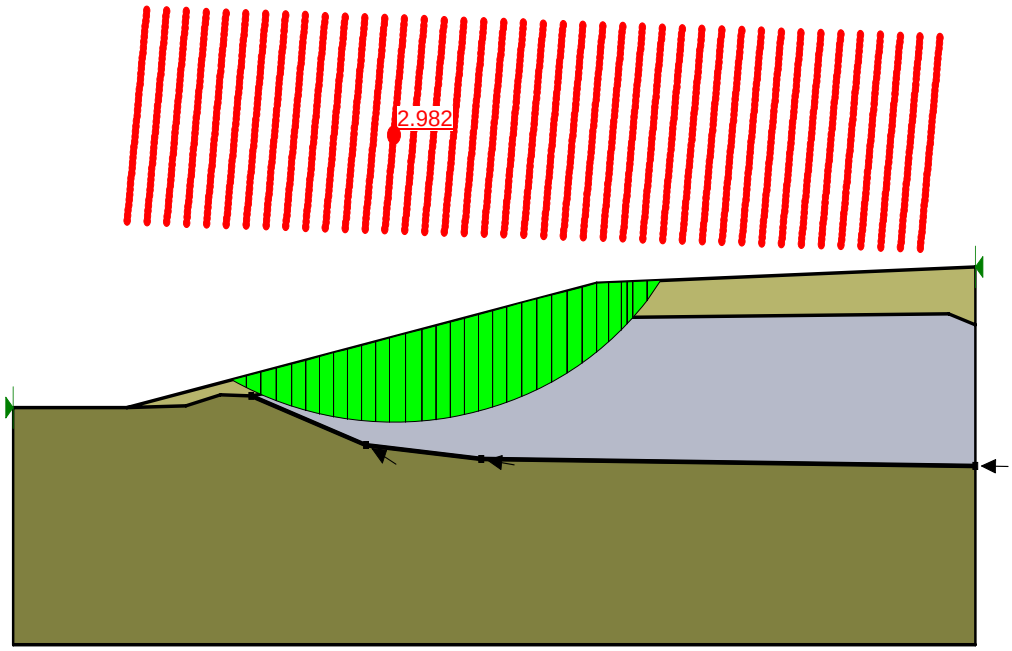

Figure 2. Failure surface and factor of safety for circular static analysis.

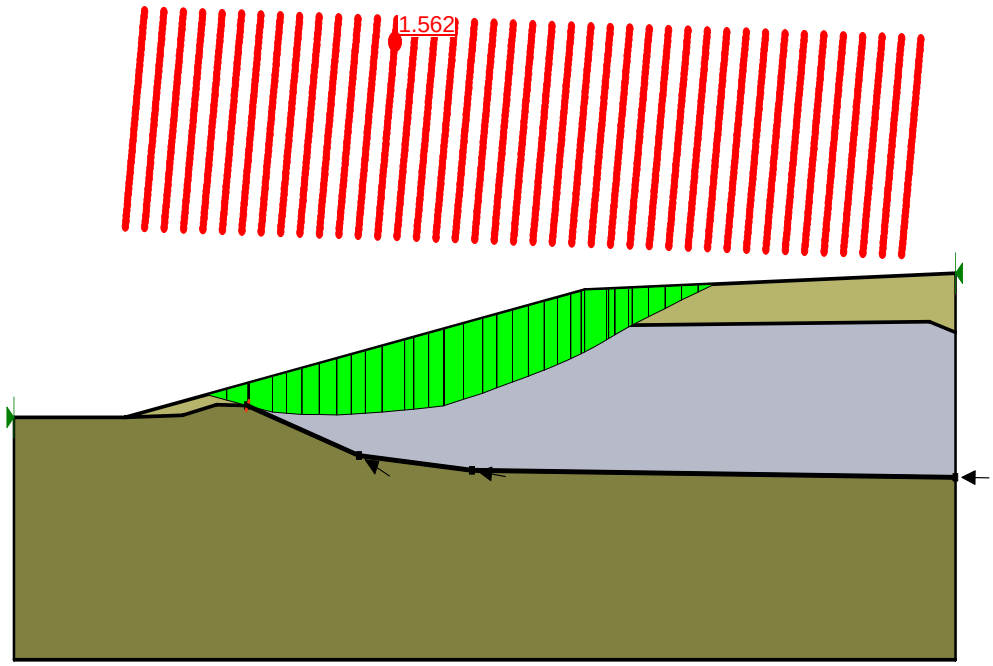

Figure 3. Failure surface and factor of safety for circular seismic analysis.

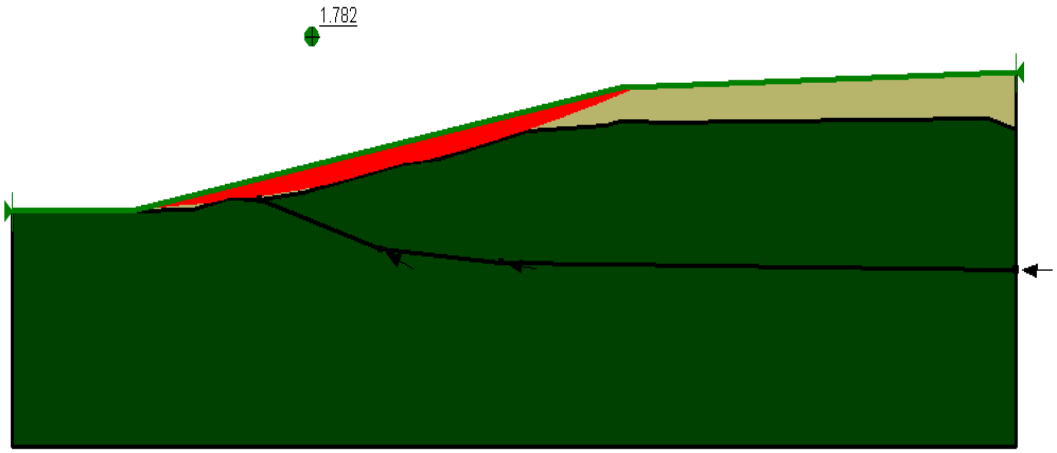

Figure 4. Failure surface and factor of safety for auto-search static analysis.

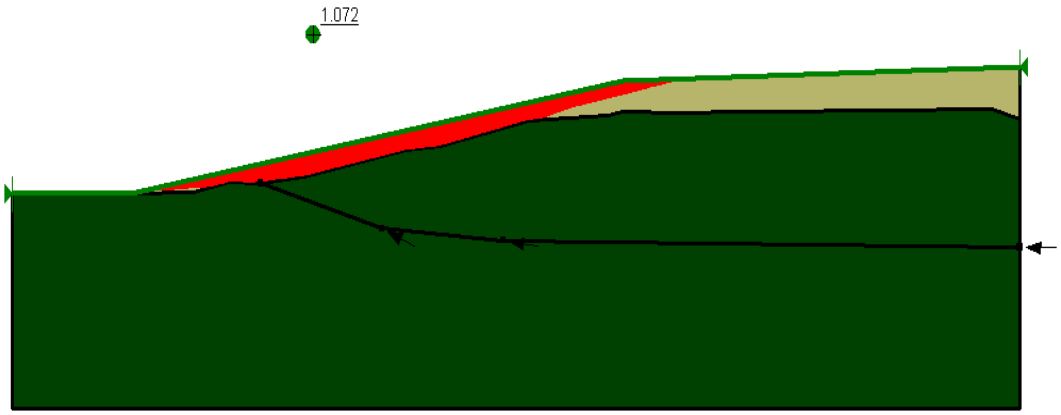

Figure 5. Failure surface and factor of safety for auto-search seismic analysis.

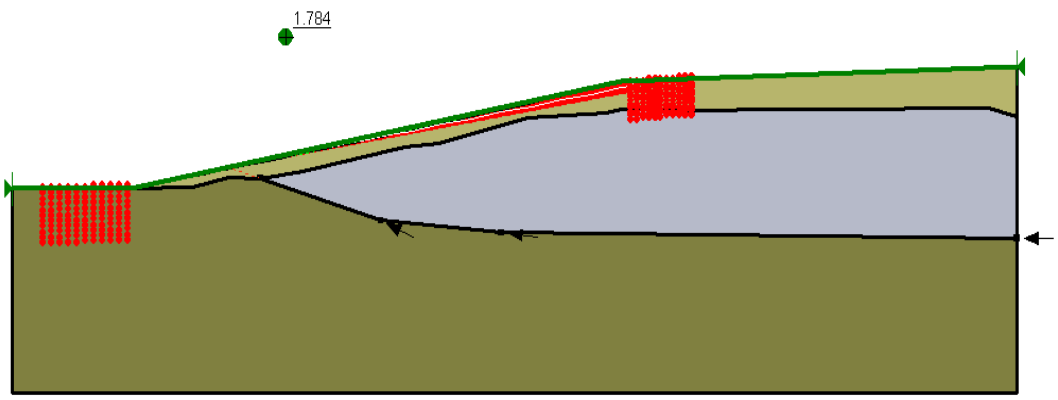

Figure 6. Failure surface and factor of safety for block static analysis.

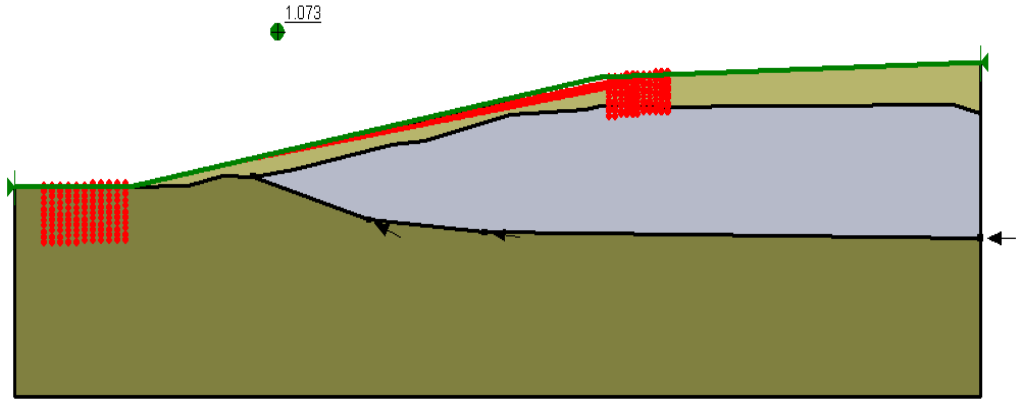

Figure 7. Failure surface and factor of safety for block seismic analysis.

USEI Cell 14 Profile 1

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File Information

Created By: Pease, Eric
Revision Number: 55
Last Edited By: Pease, Eric
Date: 11/25/2009
Time: 4:28:44 PM
File Name: USEI 14-1 complex static mod1.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Slope Stability\Mod - July 2009\Cell 14\
Last Solved Date: 11/25/2009
Last Solved Time: 4:29:24 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 14 Profile 1

Description: Complex rendition of profile 1
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Grid and Radius
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

FOS Distribution
- FOS Calculation Option: Constant

Advanced

Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (19.38763, 2805.6217) ft
Lower Left: (9.22004, 2687.8292) ft
Lower Right: (421.54803, 2672.5778) ft
Grid Horizontal Increment: 40
Grid Vertical Increment: 40
Left Projection Angle: 0 °
Right Projection Angle: 0 °

Slip Surface Radius

Upper Left Coordinate: (-9.38447, 2564.8447) ft
Upper Right Coordinate: (274.65889, 2582.3675) ft

Lower Left Coordinate: (-5.92317, 2468.4689) ft
Lower Right Coordinate: (272.06291, 2468.4689) ft
Number of Increments: 25
Left Projection: No
Left Projection Angle: 135 °
Right Projection: No
Right Projection Angle: 45 °
UsePoints: 0

Slip Surface Limits

Left Coordinate: (-50, 2583) ft
Right Coordinate: (450, 2662) ft

Seismic Loads

Horz Seismic Load: 0
Vert Seismic Load: 0

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (133.37, 2562) ft
Inside Point: (73.77, 2589.45) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 65.617547 ft
Reinforcement Direction: 335.27 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric

Outside Point: (193.34, 2554) ft
Inside Point: (133.37, 2562) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 60.501247 ft
Reinforcement Direction: 352.4 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (450, 2550.13) ft
Inside Point: (193.34, 2554) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 256.68917 ft
Reinforcement Direction: 359.14 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Regions

	Material	Points	Area (ft²)
Region 1	ET Cover	17,14,13,12,11,10,9,8,7,6,5,4,3,2,1,15	7358.9485
Region 2	Waste	4,18,19,20,14,13,12,11,10,9,8,7,6,5	25476.42
Region 3	Natural Subgrade	1,21,22,23,20,19,18,4,3,2	56823.03

Points

	X (ft)	Y (ft)
Point 1	8.99	2583
Point 2	39.66	2584
Point 3	57.67	2590
Point 4	73.77	2589.45
Point 5	94.7	2593.62
Point 6	145.54	2609.89
Point 7	162.39	2612.42
Point 8	206.43	2628.73
Point 9	245.68	2631.92
Point 10	253.3	2634.24
Point 11	265.9	2634.31
Point 12	269.07	2633.51
Point 13	436.21	2635.55
Point 14	450	2629.53
Point 15	253.14	2652.76
Point 16	437.96	2662
Point 17	450	2662
Point 18	133.37	2562
Point 19	193.34	2554
Point 20	450	2550.13
Point 21	-50	2583
Point 22	-50	2450
Point 23	450	2450

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	19527	2.982	(147.802, 2735.88)	161.031	(286.659, 2654.33)	(63.6141, 2598.61)

Slices of Slip Surface: 19527

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	19527	67.38404	2596.4335	0	375.52451	191.3393	0
2	19527	74.923905	2592.345	0	1113.0321	567.1182	0
3	19527	82.69538	2588.6615	0	1922.2275	1109.7986	125
4	19527	90.69846	2585.3735	0	2693.769	1555.2483	125

5	19527	98.33145	2582.6825	0	3368.7755	1944.9634	125
6	19527	105.5943	2580.5235	0	3946.7827	2278.6761	125
7	19527	112.85715	2578.7295	0	4450.7889	2569.6642	125
8	19527	120.12	2577.288	0	4877.3388	2815.9329	125
9	19527	127.38285	2576.1895	0	5225.7644	3017.0965	125
10	19527	134.6457	2575.4275	0	5497.1497	3173.7809	125
11	19527	141.90855	2574.997	0	5694.9014	3287.9529	125
12	19527	149.7525	2574.915	0	5819.2764	3359.7608	125
13	19527	158.1775	2575.238	0	5865.9974	3386.7352	125
14	19527	166.06	2575.929	0	5856.5197	3381.2632	125
15	19527	173.4	2576.939	0	5807.5879	3353.0124	125
16	19527	180.74	2578.297	0	5716.9132	3300.6614	125
17	19527	188.08	2580.0125	0	5590.6047	3227.7371	125
18	19527	195.42	2582.0975	0	5433.6191	3137.1014	125
19	19527	202.76	2584.567	0	5249.8645	3031.0107	125
20	19527	210.355	2587.555	0	5020.4612	2898.5646	125
21	19527	218.205	2591.119	0	4746.6264	2740.4661	125
22	19527	226.055	2595.2115	0	4447.56	2567.8	125
23	19527	233.905	2599.88	0	4120.7594	2379.1215	125
24	19527	241.755	2605.1865	0	3761.2016	2171.5308	125
25	19527	249.41	2611.044	0	3381.4144	1952.2605	125
26	19527	256.37	2617.0305	0	2931.0997	1692.2712	125
27	19527	262.75	2623.1945	0	2394.364	1382.3867	125
28	19527	267.485	2628.169	0	1963.7987	1133.7997	125
29	19527	270.6038	2631.7385	0	1654.7741	955.38428	125
30	19527	275.76805	2638.3085	0	1211.2472	617.16127	0
31	19527	283.029	2648.7015	0	425.56399	216.83568	0

USEI Cell 14 Profile 1

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File Information

Created By: Pease, Eric
Revision Number: 50
Last Edited By: Pease, Eric
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Time: 3:10:08 PM
File Name: USEI 14-1 complex seismic mod1.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Slope Stability\Mod - July 2009\Cell 14\
Last Solved Date: 7/8/2009
Last Solved Time: 3:10:42 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 14 Profile 1

Description: Complex rendition of profile 1
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: (none)
SlipSurface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: Yes
    Tension Crack
        Tension Crack Option: (none)

FOS Distribution
FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (19.38763, 2805.6217) ft
Lower Left: (9.22004, 2687.8292) ft
Lower Right: (421.54803, 2672.5778) ft
Grid Horizontal Increment: 40
Grid Vertical Increment: 40
Left Projection Angle: 0 °
Right Projection Angle: 0 °

Slip Surface Radius

Upper Left Coordinate: (-9.38447, 2564.8447) ft
Upper Right Coordinate: (274.65889, 2582.3675) ft
Lower Left Coordinate: (-5.92317, 2468.4689) ft
Lower Right Coordinate: (272.06291, 2468.4689) ft
Number of Increments: 25
Left Projection: No
Left Projection Angle: 135 °
Right Projection: No
Right Projection Angle: 45 °
UsePoints: 0

Slip Surface Limits

Left Coordinate: (-50, 2583) ft
Right Coordinate: (450, 2662) ft

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (133.37, 2562) ft
Inside Point: (73.77, 2589.45) ft
Slip Surface Intersection: (74.275, 2589.2) ft
Total Length: 65.617547 ft
Reinforcement Direction: 335.27 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 122.6 lbs

Resisting Force Used: 220.72 lbs/ft
Available Bond Length: 0.55545 ft
Required Bond Length: 0.55545 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (193.34, 2554) ft
Inside Point: (133.37, 2562) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 60.501247 ft
Reinforcement Direction: 352.4 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (450, 2550.13) ft
Inside Point: (193.34, 2554) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 256.68917 ft
Reinforcement Direction: 359.14 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0

Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Regions

	Material	Points	Area (ft^2)
Region 1	ET Cover	17,14,13,12,11,10,9,8,7,6,5,4,3,2,1,15	7358.9485
Region 2	Waste	4,18,19,20,14,13,12,11,10,9,8,7,6,5	25476.42
Region 3	Natural Subgrade	1,21,22,23,20,19,18,4,3,2	56823.03

Points

	X (ft)	Y (ft)
Point 1	8.99	2583
Point 2	39.66	2584
Point 3	57.67	2590
Point 4	73.77	2589.45
Point 5	94.7	2593.62
Point 6	145.54	2609.89
Point 7	162.39	2612.42
Point 8	206.43	2628.73
Point 9	245.68	2631.92
Point 10	253.3	2634.24
Point 11	265.9	2634.31
Point 12	269.07	2633.51
Point 13	436.21	2635.55
Point 14	450	2629.53
Point 15	253.14	2652.76
Point 16	437.96	2662
Point 17	450	2662
Point 18	133.37	2562
Point 19	193.34	2554
Point 20	450	2550.13
Point 21	-50	2583

Point 22	-50	2450
Point 23	450	2450

Critical Slip Surfaces

	Number	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.562	(152.377, 2788.89)	123.0115	(321.98, 2655.99)	(52.6018, 2595.46)
2	38715	1.764	(152.377, 2788.89)	213.656	(319.584, 2655.88)	(58.2589, 2597.08)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	57.80816	2593.961	0	414.99826	211.45218	0
2	Optimized	68.644525	2590.8395	0	1339.4038	682.46033	0
3	Optimized	74.56721	2589.1335	0	1834.8946	1059.3769	125
4	Optimized	81.118295	2587.5235	0	2583.9533	1491.8461	125
5	Optimized	91.038345	2585.6555	0	3166.8738	1828.3955	125
6	Optimized	98.8191	2584.9285	0	3722.608	2149.2487	125
7	Optimized	107.57085	2584.507	0	4013.0892	2316.9581	125
8	Optimized	116.8362	2584.433	0	4501.2347	2598.789	125
9	Optimized	125.269	2584.5805	0	4669.3617	2695.8573	125
10	Optimized	132.8692	2584.95	0	4958.4863	2862.7834	125
11	Optimized	141.10465	2585.5175	0	5058.4096	2920.4741	125
12	Optimized	151.55455	2586.4185	0	5327.4948	3075.8305	125
13	Optimized	159.97955	2587.22	0	5350.209	3088.9446	125
14	Optimized	166.3553	2587.969	0	5466.4223	3156.0404	125
15	Optimized	174.28585	2588.901	0	5613.8216	3241.1414	125
16	Optimized	178.4134	2589.418	0	4778.2108	2758.7013	125
17	Optimized	183.67775	2591.1925	0	4625.946	2670.7911	125
18	Optimized	193.8818	2594.64	0	4515.926	2607.2711	125
19	Optimized	202.7069	2597.782	0	4268.3033	2464.3061	125
20	Optimized	210.62945	2600.799	0	4154.4258	2398.5588	125
21	Optimized	219.02835	2603.997	0	4029.1376	2326.2237	125
22	Optimized	227.42725	2607.1955	0	3913.7524	2259.606	125

23	Optimized	235.14005	2610.409	0	3586.6332	2070.7437	125
24	Optimized	242.1667	2613.637	0	3459.5091	1997.3485	125
25	Optimized	248.5005	2616.5465	0	3357.4242	1938.4098	125
26	Optimized	252.2305	2618.365	0	3070.0722	1772.507	125
27	Optimized	258.9421	2622.2245	0	2774.2335	1601.7044	125
28	Optimized	265.3221	2625.9115	0	2424.316	1399.6795	125
29	Optimized	267.485	2627.2235	0	2310.3762	1333.8963	125
30	Optimized	272.73185	2630.406	0	2037.4398	1176.3164	125
31	Optimized	277.348	2633.125	0	1888.3605	1090.2454	125
32	Optimized	282.68145	2635.907	0	1705.1186	868.80134	0
33	Optimized	291.4397	2640.475	0	1346.1356	685.89037	0
34	Optimized	300.1979	2645.043	0	971.46105	494.98413	0
35	Optimized	308.9277	2649.493	0	594.86351	303.0981	0
36	Optimized	317.6291	2653.825	0	202.52643	103.19237	0

Slices of Slip Surface: 38715

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	38715	62.460655	2595.1275	0	458.80086	233.77071	0
2	38715	70.864225	2591.443	0	1375.6715	700.93964	0
3	38715	79.974505	2587.9395	0	2497.4125	1441.8818	125
4	38715	89.7915	2584.6665	0	3622.0522	2091.1928	125
5	38715	98.93665	2582.0675	0	4589.8842	2649.9709	125
6	38715	107.41	2580.0605	0	5391.2526	3112.6411	125
7	38715	115.88335	2578.4135	0	6074.2365	3506.9621	125
8	38715	124.35665	2577.1185	0	6627.2089	3826.2208	125
9	38715	132.83	2576.1685	0	7045.8048	4067.8973	125
10	38715	141.30335	2575.559	0	7332.5733	4233.4632	125
11	38715	149.7525	2575.2875	0	7483.5894	4320.6523	125
12	38715	158.1775	2575.3505	0	7514.3802	4338.4294	125
13	38715	166.794	2575.763	0	7467.6072	4311.425	125
14	38715	175.602	2576.5425	0	7355.771	4246.8564	125
15	38715	184.41	2577.692	0	7180.9281	4145.9108	125
16	38715	193.218	2579.218	0	6960.3523	4018.5613	125
17	38715	202.026	2581.128	0	6708.5814	3873.2013	125

18	38715	210.355	2583.287	0	6437.597	3716.7483	125
19	38715	218.205	2585.6655	0	6156.1678	3554.2651	125
20	38715	226.055	2588.379	0	5870.8417	3389.532	125
21	38715	233.905	2591.442	0	5583.7327	3223.7696	125
22	38715	241.755	2594.871	0	5294.739	3056.919	125
23	38715	249.41	2598.581	0	5020.8067	2898.7641	125
24	38715	259.52	2604.184	0	4490.8128	2592.772	125
25	38715	267.485	2608.8985	0	4003.3687	2311.346	125
26	38715	274.1287	2613.422	0	3561.5969	2056.2889	125
27	38715	284.24605	2620.9035	0	2871.166	1657.6685	125
28	38715	294.3634	2629.3775	0	2108.8178	1217.5265	125
29	38715	304.46245	2638.9945	0	1386.7409	706.57978	0
30	38715	314.54315	2649.994	0	492.02257	250.69802	0

USEI Cell 14

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File Information

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File Name: USEI 14-1 auto-locate static.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 4:37:48 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 14

Description: Auto Locate Slip Surface - Static Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Auto-Search
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: Yes

FOS Distribution
- FOS Calculation Option: Constant

Advanced
- Number of Slices: 30
- Optimization Tolerance: 0.01

Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Impenetrable

Model: Bedrock (Impenetrable)

Slip Surface Limits

Left Coordinate: (-50, 2583) ft
Right Coordinate: (450, 2662) ft

Seismic Loads

Horz Seismic Load: 0
Vert Seismic Load: 0

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (133.37, 2562) ft
Inside Point: (73.77, 2589.45) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 65.617547 ft
Reinforcement Direction: 335.27 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs

Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (193.34, 2554) ft
Inside Point: (133.37, 2562) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 60.501247 ft
Reinforcement Direction: 352.4 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (450, 2550.13) ft
Inside Point: (193.34, 2554) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 256.68917 ft
Reinforcement Direction: 359.14 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs

Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.782	(-234.715, 4017.83)	17.24709	(183.126, 2632.76)	(145.088, 2621.89)
2	11	1.783	(-234.715, 4017.83)	1446.674	(178.927, 2631.55)	(146.482, 2622.28)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	145.53535	2621.944	0	6.9932015	3.5632141	0
2	Optimized	146.7097	2622.1605	0	18.300456	9.324548	0
3	Optimized	148.04165	2622.484	0	23.414913	11.930494	0
4	Optimized	149.25215	2622.812	0	25.149941	12.814535	0
5	Optimized	150.40725	2623.1395	0	25.098792	12.788473	0
6	Optimized	151.50695	2623.466	0	23.921918	12.188826	0
7	Optimized	152.6729	2623.815	0	22.294745	11.35974	0
8	Optimized	153.9051	2624.1875	0	20.364279	10.376119	0
9	Optimized	155.00475	2624.518	0	18.924024	9.642272	0
10	Optimized	155.97185	2624.8055	0	17.844719	9.0923383	0
11	Optimized	157.1156	2625.1475	0	16.333534	8.3223514	0
12	Optimized	158.43605	2625.545	0	14.47333	7.3745301	0
13	Optimized	159.75655	2625.9425	0	12.619653	6.4300345	0
14	Optimized	161.0972	2626.3515	0	10.114787	5.1537415	0
15	Optimized	162.45805	2626.7725	0	7.1278749	3.6318337	0
16	Optimized	163.7773	2627.163	0	6.0119866	3.0632602	0
17	Optimized	165.0549	2627.523	0	6.4951424	3.3094404	0
18	Optimized	166.1811	2627.8565	0	5.2218823	2.6606819	0
19	Optimized	167.15585	2628.164	0	2.5689215	1.3089309	0
20	Optimized	168.21645	2628.4735	0	2.0559966	1.0475826	0
21	Optimized	169.36295	2628.785	0	3.591639	1.8300315	0
22	Optimized	170.4789	2629.0965	0	4.2242633	2.1523696	0
23	Optimized	171.56425	2629.408	0	4.0630961	2.0702509	0
24	Optimized	172.6496	2629.72	0	3.9019289	1.9881321	0
25	Optimized	173.93935	2630.0995	0	2.8505112	1.452408	0

26	Optimized	175.4335	2630.5465	0	0.96927767	0.49387164	0
27	Optimized	176.73185	2630.9255	0	0.24786844	0.12629528	0
28	Optimized	177.8344	2631.236	0	0.68824504	0.35067836	0
29	Optimized	178.9782	2631.5615	0	0.79243257	0.40376456	0
30	Optimized	180.16325	2631.9025	0	0.56612985	0.28845756	0
31	Optimized	181.3483	2632.2435	0	0.33974603	0.17310925	0
32	Optimized	182.53335	2632.5845	0	0.113273	0.057715478	0

Slices of Slip Surface: 11

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	11	147.02325	2622.433	0	0.61959571	0.31569978	0
2	11	148.10475	2622.7295	0	1.8163919	0.92549792	0
3	11	149.1862	2623.0265	0	2.9282522	1.492019	0
4	11	150.26765	2623.3245	0	3.9549634	2.0151545	0
5	11	151.34915	2623.6235	0	4.8963039	2.4947914	0
6	11	152.43065	2623.9235	0	5.7521556	2.9308697	0
7	11	153.5121	2624.2245	0	6.5222058	3.3232298	0
8	11	154.59355	2624.526	0	7.2064298	3.6718594	0
9	11	155.67505	2624.8285	0	7.8046982	3.9766924	0
10	11	156.75655	2625.132	0	8.3170656	4.2377566	0
11	11	157.838	2625.4365	0	8.7435054	4.4550385	0
12	11	158.91945	2625.742	0	9.0837019	4.6283773	0
13	11	160.00095	2626.0485	0	9.3387942	4.7583533	0
14	11	161.08245	2626.3555	0	9.5074957	4.844311	0
15	11	162.1639	2626.6635	0	9.5907525	4.8867325	0
16	11	163.24535	2626.9725	0	9.588621	4.8856464	0
17	11	164.32685	2627.2825	0	9.5011581	4.8410818	0
18	11	165.40835	2627.5935	0	9.3284295	4.7530722	0
19	11	166.48985	2627.905	0	9.0704761	4.6216384	0
20	11	167.5713	2628.2175	0	8.7272834	4.446773	0
21	11	168.65275	2628.531	0	8.2993455	4.2287277	0
22	11	169.73425	2628.8455	0	7.7865432	3.9674419	0
23	11	170.81575	2629.161	0	7.1888469	3.6629005	0
24	11	171.8972	2629.4775	0	6.506233	3.3150913	0
25	11	172.97865	2629.7945	0	5.7385717	2.9239483	0
26	11	174.06015	2630.1125	0	4.8856682	2.4893723	0
27	11	175.14165	2630.4315	0	3.9475773	2.0113911	0
28	11	176.2231	2630.7515	0	2.9239144	1.4898088	0
29	11	177.30455	2631.0725	0	1.8144816	0.92452457	0
30	11	178.38605	2631.394	0	0.61918789	0.31549199	0

USEI Cell 14

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File Information

Created By: Pease, Eric
Revision Number: 74
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 4:23:20 PM
File Name: USEI 14-1 auto-locate seismic.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 4:23:30 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 14

Description: Auto Locate Slip Surface - Seismic Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Auto-Search
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: Yes

FOS Distribution
- FOS Calculation Option: Constant

Advanced
- Number of Slices: 30
- Optimization Tolerance: 0.01

Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Impenetrable

Model: Bedrock (Impenetrable)

Slip Surface Limits

Left Coordinate: (-50, 2583) ft
Right Coordinate: (450, 2662) ft

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (133.37, 2562) ft
Inside Point: (73.77, 2589.45) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 65.617547 ft
Reinforcement Direction: 335.27 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1

Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (193.34, 2554) ft
Inside Point: (133.37, 2562) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 60.501247 ft
Reinforcement Direction: 352.4 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (450, 2550.13) ft
Inside Point: (193.34, 2554) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 256.68917 ft
Reinforcement Direction: 359.14 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1

Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.072	(-234.715, 4017.83)	15.52098	(180.531, 2632.01)	(146.308, 2622.24)
2	11	1.073	(-234.715, 4017.83)	1446.674	(178.927, 2631.55)	(146.482, 2622.28)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	146.788	2622.344	0	3.1395034	1.5996569	0
2	Optimized	147.7488	2622.562	0	9.460128	4.820176	0
3	Optimized	148.7096	2622.7795	0	15.844194	8.0730203	0
4	Optimized	149.6418	2623.0045	0	20.120845	10.252083	0
5	Optimized	150.5454	2623.2375	0	22.954374	11.695838	0
6	Optimized	151.51695	2623.494	0	25.119079	12.79881	0
7	Optimized	152.5565	2623.774	0	27.002801	13.758615	0
8	Optimized	153.8447	2624.1275	0	28.427052	14.484306	0
9	Optimized	155.3703	2624.5555	0	29.159802	14.857661	0
10	Optimized	156.5625	2624.893	0	29.468073	15.014733	0
11	Optimized	157.4325	2625.139	0	29.685929	15.125736	0
12	Optimized	158.55745	2625.466	0	28.712524	14.629762	0
13	Optimized	159.9373	2625.8735	0	27.262649	13.891014	0
14	Optimized	161.24345	2626.262	0	25.452542	12.968718	0
15	Optimized	162.47595	2626.632	0	23.552461	12.000578	0
16	Optimized	163.5454	2626.9535	0	21.855249	11.135806	0
17	Optimized	164.45175	2627.2265	0	20.395134	10.39184	0
18	Optimized	165.3639	2627.5005	0	18.964353	9.6628202	0
19	Optimized	166.28185	2627.776	0	17.540226	8.9371917	0
20	Optimized	167.3375	2628.095	0	15.675944	7.9872926	0
21	Optimized	168.5309	2628.457	0	13.473983	6.8653373	0
22	Optimized	169.7243	2628.819	0	11.273625	5.744199	0
23	Optimized	170.95375	2629.199	0	8.1643452	4.1599417	0
24	Optimized	172.2192	2629.597	0	4.3516541	2.2172785	0

25	Optimized	173.41815	2629.9515	0	3.2283777	1.6449406	0
26	Optimized	174.5506	2630.262	0	4.6354599	2.3618848	0
27	Optimized	175.68305	2630.5725	0	6.0394763	3.0772669	0
28	Optimized	176.7317	2630.8685	0	6.3670214	3.2441595	0
29	Optimized	177.6965	2631.1495	0	5.773456	2.9417228	0
30	Optimized	178.76685	2631.471	0	4.0755895	2.0766166	0
31	Optimized	179.94275	2631.833	0	1.361158	0.69354463	0

Slices of Slip Surface: 11

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	11	147.02325	2622.433	0	0.70945358	0.36148466	0
2	11	148.10475	2622.7295	0	2.0795325	1.0595747	0
3	11	149.1862	2623.0265	0	3.352165	1.7080134	0
4	11	150.26765	2623.3245	0	4.5269232	2.3065826	0
5	11	151.34915	2623.6235	0	5.6037705	2.8552637	0
6	11	152.43065	2623.9235	0	6.5824197	3.3539103	0
7	11	153.5121	2624.2245	0	7.4627424	3.8024572	0
8	11	154.59355	2624.526	0	8.2445454	4.2008057	0
9	11	155.67505	2624.8285	0	8.9276175	4.5488483	0
10	11	156.75655	2625.132	0	9.5131784	4.8472065	0
11	11	157.838	2625.4365	0	9.9988074	5.0946469	0
12	11	158.91945	2625.742	0	10.387221	5.2925533	0
13	11	160.00095	2626.0485	0	10.67672	5.4400606	0
14	11	161.08245	2626.3555	0	10.86825	5.5376502	0
15	11	162.1639	2626.6635	0	10.961876	5.5853549	0
16	11	163.24535	2626.9725	0	10.957662	5.5832076	0
17	11	164.32685	2627.2825	0	10.855673	5.5312417	0
18	11	165.40835	2627.5935	0	10.656873	5.4299481	0
19	11	166.48985	2627.905	0	10.36042	5.2788979	0
20	11	167.5713	2628.2175	0	9.9672879	5.0785868	0
21	11	168.65275	2628.531	0	9.4775325	4.829044	0
22	11	169.73425	2628.8455	0	8.8912208	4.5303033	0
23	11	170.81575	2629.161	0	8.2073549	4.1818562	0
24	11	171.8972	2629.4775	0	7.4270745	3.7842835	0
25	11	172.97865	2629.7945	0	6.5499014	3.3373415	0
26	11	174.06015	2630.1125	0	5.575828	2.8410263	0
27	11	175.14165	2630.4315	0	4.5046507	2.2952342	0
28	11	176.2231	2630.7515	0	3.3360817	1.6998185	0
29	11	177.30455	2631.0725	0	2.0701098	1.0547737	0
30	11	178.38605	2631.394	0	0.70631532	0.35988563	0

USEI Cell 14

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File Information

Created By: Pease, Eric
Revision Number: 71
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 4:51:22 PM
File Name: USEI 14-1 static block.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 4:51:38 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 14

Description: Optimized Block Slip Surface - Static Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: (none)
SlipSurface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Block
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: Yes
FOS Distribution
    FOS Calculation Option: Constant
Restrict Block Crossing: Yes
Advanced
    Number of Slices: 30

Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

Slip Surface Limits

Left Coordinate: (-50, 2583) ft
Right Coordinate: (450, 2662) ft

Slip Surface Block

Left Grid

Upper Left: (-34.75578, 2583.0482) ft
Lower Left: (-34.75578, 2547.7509) ft
Lower Right: (7.63116, 2549.561) ft
X Increments: 10
Y Increments: 10
Starting Angle: 135 °
Ending Angle: 180 °

Angle Increments: 2
Right Grid
Upper Left: (258.03089, 2652.059) ft
Lower Left: (258.03089, 2628.0749) ft
Lower Right: (288.04869, 2631.6952) ft
X Increments: 10
Y Increments: 10
Starting Angle: 45 °
Ending Angle: 65 °
Angle Increments: 2

Seismic Loads

Horz Seismic Load: 0
Vert Seismic Load: 0

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (133.37, 2562) ft
Inside Point: (73.77, 2589.45) ft
Slip Surface Intersection: (59.815, 2595.9) ft
Total Length: 65.617547 ft
Reinforcement Direction: 335.27 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 25.869 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (193.34, 2554) ft
Inside Point: (133.37, 2562) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 60.501247 ft

Reinforcement Direction: 352.4 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (450, 2550.13) ft
Inside Point: (193.34, 2554) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 256.68917 ft
Reinforcement Direction: 359.14 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.784	(135.942, 2668.61)	110.6834	(252.884, 2652.69)	(9.30422, 2583.09)
2	1883	1.874	(135.942, 2668.61)	100.395	(260.441, 2653.1)	(37.2949, 2591.09)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	12.90316	2583.987	0	12.468188	6.3528588	0
2	Optimized	20.101035	2585.781	0	37.458485	19.086051	0
3	Optimized	27.29891	2587.575	0	62.528318	31.859769	0
4	Optimized	34.49679	2589.369	0	87.673642	44.671952	0
5	Optimized	41.487985	2591.1195	0	111.29466	56.707463	0
6	Optimized	48.272495	2592.8265	0	133.55617	68.050266	0
7	Optimized	55.428405	2594.6945	0	149.35652	76.100947	0
8	Optimized	62.95571	2596.724	0	160.91356	81.989556	0
9	Optimized	70.483015	2598.7535	0	172.47061	87.878164	0
10	Optimized	79.8418	2601.364	0	177.09869	90.236287	0
11	Optimized	88.56064	2603.8205	0	181.24091	92.346856	0
12	Optimized	94.808055	2605.542	0	187.21283	95.389703	0
13	Optimized	101.67838	2607.4555	0	191.28096	97.462519	0
14	Optimized	109.1716	2609.5605	0	194.59575	99.151486	0
15	Optimized	116.4068	2611.578	0	199.74715	101.77626	0
16	Optimized	123.38405	2613.508	0	205.72852	104.82391	0
17	Optimized	130.31495	2615.4645	0	206.48881	105.2113	0
18	Optimized	137.19945	2617.448	0	204.85577	104.37923	0
19	Optimized	144.08395	2619.4315	0	203.23668	103.55426	0
20	Optimized	151.4126	2621.571	0	198.05391	100.91351	0
21	Optimized	159.18545	2623.867	0	191.00876	97.323823	0
22	Optimized	166.4171	2625.9855	0	186.62611	95.090752	0
23	Optimized	173.1075	2627.927	0	183.79822	93.649873	0
24	Optimized	181.4322	2630.391	0	174.91349	89.122872	0
25	Optimized	191.3912	2633.3775	0	161.84258	82.462915	0
26	Optimized	201.43415	2636.416	0	145.84601	74.312251	0
27	Optimized	211.08715	2639.3625	0	128.40543	65.425834	0
28	Optimized	220.2663	2642.166	0	111.70355	56.915804	0
29	Optimized	227.90455	2644.5325	0	94.298009	48.047235	0
30	Optimized	234.00185	2646.4615	0	77.035215	39.251403	0
31	Optimized	241.00875	2648.7415	0	51.081355	26.02725	0
32	Optimized	248.92525	2651.372	0	17.060684	8.6928524	0

Slices of Slip Surface: 1883

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	1883	41.01635	2592.0745	0	7.1866613	3.6617868	0
2	1883	48.459285	2594.0495	0	21.568684	10.989794	0
3	1883	55.90222	2596.0245	0	35.962525	18.323822	0
4	1883	63.345155	2597.9995	0	50.366755	25.663143	0

5	1883	70.78809	2599.9745	0	64.782672	33.00842	0
6	1883	78.231025	2601.95	0	79.205082	40.357005	0
7	1883	85.67396	2603.9255	0	93.635284	47.70956	0
8	1883	93.116895	2605.9005	0	108.06808	55.063438	0
9	1883	100.55983	2607.8755	0	122.50218	62.417979	0
10	1883	108.00275	2609.8505	0	136.93888	69.773842	0
11	1883	115.4457	2611.8255	0	151.36648	77.125074	0
12	1883	122.88865	2613.8005	0	165.7811	84.469689	0
13	1883	130.33155	2615.7755	0	180.18273	91.807687	0
14	1883	137.7745	2617.7505	0	194.58436	99.145685	0
15	1883	145.21745	2619.7255	0	208.96002	106.47045	0
16	1883	152.66035	2621.7005	0	223.3227	113.7886	0
17	1883	160.1033	2623.6755	0	237.6594	121.09351	0
18	1883	167.54625	2625.6505	0	251.97013	128.38519	0
19	1883	174.98915	2627.6255	0	266.26787	135.67026	0
20	1883	182.4321	2629.6005	0	280.52666	142.93547	0
21	1883	189.87505	2631.5755	0	294.77245	150.19407	0
22	1883	197.318	2633.5505	0	308.99228	157.43943	0
23	1883	204.76095	2635.5255	0	323.18613	164.67156	0
24	1883	212.20385	2637.5005	0	337.35402	171.89046	0
25	1883	219.6468	2639.4755	0	351.50891	179.10274	0
26	1883	227.08975	2641.4505	0	365.65082	186.3084	0
27	1883	234.53265	2643.4255	0	379.76676	193.50083	0
28	1883	241.9756	2645.4005	0	393.8827	200.69326	0
29	1883	249.41855	2647.3755	0	407.99863	207.88569	0
30	1883	255.58545	2649.012	0	364.33695	185.63895	0
31	1883	259.236	2651.382	0	120.38949	61.341508	0

USEI Cell 14

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File Information

Created By: Pease, Eric
Revision Number: 74
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 4:44:19 PM
File Name: USEI 14-1 seismic block.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 4:44:46 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 14

Description: Optimized Block Slip Surface - Seismic Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: (none)
SlipSurface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Block
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: Yes
FOS Distribution
    FOS Calculation Option: Constant
Restrict Block Crossing: Yes
Advanced
    Number of Slices: 30

Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

Slip Surface Limits

Left Coordinate: (-50, 2583) ft
Right Coordinate: (450, 2662) ft

Slip Surface Block

Left Grid

Upper Left: (-34.75578, 2583.0482) ft
Lower Left: (-34.75578, 2547.7509) ft
Lower Right: (7.63116, 2549.561) ft
X Increments: 10
Y Increments: 10
Starting Angle: 135 °
Ending Angle: 180 °

Angle Increments: 2
Right Grid
Upper Left: (258.03089, 2652.059) ft
Lower Left: (258.03089, 2628.0749) ft
Lower Right: (288.04869, 2631.6952) ft
X Increments: 10
Y Increments: 10
Starting Angle: 45 °
Ending Angle: 65 °
Angle Increments: 2

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (133.37, 2562) ft
Inside Point: (73.77, 2589.45) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 65.617547 ft
Reinforcement Direction: 335.27 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (193.34, 2554) ft
Inside Point: (133.37, 2562) ft
Slip Surface Intersection: (0, 0) ft

Total Length: 60.501247 ft
Reinforcement Direction: 352.4 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (450, 2550.13) ft
Inside Point: (193.34, 2554) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 256.68917 ft
Reinforcement Direction: 359.14 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.073	(190.891, 2661.36)	54.04393	(253.2, 2652.76)	(135.415, 2619.12)

2	1026	1.110	(190.891, 2661.36)	54.272	(258.474, 2653.01)	(137.099, 2619.6)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	136.89215	2619.388	0	17.716154	9.0268315	0
2	Optimized	139.84585	2619.918	0	53.501027	27.260135	0
3	Optimized	143.0346	2620.583	0	79.595988	40.556181	0
4	Optimized	146.45845	2621.383	0	99.785787	50.843398	0
5	Optimized	150.20295	2622.2995	0	115.82719	59.0169	0
6	Optimized	154.268	2623.332	0	130.42391	66.4543	0
7	Optimized	159.14695	2624.626	0	139.65867	71.159647	0
8	Optimized	164.0451	2625.971	0	145.31846	74.043452	0
9	Optimized	168.1485	2627.105	0	149.52786	76.188252	0
10	Optimized	172.25195	2628.2385	0	153.69968	78.313901	0
11	Optimized	176.3885	2629.397	0	154.99129	78.972009	0
12	Optimized	180.55815	2630.581	0	155.63959	79.302332	0
13	Optimized	184.92025	2631.837	0	153.12786	78.02254	0
14	Optimized	189.4747	2633.1655	0	149.92825	76.39226	0
15	Optimized	193.5831	2634.362	0	147.55479	75.182921	0
16	Optimized	197.24555	2635.4255	0	145.56984	74.17154	0
17	Optimized	201.0725	2636.5385	0	143.16854	72.948013	0
18	Optimized	205.0639	2637.7015	0	140.64288	71.661128	0
19	Optimized	208.54915	2638.732	0	135.48192	69.031488	0
20	Optimized	211.52825	2639.63	0	130.48443	66.485137	0
21	Optimized	214.953	2640.659	0	125.34862	63.868312	0
22	Optimized	218.8234	2641.8195	0	119.64151	60.960392	0
23	Optimized	222.91145	2643.059	0	111.55725	56.841259	0
24	Optimized	227.21715	2644.3775	0	102.39905	52.174923	0
25	Optimized	231.1792	2645.5925	0	93.7687	47.777539	0
26	Optimized	234.7976	2646.7035	0	85.77169	43.702859	0
27	Optimized	238.2384	2647.783	0	75.101423	38.266086	0
28	Optimized	241.50155	2648.8305	0	63.214279	32.209284	0
29	Optimized	244.8009	2649.919	0	47.640007	24.273796	0
30	Optimized	248.13655	2651.0485	0	29.423958	14.992256	0
31	Optimized	251.4722	2652.178	0	11.064794	5.6377942	0
32	Optimized	253.17	2652.753	0	0.91855811	0.46802874	0

Slices of Slip Surface: 1026

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	1026	139.0992	2620.141	0	3.771398	1.9216233	0
2	1026	143.10065	2621.215	0	11.323125	5.7694202	0
3	1026	147.1021	2622.289	0	18.889575	9.6247191	0

4	1026	151.1035	2623.3625	0	26.473404	13.488873	0
5	1026	155.10495	2624.436	0	34.074128	17.361636	0
6	1026	159.1064	2625.51	0	41.696576	21.245467	0
7	1026	163.1078	2626.584	0	49.33592	25.137907	0
8	1026	167.10925	2627.658	0	56.989746	29.037726	0
9	1026	171.1107	2628.732	0	64.650813	32.941235	0
10	1026	175.1121	2629.806	0	72.316708	36.847203	0
11	1026	179.11355	2630.88	0	79.975361	40.749482	0
12	1026	183.115	2631.9535	0	87.617119	44.643152	0
13	1026	187.1164	2633.027	0	95.232325	48.523293	0
14	1026	191.1178	2634.101	0	102.80891	52.383758	0
15	1026	195.11925	2635.175	0	110.33964	56.220855	0
16	1026	199.1207	2636.249	0	117.81968	60.032126	0
17	1026	203.1221	2637.323	0	125.24662	63.81634	0
18	1026	207.12355	2638.397	0	132.62528	67.575957	0
19	1026	211.125	2639.471	0	139.9605	71.313438	0
20	1026	215.1264	2640.545	0	147.26193	75.0337	0
21	1026	219.12785	2641.6185	0	154.54163	78.742895	0
22	1026	223.1293	2642.692	0	161.81168	82.447169	0
23	1026	227.1307	2643.766	0	169.08414	86.152674	0
24	1026	231.1321	2644.84	0	176.3735	89.866787	0
25	1026	235.13355	2645.914	0	183.68458	93.591969	0
26	1026	239.135	2646.988	0	191.02704	97.333139	0
27	1026	243.1364	2648.062	0	198.40329	101.09153	0
28	1026	247.13785	2649.136	0	205.81092	104.8659	0
29	1026	251.1393	2650.2095	0	213.24993	108.65627	0
30	1026	255.58545	2651.4025	0	158.13711	80.574882	0
31	1026	258.2527	2652.5345	0	27.662114	14.094551	0

Appendix D1-2
Cell 15 Calculations

U.S. Ecology Idaho (USEI)
Slope Stability of Final Cover
Cell 15

Stability Calculations

Objective:

This calculation is performed to determine the stability of the final geometry of USEI cell 15 using the proposed cover design.

References:

1) Koerner, R. M. 1990. *Designing with Geosynthetics.* Second Edition. Prentice Hall, New Jersey.

2) Gundle/SLT Environmental, Inc. (GSE). 2006. GSE Technical Note 17. Direct Shear & Friction Angle Testing for GSE Membranes.

3) Geosynthetic Research Institute (GRI). 2006. Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes. GRI Test Method GM13.

4) GeoStudio 2007 (Version 7.12 Build 4250). Geoslope International, Ltd., Calgary, Alberta, Canada.

5) Washington Group International, Inc. 2002. Engineering Report for Landfill Cell 15 - Grand View Facility. Boise, Idaho.

6) USEPA, 1995. RCRA Subtitle D (258) Seismic design Guidance for Municipal Solid Waste Landfill Facilities. EPA/600/R-95/051. Washington D.C.

7) USGS National Seismic Hazard Map, 2008.

$\delta_1 := 26 \cdot deg$ friction angle between textured geomembrane and geocomposite peak value reference 2

$c_1 := 60 \cdot \frac{lbf}{ft^2}$ cohesion between textured geomembrane and geocomposite

$\delta_2 := 17 \cdot deg$ angle of shearing resistance between HDPE geomembrane and Mica Schist Sand

$c_2 := 0 \cdot \frac{lbf}{ft^2}$ reference 1 - Table 5.5 (a), Pg. 382

$\delta_3 := 15 \cdot deg$ angle of shearing resistance between HDPE and CL soil

$c_3 := 14 \frac{kN}{m^2}$ $c_3 = 292.396 \cdot \frac{lbf}{ft^2}$ reference 1 - Table 5.6, Soil No. 3, Pg. 384

$\delta_{min} := \min(\delta_1, \delta_2, \delta_3)$ $\delta_{min} = 15 \cdot deg$ weakest liner strength parameters

RCRA Subtitle C (40 CFR 264, 265) does not provide direction for seismic design. At a minimum, the landfill should satisfy the criteria for municipal waste landfills, RCRA Subtitle D, 40 CFR 258.14.

USEI cells 14 and 15 are located in a seismic impact zone. Seismic impact zones are defined as those regions having a peak bedrock acceleration exceeding 0.1 g based on a 90% probability of non-exceedance over a 250 year time period (reference 6).

$a_{max} := 0.11 \cdot g$ $a_{max} = 3.539 \cdot \frac{ft}{s^2}$ Peak Ground Acceleration (PGA) value from the USGS National Seismic Hazard Maps, 2008
2% probability of exceedance in 50 years

note: This value represents the maximum ***bedrock*** (lithified earth) acceleration in the area. Reference 5 (3.4.2) indicates that the surface of USEI is approximately 2,250 ft. to the Banbury formation, representing bedrock at the site. Soils at the site are described as (Reference 5, 3.2.3) silty and gravelly sands, silty sands, sandy silts, and silts. There are interspersed layers of clay. Soils are decribed as very hard to hard, but shear wave velocities are not available for the site.

Reference 6, Figure 4.4 and Figure 4.5 were used to relate the maximum bedrock acceleration to the landfill cover acceleration. Both figures consistently predict a surface acceleration of approximately 0.2g from a bedrock acceleration of 0.11g, for soft soils and/or municipal waste. The seismic, horizontal acceleration of 0.2g was used in this analysis.

$a_{max} := 0.2 \cdot g$ $a_{max} = 6.435 \cdot \frac{ft}{s^2}$

Slope Stability Calculations Using Slope/W (reference 4)

Static and seismic slope stability calculations were performed for the cross-section presented in Figure 1.

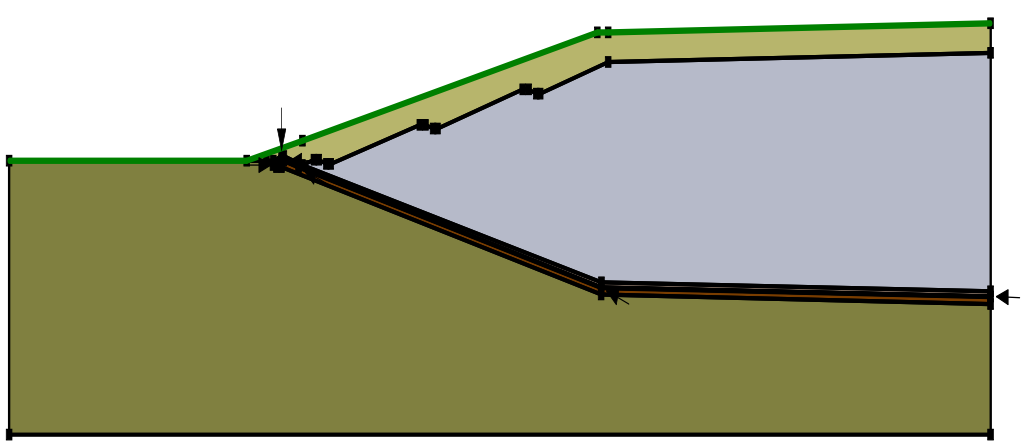

Figure 1. Profile of Cell 15 used for stability analysis.

Assumptions:

1) Saturated conditions were not considered in the analysis, due to the nature of the waste and depth to the groundwater.

2) The peak bedrock acceleration was obtained from the USGS National Seismic Hazard Maps, 2008, 2% probability of exceedance in 50 years.

3) The peak ground acceleration represents the value for bedrock in the area. The subsurface materials on top of the bedrock were considered to amplify the bedrock acceleration. The combination of waste and subgrade soils were treated as soft soil; a conservative estimate due to the lack of subgrade shear wave velocities from the site.

Summary of Minimum Factors of Safety

Method	Static FS	Seismic FS	Geometry
Morgenstern-Price	2.96	1.76	Circular
Ordinary	2.62	1.54	Circular
Bishop	2.99	1.78	Circular
Janbu	2.59	1.50	Circular
Morgenstern-Price	1.65	1.02	Auto Search
Ordinary	1.65	1.02	Auto Search
Bishop	1.65	1.02	Auto Search
Janbu	1.65	1.02	Auto Search
Morgenstern-Price	1.66	1.02	Block
Ordinary	1.66	1.04	Block
Bishop	1.74	1.08	Block
Janbu	1.66	1.02	Block

Conclusion

A 3:1 (horizontal:vertical) sloped ET soil cover will be adequately stable against typical seismic events expected at this site. Critical failure surfaces are displayed in Figures 2 through 7, for static and seismic stability, respectively. Specific report analyses are attached to this calculation.

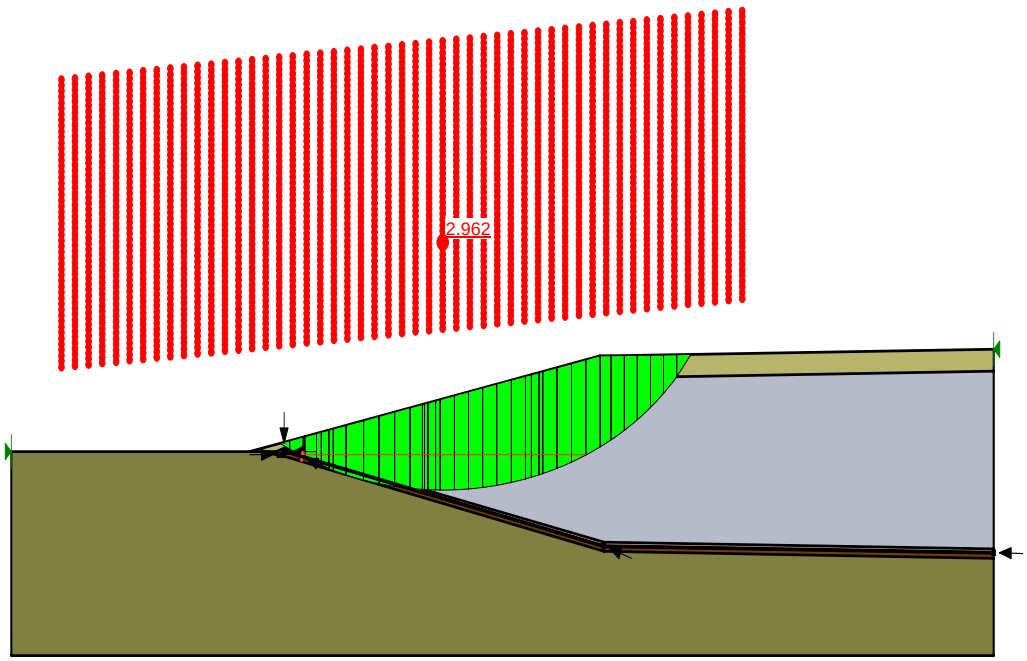

Figure 2. Failure surface and factor of safety for static analysis.

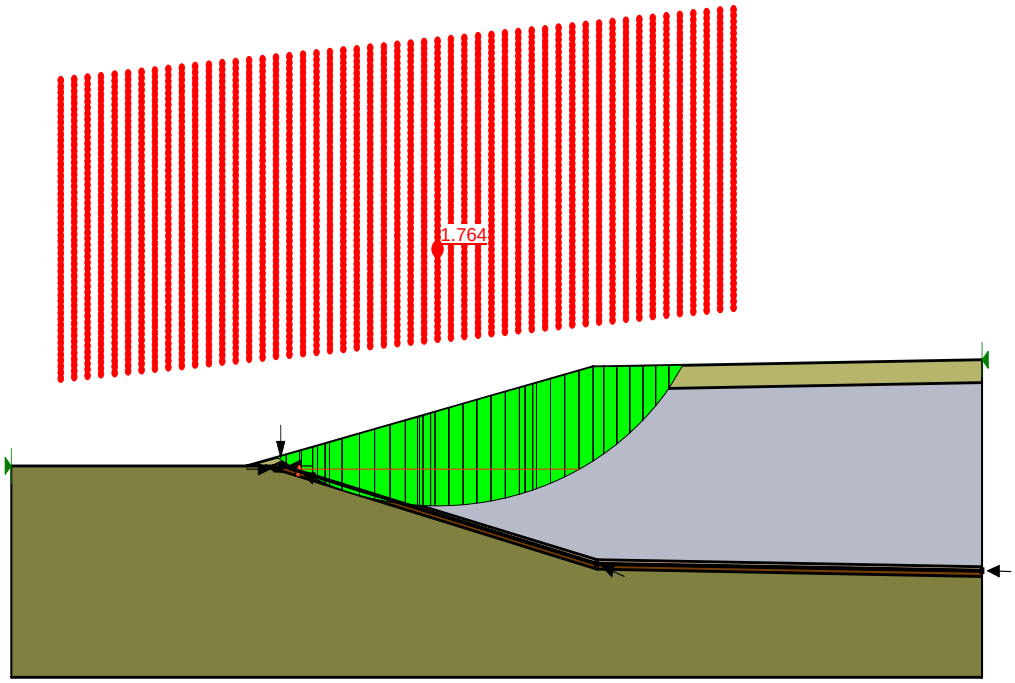

Figure 3. Failure surface and factor of safety for seismic analysis.

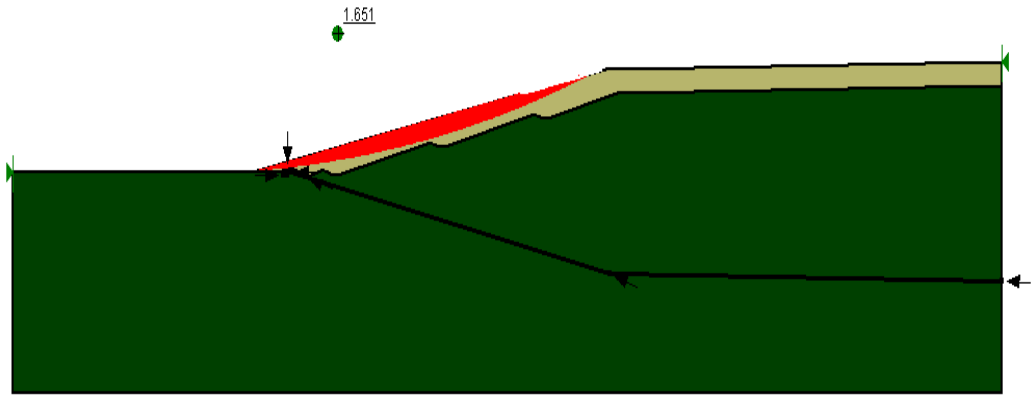

Figure 4. Failure surface and factor of safety for auto-search static analysis.

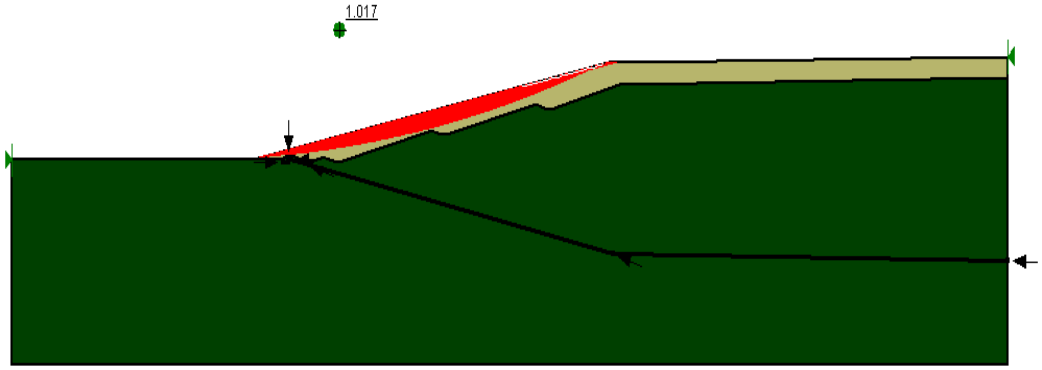

Figure 5. Failure surface and factor of safety for auto-search seismic analysis.

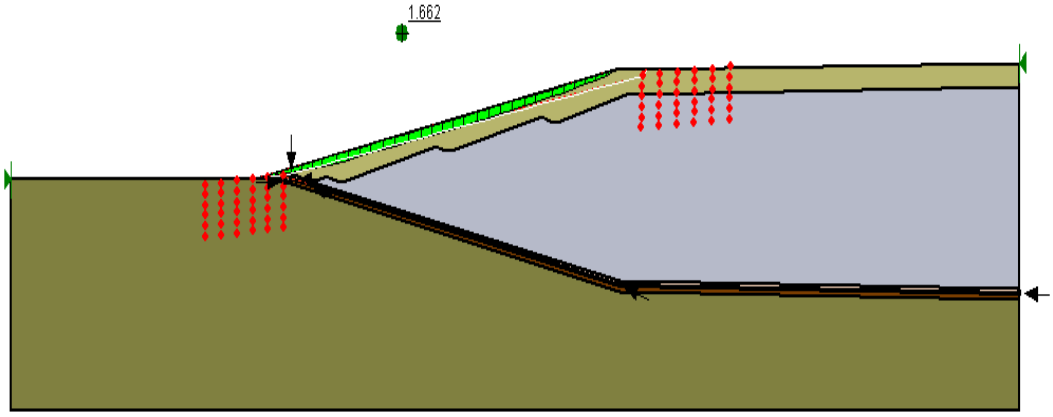

Figure 6. Failure surface and factor of safety for block static analysis.

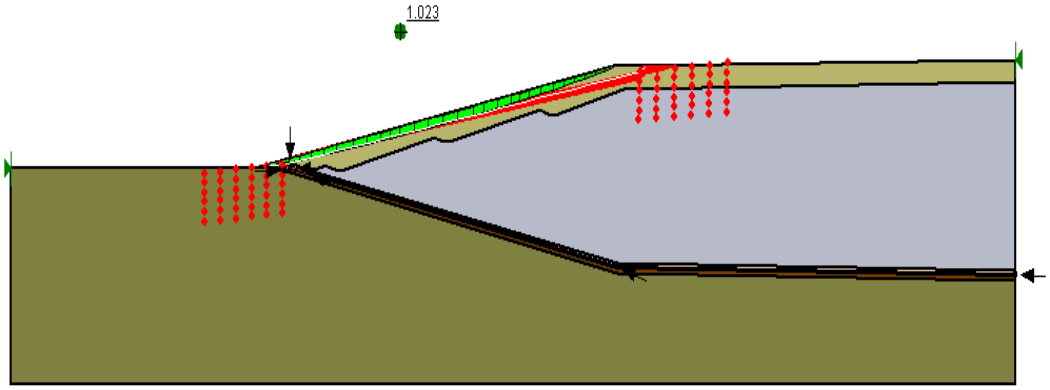

Figure 7. Failure surface and factor of safety for block seismic analysis.

USEI Cell 15 Profile 1

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File Information

Created By: Pease, Eric
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File Name: USEI 15-1 complex static mod2.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Slope Stability\Mod - July 2009\
Last Solved Date: 7/8/2009
Last Solved Time: 11:06:34 AM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15 Profile 1

Description: Complex rendition of profile 1
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: (none)
SlipSurface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack
        Tension Crack Option: (none)

FOS Distribution
FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

CCL

Model: Mohr-Coulomb
Unit Weight: 94 pcf
Cohesion: 60 psf
Phi: 22 °
Phi-B: 0 °

Common Fill

Model: Mohr-Coulomb

Unit Weight: 124.8 pcf
Cohesion: 1000 psf
Phi: 31 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (-69.42868, 2895.3305) ft
Lower Left: (-69.42868, 2698.0223) ft
Lower Right: (346.5513, 2745.1749) ft
Grid Horizontal Increment: 50
Grid Vertical Increment: 50
Left Projection Angle: 0 °
Right Projection Angle: 0 °

Slip Surface Radius

Upper Left Coordinate: (-30.36379, 2614.2465) ft
Upper Right Coordinate: (269.33712, 2613.3309) ft
Lower Left Coordinate: (-30.36379, 2519.9414) ft
Lower Right Coordinate: (268.72673, 2520.857) ft
Number of Increments: 25
Left Projection: No
Left Projection Angle: 135 °
Right Projection: No
Right Projection Angle: 45 °
UsePoints: 0

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2710.457) ft

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (251.15, 2638) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf

Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 644.02 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable

F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (262.00762, 2575.3308) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (78.287, 2636.6) ft
Total Length: 195.01515 ft

Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 122.49 lbs
Resisting Force Used: 90.322 lbs/ft
Available Bond Length: 1.3562 ft
Required Bond Length: 1.3562 ft
Governing Component: Bond

Reinforcement 6

Type: Fabric
Outside Point: (500, 2570.57) ft
Inside Point: (262.00762, 2575.3308) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 238.03999 ft
Reinforcement Direction: 358.85 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Regions

	Material	Points	Area (ft²)

Region 1	ET Cover	31,35,34,33,32,3,5,6,7,8,9,18,19,20,21,22,23,24,25,26,27,28,29,30	6808.3767
Region 2	Waste	9,18,19,20,21,22,23,24,25,26,27,28,29,30,31,37,36	37753.97
Region 3	CCL	11,16,17,41,39,38,40,15,14,13,12	1563.5952
Region 4	Common Fill	15,14,13,12,11,10,5,6,7,8,9,36,37,38,40	1100.1293
Region 5	Natural Subgrade	17,16,11,10,5,3,2,1,4,39,41	60191.552

Points

	X (ft)	Y (ft)
Point 1	-100	2500
Point 2	-100	2640
Point 3	45.2	2640
Point 4	500	2500
Point 5	57.3	2640
Point 6	61.5	2640
Point 7	66.5	2642.5
Point 8	68	2642.5
Point 9	79.32	2637.93
Point 10	61.3	2638
Point 11	63.5	2638
Point 12	66.5	2638
Point 13	66.5	2640
Point 14	68	2640
Point 15	77	2637
Point 16	63.5	2636.9
Point 17	66.5	2636.9
Point 18	86.3	2640.58
Point 19	89.28	2640.58
Point 20	93.94	2638.58
Point 21	96.7	2638.45
Point 22	151.08	2658.58
Point 23	154.45	2658.58

Point 24	159.09	2656.58
Point 25	161.81	2656.58
Point 26	213.95	2676.58
Point 27	217.58	2676.58
Point 28	222.2	2674.58
Point 29	224.58	2674.58
Point 30	266.29	2690.78
Point 31	500	2695.407
Point 32	79.32	2650.31
Point 33	259.63	2705.97
Point 34	266.29	2705.83
Point 35	500	2710.457
Point 36	262.03	2578.05
Point 37	500	2573.29
Point 38	500	2570.57
Point 39	500	2566.97
Point 40	262.00762	2575.3308
Point 41	262.00933	2571.7302

Critical Slip Surfaces

	Number	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	20619	2.590	(163.52, 2783.62)	169.965	(315.133, 2706.8)	(64.1536, 2645.73)

Slices of Slip Surface: 20619

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	20619	67.085645	2643.706	0	341.74428	174.12741	0
2	20619	74.152125	2639.128	0	1438.8995	864.57806	1000
3	20619	78.80329	2636.274	0	1607.3111	649.39583	60
4	20619	82.81	2634.093	0	2004.3102	809.79388	60
5	20619	87.79	2631.4675	0	2483.2706	1003.3064	60
6	20619	91.61	2629.638	0	2799.0841	1130.9034	60
7	20619	95.32	2627.9455	0	3093.2153	1249.7401	60

8	20619	100.5733	2625.796	0	3522.2886	1423.097	60
9	20619	109.802	2622.466	0	4235.1887	1711.1273	60
10	20619	119.8774	2619.4265	0	4941.0287	1996.3052	60
11	20619	129.31745	2617.202	0	5530.6778	2234.5389	60
12	20619	138.7575	2615.5365	0	6057.1654	2447.2537	60
13	20619	147.27875	2614.476	0	6538.8154	3928.9167	1000
14	20619	151.66395	2614.07	0	6684.428	4016.4096	1000
15	20619	153.34895	2613.963	0	6705.0451	3871.1596	125
16	20619	156.77	2613.805	0	6786.6667	3918.2839	125
17	20619	160.45	2613.6885	0	6868.7317	3965.6641	125
18	20619	166.155	2613.731	0	7011.3548	4048.0076	125
19	20619	174.845	2614.0885	0	7201.7863	4157.9533	125
20	20619	183.535	2614.8945	0	7336.937	4235.9825	125
21	20619	192.225	2616.1545	0	7417.1456	4282.291	125
22	20619	200.915	2617.8795	0	7442.3805	4296.8604	125
23	20619	209.605	2620.0845	0	7411.8969	4279.2607	125
24	20619	215.765	2621.895	0	7353.1089	4245.3194	125
25	20619	219.89	2623.2935	0	7266.7462	4195.4579	125
26	20619	223.39	2624.554	0	7184.0403	4147.7076	125
27	20619	228.96125	2626.8305	0	7063.1041	4077.8851	125
28	20619	237.72375	2630.786	0	6841.8214	3950.1274	125
29	20619	246.48625	2635.365	0	6554.8481	3784.4433	125
30	20619	255.24875	2640.6275	0	6197.5108	3578.1345	125
31	20619	262.96	2645.8415	0	5728.9064	3307.5856	125
32	20619	270.30135	2651.4865	0	5098.2164	2943.4566	125
33	20619	278.3241	2658.406	0	4345.7449	2509.017	125
34	20619	286.34685	2666.283	0	3519.027	2031.7112	125
35	20619	294.36955	2675.329	0	2608.0032	1505.7314	125
36	20619	302.3923	2685.875	0	1599.4341	923.4337	125
37	20619	310.7682	2699.1855	0	569.03545	289.93805	0

USEI Cell 15 Profile 1

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File Information

Created By: Pease, Eric
Revision Number: 38
Last Edited By: Pease, Eric
Date: 7/8/2009
Time: 11:11:43 AM
File Name: USEI 15-1 complex seismic mod2.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Slope Stability\Mod - July 2009\
Last Solved Date: 7/8/2009
Last Solved Time: 11:12:57 AM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15 Profile 1

Description: Complex rendition of profile 1
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: (none)
SlipSurface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Grid and Radius
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack
        Tension Crack Option: (none)

FOS Distribution
FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

CCL

Model: Mohr-Coulomb
Unit Weight: 94 pcf
Cohesion: 60 psf
Phi: 22 °
Phi-B: 0 °

Common Fill

Model: Mohr-Coulomb

Unit Weight: 124.8 pcf
Cohesion: 1000 psf
Phi: 31 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (-69.42868, 2895.3305) ft
Lower Left: (-69.42868, 2698.0223) ft
Lower Right: (346.5513, 2745.1749) ft
Grid Horizontal Increment: 50
Grid Vertical Increment: 50
Left Projection Angle: 0 °
Right Projection Angle: 0 °

Slip Surface Radius

Upper Left Coordinate: (-30.36379, 2614.2465) ft
Upper Right Coordinate: (269.33712, 2613.3309) ft
Lower Left Coordinate: (-30.36379, 2519.9414) ft
Lower Right Coordinate: (268.72673, 2520.857) ft
Number of Increments: 25
Left Projection: No
Left Projection Angle: 135 °
Right Projection: No
Right Projection Angle: 45 °
UsePoints: 0

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2710.457) ft

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft

Slip Surface Intersection: (251.15, 2638) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 1083.7 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric

Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (262.00762, 2575.3308) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (78.287, 2636.6) ft
Total Length: 195.01515 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 206.13 lbs
Resisting Force Used: 151.99 lbs/ft
Available Bond Length: 1.3562 ft
Required Bond Length: 1.3562 ft
Governing Component: Bond

Reinforcement 6

Type: Fabric
Outside Point: (500, 2570.57) ft
Inside Point: (262.00762, 2575.3308) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 238.03999 ft
Reinforcement Direction: 358.85 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft

Required Bond Length: 0 ft
Governing Component: Bond

Regions

	Material	Points	Area (ft²)
Region 1	ET Cover	31,35,34,33,32,3,5,6,7,8,9,18,19,20,21,22,23,24,25,26,27,28,29,30	6808.3767
Region 2	Waste	9,18,19,20,21,22,23,24,25,26,27,28,29,30,31,37,36	37753.97
Region 3	CCL	11,16,17,41,39,38,40,15,14,13,12	1563.5952
Region 4	Common Fill	15,14,13,12,11,10,5,6,7,8,9,36,37,38,40	1100.1293
Region 5	Natural Subgrade	17,16,11,10,5,3,2,1,4,39,41	60191.552

Points

	X (ft)	Y (ft)
Point 1	-100	2500
Point 2	-100	2640
Point 3	45.2	2640
Point 4	500	2500
Point 5	57.3	2640
Point 6	61.5	2640
Point 7	66.5	2642.5
Point 8	68	2642.5
Point 9	79.32	2637.93
Point 10	61.3	2638
Point 11	63.5	2638
Point 12	66.5	2638
Point 13	66.5	2640
Point 14	68	2640
Point 15	77	2637
Point 16	63.5	2636.9
Point 17	66.5	2636.9
Point 18	86.3	2640.58

Point 19	89.28	2640.58
Point 20	93.94	2638.58
Point 21	96.7	2638.45
Point 22	151.08	2658.58
Point 23	154.45	2658.58
Point 24	159.09	2656.58
Point 25	161.81	2656.58
Point 26	213.95	2676.58
Point 27	217.58	2676.58
Point 28	222.2	2674.58
Point 29	224.58	2674.58
Point 30	266.29	2690.78
Point 31	500	2695.407
Point 32	79.32	2650.31
Point 33	259.63	2705.97
Point 34	266.29	2705.83
Point 35	500	2710.457
Point 36	262.03	2578.05
Point 37	500	2573.29
Point 38	500	2570.57
Point 39	500	2566.97
Point 40	262.00762	2575.3308
Point 41	262.00933	2571.7302

Critical Slip Surfaces

	Number	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	20619	1.500	(163.52, 2783.62)	169.965	(315.133, 2706.8)	(64.1536, 2645.73)

Slices of Slip Surface: 20619

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	20619	67.085645	2643.706	0	462.41276	235.61107	0
2	20619	74.152125	2639.128	0	2126.0538	1277.462	1000

3	20619	78.80329	2636.274	0	2084.555	842.21488	60
4	20619	82.81	2634.093	0	2583.6161	1043.8487	60
5	20619	87.79	2631.4675	0	3179.6053	1284.6439	60
6	20619	91.61	2629.638	0	3567.1017	1441.2026	60
7	20619	95.32	2627.9455	0	3925.3428	1585.9414	60
8	20619	100.5733	2625.796	0	4444.5873	1795.7298	60
9	20619	109.802	2622.466	0	5296.023	2139.7322	60
10	20619	119.8774	2619.4265	0	6123.5872	2474.0898	60
11	20619	129.31745	2617.202	0	6801.7759	2748.0959	60
12	20619	138.7575	2615.5365	0	7395.8894	2988.1333	60
13	20619	147.27875	2614.476	0	7997.8066	4805.567	1000
14	20619	151.66395	2614.07	0	8132.3577	4886.4135	1000
15	20619	153.34895	2613.963	0	8127.0115	4692.1323	125
16	20619	156.77	2613.805	0	8197.8369	4733.0233	125
17	20619	160.45	2613.6885	0	8267.0329	4772.9737	125
18	20619	166.155	2613.731	0	8392.3165	4845.3062	125
19	20619	174.845	2614.0885	0	8549.9899	4936.339	125
20	20619	183.535	2614.8945	0	8640.9131	4988.8335	125
21	20619	192.225	2616.1545	0	8666.4745	5003.5914	125
22	20619	200.915	2617.8795	0	8627.4365	4981.0528	125
23	20619	209.605	2620.0845	0	8524.2685	4921.4887	125
24	20619	215.765	2621.895	0	8408.7584	4854.7989	125
25	20619	219.89	2623.2935	0	8278.1322	4779.3818	125
26	20619	223.39	2624.554	0	8156.5145	4709.1658	125
27	20619	228.96125	2626.8305	0	7976.521	4605.2465	125
28	20619	237.72375	2630.786	0	7659.7314	4422.348	125
29	20619	246.48625	2635.365	0	7271.6897	4198.312	125
30	20619	255.24875	2640.6275	0	6808.6263	3930.9622	125
31	20619	262.96	2645.8415	0	6235.8806	3600.2873	125
32	20619	270.30135	2651.4865	0	5495.6966	3172.9419	125
33	20619	278.3241	2658.406	0	4629.2689	2672.7097	125
34	20619	286.34685	2666.283	0	3697.0835	2134.5122	125
35	20619	294.36955	2675.329	0	2693.5936	1555.147	125
36	20619	302.3923	2685.875	0	1612.4913	930.97228	125
37	20619	310.7682	2699.1855	0	576.64888	293.81728	0

USEI Cell 15

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File Information

Created By: Pease, Eric
Revision Number: 46
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 5:00:54 PM
File Name: USEI 15-1 auto-locate static.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 5:01:14 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15

Description: Auto Locate Slip Surface - Static Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Auto-Search
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: Yes

FOS Distribution
- FOS Calculation Option: Constant

Advanced
- Number of Slices: 30
- Optimization Tolerance: 0.01

Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

New Material

Model: Bedrock (Impenetrable)

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2710.457) ft

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs

Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs

Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (262.00762, 2575.3308) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 195.01515 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs

Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 6

Type: Fabric
Outside Point: (500, 2570.57) ft
Inside Point: (262.00762, 2575.3308) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 238.03999 ft
Reinforcement Direction: 358.85 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.651	(-291.406, 4394.2)	1775.839	(256.997, 2705.16)	(207.673, 2689.93)
2	331	1.651	(-291.406, 4394.2)	1775.839	(256.997, 2705.16)	(207.673, 2689.93)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	208.49535	2690.1725	0	1.1740976	0.59823261	0
2	Optimized	210.13945	2690.656	0	3.4420589	1.7538166	0
3	Optimized	211.78355	2691.141	0	5.549486	2.8276043	0
4	Optimized	213.42765	2691.6275	0	7.4956338	3.8192162	0
5	Optimized	215.07175	2692.1155	0	9.2802839	4.7285408	0
6	Optimized	216.71585	2692.6055	0	10.902462	5.5550818	0
7	Optimized	218.36	2693.0975	0	12.362302	6.2989075	0

8	Optimized	220.00415	2693.591	0	13.659358	6.9597904	0
9	Optimized	221.64825	2694.0865	0	14.793184	7.5375036	0
10	Optimized	223.29235	2694.5835	0	15.763918	8.0321176	0
11	Optimized	224.93645	2695.082	0	16.57111	8.4434023	0
12	Optimized	226.58055	2695.5825	0	17.2155	8.7717354	0
13	Optimized	228.22465	2696.085	0	17.696639	9.0168881	0
14	Optimized	229.86875	2696.589	0	18.015823	9.1795204	0
15	Optimized	231.5129	2697.0945	0	18.172053	9.2591234	0
16	Optimized	233.15705	2697.602	0	18.166034	9.2560565	0
17	Optimized	234.80115	2698.111	0	17.999083	9.170991	0
18	Optimized	236.44525	2698.622	0	17.670196	9.0034147	0
19	Optimized	238.08935	2699.135	0	17.18066	8.7539836	0
20	Optimized	239.73345	2699.6495	0	16.530053	8.4224826	0
21	Optimized	241.37755	2700.1655	0	15.718523	8.0089875	0
22	Optimized	243.02165	2700.6835	0	14.7468	7.5138701	0
23	Optimized	244.66575	2701.2035	0	13.615035	6.9372071	0
24	Optimized	246.3099	2701.725	0	12.322213	6.278481	0
25	Optimized	247.95405	2702.248	0	10.868501	5.5377777	0
26	Optimized	249.59815	2702.773	0	9.2534607	4.7148737	0
27	Optimized	251.24225	2703.3	0	7.4766766	3.809557	0
28	Optimized	252.88635	2703.8285	0	5.5384216	2.8219668	0
29	Optimized	254.53045	2704.3585	0	3.437349	1.7514168	0
30	Optimized	256.17455	2704.8905	0	1.1730405	0.59769401	0

Slices of Slip Surface: 331

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	331	208.49535	2690.1725	0	1.1740976	0.59823261	0
2	331	210.13945	2690.656	0	3.4420589	1.7538166	0
3	331	211.78355	2691.141	0	5.549486	2.8276043	0
4	331	213.42765	2691.6275	0	7.4956338	3.8192162	0
5	331	215.07175	2692.1155	0	9.2802839	4.7285408	0
6	331	216.71585	2692.6055	0	10.902462	5.5550818	0
7	331	218.36	2693.0975	0	12.362302	6.2989075	0
8	331	220.00415	2693.591	0	13.659358	6.9597904	0
9	331	221.64825	2694.0865	0	14.793184	7.5375036	0
10	331	223.29235	2694.5835	0	15.763918	8.0321176	0
11	331	224.93645	2695.082	0	16.57111	8.4434023	0
12	331	226.58055	2695.5825	0	17.2155	8.7717354	0
13	331	228.22465	2696.085	0	17.696639	9.0168881	0
14	331	229.86875	2696.589	0	18.015823	9.1795204	0
15	331	231.5129	2697.0945	0	18.172053	9.2591234	0
16	331	233.15705	2697.602	0	18.166034	9.2560565	0
17	331	234.80115	2698.111	0	17.999083	9.170991	0

18	331	236.44525	2698.622	0	17.670196	9.0034147	0
19	331	238.08935	2699.135	0	17.18066	8.7539836	0
20	331	239.73345	2699.6495	0	16.530053	8.4224826	0
21	331	241.37755	2700.1655	0	15.718523	8.0089875	0
22	331	243.02165	2700.6835	0	14.7468	7.5138701	0
23	331	244.66575	2701.2035	0	13.615035	6.9372071	0
24	331	246.3099	2701.725	0	12.322213	6.278481	0
25	331	247.95405	2702.248	0	10.868501	5.5377777	0
26	331	249.59815	2702.773	0	9.2534607	4.7148737	0
27	331	251.24225	2703.3	0	7.4766766	3.809557	0
28	331	252.88635	2703.8285	0	5.5384216	2.8219668	0
29	331	254.53045	2704.3585	0	3.437349	1.7514168	0
30	331	256.17455	2704.8905	0	1.1730405	0.59769401	0

USEI Cell 15

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File Information

Created By: Pease, Eric
Revision Number: 50
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 4:57:38 PM
File Name: USEI 15-1 auto-locate seismic.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 4:57:46 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15

Description: Auto Locate Slip Surface - Seismic Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Auto-Search
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: Yes

FOS Distribution
- FOS Calculation Option: Constant

Advanced
- Number of Slices: 30
- Optimization Tolerance: 0.01

Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

New Material

Model: Bedrock (Impenetrable)

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2710.457) ft

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1

Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1

Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (262.00762, 2575.3308) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 195.01515 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1

Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 6

Type: Fabric
Outside Point: (500, 2570.57) ft
Inside Point: (262.00762, 2575.3308) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 238.03999 ft
Reinforcement Direction: 358.85 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.017	(-291.406, 4394.2)	1775.839	(256.997, 2705.16)	(207.673, 2689.93)
2	331	1.017	(-291.406, 4394.2)	1775.839	(256.997, 2705.16)	(207.673, 2689.93)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	208.49535	2690.1725	0	1.339558	0.68253889	0
2	Optimized	210.13945	2690.656	0	3.9266883	2.0007476	0

3	Optimized	211.78355	2691.141	0	6.3300036	3.225298	0
4	Optimized	213.42765	2691.6275	0	8.5487779	4.3558199	0
5	Optimized	215.07175	2692.1155	0	10.582054	5.3918257	0
6	Optimized	216.71585	2692.6055	0	12.430567	6.33369	0
7	Optimized	218.36	2693.0975	0	14.092721	7.1806002	0
8	Optimized	220.00415	2693.591	0	15.568674	7.9326356	0
9	Optimized	221.64825	2694.0865	0	16.857999	8.5895794	0
10	Optimized	223.29235	2694.5835	0	17.961437	9.1518091	0
11	Optimized	224.93645	2695.082	0	18.877971	9.6188069	0
12	Optimized	226.58055	2695.5825	0	19.608368	9.9909625	0
13	Optimized	228.22465	2696.085	0	20.153359	10.268649	0
14	Optimized	229.86875	2696.589	0	20.512513	10.451648	0
15	Optimized	231.5129	2697.0945	0	20.686601	10.540349	0
16	Optimized	233.15705	2697.602	0	20.676342	10.535123	0
17	Optimized	234.80115	2698.111	0	20.481916	10.436057	0
18	Optimized	236.44525	2698.622	0	20.104661	10.243836	0
19	Optimized	238.08935	2699.135	0	19.54356	9.9579411	0
20	Optimized	239.73345	2699.6495	0	18.800534	9.5793504	0
21	Optimized	241.37755	2700.1655	0	17.874591	9.1075588	0
22	Optimized	243.02165	2700.6835	0	16.767061	8.5432443	0
23	Optimized	244.66575	2701.2035	0	15.476955	7.8859026	0
24	Optimized	246.3099	2701.725	0	14.005018	7.1359129	0
25	Optimized	247.95405	2702.248	0	12.350859	6.2930768	0
26	Optimized	249.59815	2702.773	0	10.514638	5.3574756	0
27	Optimized	251.24225	2703.3	0	8.4948019	4.3283178	0
28	Optimized	252.88635	2703.8285	0	6.2915293	3.2056943	0
29	Optimized	254.53045	2704.3585	0	3.9040158	1.9891954	0
30	Optimized	256.17455	2704.8905	0	1.3320959	0.67873677	0

Slices of Slip Surface: 331

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	331	208.49535	2690.1725	0	1.339558	0.68253889	0
2	331	210.13945	2690.656	0	3.9266883	2.0007476	0
3	331	211.78355	2691.141	0	6.3300036	3.225298	0
4	331	213.42765	2691.6275	0	8.5487779	4.3558199	0
5	331	215.07175	2692.1155	0	10.582054	5.3918257	0
6	331	216.71585	2692.6055	0	12.430567	6.33369	0
7	331	218.36	2693.0975	0	14.092721	7.1806002	0
8	331	220.00415	2693.591	0	15.568674	7.9326356	0
9	331	221.64825	2694.0865	0	16.857999	8.5895794	0
10	331	223.29235	2694.5835	0	17.961437	9.1518091	0
11	331	224.93645	2695.082	0	18.877971	9.6188069	0
12	331	226.58055	2695.5825	0	19.608368	9.9909625	0

13	331	228.22465	2696.085	0	20.153359	10.268649	0
14	331	229.86875	2696.589	0	20.512513	10.451648	0
15	331	231.5129	2697.0945	0	20.686601	10.540349	0
16	331	233.15705	2697.602	0	20.676342	10.535123	0
17	331	234.80115	2698.111	0	20.481916	10.436057	0
18	331	236.44525	2698.622	0	20.104661	10.243836	0
19	331	238.08935	2699.135	0	19.54356	9.9579411	0
20	331	239.73345	2699.6495	0	18.800534	9.5793504	0
21	331	241.37755	2700.1655	0	17.874591	9.1075588	0
22	331	243.02165	2700.6835	0	16.767061	8.5432443	0
23	331	244.66575	2701.2035	0	15.476955	7.8859026	0
24	331	246.3099	2701.725	0	14.005018	7.1359129	0
25	331	247.95405	2702.248	0	12.350859	6.2930768	0
26	331	249.59815	2702.773	0	10.514638	5.3574756	0
27	331	251.24225	2703.3	0	8.4948019	4.3283178	0
28	331	252.88635	2703.8285	0	6.2915293	3.2056943	0
29	331	254.53045	2704.3585	0	3.9040158	1.9891954	0
30	331	256.17455	2704.8905	0	1.3320959	0.67873677	0

USEI Cell 15

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File Information

Created By: Pease, Eric
Revision Number: 60
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 5:09:32 PM
File Name: USEI 15-1 block static.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 5:09:52 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15

Description: Optimized Block Slip Surface - Static Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Block
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: Yes

FOS Distribution
- FOS Calculation Option: Constant

Restrict Block Crossing: No
Advanced
- Number of Slices: 30

Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

CCL

Model: Mohr-Coulomb
Unit Weight: 94 pcf
Cohesion: 60 psf
Phi: 22 °
Phi-B: 0 °

Common Fill

Model: Mohr-Coulomb
Unit Weight: 124.8 pcf
Cohesion: 1000 psf
Phi: 31 °
Phi-B: 0 °

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2710.457) ft

Slip Surface Block

Left Grid
- Upper Left: (15.69357, 2636.4883) ft
- Lower Left: (15.69357, 2605.1529) ft
- Lower Right: (62.29489, 2610.5094) ft
- X Increments: 5
- Y Increments: 5
- Starting Angle: 135 °
- Ending Angle: 180 °
- Angle Increments: 2

Right Grid
- Upper Left: (275.83963, 2702.3729) ft
- Lower Left: (275.12543, 2671.0375) ft
- Lower Right: (327.44032, 2676.394) ft
- X Increments: 5
- Y Increments: 5
- Starting Angle: 45 °
- Ending Angle: 65 °
- Angle Increments: 2

Seismic Loads

Horz Seismic Load: 0
Vert Seismic Load: 0

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.

Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.

Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (59.863, 2642.7) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 23.402 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (262.00762, 2575.3308) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (59.863, 2642.7) ft
Total Length: 195.01515 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.

Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 23.402 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 6

Type: Fabric
Outside Point: (500, 2570.57) ft
Inside Point: (262.00762, 2575.3308) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 238.03999 ft
Reinforcement Direction: 358.85 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.662	(151.246, 2722.13)	101.5521	(259.8, 2705.97)	(45.5517, 2640.11)
2	11648	1.807	(151.246, 2722.13)	103.551	(278.429, 2706.07)	(51.3052, 2641.84)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	49.709465	2640.809	0	53.798331	27.411619	0
2	Optimized	57.015915	2642.1425	0	138.13523	70.383413	0
3	Optimized	63.313225	2643.4035	0	201.21981	102.52661	0
4	Optimized	69.610535	2644.6645	0	264.90386	134.97526	0
5	Optimized	76.039595	2646.026	0	319.82238	162.95764	0

6	Optimized	81.9456	2647.3425	0	368.06014	187.53601	0
7	Optimized	88.930995	2648.9415	0	421.61991	214.82607	0
8	Optimized	96.893495	2650.9165	0	461.22121	235.00395	0
9	Optimized	103.89555	2652.845	0	479.03668	244.08138	0
10	Optimized	110.69425	2654.7795	0	494.42878	251.92405	0
11	Optimized	117.70565	2656.808	0	504.28226	256.94465	0
12	Optimized	124.92975	2658.9295	0	513.92457	261.85765	0
13	Optimized	132.4633	2661.1715	0	518.68705	264.28425	0
14	Optimized	140.30635	2663.5345	0	523.32615	266.64799	0
15	Optimized	147.3545	2665.6835	0	522.38156	266.1667	0
16	Optimized	153.60775	2667.6185	0	521.25106	265.59068	0
17	Optimized	159.861	2669.5535	0	520.13584	265.02245	0
18	Optimized	166.1142	2671.4885	0	519.0359	264.462	0
19	Optimized	173.17535	2673.7235	0	509.3149	259.5089	0
20	Optimized	180.6608	2676.1275	0	500.81269	255.17681	0
21	Optimized	187.76255	2678.4005	0	492.92715	251.15893	0
22	Optimized	194.8643	2680.6735	0	485.14889	247.1957	0
23	Optimized	201.9661	2682.9465	0	477.4645	243.28031	0
24	Optimized	208.62755	2685.1655	0	455.96161	232.32405	0
25	Optimized	216.96485	2688.138	0	417.83053	212.89529	0
26	Optimized	225.4183	2691.272	0	367.83683	187.42222	0
27	Optimized	231.8717	2693.76	0	324.69288	165.43929	0
28	Optimized	238.32505	2696.248	0	281.37544	143.36795	0
29	Optimized	244.7784	2698.736	0	237.82666	121.17873	0
30	Optimized	250.91135	2701.455	0	158.20372	80.608821	0
31	Optimized	256.7238	2704.405	0	58.369072	29.740528	0
32	Optimized	259.715	2705.923	0	3.9484212	2.0118211	0

Slices of Slip Surface: 11648

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	11648	56.800045	2641.845	0	171.71549	87.493412	0
2	11648	66.55117	2643.0515	0	322.61885	164.38252	0
3	11648	75.063725	2645.464	0	337.49244	171.96099	0
4	11648	83.07646	2647.735	0	353.76374	180.25163	0
5	11648	90.589375	2649.8645	0	371.43592	189.25605	0
6	11648	98.102265	2651.994	0	389.08249	198.24743	0
7	11648	105.6152	2654.1235	0	406.70344	207.22575	0
8	11648	113.12815	2656.253	0	424.3244	216.20408	0
9	11648	120.64105	2658.3825	0	441.90694	225.16283	0
10	11648	128.15395	2660.512	0	459.48947	234.12158	0
11	11648	135.66685	2662.6415	0	477.05921	243.07381	0
12	11648	143.1798	2664.771	0	494.62894	252.02603	0
13	11648	150.69275	2666.9005	0	512.19867	260.97826	0

14	11648	158.20565	2669.03	0	529.7556	269.92396	0
15	11648	165.71855	2671.1595	0	547.33813	278.88271	0
16	11648	173.23145	2673.289	0	564.90787	287.83493	0
17	11648	180.74435	2675.4185	0	582.50321	296.80021	0
18	11648	188.25725	2677.548	0	600.11136	305.77201	0
19	11648	195.7702	2679.6775	0	617.74512	314.75686	0
20	11648	203.28315	2681.807	0	635.39169	323.74824	0
21	11648	210.79605	2683.9365	0	653.06387	332.75266	0
22	11648	218.30895	2686.066	0	670.74885	341.76361	0
23	11648	225.82185	2688.1955	0	688.47226	350.79414	0
24	11648	233.3348	2690.325	0	706.22127	359.83771	0
25	11648	240.84775	2692.4545	0	723.9959	368.89434	0
26	11648	248.36065	2694.584	0	741.79614	377.96401	0
27	11648	255.87355	2696.7135	0	759.6348	387.05326	0
28	11648	262.96	2698.722	0	673.19459	343.00978	0
29	11648	271.0648	2701.0195	0	459.40733	234.07973	0
30	11648	277.1341	2704.2215	0	130.48448	66.485162	0

USEI Cell 15

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File Information

Created By: Pease, Eric
Revision Number: 56
Last Edited By: Pease, Eric
Date: 11/17/2009
Time: 5:06:22 PM
File Name: USEI 15-1 block seismic.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Permit Mod Revisions 11-09\Block Slope Stability Analysis\
Last Solved Date: 11/17/2009
Last Solved Time: 5:06:46 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15

Description: Optimized Block Slip Surface - Seismic Analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: (none)
SlipSurface
    Direction of movement: Right to Left
    Use Passive Mode: No
    Slip Surface Option: Block
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: Yes
FOS Distribution
    FOS Calculation Option: Constant
Restrict Block Crossing: No
Advanced
    Number of Slices: 30

Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

CCL

Model: Mohr-Coulomb
Unit Weight: 94 pcf
Cohesion: 60 psf
Phi: 22 °
Phi-B: 0 °

Common Fill

Model: Mohr-Coulomb
Unit Weight: 124.8 pcf
Cohesion: 1000 psf
Phi: 31 °
Phi-B: 0 °

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2710.457) ft

Slip Surface Block

Left Grid
- Upper Left: (15.69357, 2636.4883) ft
- Lower Left: (15.69357, 2605.1529) ft
- Lower Right: (62.29489, 2610.5094) ft
- X Increments: 5
- Y Increments: 5
- Starting Angle: 135 °
- Ending Angle: 180 °
- Angle Increments: 2

Right Grid
- Upper Left: (275.83963, 2702.3729) ft
- Lower Left: (275.12543, 2671.0375) ft
- Lower Right: (327.44032, 2676.394) ft
- X Increments: 5
- Y Increments: 5
- Starting Angle: 45 °
- Ending Angle: 65 °
- Angle Increments: 2

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs

Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs

Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (60.551, 2642.5) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 62.822 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (262.00762, 2575.3308) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (60.551, 2642.5) ft
Total Length: 195.01515 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs

Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 62.822 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 6

Type: Fabric
Outside Point: (500, 2570.57) ft
Inside Point: (262.00762, 2575.3308) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 238.03999 ft
Reinforcement Direction: 358.85 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	Optimized	1.023	(151.869, 2722.16)	102.2339	(260.311, 2705.96)	(45.202, 2640)
2	11647	1.083	(151.869, 2722.16)	103.797	(279.559, 2706.09)	(51.3052, 2641.84)

Slices of Slip Surface: Optimized

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	Optimized	49.261585	2640.4985	0	84.90009	43.258756	0
2	Optimized	56.441885	2641.638	0	198.09538	100.93464	0
3	Optimized	62.68339	2642.922	0	268.0557	136.5812	0
4	Optimized	68.924895	2644.2055	0	339.11455	172.7875	0
5	Optimized	75.682825	2645.722	0	392.39666	199.93609	0

6	Optimized	83.03861	2647.491	0	448.4897	228.51692	0
7	Optimized	90.47583	2649.279	0	508.16893	258.925	0
8	Optimized	99.09127	2651.4855	0	548.21055	279.32723	0
9	Optimized	108.1429	2653.989	0	570.91316	290.89478	0
10	Optimized	116.4525	2656.3715	0	590.16262	300.70288	0
11	Optimized	123.51375	2658.382	0	610.78068	311.2083	0
12	Optimized	129.32665	2660.02	0	627.02423	319.4848	0
13	Optimized	136.49525	2662.08	0	636.04605	324.08165	0
14	Optimized	145.0195	2664.562	0	650.02397	331.20375	0
15	Optimized	153.6635	2667.134	0	649.30166	330.83572	0
16	Optimized	162.4273	2669.796	0	651.36519	331.88714	0
17	Optimized	171.34915	2672.562	0	639.52088	325.85216	0
18	Optimized	179.3048	2675.0595	0	636.5975	324.36263	0
19	Optimized	186.7095	2677.451	0	611.1147	311.37849	0
20	Optimized	194.68755	2680.1095	0	590.63758	300.94488	0
21	Optimized	201.37435	2682.3885	0	559.70994	285.18646	0
22	Optimized	206.76985	2684.2875	0	536.96489	273.59728	0
23	Optimized	213.02405	2686.5205	0	504.0774	256.84026	0
24	Optimized	220.13695	2689.0875	0	468.57061	238.74865	0
25	Optimized	226.8386	2691.605	0	416.48969	212.2121	0
26	Optimized	233.12905	2694.0725	0	366.97207	186.98161	0
27	Optimized	239.41955	2696.54	0	316.99567	161.51736	0
28	Optimized	245.71005	2699.008	0	266.45691	135.76658	0
29	Optimized	251.54895	2701.5855	0	180.93524	92.191111	0
30	Optimized	256.9363	2704.2725	0	83.835156	42.716146	0
31	Optimized	259.97035	2705.786	0	17.264954	8.7969335	0

Slices of Slip Surface: 11647

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	11647	56.800045	2641.845	0	214.34636	109.21492	0
2	11647	66.55117	2643.0515	0	376.56385	191.86886	0
3	11647	75.063725	2645.464	0	393.61874	200.55876	0
4	11647	83.07646	2647.735	0	412.14596	209.99886	0
5	11647	90.589375	2649.8645	0	432.12321	220.17777	0
6	11647	98.102265	2651.994	0	451.94678	230.27839	0
7	11647	105.6152	2654.1235	0	471.59107	240.28765	0
8	11647	113.12815	2656.253	0	491.05608	250.20557	0
9	11647	120.64105	2658.3825	0	510.38023	260.05172	0
10	11647	128.15395	2660.512	0	529.57631	269.83261	0
11	11647	135.66685	2662.6415	0	548.65714	279.55478	0
12	11647	143.1798	2664.771	0	567.64833	289.23127	0
13	11647	150.69275	2666.9005	0	586.61391	298.89472	0
14	11647	158.20565	2669.03	0	605.56669	308.55164	0

15	11647	165.71855	2671.1595	0	624.54507	318.22161	0
16	11647	173.23145	2673.289	0	643.60029	327.93073	0
17	11647	180.74435	2675.4185	0	662.75796	337.69205	0
18	11647	188.25725	2677.548	0	682.05649	347.52514	0
19	11647	195.7702	2679.6775	0	701.50869	357.43653	0
20	11647	203.28315	2681.807	0	721.14018	367.43927	0
21	11647	210.79605	2683.9365	0	740.96375	377.53989	0
22	11647	218.30895	2686.066	0	760.97942	387.73838	0
23	11647	225.82185	2688.1955	0	781.18717	398.03474	0
24	11647	233.3348	2690.325	0	801.57421	408.42246	0
25	11647	240.84775	2692.4545	0	822.11491	418.88847	0
26	11647	248.36065	2694.584	0	842.8221	429.43931	0
27	11647	255.87355	2696.7135	0	863.64454	440.04887	0
28	11647	262.96	2698.722	0	765.27292	389.92603	0
29	11647	271.0648	2701.0195	0	521.3165	265.62402	0
30	11647	277.6995	2704.233	0	146.58013	74.686305	0

Appendix D1-3
References for
Slope Stability Calculations

REFERENCE 1

Designing with Geosynthetics

Second Edition

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TABLE 5.5 FRICTION VALUES AND EFFICIENCIES (IN PARENTHESES) FOR (a) SOIL-TO-GEOMEMBRANE, (b) GEOMEMBRANE-TO-GEOTEXTILE, AND (c) SOIL-TO-GEOTEXTILE COMBINATIONS*

(a) Soil-to-geomembrane friction angles

	Soil types		
Geomembrane	Concrete sand (ϕ = 30°)	Ottawa sand (ϕ = 28°)	Mica schist sand (ϕ = 26°)
EPDM	24° (0.77)	20° (0.68)	24° (0.91)
PVC			
rough	27° (0.88)	—	25° (0.96)
smooth	25° (0.81)	—	21° (0.79)
CSPE	25° (0.81)	21° (0.72)	23° (0.87)
HDPE	18° (0.56)	18° (0.61)	17° (0.63)

(b) Geomembrane-to-geotextile friction angle

	Geomembrane				
		PVC			
Geotextile	EPDM	Rough	Smooth	CSPE	HDPE
nonwoven, needle-punched	23°	23°	21°	15°	8°
nonwoven, melt-bonded	18°	20°	18°	21°	11°
woven, monofilament	17°	11°	10°	9°	6°
woven, slit film	21°	28°	24°	13°	10°

(c) Soil-to-geotextile friction angle

	Soil types		
Geotextile	Concrete sand (ϕ = 30°)	Ottawa sand (ϕ = 28°)	Mica schist sand (ϕ = 26°)
nonwoven, needle-punched	30° (1.00)	26° (0.92)	25° (0.96)
nonwoven, melt-bonded	26° (0.84)	—	—
woven, monofilament	26° (0.84)	—	—
woven, slit film	24° (0.77)	24° (0.84)	23° (0.87)

Source: After Martin, et al. [8]

*Efficiency values in parentheses are based on the relationship $E = (\tan \delta)/(\tan \phi)$

on smooth geotextiles giving the lowest friction values. For reference purposes, Part c of Table 5.5 gives the soil-to-geotextile friction values that are necessary for slope design of lined slopes with geotextiles under or over the liner.

The frictional behavior of geomembranes placed on clay soils is of considerable importance in the composite liners of waste landfills. Current requirements are for the

TABLE 5.6 FRICTION VALUES AND EFFICIENCIES (IN PARENTHESES) FOR VARIOUS CLAY SOILS TO VARIOUS GEOMEMBRANES [9]

	Soil no. 1 ML-CL				Soil no. 2 CL-ML			
Description	c	E_c (%)	ϕ	E_ϕ (%)	c	E_c (%)	ϕ	E_ϕ (%)
Soil-to-soil	9.0	100	38	100	12.0	100	34	100
	c_a	E_c (%)	δ	E_ϕ (%)	c_a	E_c (%)	δ	E_ϕ (%)
Geomembrane-to-soil								
PVC	8.5	94	39	100	3.7	31	23	69
CPE	8.0	89	40	100	3.2	27	24	71
EPDM	5.0	55	33	87	5.0	42	23	67
HDPE	5.0	88	26	68	2.0	17	23	67
Embossed HDPE	9.0	100	35	92	11.0	92	29	58

	Soil no. 3 CL				Soil no. 4 SP-CH			
Description	c	E_c (%)	ϕ	E_ϕ (%)	c	E_c (%)	ϕ	E_ϕ (%)
Soil-to-soil	20	100	30	100	25	100	24	100
	c_a	E_c (%)	δ	E_ϕ (%)	c_a	E_c (%)	δ	E_ϕ (%)
Geomembrane-to-soil								
PVC	14.0	70	16	53	7.0	28	24	100
CPE	13.0	65	17	57	8.0	32	23	96
EPDM	8.0	40	23	77	7.5	30	20	83
HDPE	14.0	70	15	50	3.0	12	21	88
Embossed HDPE	18.0	90	27	90	15.0	60	26	100

	Soil no. 5 CL-SP			
Description	c	E_c (%)	ϕ	E_ϕ (%)
Soil-to-soil	28	100	22	100
	c_a	E_c (%)	δ	E_ϕ (%)
Geomembrane-to-soil				
PVC	12.0	43	17	77
CPE	10.0	36	19	86
EPDM	9.0	32	18	82
HDPE	14.0	50	15	68
Embossed HDPE	16.0	57	25	100

Note: c and c_a are in units of kN/m^2, ϕ and δ are in degrees.

REFERENCE 2

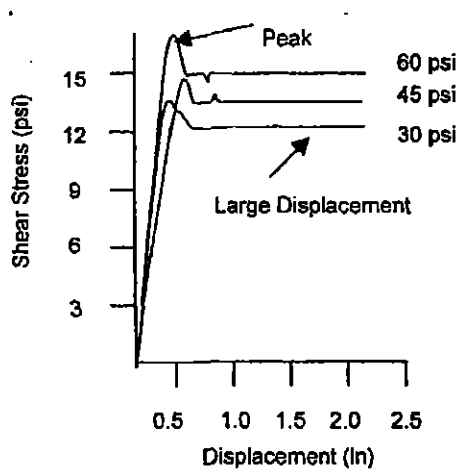
GSE®

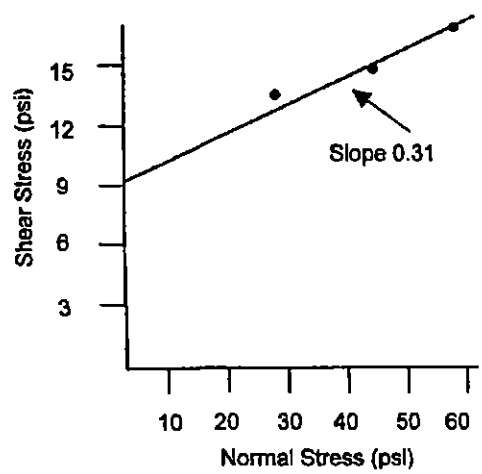
Technical Note

Direct Shear & Friction Angle Testing For GSE Geomembranes

Potential sources of failure of geosynthetic lined slopes are the interfaces of geosynthetic components, geosynthetic and the subgrade or a geosynthetic with the cover soil. Direct shear testing is often performed to determine this critical combination of loading and angle. The most common test performed to make this determination is ASTM D 5321. In order to make this test and the ensuing results meaningful, it is important that the testing be performed with site-specific interfaces (geosynthetics and soils) and site specific loading conditions. Furthermore, the soil must be conditioned such that it is not only the same basic type but also that the compaction and the moisture content are the same as actual field conditions. The last component that must be selected is the shear rate. ASTM D 5321 stipulates default rate of 0.2 in/min for geosynthetic/geosynthetic interfaces and 0.04 in/min for geosynthetic/soil interfaces. However, slower rates will give a better picture of the peak curve and will better simulate actual field conditions. Conversely, the slower rates take longer to complete and are thus more costly to run. The designer must weigh the importance of slope stability with the costs associated with a slower and potentially more accurate test. By specifying these site-specific conditions, the test becomes a more meaningful performance test rather than a standard index test[1].

A typical direct shear test consists of a minimum of three tests run at three different normal pressures as shown in the sample below:





The first graph shows a plot of shear stress versus displacement. The lines begin to flatten out after the initial rise and fall. This area where the line becomes flat, that is, the stress required to shear the interface is constant, is the large displacement strength (residual). The peak stress corresponds to the peak friction angle.

The second graph shows a plot of peak shear stress versus normal stress. The friction angle is derived from the slope of this line. In the previous example, the slope is 0.31. The friction angle is thus tan-1 (0.31) = 17°. A similar graph could be plotted showing large displacement stress versus normal stress. Determination of the slope of this line would give the large displacement friction angle.

Again, friction testing can be performed for a variety of interfaces, normal pressures and seat times. The materials can be run dry or, for worst case scenarios, can be run with saturated conditions. No manufacturer can guarantee a specific friction angle for a given set of site-specific conditions. Testing must be performed to ensure that the particular interfaces will meet the needs for the particular application. That being said, the tables on the back of this page list representative results from tests that have been performed on various materials. These values are intended as a guide only, not a guarantee.

- Continued -

Table 1. Geosynthetic vs. Geosynthetic Normal stress 50, 400, 800 psf

Interface	Peak		Large Displacement	
	Angle (degrees)	Adhesion (psf)	Angle (degrees)	Adhesion(psf)
Smooth geomembrane/geocomposite	12	10	10	10
Co-extruded textured geomembrane/geocomposite	26	60	21	40
Woven GCL/geocomposite	25	15	22	5

Table 2. Geosynthetic vs. Geosynthetic Normal stress 4000, 8000, 15000 psf

Interface	Peak		Large Displacement	
	Angle (degrees)	Adhesion (psf)	Angle (degrees)	Adhesion(psf)
Smooth geomembrane/geocomposite	12	80	10	25
Co-extruded textured geomembrane/geocomposite	24	520	19	20
Woven GCL/geocomposite	21	365	19	50

References:

[1] GSE Technical Note TN017 - Index Testing vs. Performance Testing.

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SUPPLEMENT TO REFERENCE 2

A recommendation to use peak shear strengths for geosynthetic interface design

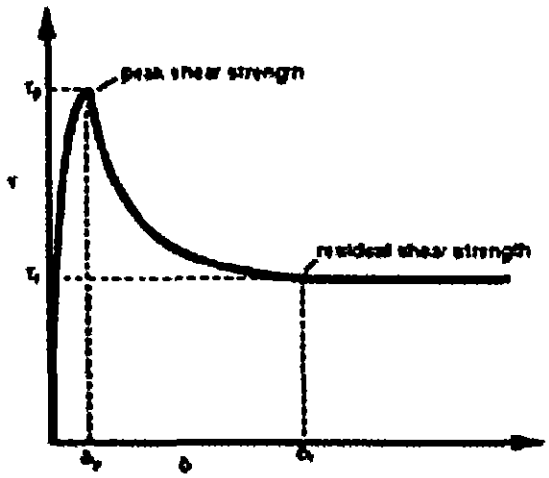
Since many geosynthetic designers are also geotechnical engineers, it is only natural to consider shear stress versus shear strain curves beyond peak strength into large-deformation, or even residual, strength conditions. A. Casagrande in the 1930s defined residual shear strength from triaxial soil testing as the strength achieved when the corresponding strain indicated a horizontal response plotted on a logarithmic scale. This is very difficult to achieve with conventional direct shear testing (the moving portion of most shear boxes have insufficient space to travel), and the concept of large-displacement shear strength is often the desired value. Note, however, that it is achievable using a torsional shear box but both ASTM and ISO Standards use a conventional direct shear setup (square shear box) and the industry is based accordingly.

Whether residual or large-displacement, the corresponding strength value is considerably less than peak strength for many geosynthetic-to-geosynthetic and geosynthetic-to-soil interfaces. In likely order from greatest difference to least difference between peak and residual are the following:

- internal shear strength of stitch bonded GCLs
- internal shear strength of needle-punched GCLs
- external shear strength of hydrated GCLs with woven geotextiles on one or both surfaces
- shear strength of textured geomembranes made by particle impingement
- internal shear strength of thick needle punched geotextiles
- shear strength of textured geomembranes made by blown film and calendering
- shear strength of geomembrane-to-compacted clay liners under expelled pore water conditions from the clay
- other geosynthetic-to-geosynthetic interfaces
- other geosynthetic-to-soil interfaces.

The literature is rich with hundreds of direct shear laboratory test results consisting of many of the above geosynthetic-related interfaces showing the general behavior. The most important interfaces in this regard have recently been summarized by Marr (2001, 2002) and Allen (2001): see Figure 1 for the generalized behavior. In obtaining such a response the selection of specific products and subsequent testing conditions is extremely important. For example, if one selects particle impinged textured geomembranes at high normal stresses such behavior will indeed result. However, such materials are no longer produced (all texturing is either by co-extrusion or calendered structuring and thus cannot rub-off) and the normal stresses should replicate the field conditions and not be high for the sake of obtaining a desired result.

Figure 1. Typical shear stress versus displacement relationship for geosynthetic interface (after Filz, et al., 2001 and many others).



Options for design

In viewing the appropriate direct shear test response for the interface of concern, the designer's dilemma has to do with what value to select in light of the site-specific situation under consideration. Invariably, the site-specific situation is some type of slope, characterized by its slope angle and slope length. Furthermore, the situation can consist of several distinct slopes at different angles. A common situation in this regard is a solid waste landfill with steep side slopes and a relatively flat base slope.

The following choices for this decision of using peak, residual, or in-between (some of which have appeared in the open literature) are as follows. They are listed from the most conservative to the least conservative.

(i) Use of residual strength for all conditions (Stark and Peoppel, 1994).

(ii) Use of residual strength of the interface having the lowest peak strength (Gilbert, 2001). This concept applies to multiple geosynthetic interfaces.

(iii) Use of peak strength on the base and residual strength throughout the steeper side slope (Jones, et al., 2000).

(iv) Use of peak strength at the top of the slope and residual at the base of the slope, with peak strength along the base slope (Heerten, 1995).

(v) Use of peak strengths for all nonseismic conditions (Koerner, via this communication).

The case for peak strength design

The writer has always believed in full scale (i.e., actual field feedback) behavior insofar as illustrating satisfactory versus nonsatisfactory performance. By direct association, the field performance reflects on the de-

signer and (in particular) on the designer's assumptions. In this regard, we present numerous field failures involving geosynthetic lined slopes in solid waste landfills, hydraulic applications and geotechnical structures.

Group 1: Solid Waste Landfill Failures – Koerner and Soong (2000) have analyzed 10 massive landfill failures. In all of them, excessive liquids were involved. There were three different groupings: (i) excessively wet foundation soils (poor foundation exploration), (ii) high interface moisture conditions (poor field installation), and (iii) hydrostatic pressures within the waste mass (poor operations practices). Clearly, the designs of these landfills were simply inadequate or the designers did not properly anticipate installation or operations conditions. In some cases there was simply no design whatsoever.

Group 2: Veneer Landfill Slope Failures – Koerner and Soong (1998) have analyzed eight veneer slope failures; four were leachate collection soil and four were final covers in landfills. All eight failed during or immediately after rainstorms. Obviously, all eight had inadequate drainage systems above their geomembrane interfaces, which were located 0.3 to 1.0 m beneath the ground surface. As with the previous failures, the designs were all inadequate and either underestimated the seepage pressures or ignored them altogether.

Group 3: Veneer Canal/Reservoir Slope Failures – The incidence of relatively thin cover soils sliding (or sloughing) on geomembrane lined canals and reservoirs is so common that it is becoming a routine maintenance item for many installations. In all cases, the designs never considered sudden drawdown which was the triggering mechanism for the five cases we have analyzed. As with the previous failures, design was inadequate insofar as omission of this well-known and usually critical hydraulic condition.

Group 4: Segmental Retaining Wall Failures – Koerner and Soong (2001) have analyzed 26 sliding failures of segmental retaining walls. All but one were lateral sliding within the reinforced soil mass, thus involving geogrid to backfill soil interfaces. Of the entire group, 20 (77%) were backfilled with silts, clays or their mixtures. As such, there was insufficient permeability to transmit seepage from behind the reinforced soil mass. This resulted in hydrostatic pressure which deformed the walls, or resulted in total collapse. In none of the cases was hydrostatic pressure buildup even considered, nor was there any attempt at providing back and/or base drainage. These were all cases of design oversight and/or neglect of realistic conditions.

Thus, one can rapidly come to the conclusion that failures of the more than 40 case histories just presented were all caused by no design, poor design and/or design oversights.

To remedy this situation one could have designed on residual strength (in whole or part) of the failing interface, but that seems to the writer to be simply accepting bad technology. Designers should (even must) know their loading conditions and should (even must) anticipate aggressive installation and/or operations activities. This is why we teach, write, transmit and hopefully assimilate design-related information. Peak strength design, with an adequate factor-of-safety for the site-specific conditions, would have prevented every one of the previously mentioned failures! Even further, proper design such that peak strength is never exceeded will greatly lessen deformations and the subsequent serviceability concerns as described by Jones (2002).

Brittle materials considerations

The above recommendation on the use of peak strength with an adequate factor-of-safety should come as no surprise. All engineering materials characterized by an elastic/brittle stress vs. strain response are designed in this manner. This includes cast iron, fiberglass, graphite, carbon fiber epoxy systems, etc. All are designed on peak strength (since there is "zero" residual strength) with an adequate factor-of-safety. Even within geosynthetic materials design, geogrids and geotextiles for steepening slopes and retaining walls use peak strength with suitable reduction factors for (hopefully conservative) FS-values. This is strictly a designer's decision which depends on his/her knowledge of the materials and site-specific conditions. It is precisely what we should be doing with systems involving geosynthetic interfaces.

Conclusion

In reflecting upon the currently active discussions over peak, residual or in-between strategies for geosynthetic interface design, it appears to the writer that we are essentially defending bad or inadequate design by using anything other than peak strength. (The assumption here is that the products are properly manufactured and will not delaminate in and of themselves). Of course, these are difficult design issues (particularly on the load side of the factor-of-safety equation), but that is the duty of the system's designer. The amount of factor-of-safety over unity must reflect the uncertainty in the variables used in the design. To add safety by arbitrarily reducing peak shear strengths is simply defending poor design. Our design procedures for materials with strain softening behavior like geosynthetics should follow that required with elastic/brittle materials, as well as materials which show a pronounced yield (e.g., steel and high density polyethylene) where yield is the design target. The only caveats that I can see to this generalized conclusion are design in seismically active areas and perhaps some unusual and atypical installation considerations like backfilling down slopes, etc. where post-peak behavior should be considered.

Lastly, if one desires to consider the probability of failure, there are procedures available for such calculation (Duncan, 2000). Probability (or reliability) theory design is clearly based on peak strength and the resulting factor-of-safety. When using residual strength in design there is no likelihood of failure and while extremely conservative it is unnecessarily so and in the author's opinion is not needed at all. GFR

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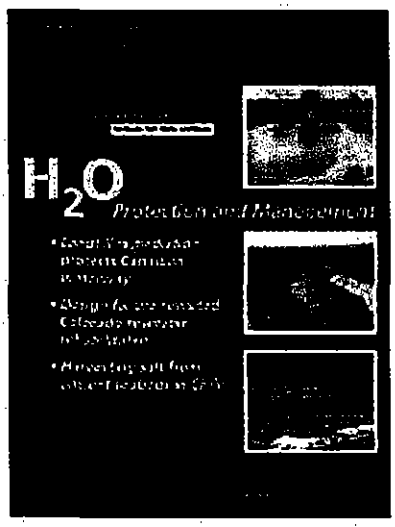

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GRI Test Method GM13*

Standard Specification for

"Test Methods, Test Properties and Testing Frequency for
High Density Polyethylene (HDPE) Smooth and Textured Geomembranes"

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

1.1 This specification covers high density polyethylene (HDPE) geomembranes with a formulated sheet density of 0.940 g/ml, or higher, in the thickness range of 0.75 mm (30 mils) to 3.0 mm (120 mils). Both smooth and textured geomembrane surfaces are included.

1.2 This specification sets forth a set of minimum, physical, mechanical and chemical properties that must be met, or exceeded by the geomembrane being manufactured. In a few cases a range is specified.

1.3 In the context of quality systems and management, this specification represents manufacturing quality control (MQC).

Note 1: Manufacturing quality control represents those actions taken by a manufacturer to ensure that the product represents the stated objective and properties set forth in this specification.

1.4 This standard specification is intended to ensure good quality and performance of HDPE geomembranes in general applications, but is possibly not adequate for the complete specification in a specific situation. Additional tests, or more restrictive

*This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This specification will be reviewed at least every 2-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

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values for test indicated, may be necessary under conditions of a particular application.

Note 2: For information on installation techniques, users of this standard are referred to the geosynthetics literature, which is abundant on the subject.

2. Referenced Documents

2.1 ASTM Standards

D 792 Specific Gravity (Relative Density) and Density of Plastics by Displacement
D 1004 Test Method for Initial Tear Resistance of Plastics Film and Sheeting
D 1238 Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
D 1505 Test Method for Density of Plastics by the Density-Gradient Technique
D 1603 Test Method for Carbon Black in Olefin Plastics
D 3895 Test Method for Oxidative Induction Time of Polyolefins by Thermal Analysis
D 4218 Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
D 4833 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D 5199 Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
D 5397 Procedure to Perform a Single Point Notched Constant Tensile Load – (SP-NCTL) Test: Appendix
D 5596 Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
D 5721 Practice for Air-Oven Aging of Polyolefin Geomembranes
D 5885 Test method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry
D 5994 Test Method for Measuring the Core Thickness of Textured Geomembranes
D 6693 Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes

2.2 GRI Standards

GM10 Specification for the Stress Crack Resistance of Geomembrane Sheet
GM 11 Accelerated Weathering of Geomembranes using a Fluorescent UVA-Condensation Exposure Device
GM 12 Measurement of the Asperity Height of Textured Geomembranes Using a Depth Gage

2.3 U. S. Environmental Protection Agency Technical Guidance Document "Quality Control Assurance and Quality Control for Waste Containment Facilities," EPA/600/R-93/182, September 1993, 305 pgs.

3. Definitions

Manufacturing Quality Control (MQC) - A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract specifications.
ref. EPA/600/R-93/182

Manufacturing Quality Assurance (MQA) - A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract specifications. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials (resins and additives) and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract specifications for the project.
ref. EPA/600/R-93/182

Formulation, n - The mixture of a unique combination of ingredients identified by type, properties and quantity. For HDPE polyethylene geomembranes, a formulation is defined as the exact percentages and types of resin(s), additives and carbon black.

4. Material Classification and Formulation

4.1 This specification covers high density polyethylene geomembranes with a formulated sheet density of 0.940 g/ml, or higher. Density can be measured by ASTM D1505 or ASTM D792. If the latter, Method B is recommended.

4.2 The polyethylene resin from which the geomembrane is made will generally be in the density range of 0.932 g/ml or higher, and have a melt index value per ASTM D1238 of less than 1.0 g/10 min.

4.3 The resin shall be virgin material with no more than 10% rework. If rework is used, it must be a similar HDPE as the parent material.

4.4 No post consumer resin (PCR) of any type shall be added to the formulation.

5. Physical, Mechanical and Chemical Property Requirements

5.1 The geomembrane shall conform to the test property requirements prescribed in Tables 1 and 2. Table 1 is for smooth HDPE geomembranes and Table 2 is for single and double sided textured HDPE geomembranes. Each of the tables are given in English and SI (metric) units. The conversion from English to SI (metric) is soft.

Note 3: The tensile strength properties in this specification were originally based on ASTM D 638 which uses a laboratory testing temperature of 23°C ± 2°C. Since ASTM Committee D35 on Geosynthetics adopted ASTM D 6693 (in place of D 638), this GRI Specification followed accordingly. The difference is that D 6693 uses a testing temperature of 21°C ± 2°C. The numeric values of strength and elongation were not changed in this specification. If a dispute arises in this regard, the original temperature of 23°C ± 2°C should be utilized for testing purposes.

Note 4: There are several tests often included in other HDPE specifications which are omitted from this standard because they are outdated, irrelevant or generate information that is not necessary to evaluate on a routine MQC basis. The following tests have been purposely omitted:

- Volatile Loss
- Dimensional Stability
- Coeff. of Linear Expansion
- Resistance to Soil Burial
- Low Temperature Impact
- ESCR Test (D 1693)
- Wide Width Tensile
- Water Vapor Transmission
- Water Absorption
- Ozone Resistance
- Modulus of Elasticity
- Hydrostatic Resistance
- Tensile Impact
- Field Seam Strength
- Multi-Axial Burst
- Various Toxicity Tests

Note 5: There are several tests which are included in this standard (that are not customarily required in other HDPE specifications) because they are relevant and important in the context of current manufacturing processes. The following tests have been purposely added:

- Oxidative Induction Time
- Oven Aging
- Ultraviolet Resistance
- Asperity Height of Textured Sheet (see Note 6)

Note 6: The minimum average value of asperity height does not represent an expected value of interface shear strength. Shear strength

associated with geomembranes is both site-specific and product-specific and should be determined by direct shear testing using ASTM D5321/ASTM D6243 as prescribed. This testing should be included in the particular site's CQA conformance testing protocol for the geosynthetic materials involved, or formally waived by the Design Engineer, with concurrence from the Owner prior to the deployment of the geosynthetic materials.

Note 7: There are other tests in this standard, focused on a particular property, which are updated to current standards. The following are in this category:

- Thickness of Textured Sheet
- Puncture Resistance
- Stress Crack Resistance
- Carbon Black Dispersion (In the viewing and subsequent quantitative interpretation of ASTM D 5596 only near spherical agglomerates shall be included in the assessment).

Note 8: There are several GRI tests currently included in this standard. Since these topics are not covered in ASTM standards, this is necessary. They are the following:

- UV Fluorescent Light Exposure
- Asperity Height Measurement

5.2 The values listed in the tables of this specification are to be interpreted according to the designated test method. In this respect they are neither minimum average roll values (MARV) nor maximum average roll values (MaxARV).

5.3 The properties of the HDPE geomembrane shall be tested at the minimum frequencies shown in Tables 1 and 2. If the specific manufacturer's quality control guide is more stringent and is certified accordingly, it must be followed in like manner.

Note 9: This specification is focused on manufacturing quality control (MQC). Conformance testing and manufacturing quality assurance (MQA) testing are at the discretion of the purchaser and/or quality assurance engineer, respectively.

6. Workmanship and Appearance

6.1 Smooth geomembrane shall have good appearance qualities. It shall be free from such defects that would affect the specified properties of the geomembrane.

6.2 Textured geomembrane shall generally have uniform texturing appearance. It shall be free from agglomerated texturing material and such defects that would affect the specified properties of the geomembrane.

6.3 General manufacturing procedures shall be performed in accordance with the manufacturer's internal quality control guide and/or documents.

7. MQC Sampling

7.1 Sampling shall be in accordance with the specific test methods listed in Tables 1 and 2. If no sampling protocol is stipulated in the particular test method, then test specimens shall be taken evenly spaced across the entire roll width.

7.2 The number of tests shall be in accordance with the appropriate test methods listed in Tables 1 and 2.

7.3 The average of the test results should be calculated per the particular standard cited and compared to the minimum value listed in these tables, hence the values listed are the minimum average values and are designated as "min. ave."

8. MQC Retest and Rejection

8.1 If the results of any test do not conform to the requirements of this specification, retesting to determine conformance or rejection should be done in accordance with the manufacturing protocol as set forth in the manufacturer's quality manual.

9. Packaging and Marketing

9.1 The geomembrane shall be rolled onto a substantial core or core segments and held firm by dedicated straps/slings, or other suitable means. The rolls must be adequate for safe transportation to the point of delivery, unless otherwise specified in the contract or order.

10. Certification

10.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

ENGLISH UNITS

Table 1(a) – High Density Polyethylene (HDPE) Geomembrane -Smooth

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness (min. ave.)	D5199	nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Per roll
• lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density mg/l (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,000 lb
Tensile Properties *(1)* (min. ave.)	D 6693 Type IV								20,000 lb
• yield strength		63 lb/in.	84 lb/in.	105 lb/in.	126 lb/in.	168 lb/in.	210 lb/in.	252 lb/in.	
• break strength		114 lb/in.	152 lb/in.	190 lb/in.	228 lb/in.	304 lb/in.	380 lb/in.	456 lb/in.	
• yield elongation		12%	12%	12%	12%	12%	12%	12%	
• break elongation		700%	700%	700%	700%	700%	700%	700%	
Tear Resistance (min. ave.)	D 1004	21 lb	28 lb	35 lb	42 lb	56 lb	70 lb	84 lb	45,000 lb
Puncture Resistance (min. ave.)	D 4833	54 lb	72 lb	90 lb	108 lb	144 lb	180 lb	216 lb	45,000 lb
Stress Crack Resistance *(2)*	D5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI-GM10
Carbon Black Content (range)	D 1603 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	20,000 lb
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(5)*									200,000 lb
(a) Standard OIT	D 3895	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	
— or —									
(b) High Pressure OIT	D 5885	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	
Oven Aging at 85°C *(5), (6)*	D 5721								
(a) Standard OIT (min. ave.) - % retained after 90 days	D 3895	55%	55%	55%	55%	55%	55%	55%	per each formulation
— or —									
(b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5885	80%	80%	80%	80%	80%	80%	80%	
UV Resistance *(7)*	GM 11								
(a) Standard OIT (min. ave.)	D 3895	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	per each formulation
— or —									
(b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	D 5885	50%	50%	50%	50%	50%	50%	50%	

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 1.3 inches
Break elongation is calculated using a gage length of 2.0 in.

(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(3) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.

(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (METRIC) UNITS

Table 1(b) – High Density Polyethylene (HPDE) Geomembrane - Smooth

Properties	Test Method	Test Value							Testing Frequency (minimum)
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness - mils (min. ave.) • lowest individual of 10 values	D5199	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	per roll
Density (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties *(1)* (min. ave.) • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	11 kN/m 20kN/m 12% 700%	15 kN/m 27 kN/m 12% 700%	18 kN/m 33 kN/m 12% 700%	22 kN/m 40 kN/m 12% 700%	29 kN/m 53 kN/m 12% 700%	37 kN/m 67 kN/m 12% 700%	44 kN/m 80 kN/m 12% 700%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	240 N	320 N	400 N	480 N	640 N	800 N	960 N	20,000 kg
Stress Crack Resistance *(2)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM-10
Carbon Black Content - %	D 1603 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	9,000 kg
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(5)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(5), (6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	 D 3895 D 5885	 N. R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	per each formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm

(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(3) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.

(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

ENGLISH UNITS

Table 2(a) – High Density Polyethylene (HDPE) Geomembrane - Textured

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mils (min. ave.) *(1)*	GM 12	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	every 2nd roll *(2)*
Density (min. ave.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,000 lb
Tensile Properties (min. ave.) *(3)* • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	63 lb/in. 45 lb/in. 12% 100%	84 lb/in. 60 lb/in. 12% 100%	105 lb/in. 75 lb/in. 12% 100%	126 lb/in. 90 lb/in. 12% 100%	168 lb/in. 120 lb/in. 12% 100%	210 lb/in. 150 lb/in. 12% 100%	252 lb/in. 180 lb/in. 12% 100%	20,000 lb
Tear Resistance (min. ave.)	D 1004	21 lb	28 lb	35 lb	42 lb	56 lb	70 lb	84 lb	45,000 lb
Puncture Resistance (min. ave.)	D 4833	45 lb	60 lb	75 lb	90 lb	120 lb	150 lb	180 lb	45,000 lb
Stress Crack Resistance *(4)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM10
Carbon Black Content (range)	D 1603 *(5)*	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	20,000 lb
Carbon Black Dispersion	D 5596	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(7)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	200,000 lb
Oven Aging at 85°C *(7), (8)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(9)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(11)*	GM11 D 3895 D 5885	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	per each formulation

(1) Of 10 readings; 8 out of 10 must be ≥ 7 mils, and lowest individual reading must be ≥ 5 mils; also see Note 6.
(2) Alternate the measurement side for double sided textured sheet
(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 1.3 inches
Break elongation is calculated using a gage length of 2.0 inches
(4) P-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(5) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(6) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3
(7) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(8) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(9) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(10) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(11) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (METRIC UNITS)

Table 2(b) – High Density Polyethylene (HDPE) Geomembrane - Textured

Properties	Test Method	Test Value							Testing Frequency (minimum)
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mils (min. ave.) *(1)*	GM 12	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm	every 2nd roll *(2)*
Density (min. ave.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties (min. ave.) *(3)* • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	11 kN/m 8 kN/m 12% 100%	15 kN/m 10 kN/m 12% 100%	18 kN/m 13 kN/m 12% 100%	22 kN/m 16 kN/m 12% 100%	29 kN/m 21 kN/m 12% 100%	37 kN/m 26 kN/m 12% 100%	44 kN/m 32 kN/m 12% 100%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	200N	267 N	333 N	400 N	534 N	667 N	800 N	20,000 kg
Stress Crack Resistance *(4)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM10
Carbon Black Content (range)	D 1603 *(5)*	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	9,000 kg
Carbon Black Dispersion	D 5596	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(7)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(7), (8)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(9)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(11)*	GM11 D 3895 D 5885	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	per each formulation

(1) Of 10 readings; 8 out of 10 must be ≥ 0.18 mm, and lowest individual reading must be ≥ 0.13 mm; also see Note 6.
(2) Alternate the measurement side for double sided textured sheet
(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm
(4) The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(5) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(6) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3
(7) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(8) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(9) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(10) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(11) UV resistance is based on percent retained value regardless of the original HP-OIT value.

Adoption and Revision Schedule

for

HDPE Specification per GRI-GM13

"Test Methods, Test Properties, Testing Frequency for
High Density Polyethylene (HDPE) Smooth and Textured Geomembranes"

Adopted:	June 17, 1997
Revision 1:	November 20, 1998; changed CB dispersion from allowing 2 views to be in Category 3 to requiring all 10 views to be in Category 1 or 2. Also reduced UV percent retained from 60% to 50%.
Revision 2:	April 29, 1999: added to Note 5 after the listing of Carbon Black Dispersion the following: "(In the viewing and subsequent quantitative interpretation of ASTM D5596 only near spherical agglomerates shall be included in the assessment)" and to Note (4) in the property tables.
Revision 3:	June 28, 2000: added a new Section 5.2 that the numeric table values are neither MARV or MaxARV. They are to be interpreted per the the designated test method.
Revision 4:	December 13, 2000: added one Category 3 is allowed for carbon black dispersion. Also, unified terminology to "strength" and "elongation".
Revision 5:	May 15, 2003: Increased minimum acceptable stress crack resistance time from 200 hrs to 300 hrs.
Revision 6:	June 23, 2003: Adopted ASTM D 6693, in place of ASTM D 638, for tensile strength testing. Also, added Note 2.
Revision 7:	February 20, 2006: Added Note 6 on Asperity Height clarification with respect to shear strength.
Revision 8:	Removed recommended warranty from specification.

REFERENCE 4 STATIC

USEI Cell 15 Profile 1

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File Information

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Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Analysis\slope stability\
Last Solved Date: 8/15/2008
Last Solved Time: 3:36:34 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15 Profile 1

Description: Complex rendition of profile 1
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Allow Passive Mode: No
- Slip Surface Option: Grid and Radius
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

FOS Distribution
FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

CCL

Model: Mohr-Coulomb
Unit Weight: 94 pcf
Cohesion: 60 psf
Phi: 22 °
Phi-B: 0 °

Common Fill

Model: Mohr-Coulomb
Unit Weight: 124.8 pcf
Cohesion: 1000 psf

Phi: 31 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (-69.428676, 2895.3305) ft
Lower Left: (-69.428676, 2698.0223) ft
Lower Right: (346.5513, 2745.1749) ft
Grid Horizontal Increment: 50
Grid Vertical Increment: 50
Left Projection Angle: 0 °
Right Projection Angle: 0 °

Slip Surface Radius

Upper Left Coordinate: (-30.363792, 2614.2465) ft
Upper Right Coordinate: (269.33712, 2613.3309) ft
Lower Left Coordinate: (-30.363792, 2519.9414) ft
Lower Right Coordinate: (268.72673, 2520.857) ft
Number of Increments: 25
Left Projection: No
Left Projection Angle: 135 °
Right Projection: No
Right Projection Angle: 45 °
UsePoints: 0

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2718.52) ft

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (251.09, 2638) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1

Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 776.95 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf

Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft
Inside Point: (68, 2640) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (488, 2500) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (78.287, 2636.6) ft
Total Length: 433.23204 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable

F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 209.08 lbs
Resisting Force Used: 154.18 lbs/ft
Available Bond Length: 1.3561 ft
Required Bond Length: 1.3561 ft
Governing Component: Bond

Regions

	Material	Points	Area (ft^2)
Region 1	Natural Subgrade	11,1,2,3,13,24,31,32	51403.505
Region 2	CCL	24,25,26,27,28,29,10,11,32,31	1502.095
Region 3	Common Fill	24,13,14,15,16,17,30,29,28,27,26,25	46.21825
Region 4	Common Fill	29,30,9,10	279.8574
Region 5	Common Fill	30,17,8,9	422.5855
Region 6	Waste	12,8,17,18,19,20,21,22,23,7	52614.854
Region 7	ET Cover	3,13,14,15,16,17,18,19,20,21,22,23,7,6,5,4	4149.6522

Points

	X (ft)	Y (ft)
Point 1	-100	2500
Point 2	-100	2640
Point 3	45.2	2640
Point 4	266.81	2713.87
Point 5	400	2720.52
Point 6	500	2718.52
Point 7	500	2713.52
Point 8	493.11	2500
Point 9	490.04	2500

Point 10	488	2500
Point 11	477.2	2500
Point 12	500	2500
Point 13	57.3	2640
Point 14	61.5	2640
Point 15	66.5	2642.5
Point 16	68	2642.5
Point 17	79.32	2637.93
Point 18	116.93	2652.97
Point 19	124.78	2650.11
Point 20	182.06	2672.99
Point 21	189.52	2670.01
Point 22	289.5	2710
Point 23	399.85	2715.52
Point 24	61.3	2638
Point 25	63.5	2638
Point 26	66.5	2638
Point 27	66.5	2640
Point 28	68	2640
Point 29	77	2637
Point 30	77.93	2637.37
Point 31	63.5	2636.9
Point 32	66.5	2636.9

Critical Slip Surfaces

	Number	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	20619	2.705	(163.52, 2783.62)	169.965	(319.675, 2716.51)	(63.5948, 2646.13)

Slices of Slip Surface: 20619

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	20619	66.8062	2643.908	0	394.13322	200.8209	0

			5				
2	20619	73.67303	2639.408	0	1586.0924	953.02043	1000
3	20619	77.629225	2636.954 5	0	2095.2004	1258.9234	1000
4	20619	78.10826	2636.674 5	0	2155.0145	1294.8633	1000
5	20619	78.80326	2636.274	0	1781.3643	719.71789	60
6	20619	83.50769	2633.741 5	0	2418.2336	977.0298	60
7	20619	91.883065	2629.558 5	0	3382.2171	1366.5044	60
8	20619	100.25843	2625.931	0	4280.9183	1729.6033	60
9	20619	109.802	2622.466	0	5205.3627	2103.1031	60
10	20619	116.04395	2620.423	0	5762.0648	2328.0253	60
11	20619	120.855	2619.147	0	6095.3287	2462.6726	60
12	20619	129.4544	2617.172	0	6655.8645	2689.1438	60
13	20619	138.8032	2615.528	0	7200.4245	2909.1603	60
14	20619	144.9975	2614.674 5	0	7854.0426	4719.1849	1000
15	20619	148.6039	2614.324	0	7966.2311	4786.5946	1000
16	20619	154.6116	2613.934	0	7974.7099	4604.2009	125
17	20619	162.454	2613.703 5	0	8116.9976	4686.3507	125
18	20619	170.2964	2613.835 5	0	8181.1574	4723.3934	125
19	20619	178.1388	2614.330 5	0	8176.496	4720.7022	125
20	20619	185.79	2615.162	0	8075.4508	4662.3637	125
21	20619	193.8139	2616.433	0	7919.4575	4572.3009	125
22	20619	202.4017	2618.220 5	0	7747.902	4473.2533	125
23	20619	210.98945	2620.479 5	0	7534.9402	4350.2997	125
24	20619	219.5772	2623.229 5	0	7287.862	4207.6491	125
25	20619	228.165	2626.497	0	7012.3288	4048.5699	125
26	20619	236.7528	2630.315	0	6711.6774	3874.9887	125

27	20619	245.34055	2634.7255	0	6386.8795	3687.4666	125
28	20619	253.9283	2639.784	0	6036.491	3485.1697	125
29	20619	262.5161	2645.562	0	5656.4422	3265.7484	125
30	20619	270.59165	2651.7105	0	5181.4248	2991.497	125
31	20619	278.155	2658.2375	0	4608.0211	2660.4422	125
32	20619	285.71835	2665.611	0	3988.3648	2302.6835	125
33	20619	294.146	2675.1205	0	3197.5003	1846.0777	125
34	20619	303.438	2687.475	0	2181.2945	1259.3709	125
35	20619	312.73	2702.815	0	944.46714	545.28836	125
36	20619	318.5255	2713.9515	0	176.87037	90.119953	0

USEI Cell 15 Profile 1

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File Information

Created By: Pease, Eric
Revision Number: 23
Last Edited By: Pease, Eric
Date: 8/15/2008
Time: 3:27:21 PM
File Name: USEI 15-1 complex seismic.gsz
Directory: S:\Projects\US Ecology\ES07.0130_US_Ecology_Closure_Cell_14_15\Analysis\slope stability\
Last Solved Date: 8/15/2008
Last Solved Time: 3:29:26 PM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

USEI Cell 15 Profile 1

Description: Complex rendition of profile 1
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: (none)

SlipSurface
- Direction of movement: Right to Left
- Allow Passive Mode: No
- Slip Surface Option: Grid and Radius
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

FOS Distribution
- FOS Calculation Option: Constant

Advanced
- Number of Slices: 30
- Optimization Tolerance: 0.01
- Minimum Slip Surface Depth: 0.1 ft
- Optimization Maximum Iterations: 2000

Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1

Materials

ET Cover

Model: Mohr-Coulomb
Unit Weight: 101.6 pcf
Cohesion: 0 psf
Phi: 27 °
Phi-B: 0 °

Natural Subgrade

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 800 psf
Phi: 36 °
Phi-B: 0 °

Waste

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion: 125 psf
Phi: 30 °
Phi-B: 0 °

CCL

Model: Mohr-Coulomb
Unit Weight: 94 pcf
Cohesion: 60 psf
Phi: 22 °
Phi-B: 0 °

Common Fill

Model: Mohr-Coulomb
Unit Weight: 124.8 pcf
Cohesion: 1000 psf
Phi: 31 °
Phi-B: 0 °

Slip Surface Grid

Upper Left: (-69.428676, 2895.3305) ft
Lower Left: (-69.428676, 2698.0223) ft
Lower Right: (346.5513, 2745.1749) ft
Grid Horizontal Increment: 50
Grid Vertical Increment: 50
Left Projection Angle: 0 °
Right Projection Angle: 0 °

Slip Surface Radius

Upper Left Coordinate: (-30.363792, 2614.2465) ft
Upper Right Coordinate: (269.33712, 2613.3309) ft
Lower Left Coordinate: (-30.363792, 2519.9414) ft
Lower Right Coordinate: (268.72673, 2520.857) ft
Number of Increments: 25
Left Projection: No
Left Projection Angle: 135 °
Right Projection: No
Right Projection Angle: 45 °
UsePoints: 0

Slip Surface Limits

Left Coordinate: (-100, 2640) ft
Right Coordinate: (500, 2718.52) ft

Seismic Loads

Horz Seismic Load: 0.2
Vert Seismic Load: 0.2
Ignore seismic load in strength: No

Reinforcements

Reinforcement 1

Type: Fabric
Outside Point: (63.5, 2638) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (271.87, 2638) ft
Total Length: 3 ft
Reinforcement Direction: 180 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 1376.9 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 2

Type: Fabric
Outside Point: (66.5, 2640) ft
Inside Point: (66.5, 2638) ft
Slip Surface Intersection: (0, 0) ft
Total Length: 2 ft
Reinforcement Direction: 90 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 0 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 3

Type: Fabric
Outside Point: (68, 2640) ft
Inside Point: (66.5, 2640) ft
Slip Surface Intersection: (67.834, 2640) ft
Total Length: 1.5 ft
Reinforcement Direction: 0 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 162.05 lbs
Resisting Force Used: 121.48 lbs/ft
Available Bond Length: 1.334 ft
Required Bond Length: 1.334 ft
Governing Component: Bond

Reinforcement 4

Type: Fabric
Outside Point: (77, 2637) ft

Inside Point: (68, 2640) ft
Slip Surface Intersection: (67.574, 2640.1) ft
Total Length: 9.486833 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 121.48 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Reinforcement 5

Type: Fabric
Outside Point: (488, 2500) ft
Inside Point: (77, 2637) ft
Slip Surface Intersection: (67.574, 2640.1) ft
Total Length: 433.23204 ft
Reinforcement Direction: 341.57 °
Applied Load Option: Variable
F of S Dependent: Yes
Contact Cohesion: 0 psf
Contact Phi: 15 °
Interface Factor: 1
Bond Safety Factor: 1
Fabric Capacity: 960 lbs
Fabric Safety Factor: 1
Fabric Load: 960 lbs
Load Distribution: Even along reinf.
Load Orientation: 0
Applied Load: 960 lbs
Fabric Load Used: 0 lbs
Resisting Force Used: 121.48 lbs/ft
Available Bond Length: 0 ft
Required Bond Length: 0 ft
Governing Component: Bond

Regions

	Material	Points	Area (ft^2)
Region 1	Natural Subgrade	11,1,2,3,13,24,31,32	51403.505
Region 2	CCL	24,25,26,27,28,29,10,11,32,31	1502.095
Region 3	Common Fill	24,13,14,15,16,17,30,29,28,27,26,25	46.21825

Region 4	Common Fill	29,30,9,10	279.8574
Region 5	Common Fill	30,17,8,9	422.5855
Region 6	Waste	12,8,17,18,19,20,21,22,23,7	52614.854
Region 7	ET Cover	3,13,14,15,16,17,18,19,20,21,22,23,7,6,5,4	4149.6522

Points

	X (ft)	Y (ft)
Point 1	-100	2500
Point 2	-100	2640
Point 3	45.2	2640
Point 4	266.81	2713.87
Point 5	400	2720.52
Point 6	500	2718.52
Point 7	500	2713.52
Point 8	493.11	2500
Point 9	490.04	2500
Point 10	488	2500
Point 11	477.2	2500
Point 12	500	2500
Point 13	57.3	2640
Point 14	61.5	2640
Point 15	66.5	2642.5
Point 16	68	2642.5
Point 17	79.32	2637.93
Point 18	116.93	2652.97
Point 19	124.78	2650.11
Point 20	182.06	2672.99
Point 21	189.52	2670.01
Point 22	289.5	2710
Point 23	399.85	2715.52
Point 24	61.3	2638
Point 25	63.5	2638
Point 26	66.5	2638
Point 27	66.5	2640
Point 28	68	2640
Point 29	77	2637
Point 30	77.93	2637.37
Point 31	63.5	2636.9
Point 32	66.5	2636.9

Critical Slip Surfaces

	Number	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	36557	1.671	(171.84, 2831.92)	218.287	(358.312, 2718.44)	(59.4889, 2644.76)

Slices of Slip Surface: 36557

	Slip	X (ft)	Y (ft)	PWP	Base Normal	Frictional	Cohesive

	Surface			(psf)	Stress (psf)	Strength (psf)	Strength (psf)
1	36557	62.156455	2643.2125	0	371.29545	189.18448	0
2	36557	65.661995	2641.1955	0	1398.3225	840.19693	1000
3	36557	67.166985	2640.3645	0	1669.6499	1003.2269	1000
4	36557	72.416985	2637.6545	0	1839.2229	743.09429	60
5	36557	77.465	2635.086	0	2495.8938	1008.4066	60
6	36557	78.625	2634.535	0	2644.6015	1068.4884	60
7	36557	84.02125	2632.14	0	3403.4217	1375.0716	60
8	36557	93.42375	2628.263	0	4713.645	1904.4362	60
9	36557	102.82625	2624.886	0	5943.1057	2401.1706	60
10	36557	112.22875	2621.984	0	7058.6793	2851.8916	60
11	36557	120.855	2619.706	0	7903.1325	3193.0728	60
12	36557	128.63285	2617.985	0	8543.4076	3451.7607	60
13	36557	136.33855	2616.5715	0	9122.001	3685.5276	60
14	36557	141.93475	2615.695	0	10661.963	6406.3535	1000
15	36557	146.06445	2615.17	0	10876.524	6535.2749	1000
16	36557	154.0523	2614.428	0	10711.277	6184.1586	125
17	36557	165.25535	2613.801	0	10914.34	6301.3973	125
18	36557	176.45845	2613.7505	0	10887.423	6285.8567	125
19	36557	185.79	2614.108	0	10682.937	6167.7967	125
20	36557	194.35065	2614.848	0	10398.369	6003.501	125
21	36557	204.0119	2616.069	0	10067.387	5812.4083	125
22	36557	213.67315	2617.7325	0	9687.2113	5592.9141	125
23	36557	223.3344	2619.849	0	9279.5268	5357.5373	125
24	36557	232.99565	2622.432	0	8860.9205	5115.8548	125
25	36557	242.6569	2625.4995	0	8442.8153	4874.4617	125
26	36557	252.31815	2629.0735	0	8032.7154	4637.6904	125
27	36557	261.9794	2633.181	0	7633.5525	4407.2336	125
28	36557	272.4825	2638.321	0	7062.0908	4077.3	125
29	36557	283.8275	2644.6625	0	6330.783	3655.0793	125
30	36557	294.18385	2651.226	0	5653.4176	3264.0022	125
31	36557	303.5515	2657.943	0	5007.2854	2890.9576	125
32	36557	312.91915	2665.459	0	4334.7609	2502.6754	125
33	36557	322.2868	2673.888	0	3615.3661	2087.3326	125
34	36557	331.65445	2683.3865	0	2823.4829	1630.1386	125
35	36557	341.02215	2694.1795	0	1925.9517	1111.9487	125
36	36557	350.3898	2706.6065	0	877.85625	506.83054	125
37	36557	356.69295	2715.8595	0	201.40125	102.61906	0

REFERENCE 5

Washington

ENGINEERING REPORT
for
LANDFILL CELL 15

GRAND VIEW FACILITY

June 2002

Prepared for

US Ecology of Idaho

Prepared by

Washington Group International, Inc.
Boise, Idaho

complies with applicable state, RCRA, and TSCA regulations. The siting and layout of the proposed landfill, including geotechnical design parameters, slope stability, and frost depth, are discussed in Section 5. The liner and leachate collection and removal system composition and design are detailed in Section 6. Section 7 addresses the operational requirements for each element of the landfill, and Section 8 describes the landfill cap design. The documents referenced within the text of this report are listed in Section 9. The figures referenced throughout this report follow Section 9.

The final design and construction specifications, as well as the as-built disposal cell, may require minor modifications to accommodate specific types of construction equipment (other than CCL liner placement), specific operational procedures, conflicts between drawings and specifications, clarification of design intent, and other issues that may affect drawings and specifications, but not compromise the design. Minor changes must not alter the performance of the disposal cell, must be equal or superior to the approved design, and must meet Minimum Technology Requirements (MTR). Such changes are normal and acceptable, and will not constitute a change to the permitted Disposal Cell. Other changes require the review and approval of IDEQ.

3.0 SITE CONDITIONS

The site is located in Owyhee County on the crest of a broad ridge between the Snake River on the east side and a creek on the west. Owyhee County is a ranching and agricultural area of approximately 7,000 square miles. The county is sparsely populated, with an average population of 1.33 persons per square mile. The closest town is Grand View, which is 10.5 miles to the southeast. Grand View has a population of about 500, and approximately 170 people live within 4 miles of the site. *Hazardous Waste Facility Siting License Application, Section 19* (Envirosafe and CH2M Hill, 2000) contains a detailed description of the site conditions, which are summarized below.

3.1 Surface

Landfill Cell 15 is located immediately south of the existing site fence and adjacent to Landfill Cell 14 (Figure 1.1). The area has been partially disturbed by excavation of surface soils to construct capping layers within the existing facility. The ground surface slopes down at approximately 2 percent to the east. Immediately west of the landfill is a soil stockpile created with the material excavated from Landfill Cell 14.

Vegetation in the site area consists of desert grasses, sage and other desert brush.

3.2 Subsurface

The hydrogeology of the site has been well characterized using information obtained from over 100 borings and wells that have been installed in and around the existing facility. Based on the information from these test borings and published literature, the geology and subsurface conditions are described below.

3.2.1 General Geology

The site lies within Owyhee County in southwestern Idaho and geographically comprises a portion of the Snake River Valley. Plutonic and volcanic rocks, which form the flanks of the valley, are buried deep beneath younger materials in the center of this structural depression. These rocks are of Mesozoic and Tertiary age. Within the trough of older rocks, thick sequences of younger sediments and igneous flow rocks mask the structure of the underlying crystallines.

The oldest rocks of the mountainous area to the north and to the southwest of the region investigated are of Jurassic and Cretaceous age and are of granitic and granodiorite composition. These rocks represent the edge outlines of the Idaho batholith, forming the extreme western limits of the Rocky Mountains. Metamorphic rocks are found locally associated with the plutonic rocks in the uplift.

Within the Snake River Valley are younger (Tertiary and Quaternary) deposits that were laid down as pediment sands, gravels, and silts of freshwater lakes or in the form of piedmont plains with intermingled and superimposed silicic and basaltic extrusive volcanic and pyroclastic flow rocks that range in age from Miocene to early Recent. The floors of the presently active watercourses and their overflow areas are blanketed with the most recent materials. These recent materials were derived from deposits of wind-blown silts, fine sands, and bench or terrace deposits of pre-existing gravelly materials.

3.2.2 General Stratigraphy

The stratigraphy and approximate thickness of each layer can be characterized as follows, in ascending order (deepest and oldest first):

- Poison Creek Formation – 600 plus feet
- Banbury Basalts – 200 plus feet
- Chalk Hills Formation – 600 plus feet
- Glenns Ferry Formation – 1500 plus feet
- Bruneau Formation – 0 to 100 plus feet

Poison Creek and Chalk Hills Formations

The Poison Creek and Chalk Hills formations are lacustrine (lake) deposits of the Snake River Plain. The Poison Creek Formation separates the general groundwater systems from the local groundwater systems.

Banbury Basalts

Approximately 200 feet of basalt, known as the Banbury Basalts, separate the Poison Creek Formation and the Chalk Hills Formation. These basalts are the first fractured rock system beneath the site.

Glenns Ferry Formation

The Glenns Ferry Formation represents lacustrine, fluvial (river), and flood plain deposits. The first encountered groundwater at the proposed siting area is in this formation. The first water-bearing zones beneath the site consist of two groups of thin sand beds that are interbedded in the fine-grained lacustrine sediments of the Glenns Ferry Formation.

Bruneau Formation

The Bruneau Formation consists of unconsolidated lake deposits to high-energy river gravels. These are coarse-grained deposits that are located at the ground surface near the site.

3.2.3 Subsurface Conditions

Subsurface conditions at the proposed site have been determined preliminarily based on a review of the subsurface conditions encountered in the excavation of Landfill Cell 14. (Landfill Cell 14 represents a large test pit excavated to a depth equal to the planned Landfill Cell 15 and provides information related to expected excavation conditions.) In addition, the detailed logging of monitoring well D-40, which is near the south edge of Landfill Cell 15, has provided additional geologic and geotechnical information.

Before construction of the landfill cell is begun, site subsurface conditions will be confirmed by drilling, sampling, and logging several additional geotechnical exploration borings within the Landfill Cell 15 area. Laboratory tests will be conducted on selected disturbed and undisturbed samples to correlate the existing site soils data with the soils encountered.

The site soils are composed primarily of layers of silty sands and sandy silts, with some silt and clay layers. The top 30 to 40 feet are composed primarily of silty and gravelly sands, which are underlain by silty sands and sandy silts to a depth of approximately 150 feet. Below 150 feet, thick beds of inorganic silt are encountered. These materials were deposited as fluvial lake deposits. Borings data show that relatively consistent, uniform soil conditions exist throughout the site. The site soils may generally be classified as over-consolidated, cohesionless soils consisting of very dense silty sands and sandy silts. The soils are generally classified as SP, SM, SP-SM, and ML according to the Unified Soil Classification System (USCS). The Standard Penetration Resistance N-values generally range from 50 to more than 100 blows per foot, indicating that these soils are very dense.

Fine-grained soil strata were also encountered at the site. These soils consist of low-plasticity silts that are classified as ML according to the USCS. The Standard Penetration Resistance values in these soils generally exceed 30 blows per foot, indicating that these soils are hard.

The general subsoil profile is given below:

- 0 – 50 ft dense unsaturated silty and gravelly sands
- 50 – 150 ft silty sands, sandy silts, few layers of clay and silt
- 150 – 200 ft stratified silts, few layers of sand

3.3 Borrow Sources

Earthen materials used in the construction of Landfill Cell 15 will be obtained primarily from local borrow sources on property owned by US Ecology. A small amount of aggregate material may be purchased from commercial sources.

3.3.1 Ketterling Clay

The Ketterling Clay, a part of the Glenns Ferry Formation, consists of silty clay to clay material. The clay material used in the construction of the compacted clay liner (CCL) for Landfill Cell 14 will also be used to construct Landfill Cell 15 CCL. The Kettering Clay is a relatively thick, discontinuous sedimentary deposit capped by a thin veneer of sand and gravel. The gravel has prevented erosion of the underlying clay, leaving the deposit in the form of ridges and knolls near the landfill site. The location of the borrow area will be selected during the final design geotechnical engineering program. Preliminary reconnaissance indicates that sufficient quantities of material are available for the landfill construction.

3.3.2 Sand and Gravel

Deposits of sand and gravel that are suitable for use as construction material are available near the siteUS. The material, part of the Glenns Ferry Formation, has been used as an aggregate source in the past. Preliminary reconnaissance indicates that screening of the material may be necessary to meet the required gradation for aggregate used around pipes in the leachate collection systems. Depending on the cost of commercial aggregates at the time of construction, drainage aggregate may be screened locally or obtained from a commercial source.

In addition, lenses of sand and gravel containing material suitable for use as granular construction material may be encountered during excavation of the disposal cell or other excavations performed in the area of the site.

Reconnaissance indicates that the local aggregate may be suitable for stabilizing ditches in the final cover. Screening of the material may not be necessary. A borrow investigation will be conducted during the final design geotechnical program to determine the need for screening.

3.4 Hydrologic

The following paragraphs describe the existing surface and groundwater conditions at the proposed site for Landfill Cell 15.

3.4.1 Surface Water

After the confluence of Castle and Catherine Creeks, the nearest surface water body is the ephemeral Castle Creek, which approaches from the northwest and is more than 2,500 feet from the site perimeter.

3.4.2 Groundwater

The first encountered water at the site, known as the lower aquifer, will be greater than 100 feet from the bottom of Cell 15. Beneath the lower aquifer are clay units of the Glenns Ferry Formation for approximately 600 feet. The first fractured rock is the Banbury Basalt, approximately 2,250 feet from the surface. Well L-40 lies within the footprint of Landfill Cell 15, and is considered representative of the groundwater conditions at Cell 15 location.

Detailed discussion of groundwater conditions are contained in *Hydrogeologic Characterization and Groundwater Monitoring Considerations for Proposed Cell 14 Expansion Area at Envirosafe Services of Idaho, Inc., Site B* (CH2M Hill, 1993). Additional details are also provided in the original RCRA Part B Application (Weston, 1987).
Groundwater considerations related to construction of Cell 15 are discussed in detail in *Cell 15 Groundwater Monitoring Program* (CH2M Hill, 2002).

3.5 Seismic

Owyhee County is not listed in Appendix VI of 40 CFR 264, so no further information is required to demonstrate compliance with Section 264.18(a). However, to further demonstrate that the facility is safe against expected seismic conditions, the site was treated as if it lies within an impact zone with the following described seismicity.

A review of published geological studies and aerial reconnaissance show that no faults or lineations are present within 3,000 feet of the facility. The nearest potentially active fault is the Water Tank Fault, located approximately 20 miles south-southeast of the site. The seismic potential of the Water Tank Fault is not known.

The historical seismicity of Idaho was also reviewed. Historical earthquakes of magnitude 6.0 or greater and occurring in Idaho or near its borders are listed below. The locations of earthquakes prior to 1934 are approximate and were therefore not included.

Date (yy/mm/dd)	Latitude (deg)	Longitude (deg)	Magnitude	Comments
1959/08/18	44.83N	111.01W	7.5	Hebgen Lake earthquake
1959/08/18	45.00N	110.70W	6.5	Hebgen Lake aftershock
1959/08/18	45.06N	111.80W	6.0	Hebgen Lake aftershock
1959/08/18	44.86N	110.71W	6.3	Hebgen Lake aftershock
1959/08/19	44.75N	111.61W	6.0	Hebgen Lake aftershock
1975/03/28	42.95N	112.51W	6.0	56 miles from Pocatello, ID
1983/10/28	43.96N	113.88W	7.3	Borah Peak earthquake

All of these earthquakes caused property damage. The Hebgen Lake and Borah Peak earthquakes caused loss of human life.

The effect of these historical earthquakes is accounted for in the horizontal accelerations depicted in USGS Map MF-2120, and a bedrock acceleration of 0.15 g was conservatively assumed as the design acceleration for Site B.

3.6 Climatologic

Climate data are available from the US Weather Service (University of Idaho, 2002). The average annual temperature of Grand View is 52°F. The temperature ranges from a monthly average maximum of about 94.1°F to a monthly average minimum of 20.2°F.

The average annual precipitation is 6.97 inches. The average monthly precipitation is a minimum of 0.18 inch in July to a maximum of 0.91 inch in May. Snow may fall as early as October and may end as late as May, with an average annual snowfall of 5.9 inches.

The historic data of earliest frost is October 29.

4.0 REGULATIONS

4.1 IDEQ (RCRA)

The Landfill Cell 15 design was conducted and produced in compliance with 40 CFR 264, Subpart N. In particular, the requirements in 40 CFR 264.301, design and operating requirements, and 40 CFR 264.302, action leakage rate, were used as controlling principles. Elements of the design for leachate control and collection, for liner design, and for construction quality assurance planning received close attention to minimize issues during construction.

4.2 TSCA

The design was conducted in compliance with 40 CFR 761. In particular, the design incorporates the chemical waste landfill design requirements from 40 CFR 761.75, which includes technical, design, and location requirements. These requirements did not

conflict with the previously stated RCRA regulations, which are generally more restrictive than TSCA requirements.

5.0 LANDFILL SITING AND LAYOUT

This section describes the layout of the proposed landfill site and discusses design considerations.

5.1 Existing Site

US Ecology of Idaho's Grand View Facility is located approximately 10 miles northwest of the community of Grand View, Idaho. The existing site occupies approximately 120 acres in the north-central portion of Section 19. US Ecology owns all of Section 19 (640 acres), as shown in Figure 1.1.

5.2 Landfill Cell 15

The Landfill Cell 15 site is located directly south of the existing facility (Site B) and Landfill Cell 14 (Figure 1.1). The approximate location was identified in the siting license application (Envirosafe and CH2M Hill, 2000).

During design, the location of Landfill Cell 15 was adjusted to the east to avoid a soil stockpile area. The southern limit of the cell area shown in the application was also adjusted southward to allow a more robust configuration for the disposal cell cover. The landfill cell (referred to as disposal cell in the siting application) area lies within the 400 acres of Section 19 proposed for siting in the siting application. These changes resulted in the 500-foot buffer area being adjusted, but it is still well within all siting restrictions or setbacks.

The location meets site exclusionary criteria that no hazardous waste disposal cell shall be sited where:

- The seasonal high depth of the groundwater, beneath the proposed site, is less than 100 feet below the lowest point of the disposal cell. Perched saturated zones may be exempt from exclusionary criterion if it can be demonstrated that the saturated zone has no economic or consumptive usable purpose.
- The fine-grained unconsolidated sediments above the water table are less than 25 feet thick.
- The depth to fractured rock is less than 100 feet below the lowest point of disposal.

The cell location also meets the siting application criteria that no new hazardous waste disposal facility shall be sited within:

- 2,500 feet (from the expanded site perimeter) of surface water bodies.

- 1,000 feet (from the expanded site perimeter) of existing public/private and irrigation water wells, unless it can be demonstrated that natural hydrologic barriers isolate the site location from the aquifer being pumped.
- A floodplain of a 500-year flood.
- Areas that are near active fault zones or other tectonically active or unstable area.
- Areas overlying any subsurface mining.
- 5,000 feet of any off-site residential structure that is routinely occupied at least 8 hours per day.
- 3 miles of schools, airports, hospitals, churches.
- 3 miles of a population center greater than 150 people.

The relocated buffer zone location still meets the criteria presented above.

The proposed Landfill Cell 15 design layout is shown on Drawing 52-01-01, Appendix A. The cell extends approximately 1,768 feet in the east-west direction and is approximately 768 feet wide, measured around the outer limit of the bottom liner at the berm crest. This location is defined as the "waste limit" for the Landfill Cell 15 design.

5.3 Slope Stability

Landfill Cell 15 has been analyzed for slope stability including the maximum allowable excavation slope, the interim waste slope between Cell 15 construction phases, the final waste slope prior to cover placement, and the final exterior cover slope.

The landfill plan, sections, and details depicting the design conditions are shown on Drawing 52-01-01 and Drawings 52-01-03 through 52-01-05, Appendix A. The simplified model geometries used in the slope stability program are shown on Figures 5.1 through 5.4.

Stability analyses were performed using the commercial slope stability program SLOPE/W, Version 4, by GEO-SLOPE International, Ltd. The Spencer method of total equilibrium analyses was used to calculate the factors of safety. Circular and/or wedge failure surfaces were analyzed, depending on which was appropriate for the slope geometry being considered.

The SLOPE/W program allows the user to model the geometry and material properties and specify the regions to search for the critical failure surface. The program calculates the minimum factor of safety for the given geometry and materials on a trial-and-error basis. Thousands of potential failure surfaces are generated and associated safety

factors are computed through a systematic process of analysis until the lowest safety factor is identified for the conditions assigned.

A comprehensive stability analysis typically addresses both short-term (immediately following construction) and long-term conditions under static and earthquake conditions. The SLOPE/W program allows the application of vertical and horizontal acceleration coefficients to simulate earthquake, or seismic, loading of the slopes. This type of analysis is referred to as a "pseudo-static" analysis. For this site, a horizontal pseudo-static coefficient of 0.08 g was applied, based on approximately one-half of the design peak bedrock acceleration. The vertical component of seismic acceleration is typically very small and can be ignored.

Slope stability was also analyzed in certain cases using the infinite slope method. This method was used to calculate the factor of safety against shallow sliding or surface raveling of cohesionless soils and sliding of a thin soil layer overlying a stronger soil along a plane parallel to the slope.

The calculated stability factors of safety are compared to the minimum acceptable factors of safety presented in Table 5-1. The values are typical industry-accepted minimums. In each case, the calculated factor of safety equals or exceeds the minimum acceptable factor of safety.

Table 5-1 Slope Stability Minimum Acceptable Factors of Safety

Condition	Short Term (end of construction)	Long Term
Static	1.3	1.5
Pseudo-static	N/A	1.1

5.3.1 Geotechnical Design Parameters

Geotechnical properties, including strength data, were selected for the various soils and materials that will be used to construct Landfill Cell 15. The data were selected from previously published reports and data provided by US Ecology of Idaho. These sources included the original RCRA permit application (Weston, 1987) and *GeoSystems Technical Report* (GeoSystems, 2001). The geotechnical properties and strength data are summarized in Table 5-2.

Table 5-2 Geotechnical Design Parameters

Material Type/Location	Material Property
In Situ Soils Sand and silty sand (SP, SM, SP-SM)	γ_t = 115 pcf (Assumed) In situ w = 5 to 26%, ave = 10.5, s=7.9, σ =7.6 Percent passing No. 200 = less than 10% Strength (based on CID [Consolidated Isotropic Drained] test) Ø' = 36° to 39°

Table 5-2 Geotechnical Design Parameters

Material Type/Location	Material Property
Clay and silt (ML with some CL and CH)	c′ = 800 to 2000 psf γ_t = 125 pcf (Assumed) clay w = 3 to 9%, avg. = 7.7% silt w = 21 to 39%, avg. = 26.4%, s=6.6, σ =6.1 Percent passing No. 200 = 60 to 100% Strength (based on UU tests) Ø = 2° to 13° c = 4,200 to 8,400 psf
Compacted Common Fill Sand and silty sand (SP, SM, SP-SM)	Max. γ_d per ASTM D698 = 124.8 pcf OMC = 9.0% c = 1000 to 1300 psf (direct shear) Ø = 31.7° to 34.7°
Cover soil (ML)	Max. γ_d per ASTM D698 = 127 pcf (assumed) OMC = 15.0% (assumed) Drained strength: c = 0 (assumed) Ø = 27° (assumed)
Compacted Clay Liner Ketterling Clay (CL, CH)	Lab. K = 1 x 10-7 to 2 x 10^{-8} cm/s % CL = 17 to 37 PI = 14.6 to 26.5 LL = 37.4 to 51.7 Max. γ_d per ASTM D698 = 97.9 to 104.5 pcf OMC = 20.0 to 22.8% In-situ γd = 93.9 to 103.4 pcf % Std. Proctor achieved = 95 to 105 Drained strength: Ø = 22° (assumed) c = 60 psf (assumed) Undrained Strength: Ø = 0° c = 3000 psf (assumed) In situ w = 2.8 to 3.4 %
Weakest Geosynthetic: GCL (saturated and complete degradation of tensile reinforcement) GCL (reinforced and hydrated)	Strength: Ø = 8° (published mfg. test data) Strength: Ø = 18° (published mfg. test data)
Waste Stabilized soil-like waste Unstabilized soil-like waste	γ_t =140 pcf Total stress (CU) Ø = 28° c = 4,900 psf Effective Stress (CU/pp) Ø′ = 32° c′ = 3,600 psf γ_t =115 pcf (assumed) Total stress (CU) Ø = 0° c = 500 psf (This is the consistency of soft clay; it is not reasonable so will be ignored.) Effective stress (CU/pp) Ø′ = 30° c′ = 125 psf

Groundwater conditions and pore pressures are also accounted for in the stability models. The groundwater table is greater than 100 feet below the bottom of Landfill Cell 15 and does not affect or impact the slope stability. The soils and materials modeled in the stability analysis are unsaturated.

5.3.2 Summary Results

Table 5-3 presents a summary of the critical, or lowest, factors of safety against slope failure calculated for each of the conditions analyzed. All conditions and geometries analyzed meet acceptable minimum factors of safety. The associated critical failure surfaces for the various cases are described in the following subsections.

Table 5-3 Summary of Slope Stability Analyses

Analysis Case		Factor of Safety	
		Required	Actual
Final Cover Configuration			
Short-term , static	Circular failure near top Wedge failure near top	1.3	2.07 2.33
Long-term, seismic	Circular failure, general Circular failure near top Wedge failure near top	1.5	1.53* 1.93 1.86
Long-term, pseudo-static	Circular failure near top Wedge failure near top	1.1	1.41 1.36
Final Waste Slope at 2.5H:1V with Two Benches			
Short-term, static		1.3	2.14
Interim (Construction) Waste Slope at 2.25H:1V			
Short-term, static		1.3	1.51
Excavation Slope			
Short-term and long-term, static		1.3 ST 1.5 LT	2.18*
Long-term, seismic		1.1	1.71*
Side Slope CCL			
Short-term, static		1.3	14
Long-term, static		1.5	1.5

* - surface raveling

5.3.3 Maximum Excavation Slope

Excavation for the bottom liner system and below-grade portion of Landfill Cell 15 consists of a 3 horizontal to 1 vertical (3H:1V) slope up to 60 feet below existing grade. A berm will be constructed around the excavation to control run-on and to form a platform for staging and anchoring the bottom liner system. The berm will be constructed of soils removed from the excavation and compacted as engineered fill. The exterior slope of the berm will remain unchanged through construction of the final cover for the cell.

REFERENCE 5

SECTION 02272

GEOTEXTILES

PART 1 GENERAL

1.1 WORK INCLUDED

A. Furnish all labor, materials, tools, equipment, surveying, testing, and supervision to furnish and install the geotextiles as indicated on the Drawings.

B. Type 1 geocomposite shall be placed as a part of the liner system for Cell 15 construction, and Type 2 geocomposite shall be placed as a part of the cap system for Cell 15 closure, as shown on the Drawings.

1.2 RELATED WORK

A. Section 01010 - Summary of Work

B. Section 01300 - Submittals

C. Section 02200 - Earthwork

D. Section 02253 - Geosynthetic Clay Liner

E. Section 02771 - Geomembrane

F. U.S. Ecology Contractor Quality Assurance Plan

1.3 APPLICABLE PUBLICATIONS

A. The publications listed below form a part of this Section to the extent referenced. The publications are referred to in the text by the basic designation only. Use the latest revision unless otherwise noted:

1. American Society for Testing and Materials (ASTM):

D1777	Standard Test Method for Thickness of Textile Materials
D3776	Standard Test Method for Mass Per Unit Area of Fabric
D3786	Standard Test Method for Burst Strength in Geotextiles

D4355	Standard Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water
D4491	Standard Test Method for Water Permeability of Geotextiles by Permittivity
D4533	Standard Test Method for Trapezoid Tearing Strength of Geotextiles
D4632	Standard Test Method for Grab Breaking Load and Elongation of Geotextiles
D4751	Standard Test Method for Determining Apparent Opening Size of a Geotextile
D4833	Standard Test Method for Index Puncture Resistance Geotextiles, Geomembrane, and Related Products
D4873	Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples

1.4 SUBMITTALS

A. The following administrative submittals are due 14 days prior to the Contractor beginning the Work:

1. Contractor's schedule of installation of the geotextile fabric.
2. Shop drawings that detail seaming procedures, special construction details, anchoring details, and temporary anchors.
3. Representative samples of all geosynthetics proposed for use on the project, together with their full designation, manufacturer name, and applicable installation instructions.
4. Manufacturer's Certification that the geotextile fabric meets or exceeds the physical strength requirements found herein.

B. Quality Control Submittals:

1. Daily report of Contractor's activities.
2. The Contractor shall submit certified laboratory test results that the geotextiles meet the physical strength requirements found in Paragraphs 2.1 and 2.2 of this Section.

C. Exceptions: Listing of all exceptions to the requirements specified herein.

1.5 DELIVERY, STORAGE, AND HANDLING OF MATERIALS

A. The Owner shall approve all submittals prior to the delivery of material at the site.

B. Material delivery, storage, and handling shall conform to the manufacturer's recommendations and shall be done in a manner that prevents damage to any part of the Work.

C. Handling of rolls shall be completed in a competent manner so that damage does not occur to the geotextile or to its protective wrapping. ASTM D4873 shall be referenced and followed.

D. Rolls shall be delivered to and stored on the site in ultraviolet light-resistant packaging. The integrity of this packaging shall be maintained until the roll is to be installed. Any protective wrapping that is accidentally damaged or stripped off the rolls shall be repaired immediately or covered if the geotextile will not be installed within 60 days.

E. Each roll of geotextile fabric shall bear a label that identifies the following:
   1. Manufacturer
   2. Product identification
   3. Roll number
   4. Batch code
   5. Physical dimensions
   6. Date of manufacture

F. Field storage shall be located in areas where water cannot accumulate. The rolls shall be elevated off the ground to avoid forming a dam that allows the ponding of water.

PART 2 PRODUCTS

2.1 SIX-OUNCE SEPARATION GEOTEXTILE

A. Geotextile fabric shall be a needle-punched non-woven polypropylene fabric.

B. The delivered geotextile fabric shall meet the physical strength properties in the following table:

Property	Test Method	Required Value
Weight	ASTM D3776	6 oz/yd^2
Thickness	ASTM D1777	75 mil
Grab Tensile Strength Elongation	 ASTM D4632 ASTM D4632	 90 lbs 50%

Property	Test Method	Required Value
Tear Strength	ASTM D4533	60 lbs
Puncture Strength	ASTM D4833	90 lbs
Burst Strength	ASTM D3786	220 lbs/in^2
Apparent Opening Size	ASTM D4751	60-100
Permittivity	ASTM D4491	1.3 sec^{-1}
Retained Strength	ASTM D4355	70%

C. The geotextile fabric shall be heat-bonded to one side of the 200-mil geonet to act as a filtration element and create a geonet composite (geocomposite).

2.2 EIGHT-OUNCE SEPARATION GEOTEXTILE

A. Geotextile fabric shall be a needle-punched non-woven polypropylene fabric.

B. The geotextile shall meet the following physical strength properties:

Property	Test Method	Required Value
Weight	ASTM D3776	8 oz/yd^2
Thickness	ASTM D1777	95 mil
Grab Tensile Strength Elongation	 ASTM D4632 ASTM D4632	 150 lbs 50%
Tear Strength	ASTM D4533	125 lbs
Puncture Strength	ASTM D4833	90 lbs
Burst Strength	ASTM D3786	325 lbs/in^2
Apparent Opening Size	ASTM D4751	80-100
Permittivity	ASTM D4491	1.5 sec^{-1}
Retained Strength	ASTM D4355	70%

C. The geotextile fabric shall be heat-bonded to one side of the 300-mil tri-planar geonet to act as a filtration element and create a geonet composite (geocomposite).

PART 3 EXECUTION

3.1 GENERAL

A. The geotextile fabric products for the geocomposite materials will be heat-bonded to geonet products to create a geocomposite material.

B. Geotextiles shall be handled in a manner that ensures they are not damaged in any way.

C. The contractor shall exercise care to ensure that the underlying layer is not damaged during installation.

D. The contractor shall exercise care to ensure that stones, mud, and dirt are not entrapped in the geotextile or geocomposite material during placement.

E. In the presence of wind, the Contractor shall weight the materials with sandbags until the overlying material has been placed. Securing pins or other methods that may damage the HDPE geomembrane will not be permitted.

F. During backfill operations, the soil shall be placed so that the geotextile is not shifted or ripped from its intended position.

3.2 GEOCOMPOSITE APPLICATION

A. Because a geosynthetic such as a HDPE geomembrane will underlie the geocomposite during installation, the materials shall be deployed by hand.

B. The Contractor shall perform a visual inspection of the deployed materials to ensure that defects do not exist. Defective areas shall be replaced.

C. The overlying material shall not be placed in a manner that causes excess tensile stress in the geotextile to be mobilized. On side slopes, this requires soil backfill to proceed from the bottom of the slope upward.

3.3 LEACHATE DETECTION AND COLLECTION SYSTEM APPLICATION

A. The geotextile shall be placed on top of the drain rock and leachate collector or header pipe as shown on the Drawings. The fabric shall be secured in place by tucking the fabric under the drain rock. Twelve inches of fabric shall be tacked on both sides of the installation.

B. Geotextiles shall be overlapped a minimum of 12 inches in the direction of flow with the upstream fabric on top of the downstream fabric.

C. Care shall be taken during installation of the drain rock and the leachate header and collector pipes to prevent damage to the fabric.

D. Do not wrap perforated or slotted pipe directly with geotextile.

3.4 PROTECTION

A. The Contractor shall protect the integrity of the geotextile materials until overlying materials are placed and until the Owner accepts the installed Work.

PART 4 FIELD QUALITY CONTROL

4.1 DOCUMENTATION

A. The Contractor shall provide a daily report to the Owner regarding installation activities. This document shall include the following minimum information:

1. Type and quantity of material placed
2. Location of material placement

B. The Contractor shall provide the Owner with a copy of the chain-of-custody record for each sample sent to an independent laboratory.

4.2 QUALITY ASSURANCE SAMPLING AND TESTING

A. The Contractor shall assist the Owner with obtaining Quality Assurance samples for laboratory testing.

B. The Contractor shall allow the Owner access to perform sampling and inspect and test all geotextiles before subsequent layers are installed on top of them.

END OF SECTION 02272

Washington

SPECIFICATION TITLE SHEET

This sheet is a record of each issue or revision to the subject specification.

The exact sheets changed and the nature of the change should be noted under "Remarks." These remarks are not a part of the specification. The revised sheets become part of the original document and shall be complied with in their entirety.

Issue Date	Originated or Revised By	Checked By	APPROVAL Department	APPROVAL Project	REMARKS

Client, Project, Location	Work Order Number	Washington Group International, Inc. Specification Title/Description
US ECOLOGY GRAND VIEW LANDFILL CELL 15	5124 Specification Section 02274	GEOCOMPOSITE

SECTION 02274

GEOCOMPOSITE

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SECTION 02274

GEOCOMPOSITE

PART 1 GENERAL

1.1 WORK INCLUDED

A. Furnish all labor, materials, tools, equipment, surveying, testing, and supervision to furnish and install the geocomposite materials as indicated on the Drawings.

B. Type 1 geocomposite shall be placed as a part of the liner during the construction of Cell 15, and Type 2 geocomposite shall be placed as a part of the cap system during the closure of Cell 15, as shown on the Drawings.

1.2 RELATED WORK

A. Section 01010 - Summary of Work

B. Section 01300 - Submittals

C. Section 02200 - Earthwork

D. Section 02228 - Low-Permeability Soil Layer

E. Section 02253 - Geosynthetic Clay Liner

F. Section 02771 - Geomembrane

G. Section 02272 - Geotextiles

H. U.S. Ecology Contractor Quality Assurance Plan

1.3 APPLICABLE PUBLICATIONS

A. The publications listed below form a part of this Section to the extent referenced. The publications are referred to in the text by the basic designation only. Use the latest revision unless otherwise noted:

1. American Society for Testing and Materials (ASTM):

D413 Standard Test Method for Rubber-Adhesion to Flexible Substrate

D1238	Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer
D1505	Standard Test Method for Density of Plastics by the Density-Gradient Technique
D1603	Standard Test Methods of Carbon Black Content in Olefin Plastics
D4632	Standard Test Method for Grab Breaking Load and Elongation of Geotextiles
D4716	Standard Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using Constant Head
D4873	Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples
D5035	Standard Test Method for Breaking Force and Elongation of Textile Fabrics
D5199	Standard Test Method for Measuring the Nominal Thickness of Geosynthetics

1.4 SUBMITTALS

A. The following administrative submittals are due 14 days prior to the Contractor beginning the Work:

1. Contractor's schedule of installation of the geocomposite materials.
2. Shop drawings that detail seaming procedures, special construction details, anchoring details, and temporary anchors.
3. Written installation procedures for the geocomposite. These procedures should cover the basic procedures of off-loading, storage, deployment, joining, and precautions to prevent damage to the underlying materials and clogging of the geocomposite with soil or other fine materials.
4. Representative samples of all geocomposite materials proposed for use on the project, together with their full designation and manufacturer name.
5. Manufacturer's Certification that the geocomposite materials meet or exceed the physical strength requirements found herein.

B. Quality Control Submittals:

1. Daily report of Contractor's activities.

2. The Contractor shall submit copies of dated quality control certificates with laboratory test results showing that the geotextiles and drainage nets meet the physical strength requirements found in Paragraphs 2.1 and 2.2 of this Section.

C. Exceptions: Listing of all exceptions to the requirements specified herein.

1.5 DELIVERY, STORAGE, AND HANDLING OF MATERIALS

A. The Owner shall approve all submittals prior to the delivery of material to the site.

B. Material delivery, storage, and handling shall conform to the manufacturer's recommendations and shall be done in a manner that prevents damage to any part of the Work.

C. Handling of rolls shall be completed in a competent manner so that damage does not occur to the geocomposite or to its protective wrapping. ASTM D4873 shall be referenced and followed.

D. Rolls shall be delivered to and stored on the site in ultraviolet light-resistant packaging if recommended by the manufacturer. The integrity of this packaging shall be maintained until the roll is to be installed. Any protective wrapping that is accidentally damaged or stripped off the rolls shall be repaired immediately or covered if the geotextile will not be installed within 60 days.

E. Each roll of geotextile fabric shall bear a label that identifies the following:
   1. Manufacturer
   2. Product identification
   3. Roll number
   4. Batch code
   5. Physical dimensions
   6. Date of manufacture

F. Fielded storage shall be located in areas where water cannot accumulate. The rolls shall be elevated off the ground to avoid forming a dam that allows the ponding of water.

G. Type 1 geocomposite shall be stored separately from Type 2 geocomposite.
   1. The protective wrapping of Type 1 geocomposites shall be painted orange at both ends of each roll.
   2. The protective wrapping of Type 2 geocomposites shall be painted green at both ends of each roll.

PART 2 PRODUCTS

2.1 TYPE 1 GEOCOMPOSITE

A. The geocomposite shall consist of a 300-mil, tri-planar HDPE core drainage net with 8-ounce geotextile fabric heat-bonded to both sides of the net.

B. Geotextile fabric shall be an 8-ounce needle-punched non-woven polypropylene fabric and shall meet the requirements of Section 02272.

C. The core drainage net shall be free from dirt, dust, and debris before the geotextile is bonded. The geotextile shall be joined to the core net in a manner that will not compromise the integrity of the geotextiles or reduce the geocomposite in-plane flow rate to below the required value.

D. The core drainage net shall consist of a minimum of 97% polyethylene resin, with the balance consisting of carbon black and additives. The parent material shall meet the physical requirements listed in the following table:

Property	Test Method	Required Value
Density	ASTM D1505	0.932 g/cm³ (min)
Melt Flow Index	ASTM D1238	0.1 to 1.1 g/10 minute

E. The core drainage net shall be manufactured of three layers of extruded ribs. The center ribs shall be vertical and shall be protected by top and bottom structural ribs. The drainage net shall meet the requirements listed in the table below:

Property	Test Method	Required Value
Density	ASTM D1505	0.94 g/cm³
Melt Flow Index	ASTM D1238	0.1 to 1.1 g/10 min
Carbon Black Content	ASTM D1603	2 to 3%
Thickness	ASTM D5199	300 mil
Tensile Strength	ASTM D5035	83 lb/in.
Transmissivity	ASTM D4716	1×10^{-3} m²/sec

F. The delivered geocomposite material shall meet the physical strength requirements listed in the following table:

Property	Test Method	Required Value
Thickness	ASTM D5199	300 mils
Transmissivity (At confining pressure of 18,000 psf)	ASTM D4716	3×10^{-4} m²/sec
Ply Adhesion	ASTM D413	1.0 lbs/in.

2.2 TYPE 2 GEOCOMPOSITE

A. The geocomposite shall consist of a 200-mil HDPE core drainage net with 6-ounce geotextile fabric heat-bonded to both sides of the net.

B. Geotextile fabric shall be a 6-ounce needle-punched non-woven polypropylene fabric and shall meet the requirements of Section 02272.

C. The core drainage net shall be free from dirt, dust, and debris before the geotextile is bonded. The geotextile shall be joined to the core net in a manner that will not compromise the integrity of the geotextiles or reduce the geocomposite in-plane flow rate to below the required value.

D. The core drainage net shall consist of a minimum of 97% polyethylene resin, with the balance consisting of carbon black and additives. The parent material shall meet the physical requirements listed in the following table:

Property	Test Method	Required Value
Density	ASTM D1505	0.932 g/cm³ (min)
Melt Flow Index	ASTM D1238	0.1 to 1.1 g/10 minute

E. The core drainage net shall be manufactured of two layers of parallel extruded HDPE polymer strands intersecting at a constant angle between 60 and 90 degrees. Strands of one set lie on top of the other set, and the two sets shall be bonded at the intersection. The drainage net shall meet the requirements listed in the table below:

Property	Test Method	Required Value
Density	ASTM D1505	0.94 g/cm³
Melt Flow Index	ASTM D1238	0.1to 1.1 g/10 min
Carbon Black Content	ASTM D1603	2 to 3%
Thickness	ASTM D5199	200 mil
Tensile Strength	ASTM D5035	32 lb/in.
Transmissivity	ASTM D4716	1.0×10^{-3} m²/sec

F. The delivered geocomposite material shall meet the physical strength requirements listed in the following table:

Property	Test Method	Required Value
Thickness	ASTM D5199	200 mils
Transmissivity	ASTM D4716	1×10^{-4} m²/sec
Ply Adhesion	ASTM D413	0.5 lbs/in.

2.3 JUNCTION TIES

A. The geocomposite panels shall be joined together with locking ties that are typically referred to as cable ties.

B. The ties shall be manufactured of an ultraviolet stabilized nylon parent material that is of contrasting color to the geocomposite being joined (white ties with a black geocomposite).

PART 3 EXECUTION

3.1 GENERAL

A. The geocomposite materials shall be laid out and installed in accordance with the approved shop drawings and submittals.

B. The geocomposite shall be installed only after the underlying layer has been fully tested and accepted by the Owner.

3.2 INSTALLATION

A. The geocomposite shall be handled in a manner that ensures it is not damaged in any way.

B. The geocomposite shall be installed to minimize the number of joints between panels that are subject to tensile stress, and panels shall be oriented so that the tensile stress in the panel is in the machine direction.

C. On slopes, the geocomposite shall be secured at the top, then rolled down the slope in a manner that continually keeps the material in tension.

D. In the presence of wind, the Contractor shall weight the materials with sandbags until the final cover is installed.

E. The Contractor shall exercise care to ensure that the underlying layers are not damaged during installation.

F. The Contractor shall use care to ensure that stones, mud, and dirt are not entrapped in the geocomposite during placement and seaming.

G. Trimming of sheets shall be performed using an upward cutting hook blade.

H. The Contractor shall take the necessary precautions during deployment to protect the underlying layers.

I. The Contractor shall conduct a visual inspection of the deployed geocomposite to document that no potentially harmful objects are present, including stones, sharp objects, small tools, and sandbags.

J. During placement of backfill, the cover soil or select waste materials shall not shift the position of the geocomposite nor damage the geocomposite, the geotextile, or the drainage net core.

K. When using cover soil or select waste as backfill on side slopes, the work shall progress from the toe of the slope and upward.

3.3 JOINING

A. Adjacent edges of drainage net cores shall be overlapped a minimum of 4 inches and joined with ties at a spacing not exceeding 3 feet on center. Filter fabrics shall be overlapped a minimum of 6 inches.

B. The ends of drainage cores and filter fabrics (in the direction of flow) shall be overlapped for at least 12 inches. Drainage cores shall be joined with ties at spacing not exceeding 6 inches on center.

C. The top geotextiles covering the joined cores shall be overlapped and sewn using a hand-held sewing machine or thermally bonded with written approval of the Owner to provide a complete seal against backfill soil entering the drainage net core.

D. Horizontal seams on side slopes shall be minimized and staggered.

E. Holes or damage to the drainage net cores shall be repaired by removing the geotextile from the geocomposite for 12 inches around the damaged area. New drainage net core shall be placed over the exposed area and tied every 6 inches. The geotextile fabric shall then be repaired in accordance with Paragraph 3.4 of this Section.

F. Holes or tears of more than 50% of the width of the drainage net core on side slopes require that the entire length of the drainage core be removed and replaced.

G. Holes or tears in the geotextile covering the drainage net core shall be repaired in accordance with Paragraph 3.4 of this Section.

3.4 REPAIRS

A. Patching shall be used to repair holes or tears in the geotextile covering made during placement.

1. The patch material used for repair of a hole or tear shall be the same as the damaged material.
2. The patch shall extend at least 24 inches beyond any portion of the damaged geotextile.
3. The patch shall be sewn or thermally bonded in place by hand or machine so that it does not shift out of position or move during backfilling or covering operations. Damage to geotextile from thermal bonding shall require the removal and replacement of the damaged patch.
4. The machine direction of the patch shall be aligned with the machine direction of the geotextile being repaired.

5. The thread shall be of contrasting color to the geotextile and of chemical and ultraviolet resistance equal to or greater than that of the geotextile.

3.5 PROTECTION

A. The Contractor shall protect the integrity of the geocomposite materials until overlying materials are placed and until the Owner accepts the installed Work.

B. The geocomposite shall be protected from UV degradation and damage, as recommended by the manufacturer.

PART 4 FIELD QUALITY CONTROL

4.1 DOCUMENTATION

A. The Contractor shall provide a daily report to the Owner regarding installation activities. This document shall include the following minimum information:

1. Type and quantity of material placed
2. Location of material placement
3. Location and sizes of patches
4. Visual inspection notes in accordance with Paragraph 3.4.I of this Section

B. The Contractor shall provide the Owner with a copy of the chain-of-custody record for each sample sent to an independent laboratory.

4.2 QUALITY ASSURANCE SAMPLING AND TESTING

A. The Contractor shall assist the Owner with obtaining Quality Assurance samples for laboratory testing.

B. The Contractor shall allow the Owner access to perform sampling and inspect and test all geocomposite materials before subsequent layers are installed on top of them.

END OF SECTION 02274

SECTION 02771

HIGH-DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

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SECTION 02771

HIGH-DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

PART 1 GENERAL

1.1 WORK INCLUDED

A. This Specification Section describes the requirements to furnish and install the HDPE geomembrane at the Grand View Facility Landfill Cell 15.

B. The work includes furnishing all labor, supervision, tools, construction equipment, testing, surveying, and materials necessary to install the geomembrane described by these Specifications and Drawings.

1.2 RELATED WORK

A. Section 01010 - Summary of Work

B. Section 01300 - Submittals

C. Section 02228 - Low-Permeability Soil Layer

D. Section 02772 - Geotextiles

E. U.S. Ecology Contractor Quality Assurance Plan

1.3 DEFINITIONS

A. Geomembrane: HDPE liner and cover material.

B. Sheet: Each separate piece of HDPE geomembrane sheeting that is seamed to other sheets at the project site.

C. Panel: Piece of geomembrane composed of two or more sheets factory-seamed together.

D. Film Tearing Bond: Failure under tension within one of the sheets by tearing instead of separation at a seam.

E. Cap Strip: Geomembrane material placed to cover a cut in a sheet or an existing weld.

F. Replacement Strip: Geomembrane material placed over a gap in the previously placed geomembrane.

1.4 APPLICABLE PUBLICATIONS

A. The publications listed below form a part of this Section to the extent referenced. The publications are referred to in the text by the basic designation only. Use the latest revision unless otherwise noted:

1. American Society for Testing and Materials (ASTM):

D638-97	Standard Test Method for Tensile Properties of Plastics
D792-91	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D816-82 (1993)	Standard Test Methods for Rubber Cement
D1004-94a	Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting
D1238-94a	Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
D1505-96	Standard Test Method for Density of Plastics by the Density-Gradient Technique
D1603-94	Standard Test Method for Carbon Black in Olefin Plastics
D3895-97	Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
D4437-84	Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes
D4833-88 (1996)	Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products
D5199-95	Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
D5397-95	Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test

D5596-94	Standard Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
D5994	Measuring Core Thickness of Textured Geomembrane

2. Geosynthetic Research Institute (GRI):

GRI Test Method GM 12	Measurement of the Asperity Height of Textured Geomembrane Using Depth Gage

3. NSF International (NSF):

NSF 54-1993	Standard for Flexible Membrane Liners

B. The following publications shall be used as applicable:

1. U.S. Environmental Protection Agency (EPA):

EPA/530-SW-86-031	Technical Guidance Document: Construction Quality Assurance for Hazardous Waste Land Disposal Facilities. October, 1986
EPA/530-SW-91/051	Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams. May, 1991.
EPA/600/SR-93/182	Quality Assurance and Quality Control for Waste Containment Facilities

1.5 SUBMITTALS

A. Administrative Submittals:

1. Production dates for geomembrane.
2. Schedule of installation of the geomembrane.
3. A Liner Installation Plan that details the required procedures for proper installation of the HDPE geomembrane. Following is an outline of the minimum required elements of the plan:
   a. Transportation and off-loading
   b. Inspection of delivered materials
   c. Storage of delivered materials
   d. On-site handling and deployment
      1) Sub-grade acceptance
      2) Installation limits
   e. Seaming procedures
      1) Hot wedge welding

2) Extrusion welding

f. Quality control testing

1) Test welds

2) Non-destructive seam testing

a) Double wedge seam air-pressure test

b) Vacuum box test

3) Destructive testing

g. General precautions to prevent damage

B. Shop Drawings:

1. Manufacturer's specifications and literature for each geomembrane and all products furnished and used to complete the installation. Descriptions shall include name of manufacturer(s) and fabricator(s) and product trade name if any.

2. Product identification and supplier of the polymer resin for geomembrane production.

3. Geomembrane seaming plan drawing(s) including the proposed size, number, position and sequence of sheet placement. Layouts shall be fully dimensioned. Seaming plan shall include the location of field seams and the approximate total length of fusion and extrusion welds.

4. Details of joining procedures, field testing, special construction details, anchoring details, temporary anchors, cap strips, and replacement strips.

C. Samples:

1. Submit a sample of 2 square yards of the material from each shipment for verification testing.

2. Pre-construction field seam samples and results of associated tests, as described in Paragraph 3.5.C.1 of this Section.

D. Qualifications: Submit documented evidence of the ability and capacity of manufacturer, installer, and geomembrane testing agency to perform this work.

1. Manufacturer and Fabricator: Certification that the manufacturer has manufactured HDPE geomembranes for at least 5 years and has manufactured a minimum of 10 million square feet of similar HDPE geomembranes. Fabricators shall have at least 5 years of continuous documented experience in the fabrication of HDPE components for liner system applications.

2. Installer: Certification of the following requirements shall be provided:

a. Corporate Requirements: The Contractor shall have successfully installed 10 million square feet of the type of geomembrane product specified in applications similar to this project.

b. Field Staff Requirements: The Contractor shall provide the following persons to the project and submit resumes as verification of past experience:

1) Installation Supervisor: The Installation Supervisor shall be on site and be in responsible charge during all geomembrane installation (including sub-grade acceptance, HDPE sheet layout, panel placement, seaming, testing, and repairs) and all other activities performed by the Contractor. The Installation Supervisor shall have installed or supervised the installation of a minimum of 10 million square feet of HDPE geomembrane.

2) Master Seamer: All seaming shall be performed under the direction of a Master Seamer. The Master Seamer may be the same person as the Installation Supervisor. The Master Seamer shall have seamed a minimum of 2 million square feet of HDPE geomembrane using the same type of seaming apparatus as that proposed for this project.

3) Seamers: Seamers shall have documented experience seaming HDPE geomembrane using the same type of seaming apparatus as that proposed for use on this project.

3. Independent Testing Laboratory: The Contractor shall provide an independent laboratory for geomembrane testing. The laboratory must provide records of equipment calibration, and documented standard procedures for performing specified testing. Test results shall be reviewed by a State of Idaho Registered Professional Engineer.

E. Quality Control Submittals:

1. Quality Control Program Plan: Written description of the manufacturer's and installer's formal programs for quality control during manufacturing, fabricating, handling, installation, seaming, testing, and repairing geomembrane.
2. Factory test results and manufacturer's certification of compliance for geomembrane. Test results and certifications shall identify the lot number and roll number for each roll delivered to the project site.
3. Certified test results from an independent testing laboratory.
4. Daily reports that include the following:
   a. Record of deployment by type, panel number, roll number, and size.
   b. Record of welding by machine, seamer, seam number, and length.
   c. Non-destructive testing by type, seam number, length, and repair location (if required).
   d. Repairs by location, type, re-testing, and technician.
   e. Destructive testing by sample number, seam number, date welded, seamer, date pulled, field pass/fail, and location.
   f. Trial welds by number, seamer, temperature, time and results.

F. Contract Closeout Submittals:

1. Record Drawings: Submit reproducible drawings of record showing changes from approved installation drawings. These shall include the identity and location of each repair, cap strip, penetration, boot, and sample taken from the installed geomembrane for testing.
2. Three copies of material and seam test results.
3. Record data.
4. Inspection certification form (follows this Specification Section) for the liner sub-grade.
5. Certificate of warranty for the HDPE geomembrane material, seams, and installation.

G. Exceptions: Listing of all exceptions to the requirements specified herein.

1.6 SEQUENCING AND SCHEDULE

A. The work in this Section requires careful coordination with the work in other Sections to prevent damage to the geomembrane and underlying materials.

B. The maximum exposed HDPE geomembrane that will be allowed at any one time, anywhere on site, is 12 acres.

C. If necessary, the HDPE geomembrane cover shall be protected from UV degradation.

D. The required submittal information, drawings, and data required shall be submitted in accordance with the following schedule:

Specification Reference	Requirements	Period
02771 (1.5.A.1)	Geomembrane production pates	Two weeks prior to manufacture
02771 (1.5.A.2)	Schedule of installation	Four weeks prior to start of construction
02771 (1.5.A.3)	Liner installation plan	Four weeks prior to start of construction
02771 (1.5.B.1)	Manufacturer's specifications	Two weeks prior to manufacture
02771 (1.5.B.2)	Polymer resin identification	Two weeks prior to manufacture
02771 (1.5.B.3/4)	Geomembrane seaming plan and details	Four weeks prior to start of construction
02771 (1.5.C.1)	Material sample	Four weeks prior to start of construction
02771 (1.5.C.2)	*Pre-construction field samples*	*At mobilization*
02771 (1.5.D.1)	Manufacturer's qualifications	Two weeks prior to manufacture
02771 (1.5.D.2)	Installer's qualifications	Four weeks prior to start of construction
02771 (1.5.D.3)	Independent laboratory qualifications	Four weeks prior to start of construction
02771 (1.5.E.1)	Quality control program plan	Four weeks prior to start of construction
02771 (1.5.E.2)	Factory test results	Four weeks prior to start of construction
02771 (1.5.E.3)	Laboratory test results	Within two working days
02771 (1.5.E.4)	Daily field activity reports	Within two working days
02771 (1.5.F.1)	Record drawings	Four weeks after acceptance of work
02771 (1.5.F.2)	Material and seam test results	Four weeks after acceptance of work
02771 (1.5.F.3)	Record data	Four weeks after acceptance of work

Specifications Reference	Requirements	Period
02771 (1.5.F.4)	Sub-grade inspection forms	Immediately prior to installation of liner over subgrade
02771 (1.5.F.5)	Certificate of warranty	Prior to acceptance of work

1.7 WITNESS POINTS

A. The Owner's Construction Quality Assurance (CQA) Manager or his designee will be present during the following inspections for verification of the work. The contractor shall give 24 hours notice to the Owner's CQA Manager prior to any of the Witness Point events.

B. Witness points are:
   1. Verification of Contractor's inspection and acceptance of subgrade conditions.
   2. Verification of Contractor's inspection of geomembrane installation.
   3. Verification of Contractor's inspection of seams welding and on-site non-destructive field seam testing.

1.8 WARRANTY

A. Provide manufacturer's extended warranty in writing, with the Owner named as the beneficiary. The warranty shall provide for correction or, at the option of the Owner, removal and replacement of Work specified in this Section that is found defective during the periods listed below, commencing on the date of substantial completion.
   1. Materials, factory seams, installation, and field seams shall be warranted by the Contractor to be free of defects and to be able to withstand normal weathering.
   2. Warranty for materials and factory seams shall be for a minimum period of 5 years from the date of acceptance.
   3. Warranty for workmanship or installation, including field seams, shall be for a minimum period of 2 years from the date of acceptance.

1.9 DELIVERY, STORAGE AND HANDLING OF MATERIALS

A. Materials shall be delivered to the site only after all required submittals have been approved by the Owner's Representative.

B. Material delivery, storage, and handling will be in accordance with the approved Liner Installation Plan.

C. Geomembrane materials shall be supplied in rolls, marked and tagged with the following information:
   1. Manufacturer's name
   2. Product identification

3. Lot number
4. Roll number
5. Product thickness
6. Roll dimensions
7. Date of manufacture

D. The geomembrane shall be shipped rolled and shall be stored on the ground in a location where it will not interfere with the on-going operations at the facility. Storage at the job site shall be in an area where standing water cannot accumulate. The ground surface shall be prepared so that no stones or other rough objects could damage the geomembrane are present. At a minimum, the ground shall be rolled with a smooth-drum roller.

E. The Contractor shall off-load all geomembrane once mobilized to the site. The work site is remote, and the Owner will not unload the delivered material.

F. Handling of materials on site shall be by suitable construction equipment,,cables, and slings. Pushing, sliding, or dragging of rolls of geomembrane is not permitted.

G. Roll stack height shall be limited to prevent deformation or damage to the rolls and cores. The limit shall be in accordance with the manufacturer's recommendations.

H. Care in accordance with the manufacturer's recommendations shall be taken to keep the materials clean and free from damage prior to installation. If rolls are stored at the job site for more than 6 months, a sacrificial covering or temporary shelter shall be provided for protection against precipitation, ultraviolet light exposure, and accidental damage.

1.10 ENVIRONMENTAL REQUIREMENTS

A. Do not install geomembrane or perform seaming unless installation procedures approved by the Owner are in place to address the following environmental conditions, when:
   1. Air temperature is less than 35 degrees F and decreasing or more than 90 degrees F.
   2. Relative humidity is greater than 80 percent.
   3. Raining or snowing, frost is on ground, or wind is excessive.

PART 2 PRODUCTS

2.1 ACCEPTABLE MANUFACTURERS

A. Manufacturers shall meet the requirements specified in Paragraph 1.5 above.

2.2 BOTTOM LINER HDPE GEOMEMBRANE

A. Composition: High-density polyethylene (HDPE) containing no plasticizers, fillers, extenders, or chemical additives, except for the following:

1. Two to three percent by weight of carbon black to resin for ultraviolet resistance
2. Antioxidants and heat stabilizers, not to exceed 1.5 percent by weight, may be added as required for manufacturing

B. Textured sheets shall be textured on both sides to the same roughness.

C. Geomembrane shall be furnished in rolled single-ply continuous sheets with no factory seams.

D. Sheet width shall be a minimum of 20 feet.

E. The raw material (resin) used in the production of the geomembrane shall meet the requirements in the table below. Testing shall be performed once per 8.17×10^4 kg (180,000 lbs), and at least one test shall be performed.

Property	Test Method	Required value
Density	ASTM D1505	0.940 – 0.950 g/cm³
Melt Flow Index	ASTM D1238, 190/2.16	≤1.0 g/10 min
OIT	ASTM D3895	≤1.0 g/10 min

F. The manufactured textured HDPE geomembrane material shall meet the following physical strength properties:

Property	Test Method	Requirement	Testing frequency (minimum)
Thickness Minimum Average Lowest Individual Reading	D5994	 60 54	per roll
Density (min avg)	D1505	0.940 g/cc	200,000 lb
Carbon Black Content (range)	D1603	2.0-3.0%	20,000 lb
Carbon Black Dispersion	D5596	note (1)	45,000 lb
Tensile Properties (min avg) (2) yield ~~stress~~ strength break ~~stress~~ strength yield elongation break elongation	D638 Type IV	 130 lb/in. 80 lb/in 80 lb/in. 130 lb/in 12% 135%	20,000 lb
Tear Resistance (lbs)	D1004	40	45,000 lb
Puncture Resistance (lbs)	D4833	78	45,000 lb

Property	Test Method	Requirement	Testing Frequency (minimum)
Stress Crack Resistance (3)	D5397 (App.)	200 hr	per GRI-GM 10
Oxidative Induction Time (OIT) (min avg)	D3895	100 min.	200,000 lb
UV Resistance(4) High Pressure OIT (min avg) - % retained after 1600 hours (5)	GM 11 D5885	 50	per each formulation
Asperity Height (min. ave.) (6)	GM 12	10 mil	every 2nd roll(7)

(1) Carbon black dispersion for 10 different views shall be Category 1 or 2.

(2) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of five test specimens each direction

Yield elongation is calculated using a gauge length of 1.3 inches.

Break elongation is calculated using a gauge length of 2.0 inches.

(3) The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation being used for the textured sheet materials. The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(4) The condition of the test should be 20-hour UV cycle at 75°C followed by 4-hour condensation at 60°C.

(5) UV resistance is based on percent retained value regardless of the original HP-OIT value.

(6) Of 10 readings, 8 out of 10 must be ≥ 7 mil, and lowest individual reading must be ≥ 5 mil.

(7) Alternate the measurement side for double-sided textured sheet.

G. Geomembrane shall have a uniform surface with no visible defects and shall be free of holes, blisters, gels, undispersed ingredients, and any contamination or defect that may affect its serviceability. The membrane shall be free of pinholes, and the liner edges shall be straight and free of nicks and cuts.

H. The weld materials used in liner seaming shall have the same resin characteristics as defined in Paragraph 2.2.F of this Section.

2.3 CAP SYSTEM HDPE GEOMEMBRANE

A. Composition: High-density polyethylene (HDPE) containing no plasticizers, fillers, extenders, or chemical additives, except for the following:

1. Two to three percent by weight of carbon black to resin for ultraviolet resistance
2. Antioxidants and heat stabilizers, not to exceed 1.5 percent by weight, may be added as required for manufacturing

B. Textured sheets shall be textured on both sides to the same roughness.

C. Geomembrane shall be furnished in rolled single-ply continuous sheets with no factory seams.

D. Sheet width shall be a minimum of 20 feet.

E. The raw material (resin) used in the production of the geomembrane shall meet the requirements in the table below. Testing shall be performed once per 8.17×10^4 kg (180,000 lbs), and at least one test shall be performed.

Property	Test Method	Required Value
Density	ASTM D1505	0.940 – 0.950 g/cm^3
Melt Flow Index	ASTM D1238, 190/2.16	≤1.0 g/10 min
OIT	ASTM D3895	≤1.0 g/10 min

F. The manufactured textured HDPE geomembrane material shall meet the following physical strength properties:

Property	Test Method	Requirement	Testing Frequency (minimum)
Thickness Minimum Average Lowest Individual Reading	D5994	 40 36	per roll
Density (min avg)	D1505	0.940 g/cc	200,000 lb
Carbon Black Content (range)	D1603	2.0-3.0%	20,000 lb
Carbon Black Dispersion	D5596	Note (1)	45,000 lb
Tensile Properties (min avg) (2) yield stress break stress yield elongation break elongation	D638 Type IV	 80 lb/in. 60 lb/in. 12% 135%	20,000 lb
Tear Resistance (lbs)	D1004	25	45,000 lb
Puncture Resistance (lbs)	D4833	70	45,000 lb
Stress Crack Resistance (3)	D5397 (App.)	200 hr	per GRI-GM 10
Oxidative Induction Time (OIT) (min avg)	D3895	100 min.	200,000 lb
UV Resistance(4) High Pressure OIT (min avg) - % retained after 1600 hours (5)	GM 11 D5885	 50	per each formulation
Asperity Height (min. ave.) (6)	GM 12	5 mil	every 2nd roll(7)

(1) Carbon black dispersion for 10 different views shall be Category 1 or 2.

(2) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of five test specimens each direction

Yield elongation is calculated using a gauge length of 1.3 inches.

Break elongation is calculated using a gauge length of 2.0 inches.

(3) The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation being used for the textured sheet materials. The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(4) The condition of the test should be 20-hour UV cycle at 75°C followed by 4-hour condensation at 60°C.

(5) UV resistance is based on percent retained value regardless of the original HP-OIT value.

(6) Of 10 readings, 8 out of 10 must be ≥ 7 mil, and lowest individual reading must be ≥ 5 mil.

(7) Alternate the measurement side for double-sided textured sheet.

G. Geomembrane shall have a uniform surface with no visible defects and shall be free of holes, blisters, gels, undispersed ingredients, and any contamination or defect that may affect its serviceability. The membrane shall be free of pinholes, and the liner edges shall be straight and free of nicks and cuts.

H. The weld materials used in liner seaming shall have the same resin characteristics as defined in Paragraph 2.3.F of this Section.

2.4 HDPE FIELD SEAMS

A. The Contractor shall seam the geomembrane sheets together in the field to meet the following requirements:

Property	Test Method	Requirement
Bonded Seam Strength in Shear (lbs/in.)	ASTM D4337	
Fusion (lbs/in.)		120
Extrusion (lbs/in.)		120
Bonded Seam Strength in Peel (lbs/in.)	ASTM D4337	
Fusion (lbs/in.)		98
Extrusion (lbs/in.)		78

2.5 WELDING EQUIPMENT

A. The extrusion welding apparatus shall be equipped with gauges giving the temperature of the apparatus at the nozzle and the extrudate barrel.

B. The fusion welding apparatus shall be an automated vehicle-mounted device that produces a double seam with enclosed air space. It shall be equipped with gauges giving the applicable temperatures and machine speed.

C. Hot-air welding is not acceptable for either permanent or temporary welds.

2.6 OTHER MATERIALS

A. Sandbags used for hold-downs shall be tied or fastened with material that will not damage the liner. Metal wire shall not be used. The material makeup of the sandbags shall be sufficiently strong to withstand the forces that will be placed upon them during their use and shall be constructed to preclude spillage of sand contained therein. Leakage of sand onto liner shall not be permitted.

B. Sandbags used for hold-downs shall be made from black 20-mil woven geotextile, weighing at least 4.5 ounces/square yard and resistant to ultraviolet light. Each stationary sandbag shall contain at least 50 pounds of clean dry sand. After each sandbag is filled, the end(s) shall be sealed using manufacturer-recommended methods and materials.

REFERENCE 6

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-95/051
April 1995

EPA

RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities

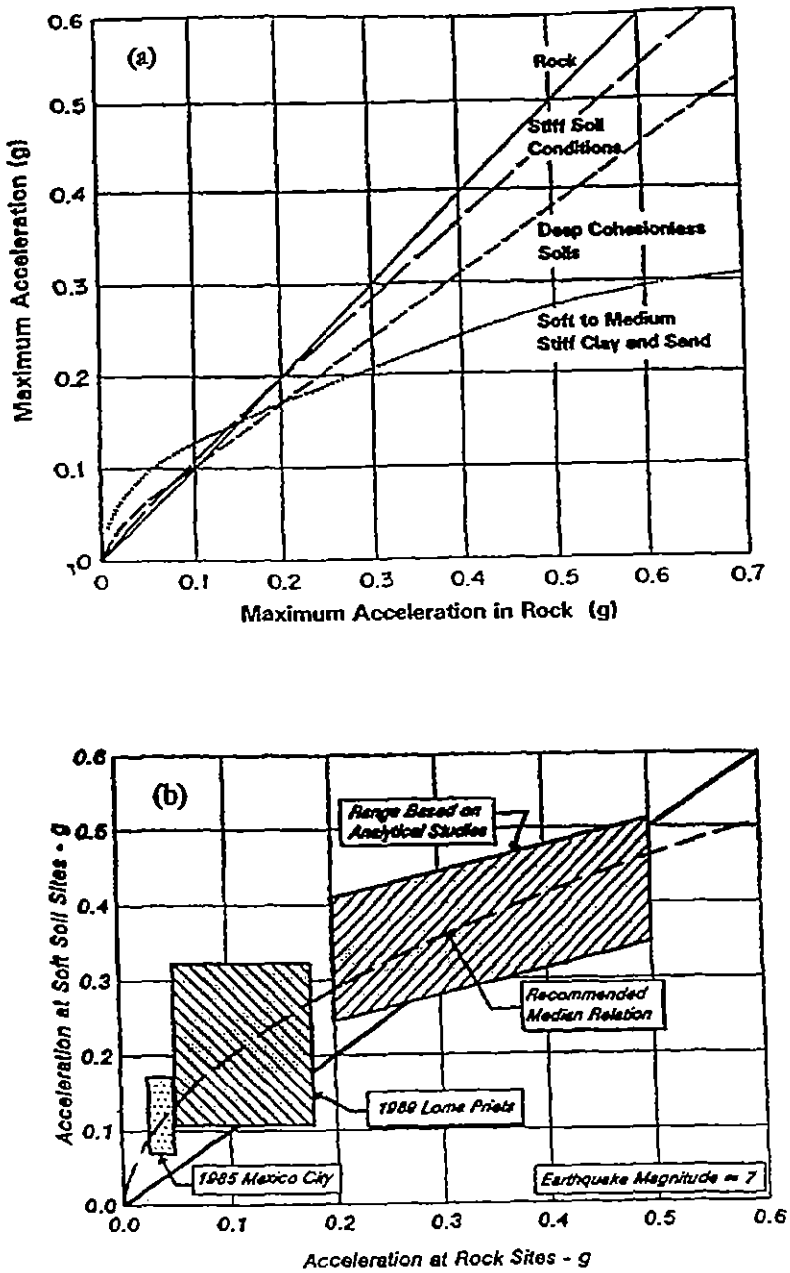

Figure 4.4 Relationship Between Maximum Acceleration on Rock and Other Local Site Conditions: (a) Seed and Idriss (1982); (b) Idriss (1990).

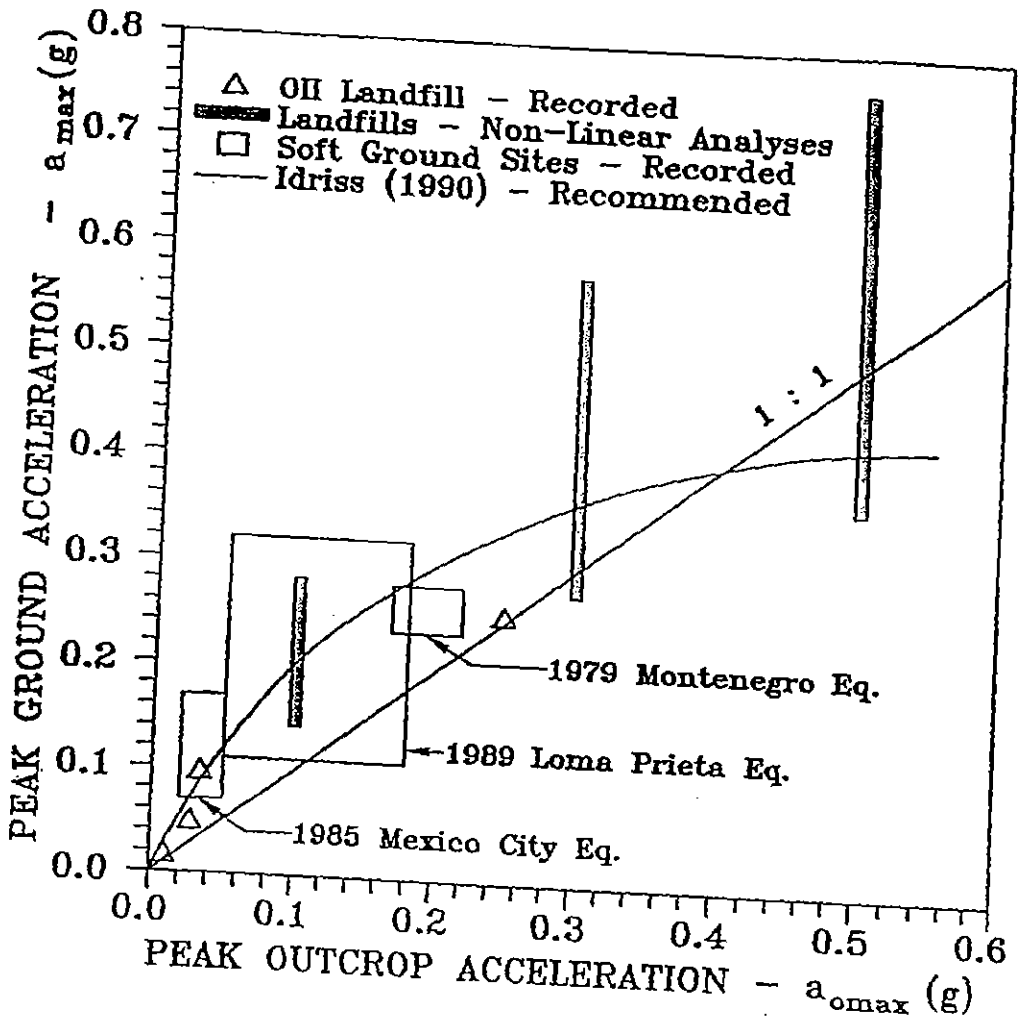

Figure 4.5 Observed Variations of Peak Horizontal Accelerations on Soft Soil and MSW Sites in Comparison to Rock Sites (Kavazanjian and Matasović, 1994).

Appendix D1-4
Supplemental
Slope Stability Analysis
January 2010

US Ecology Idaho
Supplemental Slope Stability Analysis

1. Introduction and Background

On behalf of US Ecology Idaho (USEI), Daniel B. Stephens & Associates, Inc. (DBS&A) performed slope stability analyses assuming circular critical surfaces for USEI Site B Facility (EPA ID No. IDD073114654), Cells 14 and 15. These analyses were presented in *Final Cover Design for Cells 14 and 15, Permit Modification for Alternative Evapotranspiration Final Cover, US Ecology Idaho,* dated July 20, 2009 (received by Idaho Department of Environmental Quality [DEQ] on July 22, 2009).

Based on review comments from the DEQ, DBS&A performed additional analyses to include block failure that were submitted to the DEQ in a revised permit modification dated November 25, 2009. The seismic analyses used a conservative horizontal acceleration value of 0.20 g, which represented the worst-case surface acceleration at the site. This resulted in factor of safety values greater than 1.0, but less than 1.1. In discussions between DBS&A (on behalf of USEI) and DEQ on December 22, 2009, it was proposed that a sensitivity analyses be performed on all of the slope stability analyses, to better understand the effect of seismic acceleration coefficient on the factor of safety values. This supplemental report presents the results of those analyses.

2. Calculation Approach

The sensitivity analyses were performed on profiles of Cells 14 and 15 at locations representing the maximum height of the closed cells. Slope stability analyses were performed using SLOPE/W 2007, GeoStudio Version 7.13 (Geoslope International, Ltd., Calgary, Alberta, Canada). USEI Cells 14 and 15 are located in a seismic impact zone. Seismic impact zones are defined as those regions having a peak bedrock acceleration exceeding 0.10 g based on a 90 percent probability of non-exceedance over a 250-year time period (U.S. EPA, 1995). The original slope stability analyses considered the geometry of the liner system and strength parameters of the various liner materials as presented in Table 1.

Table 1. Material Characteristics Used in Slope Stability Analysis

Material [a]	Friction Angle (degrees)	Cohesion (lb/ft^2)	Unit Weight (lb/ft^3)
ET cover	27	0	101.6
Natural subgrade	36	800	115
Waste	30	125	115
Compacted clay liner	22	60	94
Common fill	31	1,000	124.8
Textured GM to GC	26	60	NA
GM to sand	17	0	NA
GM to CL soil	15	292.4	NA

[a] Soil properties primarily derived from Washington Group International, Inc. (2002) stability analysis at the site

lb/ft^2 = Pounds per square foot
lb/ft^3 = Pounds per cubic foot
NA = Not applicable

GM = Silty gravel
GC = Clayey gravel
CL = Lean clay

The liners for Cells 14 and 15 were represented in the analysis as weak layers with an interface friction angle of 15 degrees. The weak liner layers were placed on natural subgrade and covered with waste. The waste will be capped with evapotranspiration (ET) cover soil. The waste for both cells was described by Washington Group International, Inc. as stabilized and unstabilized, soil-like waste. An interface slip surface between the waste and the ET cover was not introduced due to the similarity of the materials. The conservative range of strength parameters for all of the materials presented were used in this analysis. Saturated conditions were not considered due to the nature of the waste and depth to the groundwater.

Static and seismic (pseudostatic) analyses were performed to evaluate stability. The peak ground acceleration (PGA) for the site was determined to be 0.11 g (obtained from the U.S. Geological Survey [USGS] National Seismic Hazard Maps [2008]), based on a 2 percent probability of exceedance in 50 years. In the original analysis, DBS&A amplified the bedrock acceleration through the site from 0.11 g to 0.20 g. Subsurface materials on top of the bedrock were considered to amplify the bedrock acceleration. The combination of waste and subgrade soils were treated as soft soil, a conservative assumption due to the lack of subgrade shear wave velocities from the site (supported by U.S. Environmental Protection Agency [EPA], 1995, Figure 4.4(b)). For a bedrock acceleration of 0.11 g, the acceleration at soft soil sites is estimated at 0.2 g. Figure 4.4(a) estimates a maximum acceleration of 0.12 g for a maximum

acceleration in rock of 0.11 g, assuming soft to medium clay and sand. The site contains approximately 2,250 feet of hard to very hard silty and gravelly sands, silty sands, sandy silts, and silts, overlying the Banbury Formation bedrock.

For their 2002 stability analysis of this site, Washington Group International, Inc. used a horizontal pseudostatic coefficient of 0.08 g based on an assumption that the horizontal pseudostatic coefficient was half of the peak bedrock acceleration at the site. This would have required a peak bedrock acceleration of 0.16 g.

3. Proposed Pseudostatic Coefficients and Factors of Safety from Literature

This supplemental slope stability analysis evaluates the sensitivity of results to various considerations of ground acceleration input values. Alternatives are available in the engineering approaches used for slope stability analysis to determine the appropriate peak ground acceleration (a_p), horizontal pseudostatic coefficient (k_h) (the vertical pseudostatic coefficient [k_v] is usually disregarded due to its negligible effect) and acceptable factors of safety. Kramer (1996) states that "In recognition of the fact that actual slopes are not rigid and that the peak acceleration exists for only a short time, the pseudostatic coefficients used in practice generally correspond to acceleration values well below a_{max} [maximum acceleration]." Much of the literature focuses on design of dams, due to the importance of those structures. Kramer (1996) summarizes proposed pseudostatic coefficients:

- Terzaghi (1950) originally suggested the use of k_h = 0.1 for severe earthquakes, k_h = 0.2 for "violent, destructive" earthquakes, and k_h = 0.5 for "catastrophic" earthquakes.

- Seed (1979a) listed pseudostatic design criteria for 14 dams in 10 seismically active countries; 12 required minimum factors of safety of 1.0 to 1.5 with pseudostatic coefficients of 0.10 to 0.12.

- Marcuson (1981) suggested that appropriate pseudostatic coefficients for dams should correspond to one-third to one-half of the maximum acceleration, including amplification or deamplification effects, to which the dam is subjected.

- Seed and Martin (1966) and Dakoulas and Gazetas (1986) showed that the inertial force on a potentially unstable slope in an earth dam depends on the response of the dam and that the average seismic coefficient for a deep failure surface is substantially smaller than that of a failure surface that does not extend far below the crest.

- Seed (1979b) indicated that deformations of earth dams constructed of ductile soils (defined as those that do not generate high pore pressures or show more than 15 percent strength loss upon cyclic loading) with crest accelerations less than 0.75 g would be acceptably small for pseudostatic factors of safety of at least 1.15 with k_h = 0.10 to k_h = 0.15. This criterion would allow the use of pseudostatic accelerations as small as 13 to 20 percent of the peak crest acceleration.

- Hynes-Griffin and Franklin (1984) applied the Newmark sliding block analysis to more than 350 accelerograms and concluded that earth dams with pseudostatic factors of safety greater than 1.0 using $k_h = 0.5\ a_{max}/g$ would not develop "dangerously large" deformations.

Some additional (i.e., not included in the Kramer [1996] summary) estimates of pseudostatic coefficients include:

- Pyke (2009) references the U.S. Army Corps of Engineers manual for seismic design of new dams. This requires use of a seismic coefficient of 0.1 in Seismic Zone 3 and 0.15 in Seismic Zone 4, in conjunction with a minimum factor of safety of 1.0. DBS&A was unable to locate this manual, and it has probably been replaced by the recent U.S. Army Corps of Engineers *Slope Stability* engineering manual (USACE, 2003), which addresses analyses of stability during earthquakes (Section 2-6) with reference to an Engineer Circular, *Dynamic Analysis of Embankment Dams* (still in draft form), which will provide guidance concerning types of analyses and design criteria for earthquake loading.

- Federal Energy Regulatory Commission (FERC) *Engineering Guidelines for the Evaluation of Hydropower Projects* (Chapter 4 and Table 1) require a minimum factor of safety greater than 1.0 for an earthquake (for steady seepage conditions with seismic loading using a pseudo static lateral force coefficient) loading condition.

4. Analysis Description

For this analysis, DBS&A used the USGS peak ground acceleration of 0.11 g and evaluated a more conservative acceleration as high as 0.20 g. The results of limit-equilibrium analysis using a range of horizontal pseudostatic coefficients were compared with the proposed pseudostatic coefficients presented from literature (Section 3).

The slope stability analysis was used to check against deeper circular slip surfaces and cover veneer failure. Three different approaches were used:

1. Circular failure planes
2. Auto search of the failure plane, using Slope/W, with the waste treated as an impenetrable layer
3. Block failure analysis with optimization of the failure surface

Auto search is an option in Slope/W that estimates the entry and exit areas along the ground surface, based on the geometry of the problem. Slope/W evaluates trial slip surfaces and determines an approximate solution. The factor of safety is determined by optimizing the approximated critical slip surface. Optimization, in Slope/W, is a technique that incrementally alters segments of the approximated critical slip surface to find the shape with the lowest factor of safety. By treating the waste as an impenetrable layer, Slope/W forces the failure plane into or along the interface of the ET cover material.

Block failure analysis was performed in Slope/W by evaluating a failure surface with three planes: a bottom failure plane and two planes projecting to the ground surface. The locations for the left and right blocks of potential intersections of the bottom and projected plane surfaces were proposed, and the block surface was then optimized for the lowest factor of safety.

Auto search of the failure plane by Slope/W, with the waste treated as an impenetrable layer, and block failure analysis with optimization of the failure surface were performed for static and seismic (pseudostatic) conditions for USEI Cells 14 and 15.

5. Results and Discussion

The factors of safety determined from the analyses using various standard solutions for limit equilibrium analysis are presented in Table 2 and Figure 1. The circular failures shown in Figure 1 would represent deep disruption of the waste, whereas the auto-search and block analyses represent cover failure.

Table 2. Slope Stability Seismic Factors of Safety

	Factors of Safety					
	Cell 14			Cell 15		
Acceleration [a]	0.11 g	0.15 g	0.2 g	0.11 g	0.15 g	0.2 g
Circular Failure Plane Analysis						
Morgenstern-Price	1.888	1.702	1.56	2.116	1.937	1.76
Ordinary	1.870	1.741	1.62	1.863	1.701	1.54
Bishop	2.208	2.012	1.85	2.136	1.954	1.78
Janbu	1.755	1.604	1.46	1.817	1.656	1.50
Auto Search with Impenetrable Layers and Optimization [b]						
Morgenstern-Price	1.287	1.178	1.072	1.211	1.114	1.017
Ordinary	1.292	1.185	1.079	1.211	1.114	1.017
Bishop	1.303	1.194	1.088	1.212	1.114	1.017
Janbu	1.287	1.179	1.073	1.211	1.114	1.017
Block Analysis with Optimization [b]						
Morgenstern-Price	1.288	1.179	1.073	1.220	1.121	1.023
Ordinary	1.294	1.188	1.083	1.231	1.131	1.036
Bishop	1.317	1.206	1.100	1.279	1.177	1.078
Janbu	1.287	1.179	1.073	1.216	1.188	1.021

[a] Morgernstern-Price, Ordinary, Bishop, and Janbu refer to some of the standard solutions proposed for limit equilibrium analysis. They differ in the equations of statics that are satisfied. Ordinary and Bishop satisfy moment equilibrium. Janbu satisfies force equilibrium. Morgernstern-Price satisfies both moment and force equilibrium. For a thorough description, see Geo-Slope International Ltd. (2007).

[b] Surface raveling failure

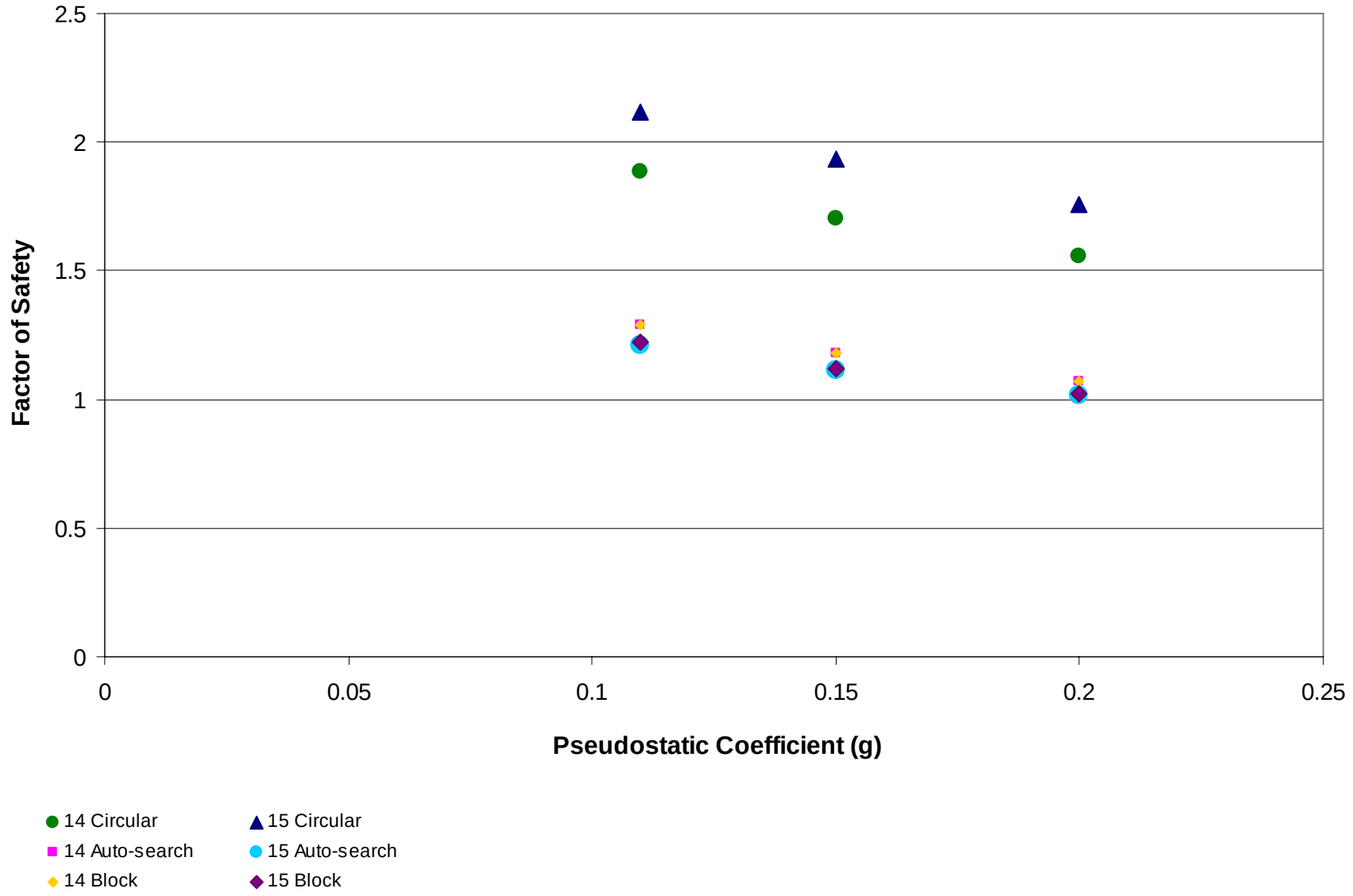

Figure 1

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Estimated Factors of Safety

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Figures 2 through 5 display critical surfaces and represent the types of failures predicted by the different analyses. All of the figures represent analysis using Morgenstern-Price and pseudostatic coefficients of 0.20 g.

Figures 2 and 4 illustrate the effects of forcing the critical surface to deeper depths. The analysis depicted in Figures 2a and 4a required the critical surface to extend 0.1 foot below the surface, whereas the analysis shown in Figures 2b and 4b required the critical surface to extend 3.0 feet below the surface. The different requirements did not change the determined factors of safety.

The block and auto-search analyses (Figures 3 and 5) represented cover failures. Only the circular critical surface analysis disrupted the waste layer.

6. Comparison of Results with Referenced Methods

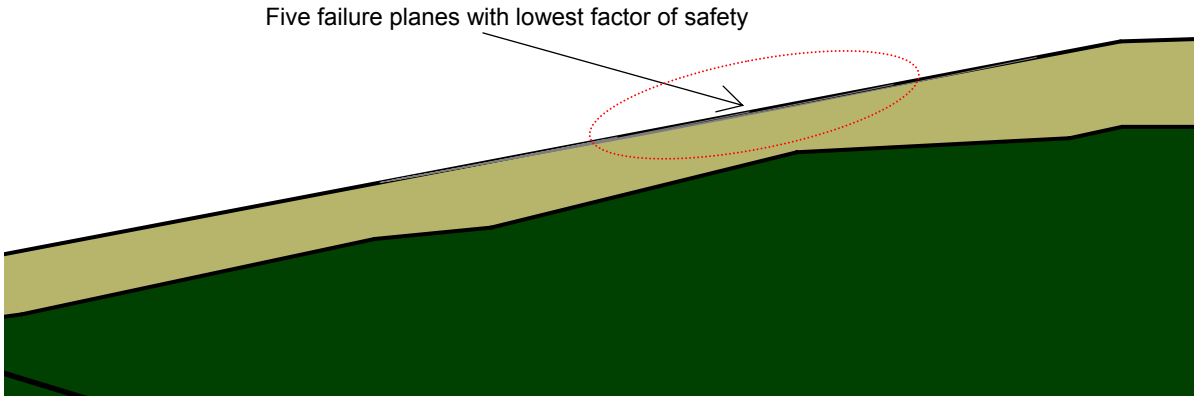
The factors of safety determined for Cells 14 and 15, using a range of pseudostatic coefficients, were compared with recommendations derived from literature. This is necessary because factor of safety values are not explicitly specified for seismic slope stability analysis.

- Based on Terzaghi's (1950) categorizations, the slope stability of Cells 14 and 15 was evaluated for a "violent, destructive" earthquake with k_h = 0.2. A pseudostatic horizontal acceleration of 0.20 g yielded factors of safety greater than 1.0 and would cause cover failure. For waste disturbance (circular failure), Cells 14 and 15 could sustain peak ground accelerations of 0.35 g and 0.40 g, respectively.

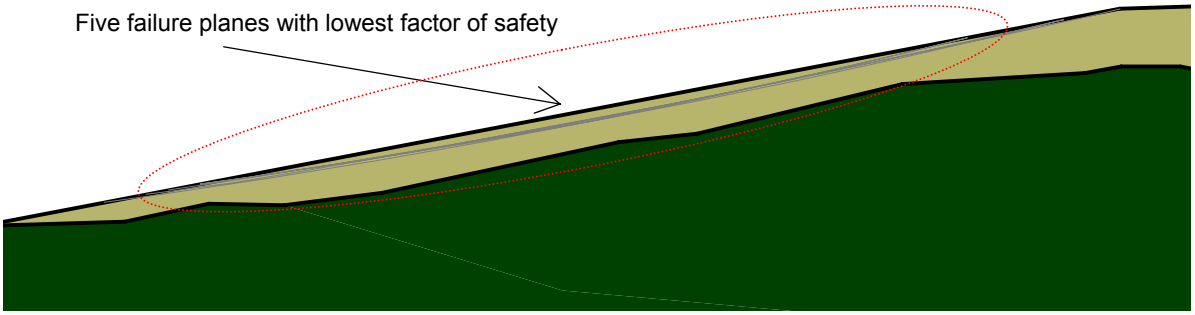
- The results fit within Seed's (1979a) factors of safety of 1.0 to 1.5 with pseudostatic coefficients of 0.10 to 0.12. For circular failure, the factors of safety for Cells 14 and 15 are closer to 2.0.

- Pseudostatic coefficients used in these analyses ranged from 0.11 g to 0.2 g. These were not reduced from the peak ground acceleration at the site. Based on Marcuson's (1981) recommendation, these analyses would have used 0.036 g (⅓) / 0.055g (½) to 0.067 g (⅓) / 0.01 g (½). Not reducing the peak ground accelerations for the horizontal pseudostatic coefficients was a conservative aspect of this analysis.

a. Minimum slip surface depth of 0.1 foot



b. Minimum slip surface depth of 3 feet



Explanation

- ET cover
- Impenetrable layer

Note: Morgenstern-Price analyses, using horizontal pseudostatic coefficients of 0.20 g

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Cell 14 Critical Surface Auto-Search Analysis

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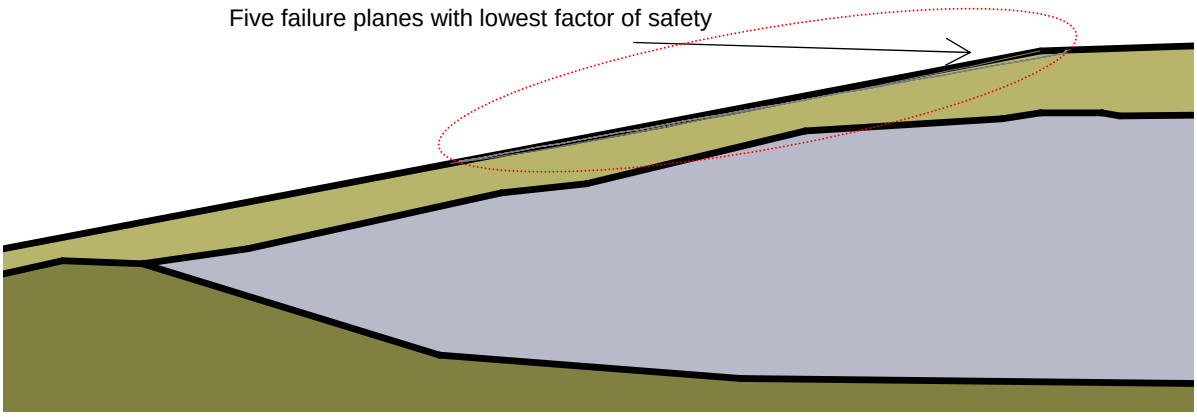
1/6/10

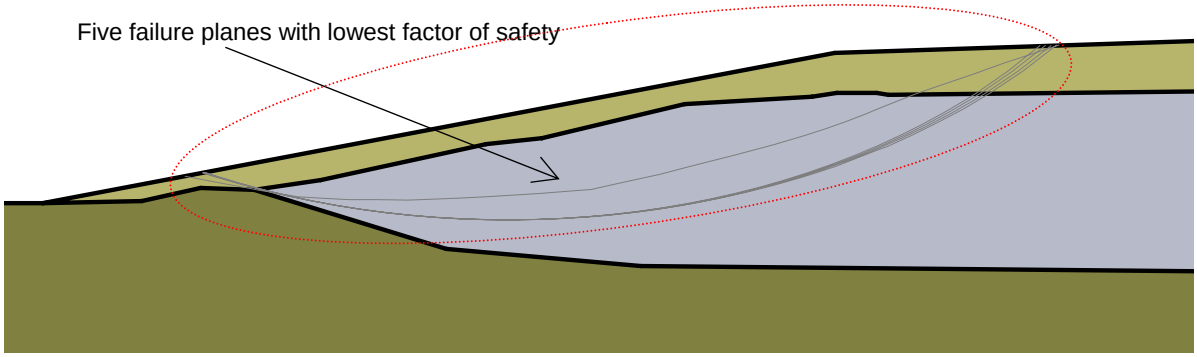
Figure 2

P:_ES07-130\CvrPrmtMod-Addndm.1-10\F02_Auto-Search_Cell 14.doc

a. Block analysis



b. Circular analysis



Explanation

- ET cover
- Waste
- Subgrade

Note: Morgenstern-Price analyses, using horizontal pseudostatic coefficients of 0.20 g

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Cell 14 Critical Surface Block and Circular Analyses

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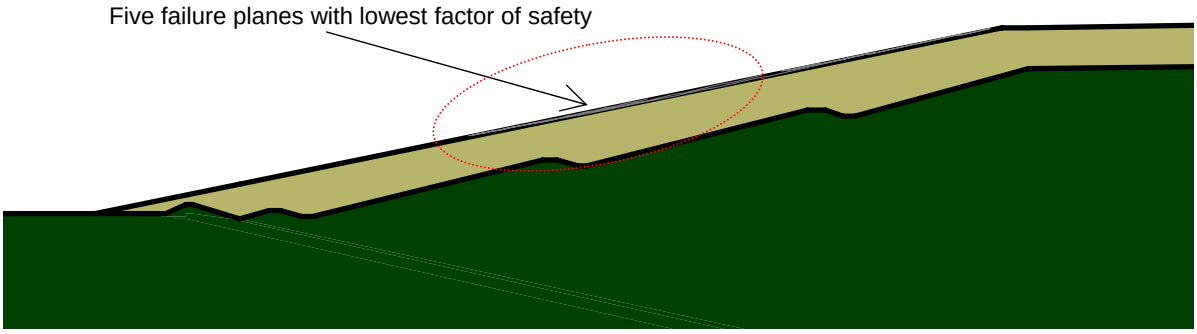
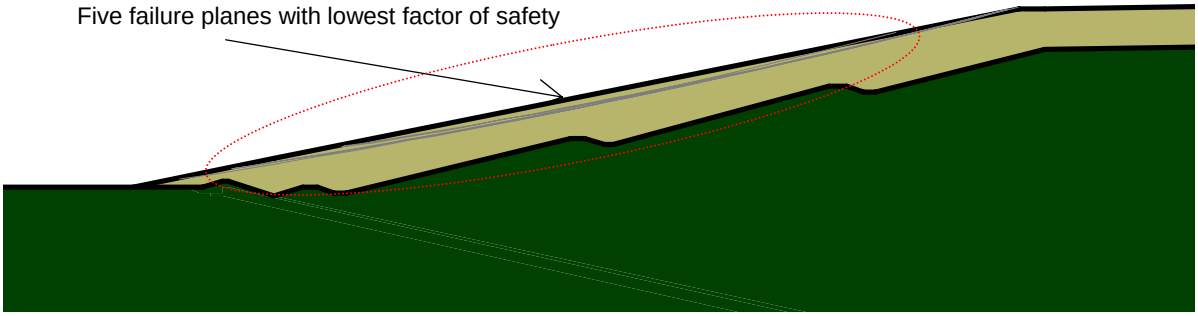
Figure 3

P:_ES07-130\CvrPrmt\Mod-Addndm.1-10\F03_Circular-Block_Cell 14.doc

a. Minimum slip surface depth of 0.1 foot



b. Minimum slip surface depth of 3 feet



Explanation

- ET cover
- Impenetrable layer

Note: Morgenstern-Price analyses, using horizontal pseudostatic coefficients of 0.20 g

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Cell 15 Critical Surface Auto-Search Analysis

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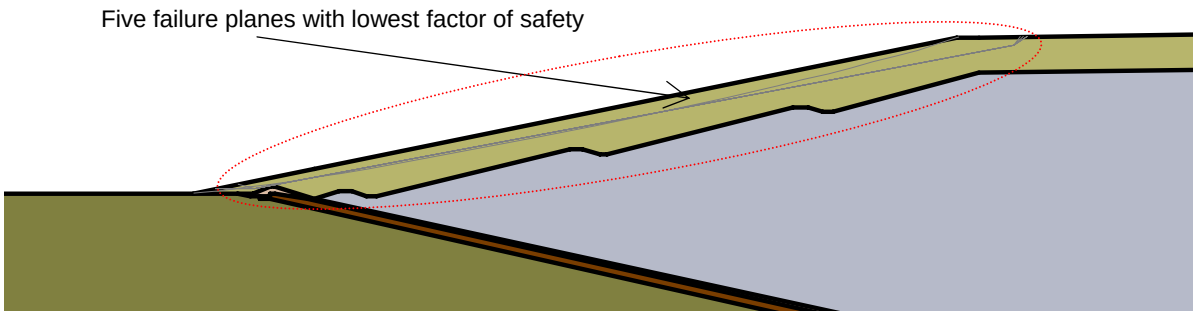
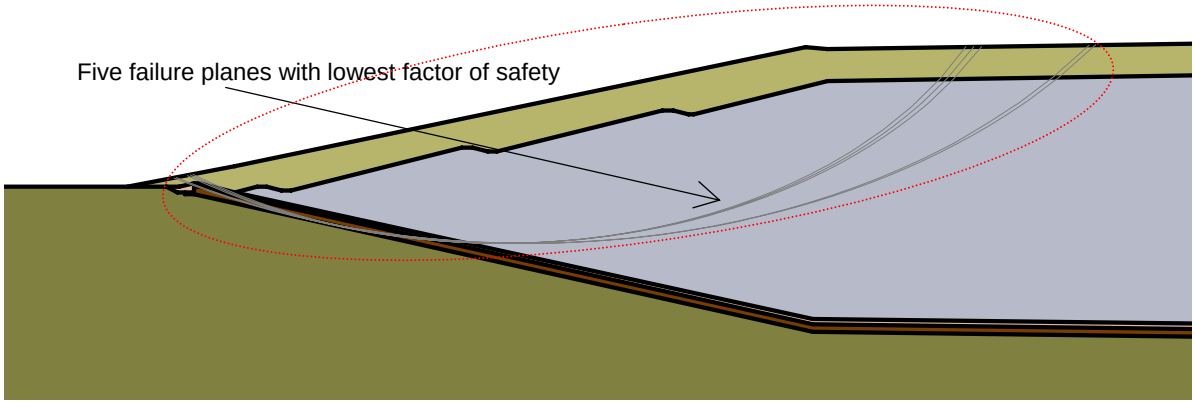
Figure 4

P:_ES07-130\CvrPrmtMod-Addndm.1-10\F04_Auto-Search_Cell 15.doc

a. Block analysis



b. Circular analysis



Explanation

- ET cover
- Waste
- Subgrade
- Liner system

Note: Morgenstern-Price analyses, using horizontal pseudostatic coefficients of 0.20 g

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Cell 15 Critical Surface Block and Circular Analyses

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1/6/10

Figure 5

P:_ES07-130\CvrPrmt\Mod-Addndm.1-10\F05_Circular-Block_Cell 15.doc

- Seed and Martin's (1966) and Dakoulas and Gazetas' (1986) comments were considered in the slope stability analysis. A much greater pseudostatic coefficient was required for deep failure (circular analysis) as compared to the surface failures (auto-search and block).

- Based on Seed's (1979) analyses, Cells 14 and 15 had factors of safety greater than 1.15 for a k_h of 0.10 for all analyses. Cell 14 had factors of safety greater than 1.15 for a k_h of 0.15. With factors of safety below 1.15 but greater than 1.0, Cell 15 may experience some surface (cover) failure (auto-search analysis) for a k_h of 0.15.

- Cells 14 and 15 satisfied the criteria of Hynes-Griffin and Franklin (1984). All analyses had pseudostatic factors of safety greater than 1.0 using k_h = 1.0 a_{max}/g, and/or k_h = 0.5 a_{max}/g as recommended.

- These analyses satisfy the criteria explained by Pyke (2009), who referenced the U.S. Army Corps of Engineers manual for seismic design of new dams and the criteria presented by the FERC.

In summary, the slope stability analysis was conservative in several respects:

- Choosing soil strength parameters at the lower end of the range presented by Washington Group, Inc.

- Amplifying the bedrock acceleration to an assumed peak ground acceleration

- Not reducing the peak ground acceleration when used as the horizontal pseudostatic coefficient.

Based on these conservative elements of the analyses and comparison with proposed factors of safety for dams, DBS&A determined that ET soil cover with slopes not exceeding 3:1 will maintain proper stability for Cells 14 and 15.

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Appendix D2

Erosion and Stormwater Protection

Appendix D2-1
Water Erosion

Daniel B. Stephens and Associates - Calculation Sheet

Project Name: USEI
Project Number: ES07.0130
Calculation Number:
Number of Sheets:

Calculation Performed By: REP ***Date:*** October 5, 2010

Calculation Checked By: ***Date:***

Status (Draft or Final):

Objective of Calculation:

This calculation is performed to estimate the soil loss due to surface water runoff.

Assumptions:

1) The maximum slope length on the top of cover is 800 feet and the slope is 5%.
2) The maximum sideslope length is 250 feet and the slope is approximated at 30%.
3) The specification calls for 2% organic matter but it is assumed that after the soil has been amended with 25% gravel that organic matter is 1%.

References:

1) United States Department of Agriculture (USDA). 1996. AH 703 - Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). Tucson.

2) US EPA, Storm Water Phase II Final Rule, EPA 833-F-00-014, Isoerodent map of United States - attached

3) Goldman et. al. 1986 - attached

4) Box, J. E. and L. D. Meyer. 1984. Adjustment of the Universal Soil Loss Equation for Cropland Soils Containing Coarse Fragments. Soil Science Society of America. Erosion and Productivity of Soils Containing Rock Fragments. Madison, WI.

Variables:

$R_e := 31$	rainfall energy/erosivity factor - reference 2
$C := 0.05$	vegetative cover and management factor - reference 3 straw mulch, 4.0 tons/acre, tacked down
$C_f := 0.5$	cover effect subfactor to account for 25% area cover of rock fragments reference 4, Table 4.
$P_c := 1$	conservation support practice factor - not used
$OM := 0.01$	organic matter - value based on other soils in the area
$LS := 1.04$	slope length and steepness factor, slope = 5%, slope length = 800 ft

$LS_2 := 7.94$ slope length and steepness factor, slope = 30%, slope length = 250 ft

soil erodibility factor - attached figure 3-1

$K_{S13} := 0.31$

$K_{S1}\,cm_water := 0.014209 \cdot psi$

$K_{S15} := 0.47$

$K := mean(K_{S13}, K_{S14}, K_{S15})$ $K = 0.417$

Calculation:

$A_s := R_e \cdot K \cdot LS \cdot C \cdot C_f \cdot P_c$ $A_s = 0.34$ tons/acre/year, 5% slope

$A_s := R_e \cdot K \cdot LS_2 \cdot C_f \cdot C \cdot P_c$ $A_s = 2.56$ tons/acre/year, 30% slope

Daniel B. Stephens and Associates - Calculation Sheet

Project Name: USEI
Project Number: ES07.0130
Calculation Number:
Number of Sheets:

Calculation Performed By: REP ***Date:*** October 5, 2010

Calculation Checked By: ***Date:***

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3) Goldman et. al. 1986 - attached

4) Box, J. E. and L. D. Meyer. 1984. Adjustment of the Universal Soil Loss Equation for Cropland Soils Containing Coarse Fragments. Soil Science Society of America. Erosion and Productivity of Soils Containing Rock Fragments. Madison, WI.

Variables:

$R_e := 31$	rainfall energy/erosivity factor - reference 2
$C := 0.01$	vegetative cover and management factor - reference 3 native vegetation, undisturbed
$C_f := 0.5$	cover effect subfactor to account for 25% area cover of rock fragments reference 4, Table 4.
$P_c := 1$	conservation support practice factor - not used
$OM := 0.01$	organic matter - value based on other soils in the area
$LS := 1.04$	slope length and steepness factor, slope = 5%, slope length = 800 ft

$LS_2 := 7.94$ slope length and steepness factor, slope = 30%, slope length = 250 ft

soil erodibility factor - attached figure 3-1

$K_{S13} := 0.31$

$K_{S1}cm_water := 0.014209 \cdot psi$

$K_{S15} := 0.47$

$K := mean(K_{S13}, K_{S14}, K_{S15})$ $K = 0.417$

Calculation:

$A_s := R_e \cdot K \cdot LS \cdot C \cdot C_f \cdot P_c$ $A_s = 0.07$ tons/acre/year, 5% slope

$A_s := R_e \cdot K \cdot LS_2 \cdot C_f \cdot C \cdot P_c$ $A_s = 0.51$ tons/acre/year, 30% slope

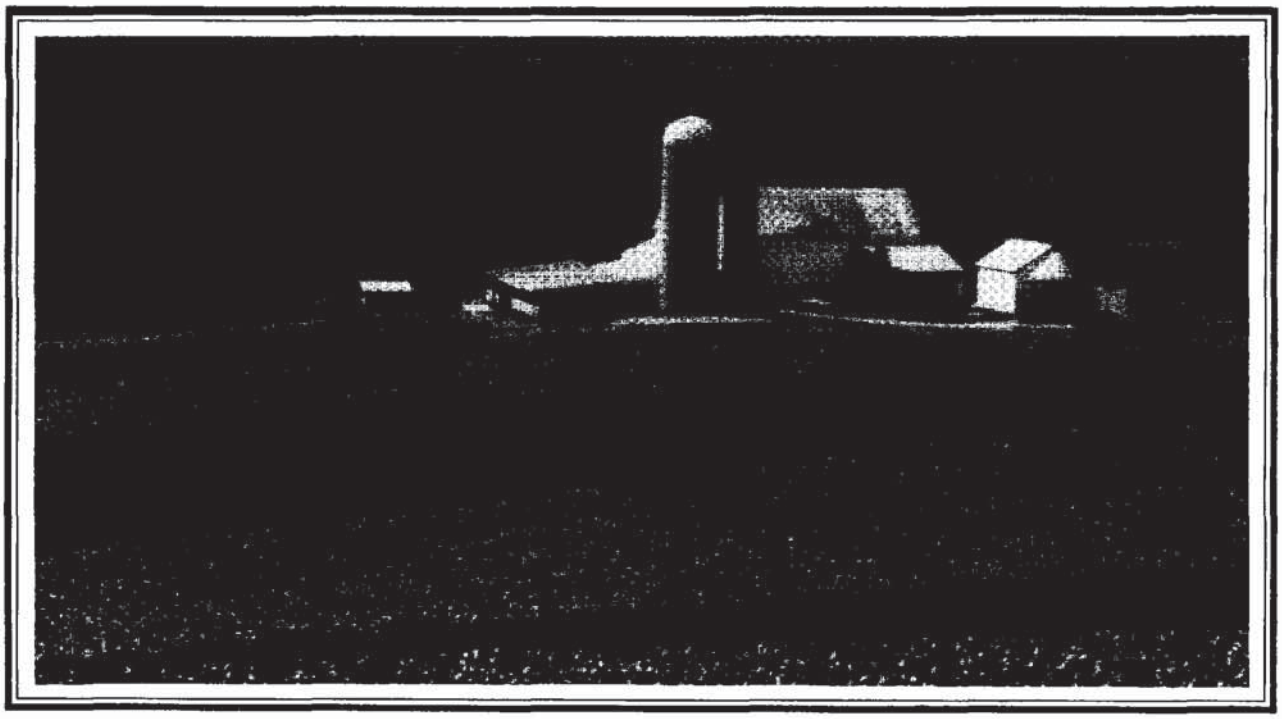
USDA

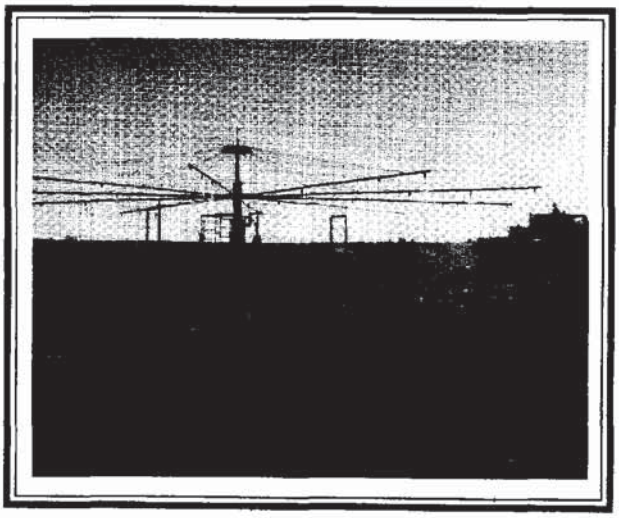
United States
Department of
Agriculture

Agricultural
Research
Service

Agriculture
Handbook
Number 703

Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE)





SOIL-LOSS TOLERANCE

A major purpose of the soil-loss equation is to guide the making of methodical decisions in conservation planning. The equation enables the planner to predict the average rate of soil erosion for each of various alternative combinations of cropping systems, management techniques, and erosion-control practices on any particular site. The term "soil-loss tolerance" (T) denotes the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically The term considers the loss of productivity due to erosion but also considers rate of soil formation from parent material, role of topsoil formation, loss of nutrients and the cost to replace them, erosion rate at which gully erosion might be expected to begin, and erosion-control practices that farmers might reasonably be able to implement. When predicted soil losses are compared with the value for soil-loss tolerance at that site, RUSLE provides specific guidelines for bringing about erosion control within the specified limits. Any combination of cropping, ranching, and management for which the predicted erosion rate is less than the rate for soil-loss tolerance may be expected to provide satisfactory control of erosion. Of the satisfactory alternatives offered by this procedure, the alternative(s) best suited to a particular farm or other enterprise may then be selected.

Values of soil-loss tolerance ranging from 1 to 5 $ton \cdot acre^{-1} \cdot yr^{-1}$ for the soils of the United States were derived by soil scientists/conservationists, agronomists, engineers, geologists, and Federal and state researchers at six regional workshops between 1959 and 1962. Factors considered in defining these limits include soil depth, physical properties and other characteristics affecting root development, gully prevention, on-field sediment problems, seeding losses, reduction of soil organic matter, and loss of plant nutrients. Since the early discussions, several reports have been produced in which soil-loss tolerance is discussed (Schmidt et al. 1982, Johnson 1987). The passage of Public Law 95-192 and the 1977 Soil and Water Resources Conservation Act (RCA) prompted considerable interest in the effect of soil erosion on crop productivity New experimental research and computer simulation models have furthered the interest in soil-loss tolerances. Two symposia proceedings of note that resulted from this activity are "Erosion and Soil Productivity" (ASAE 1985) and "Soil Erosion and Crop Productivity" (Follett and Stewart 1985). Needless to say, many issues about soil-loss tolerance remain unresolved.

USLE is essentially an expression of the functional relationship shown in equation [1-1] (Wischmeier and Smith 1965, 1978). Both USLE and RUSLE compute the average annual erosion expected on field slopes as

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad [1\text{-}2]$$

where

A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in $ton \cdot acre^{-1} \cdot yr^{-1}$, but other units can be selected (that is, $t \cdot ha^{-1} \cdot yr^{-1}$).

R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K = soil erodibility factor—the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow.

L = slope length factor—the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions.

S = slope steepness factor—the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = cover-management factor—the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow

P = support practice factor—the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

RUSLE is an erosion model designed to predict the longtime average annual soil loss (A) carried by runoff from specific field slopes in specified cropping and management systems as well as from rangeland. Widespread use has substantiated the usefulness and validity of RUSLE for this purpose. It is also applicable to nonagricultural conditions such as construction sites.

RUSLE users need to be aware that A (in addition to being a longtime average annual soil loss) is the average loss over a field slope and that the losses at various points on the slope may differ greatly from one another On a long uniform slope, the loss from the top part of the slope is much lower than the slope average, and the loss near the bottom of the slope is considerably higher For instance, a 360-ft uniform slope that averages 20

RELATIONSHIPS OF K FACTOR AND SOIL PROPERTIES

The physical, chemical, and mineralogical soil properties and their interactions that affect K values are many and varied. Moreover, several erosion mechanisms are operating at the same time, each one relating differently to a specific soil property. It is therefore unlikely that a relatively few soil characteristics will accurately describe K values for each soil. Yet several attempts have been made to relate measured K values to soil properties. Table 3-2 lists the principal studies in the United States and a summary of the results.

Of these studies, the most widely used and frequently cited relationship is the soil-erodibility nomograph (Wischmeier et al. 1971). The nomograph, shown in figure 3-1, comprises five soil and soil-profile parameters: percent modified silt (0.002-0.1 mm), percent modified sand (0.1-2 mm), percent organic matter (OM), and classes for structure (s) and permeability (p). The structure and permeability classes and groups of classes were taken from the Soil Survey Manual (USDA 1951). A useful algebraic approximation (Wischmeier and Smith 1978) of the nomograph for those cases where the silt fraction does not exceed 70% is

$$K = \left[2.1 \cdot 10^{-4}(12-OM)\, M^{1.14} + 3.25(s-2) + 2.5(p-3)\right] / 100 \qquad [3\text{-}1]$$

where M is the product of the primary particle size fractions: (% modified silt or the 0.002-0.1 mm size fraction) · (% silt + % sand). K is expressed as ton· acre^{-1} per erosion index unit with U.S. customary units of ton· acre· h (hundreds of acre· ft-tonf · in)$^{-1}$ Division of the right side of this and subsequent K-factor equations with the factor 7.59 will yield K values expressed in SI units of t· ha· h· ha^{-1}· MJ^{-1}· mm^{-1}.

The nomograph relationship is derived from rainfall-simulation data from 55 midwestern, mostly (81%) medium-textured, surface soils. More than 60% of these soils had an aggregation index smaller than 0.3 (Mannering 1967). The nomograph is well suited for the less aggregated, medium-textured surface soils of the Midwest. Attempts by other investigators to apply the nomograph to other classes of soils have met with limited success. Figure 3-2 shows the relationship between the observed and nomograph-predicted soil-erodibility

SPECIFIC PROBLEM AREAS

Rill and Interrill Erodibility

Physically based models are being developed to explain the dynamic relationships of the erosion process (detachment, transport, deposition), and the models provide a great opportunity to improve the estimation of erosion. These models are incompatible with the empirically based RUSLE, which predicts long-term average values (effects of subprocesses are lumped). Thus, improved soil-erodibility estimates using soil properties and relating them to erosion processes are not included in this revision (Römkens et al. 1986).

Soils With Rock Fragments

In NRCS's map unit use file (MUUF), 15.6% of land area in the continental United States consists of soils with rock fragments on or in the soil surface (Miller and Guthrie 1984). These rock fragments, when present on the soil surface, significantly reduce soil detachment by rainfall. When present in a coarse-textured-soil profile (having sand and loamy sand textures), the fragments can appreciably reduce infiltration.

To account for these effects, one view has been to include the effect of rock fragments on soil loss solely in the C factor (Box and Meyer 1984, Römkens 1985), and another practice has been to include the effects solely in the K factor. Surface cover by rock fragments varies from site to site on otherwise identical soils. The fragments act as a surface mulch by protecting the soil surface from raindrop impact in a manner similar to that of surface mulches of straw and chopped stalks. Rock fragments are usually not moved by water from interrill areas but remain behind on the soil surface and act as an "armor" (Jennings and Jarrett 1985).

Subsurface rock fragments affect infiltration and thus runoff in a manner similar to that of subsurface residue by reducing the soil void space and soil hydraulic conductivity in coarse-textured soils. Moreover, because soil-mechanical-analysis procedures are based on particle-size fractions smaller than 2 mm, rock fragments larger than 2 mm are usually excluded when estimating K-factor values. However, rock fragments are part of a continuum of particle sizes in the mineral phase of the soil and therefore can be considered as part of the soil-erodibility factor

This Agriculture Handbook separates the influence of rock fragments on soil loss into two components: (1) a surface cover component that represents the surface-protecting effect of rock fragments and that is accounted for in the C factor in a manner similar to that of crop residue and vegetative mulch, and (2) a subsurface component for sand and loamy-sand textures that represents the soil-loss increase due to the reduction in water infiltration. This latter effect is accounted for in the K factor through adjustments of the permeability class. It is shown below, however, that the subsurface effect of rock fragments can be relatively minor compared to the surface effect. Soil-profile descriptions with permeability classes that include the effect of rock fragments on permeability should not receive such an adjustment.

The hydraulic-conductivity-reducing effect of rock fragments can be determined from the relationship of the saturated hydraulic conductivity and permeability class given in the National Soils Handbook No. 430 (USDA 1983). Some clarification[2] is needed concerning the terminology and tables in that handbook. Rawls et al. (1982) proposed a relationship between the permeability class and the saturated hydraulic conductivity for different soil textures (table 3-3). Many factors other than texture determine the permeability class: for instance, structure, mineralogy, fragipans, sodium, and salinity. However, this relationship provides an estimate for relating changes in the effective hydraulic conductivity due to the presence of rock fragments to changes in the permeability class.

The rate of reduction in the saturated hydraulic conductivity with the presence of increasing amounts of coarse fragments in the soil profile was theoretically derived by Peck and Watson (unpublished data) and later verified for sand columns with inclusions of glass spheres and gravel by Dunn and Mehuys (1984). The relationship is

$$K_b / K_f = 2(1 - R_v) / (2 + R_v) \qquad [3\text{-}8]$$

[2]Permeability class as defined in the Soil Survey Manual of 1951 and in the USDA-SCS National Soils Handbook No. 430 is actually a hydraulic conductivity class. The relationship between permeability K_p (an intrinsic soil matrix property with dimensions L^2) and the saturated hydraulic conductivity K_h (a property that includes fluid properties of dimensions $L \cdot T^{-1}$) is $K_h = K_p \cdot \rho g \cdot \mu^{-1}$, where μ is fluid viscosity, ρ is fluid density, and g is gravitational acceleration.

where K_b is saturated hydraulic conductivity of the soil with rock fragments, K_f is saturated hydraulic conductivity of the fine soil fraction (<2 mm), and R_v is percent by volume of rock fragments >2 mm.

Brakensiek et al. (1986) simplified equation [3-8] to show that K_b of soil containing rock fragments can be reasonably related to K_f by using only the weight percent of rock fragments >2 mm. This relationship is

$$K_b/K_f = (1 - R_w) \qquad [3\text{-}9]$$

where R_w is percent by weight of rock fragments >2 mm. Using equation [3-9], a given percentage weight of rock fragments in a soil profile will result in an equal percentage reduction in the saturated hydraulic conductivity of the soil. Hence, the corresponding change in the permeability class can be estimated from table 3-3.

For example, a 40% volume of rock fragments in a severely eroding medium-textured soil (K = 0.50) will cause at best a change of one step in the permeability class or a maximum increase of 0.025 units in the soil-erodibility factor. This represents a 5% increase in soil loss. On the other hand, a 40% surface cover with rock fragments causes a reduction in soil loss of about 65% (Box 1981). For a less erodible soil (K = 0.10), a 40% volume of rock fragments represents a maximum increase of 25% in soil loss as reflected through the K value.

Seasonal K Values

K values are difficult to estimate mainly because of antecedent soil-water and soil-surface conditions and because of seasonal variations in soil properties. Because the value of these conditions and properties tends to be consistent for a season, it is thought that seasonal K values can reduce errors in soil-loss estimates. Based on this reasoning, Mutchler and Carter (1983) in the United States and Zanchi (1983) in Italy computed monthly K values. They independently proposed a periodic function of the type

$$K_r = 1 + a \cos(bt - c) \qquad [3\text{-}10]$$

where K_r is the ratio of the average seasonal (monthly) K value over the average annual K value; t is the mean monthly temperature; and a, b, and c are location-dependent constants. Similar reasoning by El-Swaify and

Figure 1. Erosivity Index Zone Map

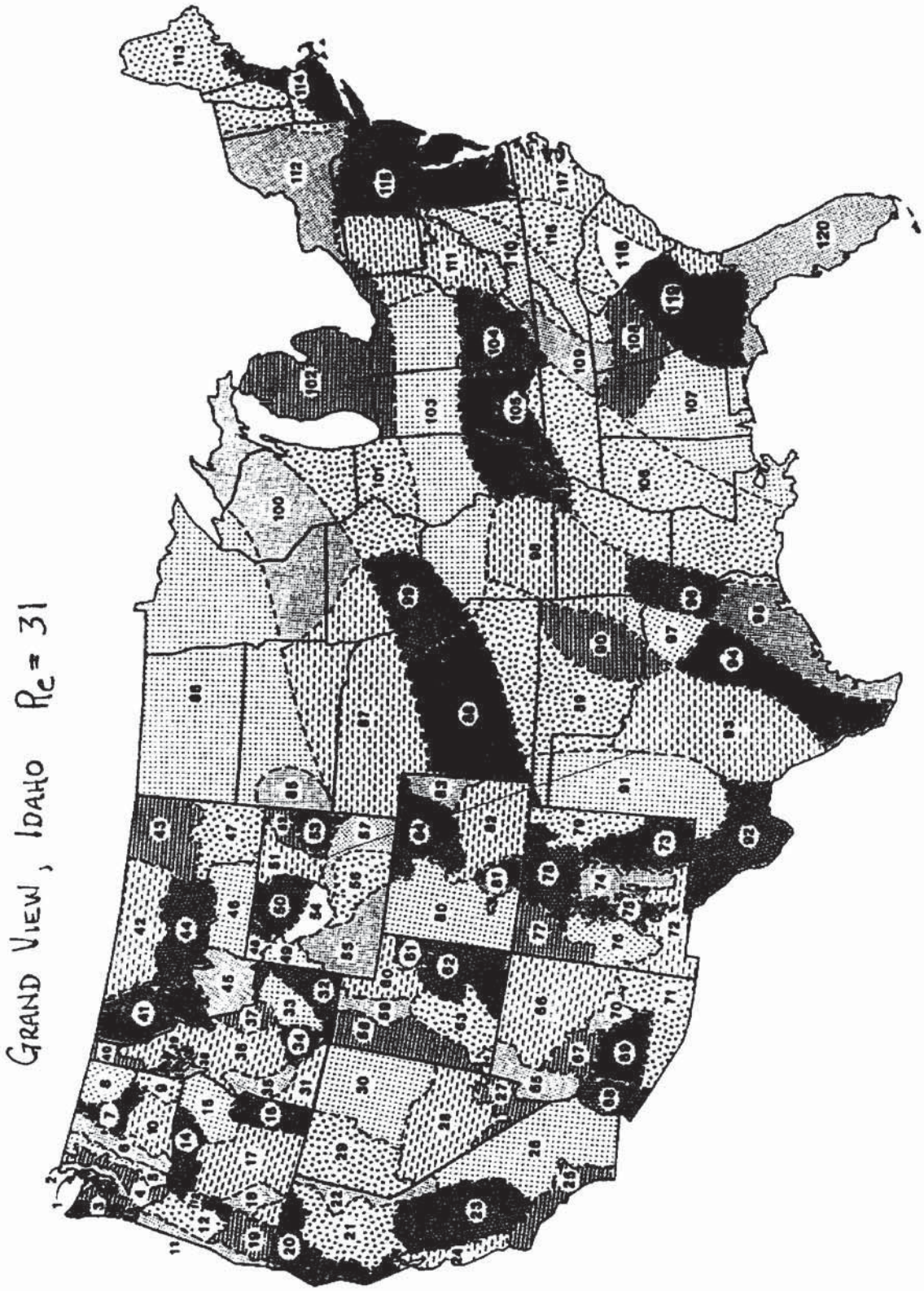


TABLE 15.6 Universal Soil Loss Equation: Vegetative Cover Factor *C*

Type of cover (1)	*C* factor (2)
No vegetative cover (bare ground)	1.0
Native vegetation (undisturbed)	0.01
Temporary seeding:	
90% cover, annual grasses, no mulch	0.1
Wood fiber mulch, 3/4 ton/acre, with seed*	0.5
Excelsior mat, jute*	0.3
Straw mulch:*	
1.5 tons/acre, tacked down	0.2
4 tons/acre, tacked down	0.05

*For slopes up to 2:1 (horizontal:vertical).

Sources: This table was developed by Goldman et al. 1986 and based on the work by Kay (1983), U.S. Department of Agriculture (1977), and Wischmeier and Smith (1965).

TABLE 15.7 Universal Soil Loss Equation: Erosion Control Practice Factor *P*

Surface condition (1)	*P* value (2)
Compacted and smooth	1.3
Trackwalked along contour*	1.2
Trackwalked up and down slope†	0.9
Punched straw	0.9
Rough, irregular cut	0.9
Loose to 12 in. (30 cm) depth	0.8

*Tread marks oriented up and down slope.

†Tread marks oriented parallel to contours.

Sources: This table was developed by Goldman et al. 1986 and based on the work by the U.S. Department of Agriculture (1977).

Chapter 9

Adjustment of the Universal Soil Loss Equation for Cropland Soils Containing Coarse Fragments[1]

J. E. BOX, JR. AND L. D. MEYER[2]

Soils with a significant content of coarse fragments are common in some parts of the United States and at various locations throughout the world. These fragments can greatly affect the erosion of such soils. Generally, the erosion rate is lessened as the surface cover of coarse fragments increases. Surface cover is important in reducing soil erosion by water because it dissipates raindrop impact energy, it reduces the area of erodible surface causing flow energy to be dissipated on nonerodible fragments, and it slows the velocity of runoff flow However, the inherent erodibility of the soil is associated with the soil particles smaller than about 2 mm (sand, silt, and clay). Normally, a soil increases in erodibility with an increase in silt fraction regardless of whether the corresponding decrease is in the sand or clay fraction (Wischmeier et al., 1971). Organic matter ranks next to particle size distribution as an indicator of erodibility Also, soil erodibility is a function of complex interactions of a substantial number of its physical properties and may vary within a standard textural class. Data from 17 soils on 50 sites indicated that soil structure and the size of the soil reservoir for storing water also have a significant effect on soil erodibility (Barnett and Rogers, 1966)

[1] Contribution from Southern Piedmont Conservation Research Center, USDA, ARS, Watkinsville, GA in cooperation with the Univ. of Georgia and USDA Sedimentation Laboratory, Oxford, MS.

[2] Soil scientist, USDA, ARS, Watkinsville, GA and agricultural engineer, USDA Sedimentation Laboratory, Oxford, MS.

Copyright © 1984 Soil Science Society of America, 677 South Segoe Road, Madison, WI 53711 *Erosion and Productivity of Soils Containing Rock Fragments.*

The Universal Soil Loss Equation (USLE) includes a soil erodibility factor, K, that "is a quantitative value experimentally determined" (Wischmeier and Smith, 1978). Based on data from 55 soils, a soil erodibility nomograph was developed (Wischmeier et al., 1971) that considers soil characteristics such as distribution of particle sizes less than 2 mm, organic matter content, soil structure, and permeability. The computed error of estimate indicated that of 100 K values obtained by this technique 68 should be within 6.4% of the true values, 90 within 11%, and all but one within 17%. In using the nomograph, "Coarse fragments are excluded when determining percentages of sand, silt, and clay. If substantial, they may have a permanent mulch effect. . " (Wischmeier and Smith, 1978). In the original 1971 paper describing the soil erodibility nomograph (Wischmeier et al., 1971) the effect of coarse fragments is discussed further: "Beyond some limiting density, stones on the surface would be expected to reduce erosion by providing a protective mulch. However, no data are available from which to determine the minimum density required or to establish numerical relationships for rates of stone cover above that amount. The situation would not be analogous to light straw or chopped-stalk mulches." One possibility suggested was to use the no-canopy curve on the graph relating the subfactor for effect of cover to percentage cover and multiply that factor by the nomograph value (Wischmeier and Smith, 1978). Subsequent research has demonstrated that the relationship between the subfactor for effect of cover and percent cover by rock fragments is similar to that of the mulch cover with zero canopy (Box, 1981).

The preponderance of arable soils in the USA do not have significant quantities of "armoring" materials, or coarse fragments, such as channery, cherty, cobbly, gravelly, shaly, or slaty fragments in their tilled horizon. However, for soils that do have coarse fragments, the fragment content and/or the textural composition may vary considerably for a particular soil series. Thus, the best understanding of the basic erodibility of soils seems to be achieved by evaluating the K factor, using only those soil materials less than 2 mm. This is also consistent with the experimental and conceptual development of the USLE.

In this chapter, we present analyses that show how the effect of coarse fragments on soil erosion may be included in the USLE. We believe that the proposed method is a logical approach and is versatile enough to accommodate the conditions encountered in the field during use of the USLE.

EFFECTS OF COARSE FRAGMENTS ON SOIL EROSION

Several studies have shown that coarse fragments on the soil surface reduce soil erosion by water. Removal of rocks larger than about 38 mm (Epstein and Grant, 1966) reduced soil surface cover from about 31 to 18% and increased erosion about 28%. In another study of unconventional mulches to control erosion on critical construction sites (Meyer et al., 1972), addition of gravel and crushed stone mulches on 20% slopes greatly reduced erosion for partial-cover rates and essentially eliminated

erosion when the soil was covered (Table 1). In a third study, research on several agricultural soils containing large amounts of natural coarse fragments (Box, 1981) showed that such fragments significantly reduced the erosion for these soils (Table 2). For soils with more than 50% rock fragment cover, removal of all fragments larger than 6 mm by sieving resulted in several times more erosion. Where cover was 15 to 25%, a 30 to 50% increase in erosion resulted from removal. When the fragments from the sieved plots were added to natural plots, erosion was much less than for the natural plots.

Table 1. Effect of crushed stone and gravel mulches on soil loss from 20% construction slopes.†

Mulch	Surface cover	Soil loss	Soil loss ratios§
	%	t/ha	
No mulch	3‡	88.7	--
35 t/ha stone	16	57.3	0.65
135 t/ha stone	62	27.1	0.31
300 t/ha stone	90	7.8	0.09
540 t/ha stone	100	<4.5	<0.05
155 t/ha gravel	62	32.9	0.37

† Meyer et al., 1972.
‡ Natural gravel of subsoil.
§ Soil loss ratio is the loss during about 130 mm of moderately intense rain from the mulched treatment divided by the loss from the unmulched treatment.

Table 2. Comparisons of the soil erodibility for nomograph, calculated, experimentally determined, and North Carolina USDA-SCS values for plots containing natural slaty fragments.

Soil	Site	Rep.	Coverage by slaty fragments	Soil slope	Cover effect‡ subfactor C_f	Nomographs§ K	Calculated¶ F	Experimental# F	Assigned†† K
			%	%		t ha h/ha MJ mm†			
Goldston very slaty silt loam	1	1	76	9.1	0.13	0.058	0.008	0.004	0.007
		2	68	8.8	0.17	0.058	0.010	0.006	0.007
Goldston very slaty silt loam	2	1	61	17.0	0.22	0.046	0.010	0.006	0.007
		2	58	16.0	0.23	0.046	0.011	0.006	0.007
Baden slaty silt loam	3	1	51	6.0	0.29	0.057	0.017	0.020	0.020
		2	53	6.5	0.27	0.057	0.015	0.016	0.020
Georgeville slaty silty clay loam	4	1	13	3.0	0.72	0.038	0.027	0.107	0.032
		2	16	2.9	0.68	0.038	0.026	0.083	0.032
Georgeville slaty loam	5	1	19	4.5	0.62	0.034	0.021	0.056	0.032
		2	26	3.9	0.53	0.034	0.018	0.058	0.032

† To convert to English Units divide by 0.1317
‡ Derived using Fig. 6, USDA *Agricultural Handbook* 537
§ Derived using Fig. 3, USDA *Agricultural Handbook* 537, soil texture for each site reported (Box 1981).
¶ Calculated $F = C_f K$.
# Values previously reported (Box, 1981) are in non-SI metric units.
†† Soil Conservation Service, USDA, North Carolina using typical content of coarse fragments.

ADJUSTMENT OF THE USLE FOR FRAGMENT EFFECTS

The results from past research, plus numerous observations, clearly show that large contents of coarse fragments in and on the surface of soils reduce erosion. However, several opinions exist concerning the way to include this effect in the USLE.

One approach is to include the effect of coarse fragments in the USLE K factor, but this has several major disadvantages. The soil erodibility factor is K, and by definition (Wischmeier et al., 1971; Wischmeier and Smith, 1978), it was meant to include only soil materials less than 2 mm, and not coarse fragments. Also, the erodible parts of the land surface are the soil materals, and not coarse fragments. The coarse fragments generally remain even when serious soil loss is occurring. Finally, a given soil series may vary greatly in its subsurface content and surface coverage of coarse fragments. If the effect of coarse fragments were to be included in the K factor, what appropriate K value could be assigned to a soil that varies in fragment content from 15 to 35%? As the soil material erodes with time and the coarse fragment content increases, what would be the appropriate K factor for that soil? Or, as coarse fragments are removed to improve cultivation and harvest (Epstein and Grant, 1966) what would be the appropriate K factor?

A more workable approach results from basing a soil's K factor on the erodibility characteristics of only the material less than 2 mm size fractions (excluding coarse fragments). The influence of coarse fragments would then be introduced as a C-factor effect With this approach the soil erodibility nomograph can be entered directly using the standard soil characteristics to obtain the K factor The base condition then is always the no-fragment condition, not some indefinite fragment-content condition somewhat within the range permitted in a given soil series. The effect of coarse fragments is consequently considered as a cropping-management-cover condition just as other soil surface covers are considered.

There are several other reasons for including the mulching effect of coarse fragments in the C rather than the K factor The K factor is annual soil loss from fallow land divided by annual EI The C factor is related to EI by 15-day periods, cropping practice, crop canopy, and mulch on the soil surface. These interactions are not simple or linear The C factor for each crop stage is multiplied by the appropriate 15-day EI and summed for the year to get an annual C factor Among the other modifications of these C factors are canopy cover, mulch cover, and canopy height. When mulching effect of rock fragments is placed in an adjusted K factor, these complex interactions are ignored.

Range and forest land erosion problems also favor placing the coarse fragment mulching effect in the C factor A USLE cover-management C factor procedure has been proposed (Dissmeyer, 1982; Foster, 1982) Values for C are estimated by evaluating six subfactors: (1) amount of bare soil, (2) canopy, (3) soil reconsolidation, (4) high organic content, (5) fine roots, and (6) residual binding effect A surface mulch of coarse fragments will respond differently to each of these subfactors. Bare soil may

be only a fraction of the surface, tree and bush canopies may be high above or near the soil surface, and the soil may be bare or covered with a heavy litter. The density of fine grass roots may vary in the surface soil along with variation in grass canopy and soil texture, and coarse fragments may vary from site to site. We believe that a much more definitive calculation of range and forest land erosion can be achieved by including the coarse fragment mulching effect as a C subfactor.

We have designated the C subfactor for coarse fragments as C_f, where f is the percentage of coarse fragment cover. Coarse fragment cover, f, should be evaluated after an erosive rainstorm has clearly exposed the fragments, not on freshly tilled soil. To determine appropriate values for a C_f subfactor, consider the zero-canopy curve (Wischmeier and Smith, 1978), which relates percentage surface cover by mulch to the resulting cover subfactor, as plotted in Fig. 1 However, this relationship was derived from data on the effect of vegetative plant residues and mulches. Cover effect subfactors from studies for soils with coarse fragments (Box, 1981) and surface mulches of crushed stone and gravel (Meyer et al., 1972) are also plotted in Fig. 1 Generally, the published curve (Wischmeier and Smith, 1978) fits the data satisfactorily and should suffice nicely along with the accompanying curves for other canopy covers until more accurate curves for coarse fragment mulch can be defined.

The effects of a vegetative mulch on top of a coarse fragment mulch are not additive. The fraction of vegetative mulch covering the coarse fragment mulch must be adjusted to determine the effective vegetative mulch cover For example, assume that coarse fragments cover 20% of

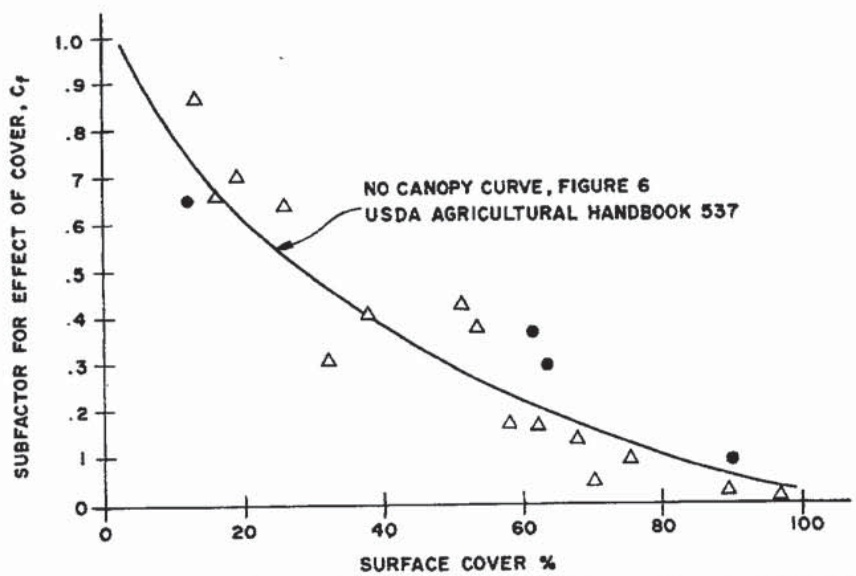


Fig. 1 The relationship between the subfactor for the effect of cover, C_f, and soil coverage by vegetative mulch or coarse fragments. (Δ, from Table 3, Box, 1981; ●, from Meyer et al., 1972).

the soil surface and on top of that is a vegetative mulch which covers 50% of the surface. For purposes of using the curve in Fig. 1 the soil surface cover would be $[0.20 + 0.50 - (0.20 \times 0.50)] = 0.60$ or 60% and not 70% The quantity, (0.20×0.50), is the 10% of the surface covered by both coarse fragments and vegetative mulch. Errors associated with including the mulching effect of coarse fragments in the K factor when vegetative mulch is also present are given in Table 3. The errors range from small percentages when surface covers are slight to more than 50% when high percentages of both types of surface cover are present.

The use of the no-canopy curve to adjust the soil erodibility value for the effect of coarse fragment coverage and fallow conditions is illustrated in Table 4 for a soil with a K factor of 0.049 t ha h/ha MJ mm. A C_f value, based on percent surface cover of fragments from Fig. 1, is multiplied by the K value, based on the no-fragment erodibility Table 4 can be modified for any soil by using the K factor of the less than 2 mm soil materials to derive the values in column 3 and 4. The K factor can be determined either by using the soil erodibility nomograph, or experimentally Use of C subfactors has been discussed (Mutchler et al., 1982). In this case, this C_f subfactor is part of their C_5 subfactor. If vegetative cover and/or canopy are also present, however, the adjusted total cover and canopy should be used for the C_5 subfactor, not just C_f.

For some purposes, users may need a single value that characterizes the combined effects of coarse fragments and soil erodibility In such cases, the C_fK value could be used where the value of f would be the most typical fragment cover. For the soil illustrated in Table 4, the $C_{30}K$ value would be 0.024. To avoid any confusion when a single value is used, we

Table 3. Soil loss prediction error resulting from K-factor adjustment for coarse fragments when the soil surface is overlain by vegetative mulch.

Example	Soil cover: Coarse fragment	Soil cover: Vegetative mulch	Cover subfactors†: Coarse fragment C_f	Cover subfactors†: Vegetative C_v	Cover subfactors†: combined C_e‡	Soil loss: A_1§	Soil loss: A_2¶	Error: No canopy
	%					t/ha		%
1	20	20	0.61	0.61	0.45	11.1	13.5	18
2	20	50	0.61	0.30	0.22	5.5	7.5	27
3	20	80	0.61	0.10	0.08	1.8	2.4	25
4	50	20	0.30	0.61	0.22	5.5	7.5	27
5	50	50	0.30	0.30	0.15	2.7	4.5	40
6	50	80	0.30	0.10	0.07	0.9	2.1	57
7	80	20	0.10	0.61	0.08	1.8	2.4	25
8	80	50	0.10	0.30	0.07	0.9	2.1	57

† Cover factors taken from Fig. 6, *USDA Handbook* 537, no-canopy curve.

‡ ¶ $A_2 = R \cdot K \cdot LS \cdot C_e \cdot P$; R = 1000, K = 0.03 (based on soil particles < 2 mm), LS and P = 1, and C_e is the effective mulch factor where percent mulch coverage equals $(f + v - f \cdot v/100)$ when f and v are percent of soil surface covered by coarse fragments and vegetative mulch, respectively

§ $A_1 = R \cdot F \cdot LS \cdot C_v \cdot P$; R = 1000, $F = C_fK$ where C_f is the coarse fragment mulch factor and K = 0.03 (based on soil particles < 2 mm) and C_v is the vegetative mulch factor LS and P = 1.

recommend that a new factor, F, be used to replace K in the USLE such that $F = C_fK$, where the appropriate f would be the most typical percent fragment cover However, if this is used, C_fK values for other rates of fragment cover that naturally occur for the soil should also be tabulated so that the user can apply the most appropriate value for a specific field.

To illustrate the method of adjusting for coarse-fragment surface cover in the USLE (using SI units as outlined in Foster et al., 1981), assume a local slaty silt loam (K = 0.049 t ha h/ha MJ mm) in northern Alabama (R = 5000 MJ mm/ha h year) on a 6% slope 60 m long (LS = 0.95) with a cropping-management system of C = 0.30 and no supporting conservation practices (P = 1 0) For a field with 20% coarse fragment cover C_f = 0.61 (Table 4) and the average annual erosion, A = (5000) (0.049) (0.95) (0.30) (0.61) (1.0) = 42.6 t/ha year. For another field with 50% coarse fragment cover, C_f = 0.29 and A = 20.2 t/ha year Instead of using C_f as a separate factor, the product C_fK (Table 4) could be used in the above computation to replace K as $C_{20}K$ = 0.030 and $C_{50}K$ = 0.014, respectively, for the two example conditions with the same results for A.

The preceding examples assume that the soil erodibility of the less than 2 mm fractions is known. If the soil erodibility of the less than 2 mm fraction is not known it can be determined by one of three ways: (a) using nomograph value for K, as discussed previously, (b) if a K factor which includes the effects of coarse fragments has been assigned, calculate the higher erodibility of the less than 2 mm soil fractions using the previously given expression $F = C_fK$; or (c) sieving material greater than 2 mm from the soil's top 80 to 100 mm and using a rainulator

Table 4. Adjustment in subfactor for the effect of cover to account for coarse fragments.

Surface cover by fragments	Cover effect subfactor	Soil erodibility factor F†	
		K = 0.37§	K = 0.049¶
%	C_f‡	C_fK	C_fK
0	1.00	0.37	0.049
10	0.78	0.29	0.038
20	0.61	0.23	0.030
30	0.48	0.18	0.024
40	0.38	0.14	0.019
50	0.29	0.11	0.014
60	0.22	0.08	0.011
70	0.16	0.06	0.008
80	0.11	0.04	0.006
90	0.06	0.02	0.004
100	0.03	0.01	0.002

† Columns 3 and 4 can be calculated for any soil by using the K-factor for the less than 2 mm soil materials of that soil. The K factor can be derived from the soil erodibility nomograph or experimentally

§ K value in customary U.S. units of ton•acre•h/hundreds of acre•ft-tonf•inch.

¶ K value in SI units of metric t•ha•h/ha•MJ•mm.

‡ C_f = subfactor for the effect of cover from Fig. 6 no-canopy curve in USDA *Agricultural Handbook* 537

CONCLUSION

We conclude that the mulching effect of coarse fragments at the soil surface should be included in a USLE C subfactor rather than in the K factor The reasons are:

1 A soil may vary in coarse fragment content and no one rate of cover is sufficient for describing a soil.

2. The K factor, by definition, and by past use, is based only on material less than 2 mm.

3. Appreciable error can occur in soil loss predictions if a single erodibility K factor, adjusted for the effects of coarse fragments on the soil surface, is assigned to a soil. The errors occur on cultivated land when vegetative mulch and crop canopies are present and on rangeland where variable density and heights of tree, brush, and grass canopies exist; variable tree, bush, and grass rooting effects are present; and variable density and spacing of vegetative mulch overlay the coarse fragments.

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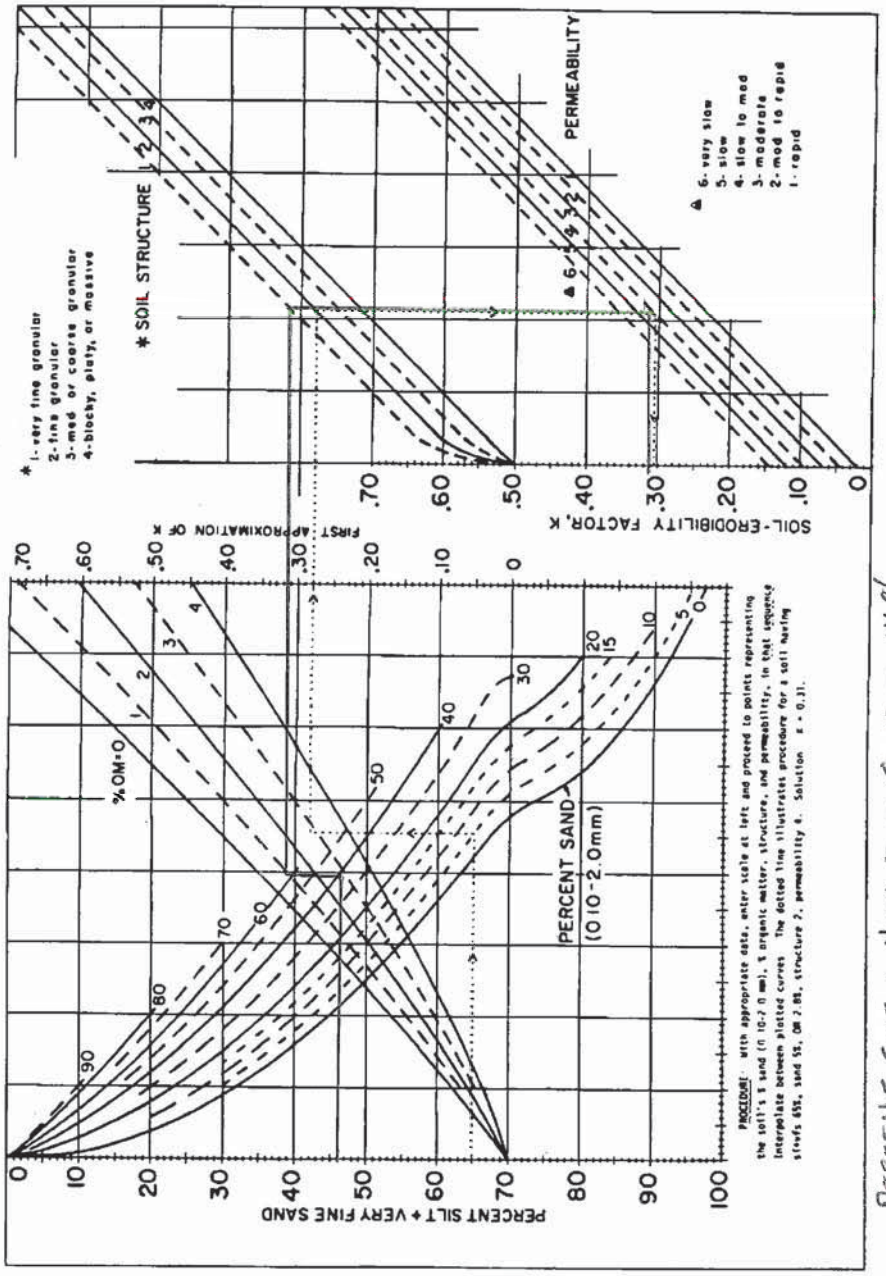
Table 4-1.
Values for topographic factor, LS, for low ratio of rill to interrill erosion.[1]

	Horizontal slope length (ft)																
Slope (%)	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1.0	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17
2.0	0.20	0.20	0.20	0.20	0.20	0.21	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.33	0.34	0.35
3.0	0.26	0.26	0.26	0.26	0.26	0.29	0.33	0.36	0.38	0.40	0.43	0.44	0.46	0.48	0.52	0.55	0.57
4.0	0.33	0.33	0.33	0.33	0.33	0.36	0.43	0.46	0.50	0.54	0.58	0.61	0.63	0.67	0.74	0.78	0.82
5.0	0.38	0.38	0.38	0.38	0.38	0.44	0.52	0.57	0.62	0.68	0.73	0.78	0.81	0.87	0.97	1.04	1.10
6.0	0.44	0.44	0.44	0.44	0.44	0.50	0.61	0.68	0.74	0.83	0.90	0.95	1.00	1.08	1.21	1.31	1.40
8.0	0.54	0.54	0.54	0.54	0.54	0.64	0.79	0.90	0.99	1.12	1.23	1.32	1.40	1.53	1.74	1.91	2.05
10.0	0.60	0.63	0.65	0.66	0.68	0.81	1.03	1.19	1.31	1.51	1.67	1.80	1.92	2.13	2.45	2.71	2.93
12.0	0.61	0.70	0.75	0.80	0.83	1.01	1.31	1.52	1.69	1.97	2.20	2.39	2.56	2.85	3.32	3.70	4.02
14.0	0.63	0.76	0.85	0.92	0.98	1.20	1.58	1.85	2.08	2.44	2.73	2.99	3.21	3.60	4.23	4.74	5.18
16.0	0.65	0.82	0.94	1.04	1.12	1.38	1.85	2.18	2.46	2.91	3.28	3.60	3.88	4.37	5.17	5.82	6.39
20.0	0.68	0.93	1.11	1.26	1.39	1.74	2.37	2.84	3.22	3.85	4.38	4.83	5.24	5.95	7.13	8.10	8.94
25.0	0.73	1.05	1.30	1.51	1.70	2.17	3.00	3.63	4.16	5.03	5.76	6.39	6.96	7.97	9.65	11.04	12.26
30.0	0.77	1.16	1.48	1.75	2.00	2.57	3.60	4.40	5.06	6.18	7.11	7.94	8.68	9.99	12.19	14.04	15.66
40.0	0.85	1.36	1.79	2.17	2.53	3.30	4.73	5.84	6.78	8.37	9.71	10.91	11.99	13.92	17.19	19.96	22.41
50.0	0.91	1.52	2.06	2.54	3.00	3.95	5.74	7.14	8.33	10.37	12.11	13.65	15.06	17.59	21.88	25.55	28.82
60.0	0.97	1.67	2.29	2.86	3.41	4.52	6.63	8.29	9.72	12.16	14.26	16.13	17.84	20.92	26.17	30.68	34.71

[1]Such as for rangeland and other consolidated soil conditions with cover (applicable to thawing soil where both interrill and rill erosion are significant).

STEINER TP-13



PERCENT SILT + VERY FINE SAND = 46%
% OM = 1%
SOIL STRUCTURE = 1
PERMEABILITY = 3

K = 0.31

Figure 3-1. Soil-erodibility nomograph (after Wischmeier and Smith 1978). For conversion to SI divide K values of this nomograph by 7.59. K is in U.S. customary units.

OM = 2% or greater

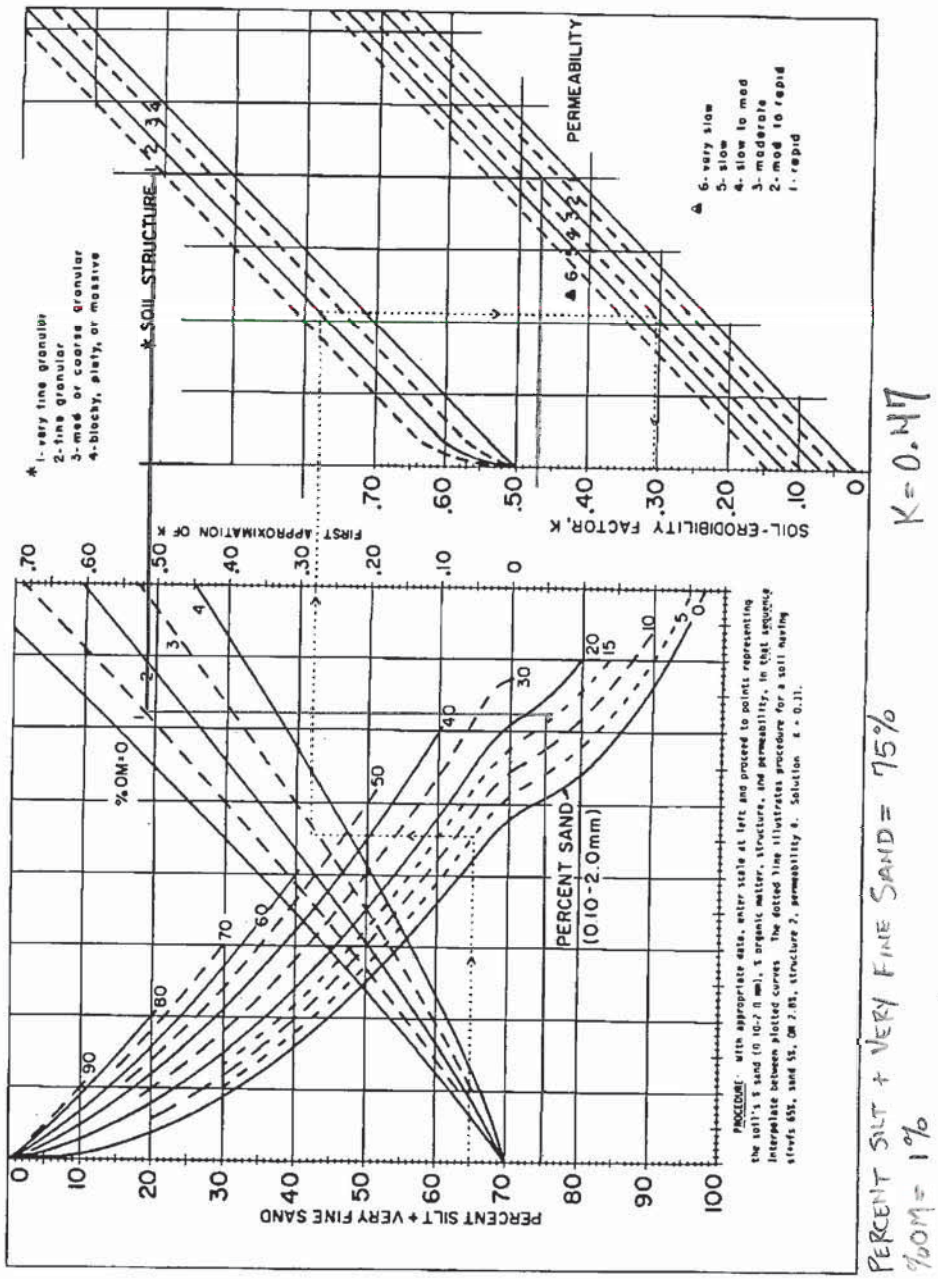


Figure 3-1. Soil-erodibility nomograph (after Wischmeier and Smith 1978). For conversion to SI divide K values of this nomograph by 7.59. K is in U.S. customary units.

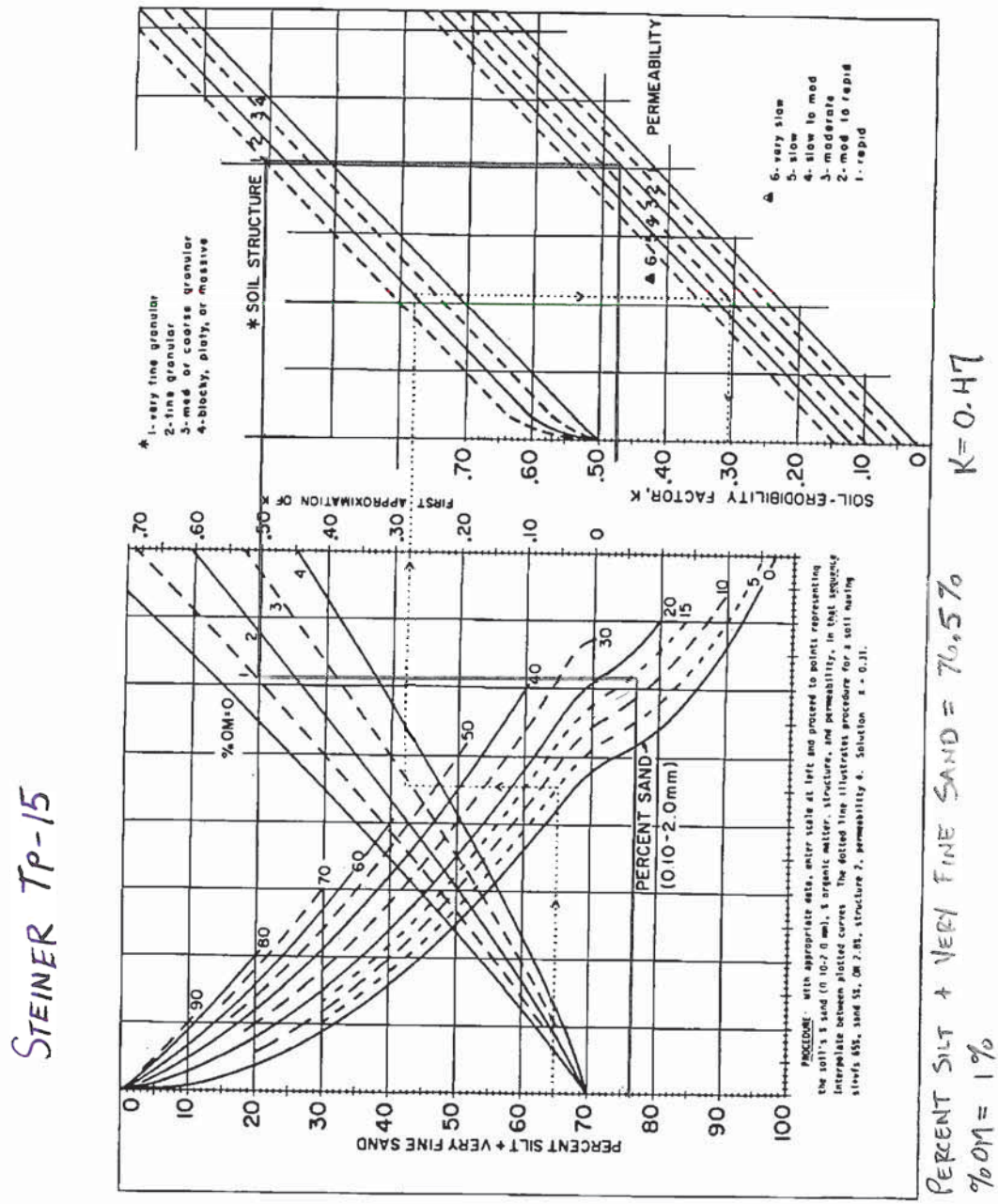
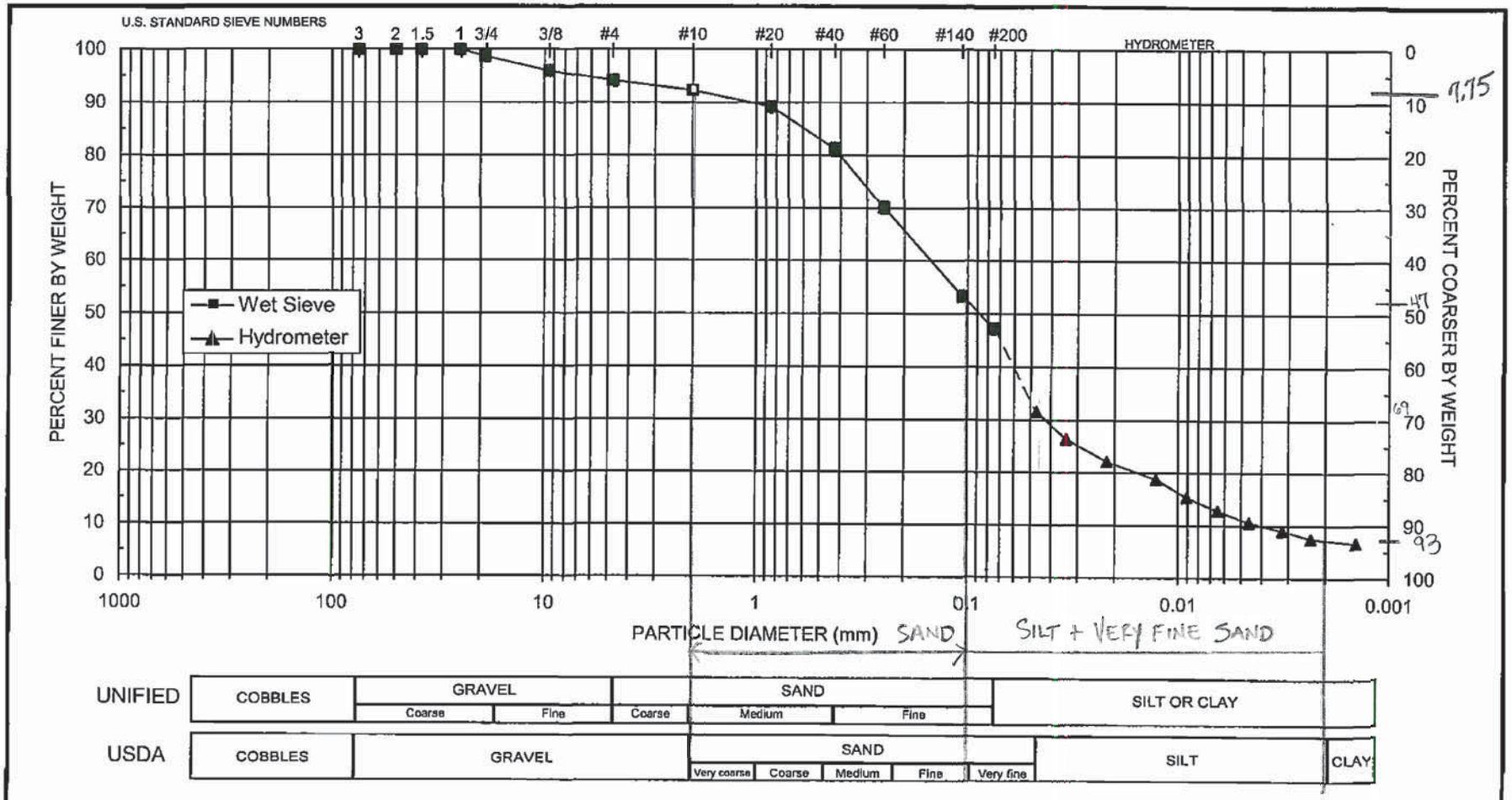


Figure 3-1. Soil-erodibility nomograph (after Wischmeier and Smith 1978). For conversion to SI divide K values of this nomograph by 7.59. K is in U.S. customary units.



d_{10} = 0.0040	d_{30} = 0.043	d_{50} = 0.088	d_{60} = 0.15	C_u = 38	C_c = 3.1

SAMPLE NUMBER	DEPTH	ASTM CLASSIFICATION	USDA CLASSIFICATION
USE1- DBSA Steiner TP-13	NA	Silty sand (SM)	Sandy Loam

SAND = 47 − 7.75 = 39.25 %

SILT + VERY FINE SAND = 93 − 47 = 46%

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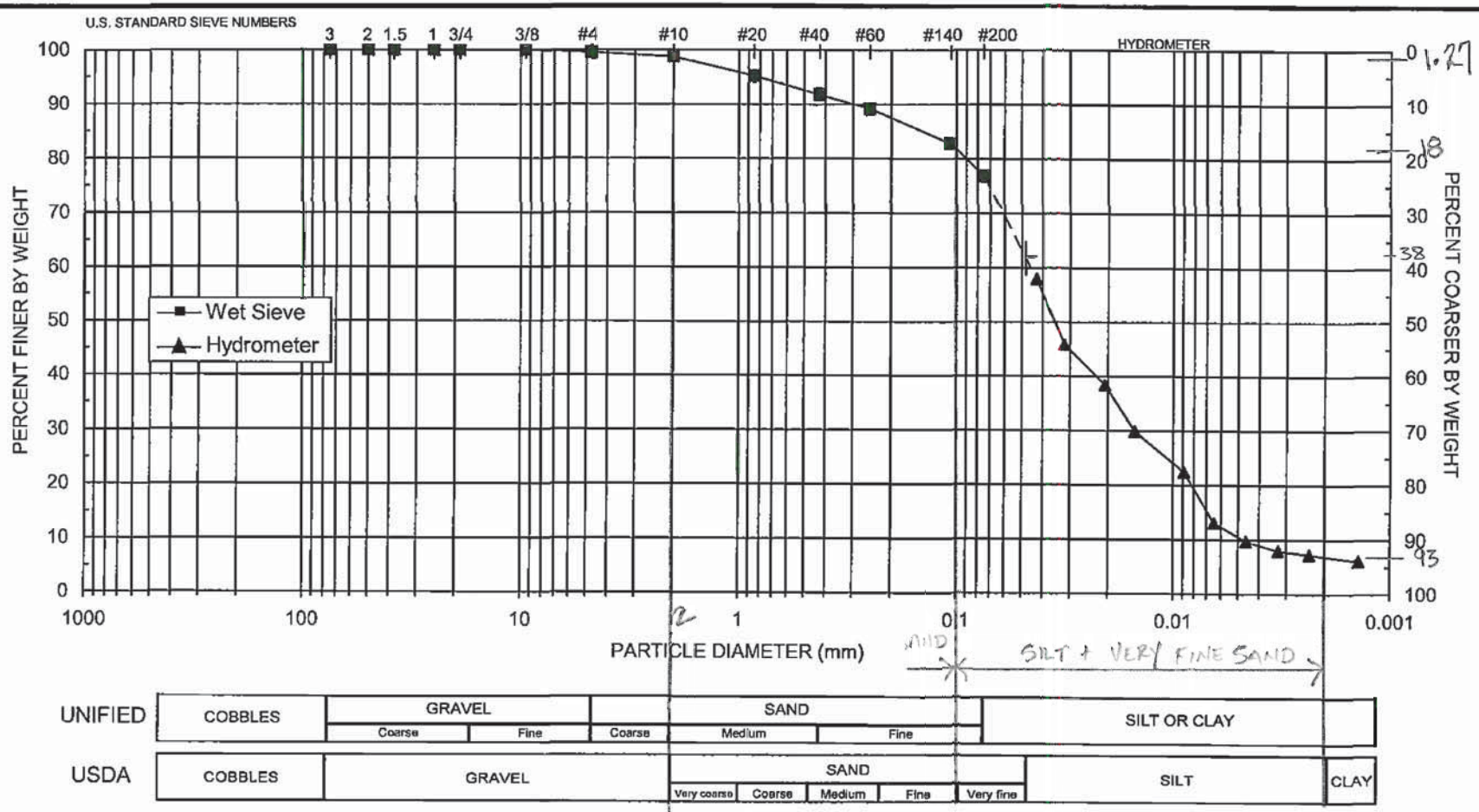
%SAND = 69 − 7.75 = 61.25

% SILT = 93 − 69 = 24

% CLAY = 100 − 93 = 7



d_{10} = 0.0047	d_{30} = 0.015	d_{50} = 0.035	d_{60} = 0.045	C_u = 9.6	C_c = 1.1

SAMPLE NUMBER	DEPTH	ASTM CLASSIFICATION	USDA CLASSIFICATION
USE1- DBSA Steiner TP-14	NA	Silt with sand (ML)s	Silt Loam

SAND = 18 - 1.27 = 16.63%

SILT + VERY FINE SAND = 93 - 18 = 75%

% SAND = 38 - 1.27 = 36.73

% SILT = 93 - 38 = 55

% CLAY = 100 - 93 = 7

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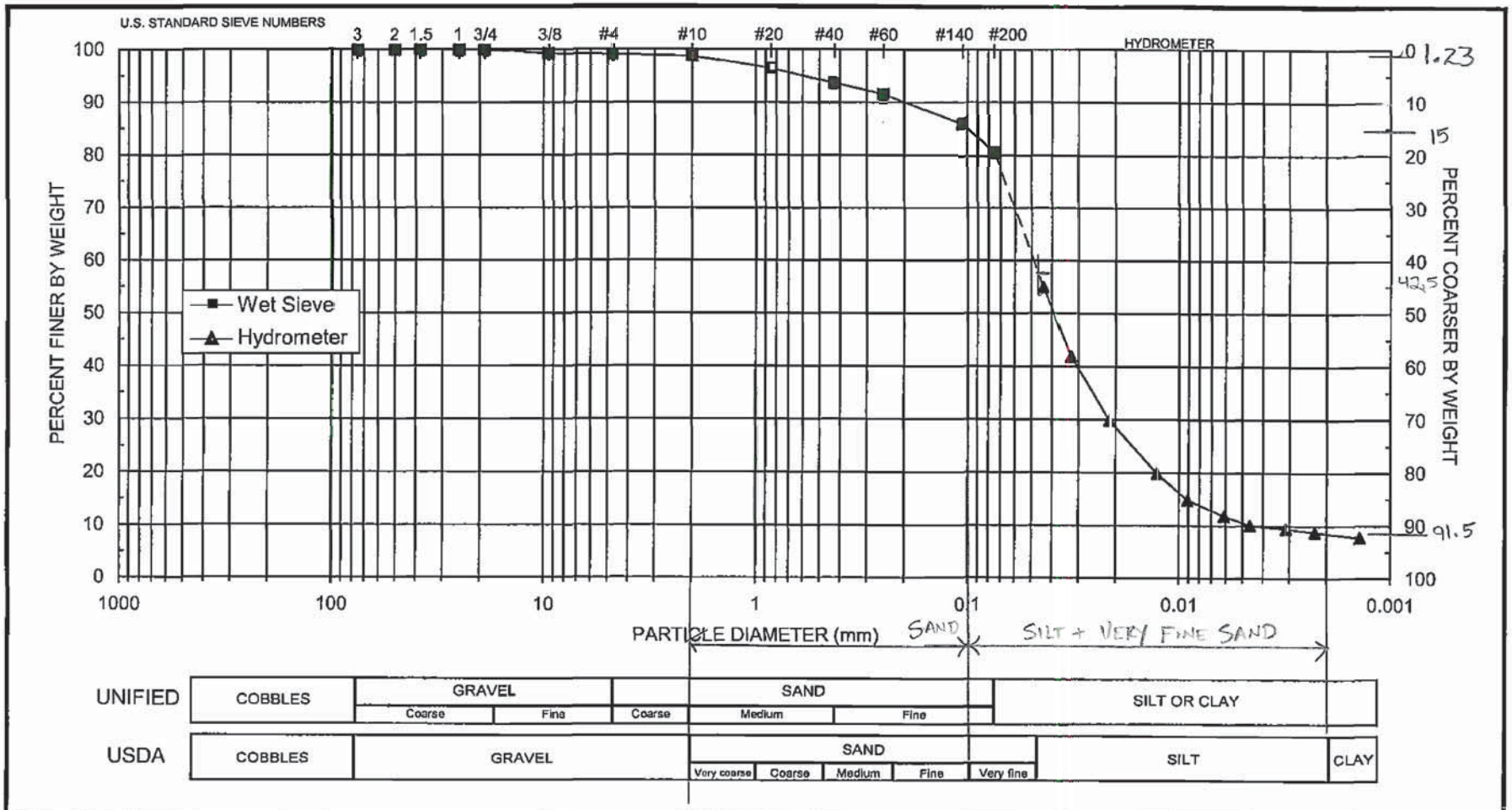

d_{10} = 0.0046	d_{30} = 0.021	d_{50} = 0.039	d_{60} = 0.049	C_u = 11	C_c = 2.0

SAMPLE NUMBER	DEPTH	ASTM CLASSIFICATION	USDA CLASSIFICATION
USE1- DBSA Steiner TP-15	**NA**	**Silt with sand (ML)s**	**Silt Loam**

SAND = 15 - 1.23 = 13.77%

SILT + VERY FINE SAND = 91.5 - 15 = 76.5 %

% SAND = 42.5 - 1.23 = 41.27

% SILT = 91.5 - 42.5 = 49

% CLAY = 100 - 91.5 = 8.5

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Table 3-3.
Soil-water data for major USDA soil textural classes

Texture	Permeability code[1]	Saturated hydraulic conductivity[2] (in/hr)	Hydrologic soil group[3]
Silty clay, clay	6	<0.04	D
Silty clay loam, sand clay	5	0.04-0.08	C-D
Sandy clay loam, clay loam	4	0.08-0.2	C
Loam, silt loam[4]	3	0.2-0.8	B
Loamy sand, sandy loam	2	0.8-2.4	A
Sand	1	>2.4	A+

[1]Permeability codes used in figure 3-1. See National Soils Handbook No. 430 (USDA 1983) for permeability classes.
[2]Rawls et al. (1982)
[3]See National Engineering Handbook (USDA 1972).
[4]Note: Although silt texture is missing because of inadequate data, this should be in permeability class 3.

Appendix D2-2
Gully Formation

Daniel B. Stephens and Associates - Calculation Sheet

Project Name: USEI
Project Number: ES07.0130
Calculation Number:
Number of Sheets:

Calculation Performed By:	SB	***Date:***	October 5, 2010
Calculation Checked By:	EP	***Date:***	

Status (Draft or Final):

Objective of Calculation:
This calculation is performed to determine the critical distance along a slope before gully formation begins. This will be used to determine portions of the cover that will remain bare soil and/or vegetation; and portions of the cover that will require designed erosion protection.

Assumptions:

1) On-site, loamy sand soil will be amended with 25% by weight gravel (10 mm - 50 mm) and organics to form the top layer of the final cover. This soil will be referred to as "amended,' has a D_{75} of 0.5 inches, the minimum size of gravel used, and a roughness factor of 0.025 (ref 2).
2) Onsite, loamy sand soil has an allowable shear stress of 0.02, typical of soils with D_{75}<0.05 inches, (ref 4) and a manning roughness factor of 0.018, (ref 2).
2) The top deck of the cover will have a slope of 5%. The sides of the cover will have a slope of 33%.
3) The 100 year - 1 hour storm intensity was used for calculation (see reference 3). 100 year - 1 hour storm event at the site is not available, the method of estimation provided in reference 3 is used.

References:

1) U.S. Nuclear Regulatory Commission (NRC), 2002. Design of Erosion Protection for Long-Term Stabilization, NUREG-1623. Washington, DC.
2) Sturm, T. W. 2001. Open Channel Hydraulics. McGraw Hill. New York.
3) NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume V-Idaho, 1973.
4) U.S. Department of Agriculture. 1987. AH 667 - Stability Design of Grass-Lined Open Channels, Tucson.

Variables:

$q_s := 1.07$	runoff intensity (inches/hour), (ref 3)
$D_{75} := 0.5$	effective diameter of gravel amended soil (inches)
$t_a := 0.4 \cdot D_{75}$	equation used to determine allowable shear stress for soils with D_{75} > 0.05 inches, (ref 4)
$t_a = 0.2$	allowable shear stress for amended soil (lbf/ft^2)
$t_s := 0.02$	allowable shear stress for on-site soil (lbf/ft^2), D_{75} < 0.05 inches (ref 4)
$n_1 := 0.018$	roughness factor for onsite soil, (ref 2)
$n_2 := 0.025$	roughness factor for amended soil, (ref 2)
$x_t := 2.9 \cdot deg$	$x_s := 18.4 \cdot deg$

Calculation:

$$f_{St} := \frac{\sin(x_t)}{\tan(x_t)^{0.3}}$$ slope function value recommended by reference 1, Pg. A-4, Step 3

$f_{St} = 0.124$

$$f_{Ss} := \frac{\sin(x_s)}{\tan(x_s)^{0.3}}$$ slope function $f_{Ss} = 0.439$

$$x_{c1} := \frac{65 \cdot t_a^{\frac{5}{3}}}{q_s \cdot n_2 \cdot f_{Ss}^{\frac{5}{3}}}$$ $x_{c1} = 655.083$ critical distance (ft) for amended soil on side slopes

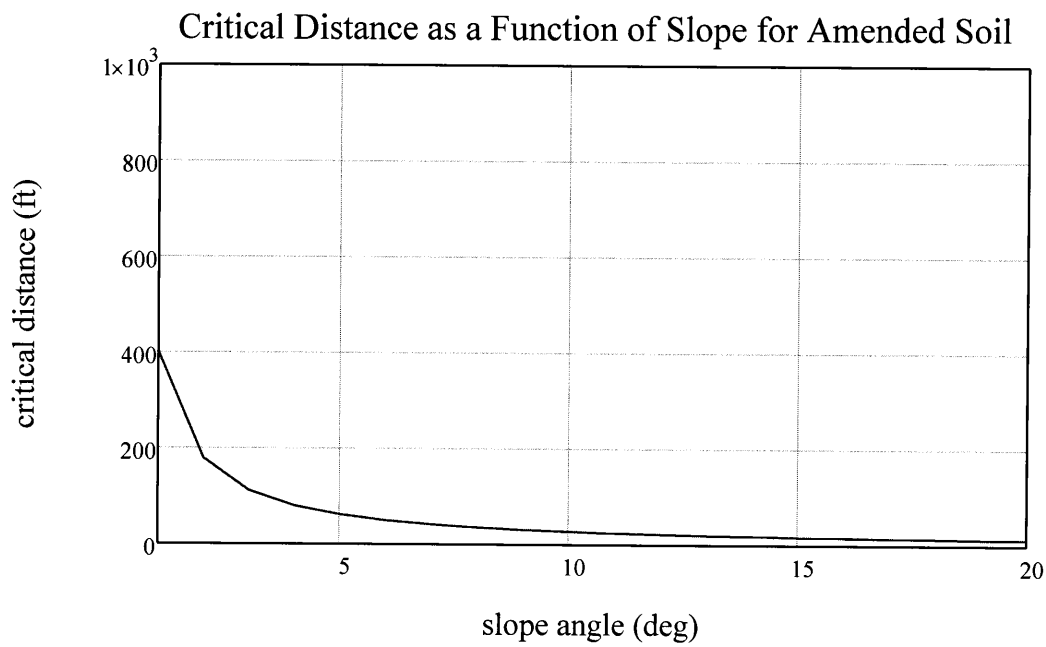
$$x_{c2} := \frac{65 \cdot t_s^{\frac{5}{3}}}{q_s \cdot n_1 \cdot f_{Ss}^{\frac{5}{3}}}$$ $x_{c2} = 19.602$ critical distance (ft) for on-site soil on side slopes

$$x_{c3} := \frac{65 \cdot t_a^{\frac{5}{3}}}{q_s \cdot n_2 \cdot f_{St}^{\frac{5}{3}}}$$ $x_{c3} = 5.405 \times 10^3$ critical distance (ft) for amended soil on top deck

$$x_{c4} := \frac{65 \cdot t_s^{\frac{5}{3}}}{q_s \cdot n_1 \cdot f_{St}^{\frac{5}{3}}}$$ $x_{c4} = 161.739$ critical distance (ft) for on-site soil on top deck

$$x_c(x_s) := \frac{65 \cdot t_s^{\frac{5}{3}}}{q_s \cdot n_2 \cdot \left(\frac{\sin(x_s)}{\tan(x_s)^{0.3}} \right)^{\frac{5}{3}}}$$

$$x_s := \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \end{pmatrix} \cdot deg$$



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NUREG-1623

Design of Erosion Protection for Long-Term Stabilization

Final Report

U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Washington, DC 20555-0001

APPENDIX A

SECTION 1

DESIGN OF SOIL COVERS

1 INTRODUCTION

Because regulations require that tailings remain stable for very long periods, and because of the limited amount of performance data available for soil slopes, it is necessary to exercise caution in their design. Such designs should be based on the premises that: (1) unconcentrated sheet flow is not a realistic assumption, and there will always be some random flow spreading and/or flow concentrations as flow progresses down embankment side slopes; (2) phenomena such as differential settlement and wind erosion can cause uneven surfaces that provide pockets for erosion and preferential flow paths to occur on a slope; and (3) freezing/thawing of the soil cover can cause deterioration and damage (e.g., frost heave) to slopes, thus producing areas prone to the formation of concentrated flow.

The management position developed by the U. S. Nuclear Regulatory Commission (NRC) staff (NRC, 1989) provides guidance in the selection of the design flood and the level of conservatism needed in designing tailings covers. In general, the position calls for use of reasonable conservatism in those areas that are not well-understood; however, extremely conservative values of design parameters are not to be used. In those areas where the phenomena are well-understood or where the range of design parameters is relatively narrow, typical or average values may be used in design. For the design of soil covers, there are several design parameters that are not well-understood, such as flow concentrations, long-term effectiveness of vegetation as erosion protection, allowable stresses or velocities, roughness of the cover when flow depths are small, and other miscellaneous problems that could occur over a period of 1000 years.

The NRC staff has therefore concluded that the slope of a soil cover should be one that is stable and will: (1) minimize the potential for development and growth of a gully over a long period of time, assuming that flow concentrations occur; and (2) prevent the erosion of tailings due to gullying.

2 DESIGN OF UNPROTECTED SOIL COVERS

2.1 Technical Basis

2.1.1 Horton/NRC Method

Horton (1945) determined that an area immune to erosion existed adjacent to a watershed divide. The distance from the watershed divide to the point down the slope at which erosion will occur was termed the critical distance, x_c. At this point the eroding force becomes equal to the soil resistance. The following expression was developed by Horton to determine the critical distance:

$$x_c = \frac{65\ R^{5/3}}{q_s\ n\ f(S)^{5/3}} \qquad \text{(A-1)}$$

where:

x_c = critical distance, in ft

q_s = runoff intensity, in inches/hour, corresponding to the computed time of concentration

n = roughness factor

R = soil resistance, lb/ft^2

$f(S)$ = slope function = $\frac{\sin x}{\tan^3 x}$

where:

x = slope angle in degrees, measured from horizontal

If the following substitutions are made, the stable slope (S_s) can be determined:

S_s = $\sin x$ = $\tan x$, for small values of slope;

t = R = allowable shear stress (pounds per square foot);

P = q_s = design precipitation intensity (inches/hour); and

L = x_c = slope length (ft).

A flow concentration factor (F) is used in the equation to account for imperfections in the slope and is multiplied by the rainfall intensity.

Therefore,

$$S_s^{7/6} = \frac{65(t)^{5/3}}{P\ L\ F\ n} \qquad \text{(A-2)}$$

Equation A-2 may also be derived by simultaneous solution of the Manning Equation, the peak shear stress formula, and the Rational Formula.

Use of equation A-2 allows direct solution of the value of the stable slope necessary to prevent the initiation of gullying. The slope thus determined represents the maximum slope that can be

provided to minimize the potential for gully initiation due to the occurrence of one single intense rainfall event, and thus should also minimize erosion due to a series of less intense storms to be expected over a period of 200 to 1000 years.

Temple et al. (1987) and Chow (1959) discuss methods for determining allowable shear stresses and recommend that the shear stress method be applied to design a stable section. The shear stress method is often used to assess the size and slope of channels needed to maintain stability. Data are available to estimate permissible shear stresses for various types of soils (Temple et al., 1987).

It is expected that the use of this method will result in relatively flat slopes for achieving long-term stability. Basic hydraulic design principles indicate that the resulting slopes are likely to be flat enough to achieve subcritical flow, even if small rills and channels are formed on the embankment slope. The staff concludes that the resulting subcritical flow regimes that are formed will generally not result in severe erosion of a tailings cover, even if a gully is formed, based on an examination of standard bed load equations and sediment transport models (Chow, 1959; Fullerton, 1983).

2.1.2 Permissible Velocity Method

Use of the permissible velocity method is discussed in detail by Chow (1959). The method is widely used to design stable channel sections, both for cohesive and non-cohesive soils. However, there is a potential for misuse when applying this method to design stable slopes or any application other than channel design. If properly applied, there is no reason for rejecting its use. The most common misuse is the failure to reduce the permissible velocity if the depth of flow is relatively shallow (less than 3 ft). As stated by Chow:

> "When other conditions are the same, a deeper channel will convey water at a higher mean velocity without erosion than a shallower one. This is probably because the scouring is caused primarily by the bottom velocities and, for the same mean velocity, the bottom velocities are greater in the shallower channel. . ."

It can be seen that reductions to the permissible mean channel velocity are needed to reflect the velocities that are to be used for slope designs, where the depths of flow are shallow. Chow has published correction factors, based on the depth of flow. Abt and Hogan (1990) have determined that such corrections are appropriate, based on an examination of the original data and based on hydraulic theory.

Additionally, based on examination of data from the Soil Conservation Service (SCS, 1984), the staff recommends that the maximum permissible velocity for grassed covers and channels be limited to about 2½ to 3 ft per second. This limit is necessary because no credit may be taken for active maintenance in designing for long-term stability. Further, SCS data suggest that maximum permissible velocities for most vegetation species, other than thick grasses, should be in this range.

2.2 Procedures

Procedures have been developed to (a) design a stable unprotected soil cover (or vegetated soil cover with no credit given for vegetation) using the allowable shear stress method, as modified and developed in the Horton/NRC Method and (b) design a stable vegetated section using the permissible velocity method for areas where vegetation can be effective. These procedures provide two acceptable methods for designing stable covers. It is recognized that in many cases, specific values of parameters may be difficult to justify. In those cases where licensees can justify values of individual parameters that depart from the values given by suggested references, the resulting designs will be considered on a case-by-case basis.

2.2.1 Unprotected Soil Cover

Step-by-step procedures for implementing the allowable shear stress method for an unprotected soil cover are presented below:

Step 1. Determine maximum allowable shear stress for bare soil using procedures developed by Temple et al. (1987). The staff considers Temple's method to be an accurate method for determining shear stresses because it is related to the Unified Soil Classification System and can be applied for specific soil types and degrees of cohesiveness. In general, the Temple procedure for determining allowable shear stress is based primarily on the soil particle size and the soil cohesiveness. The amount of resistance for granular non-cohesive soils, including rocky soils, is principally a function of the D_{75} grain size, where the allowable tractive force is equal to $0.4 \times D_{75}$ (Temple et al., 1987). For granular soils, the increase in shear resistance due to cohesiveness is minimal. For cohesive soils where the particle size is smaller, the amount of resistance is principally a function of the soil cohesiveness and not the particle size.

Step 2. Determine slope and slope length to be considered, as developed in the preliminary reclamation design.

Step 3. Determine flow concentration factor (F). Documentation of the occurrence of flow concentrations and the ability of an individual rock or soil particle to resist given flow rates is discussed further by Abt et al. (1987). The actual value of F will depend on several factors, including grading practices during cover construction, cover slope, and potential for differential settlement. The staff recommends a default value of 3, for most soil slopes; other values may be used, if properly justified.

Step 4. Estimate Manning's "n" value using general procedures given by Temple et al. (1987); by Nelson et al. (1986); or by Chow (1959).

Step 5. Determine the rainfall intensity using the procedures given by Nelson et al. (1986) and determine the peak runoff rate using the Rational Formula.

Step 6. Solve for stable slope, using the Horton/NRC equation. If the computed slope is different from that assumed, return to Step 2 with new values of slope and/or slope length.

2.2.2 Vegetated Soil Cover

Step 1. Maximum permissible velocities (MPVs) should be estimated using data developed by the U.S. Soil Conservation Service (SCS, 1984); or by Nelson et al., 1986). Based on these data, maximum MPVs should generally range from about 2½ to 3½ ft per second for any vegetation other than dense grasses. These velocities need to be further reduced, as discussed in Step 6.

Step 2. Determine slope and slope length.

Step 3. Determine flow concentration (F). See Step 3 in Section 2.2.1, above for additional information.

Step 4. Estimate Manning's "n" value using procedures recommended by Chow (1959, Table 7.6) for very low vegetal retardance (Fig. 7.14).

Step 5. Determine rainfall intensity and runoff rate using procedures discussed in Step 5 in Section 2.2.1.

Step 6. Determine the flow depth (y) by solving the Manning Equation for normal depth on a one-foot-wide strip. This equation can be solved directly in this case using the following derivation:

$$y^{5/3} = Qn / (1.486\ S^{1/2}). \qquad \text{(A-3)}$$

Step 7. Determine the permissible velocity for the slope, based on the computed depth of flow. Chow has developed correction factors that may be applied to determine the permissible velocity. The permissible velocity is multiplied by the following correction factors, depending on the depth of flow.

Depth of Flow (ft)	Correction Factor
3.0 or greater	1.0
1.9	0.9
1.0	0.8
0.65	0.7
0.4	0.6
0.25 or less	0.5

Step 8. For the assumed one-foot-wide strip, determine the actual flow velocity (V_a) by dividing the discharge by the flow depth:

$$V_a = Q/y. \qquad \text{(A-4)}$$

If this velocity is greater than the permissible velocity computed in Step 7, return to Step 2 with new values of slope and/or slope length.

2.3 Recommendations

Recommendations are discussed in Section 2.2, for various steps of the design procedure. Particular attention should be given to determining allowable shear stress values and permissible velocities, since these parameters are likely to be the most sensitive parameters in the calculations.

2.4 Examples of Procedure Application

2.4.1 Stable Slope of an Unprotected Soil Cover

For a site located in northwest New Mexico with a slope length of 1,000 ft, the stable slope of an unprotected soil cover may be computed using the allowable shear stress method.

Step 1. The allowable shear stress is estimated using methods given by Temple et al. (1987). For a clay soil having a void ratio (e) of 0.5 and a plasticity index of 15, the allowable shear stress (t_a) is computed using:

$$t_a = t_{ab}\, C_e^2, \qquad \text{(A-5)}$$

where t_a = basic allowable shear stress (pounds per square foot),

C_e = void ratio correction factor,

$$C_e = 1.38 - (0.373)(e) = 1.38 - (0.373)(.5) = 1.19 \qquad \text{(A-6)}$$

t_{ab} = 0.0966 (from Table 3.3, Temple (1987),

t_a = $(0.0966)(1.19)^2 = 0.14$ lb/ft^2.

Step 2. The slope length is assumed to be 1,000 ft. The slope magnitude is assumed to be 0.002.

Step 3. The flow concentration factor is assumed to be 3, assuming that uniform grading will be done during construction and that differential settlement has been shown to be insignificant.

Step 4. Manning's "n" value is estimated using Chow (1959). For a uniform weathered earth section (using normal values),

$$n = 0.025$$

Step 5. The rainfall intensity is estimated using the procedures given by Nelson et al. (1986). It is assumed that the intensity has been calculated to be 40 inches/hour, using this reference.

Step 6. The stable slope may be computed using the aforementioned NRC derivation of the Horton Equation:

$$(S_s)^{7/6} = (65)(.14)^{5/3} \ / \ (40)(1000)(3)(0.025) \qquad \text{(A-7)}$$

$S_s = 0.002$ ft/ft.

Since the stable slope is equal to the assumed slope, the design is acceptable.

2.4.2 Stable Slope of a Vegetated Soil Cover

Step 1. The maximum permissible velocity (MPV) is estimated using SCS (1984) to be 3.0 ft per second, representing marginal vegetation cover, other than thick grasses.

Step 2. The slope length is assumed to be 1,000 ft and the slope is assumed to be .003

Step 3. F is assumed to be 3.

Step 4. Using Chow's (1959) relationships (Figs. 7-14) for very low vegetal retardance, a velocity equal to the MPV of 3, and an assumed depth of flow of 1.0 ft, VR is calculated to be 3 where (R = 1) and "n" is estimated to be .028.

Step 5. Rainfall intensity is assumed to have been calculated to be 40 inches/hr.

Q is computed using the Rational Formula:

$Q = Fci\,A = (3)(1.0)(40)(1000)/43560$

$Q = 2.75$ cfs/ft

Step 6. The flow depth (y) is computed by

$$y^{5/3} = \frac{Qn}{1.4865^{1/2}}$$

$$y^{5/3} = \frac{(2.75)(.028)}{(1.486)(.003)^{1/2}}$$

$$y = 0.96 \text{ ft}$$

Step 7. For a depth of flow of 0.96 ft, the reduction factor is computed to be about 0.80. The permissible velocity for this depth of flow is

MPV = (0.80)(3.0) = 2.4 ft/sec

Step 8. The actual flow velocity (Va) is

$$V_a = \frac{Q}{y} = 2.75/0.96$$

$$V_a = 2.86 \text{ ft/sec}$$

Since the actual velocity is greater than the permissible velocity, return to Step 2 with new values of slope.

2.4.3 Stable Slope of a Rocky Soil Cover

It is proposed that a rocky soil will be provided to closely simulate naturally-occurring desert armor and desert pavement at a site in the semi-arid southwestern United States. Based on grain-size analysis, the rocky soil is found to have a D_{75} particle size of 1.0 inches. The rock in the soil also meets the minimum durability criteria given in Appendix D.

Step 1. The allowable shear stress is estimated using the procedures discussed by Temple et al. (1987):

$$t = 0.4 \times D_{75} \qquad \text{(A-12)}$$

where D_{75} is the particle size in inches for which 75 percent is finer.

$$t = 0.4\ (1.0) = 0.4 \text{ lb/ft}^2 \qquad \text{(A-13)}$$

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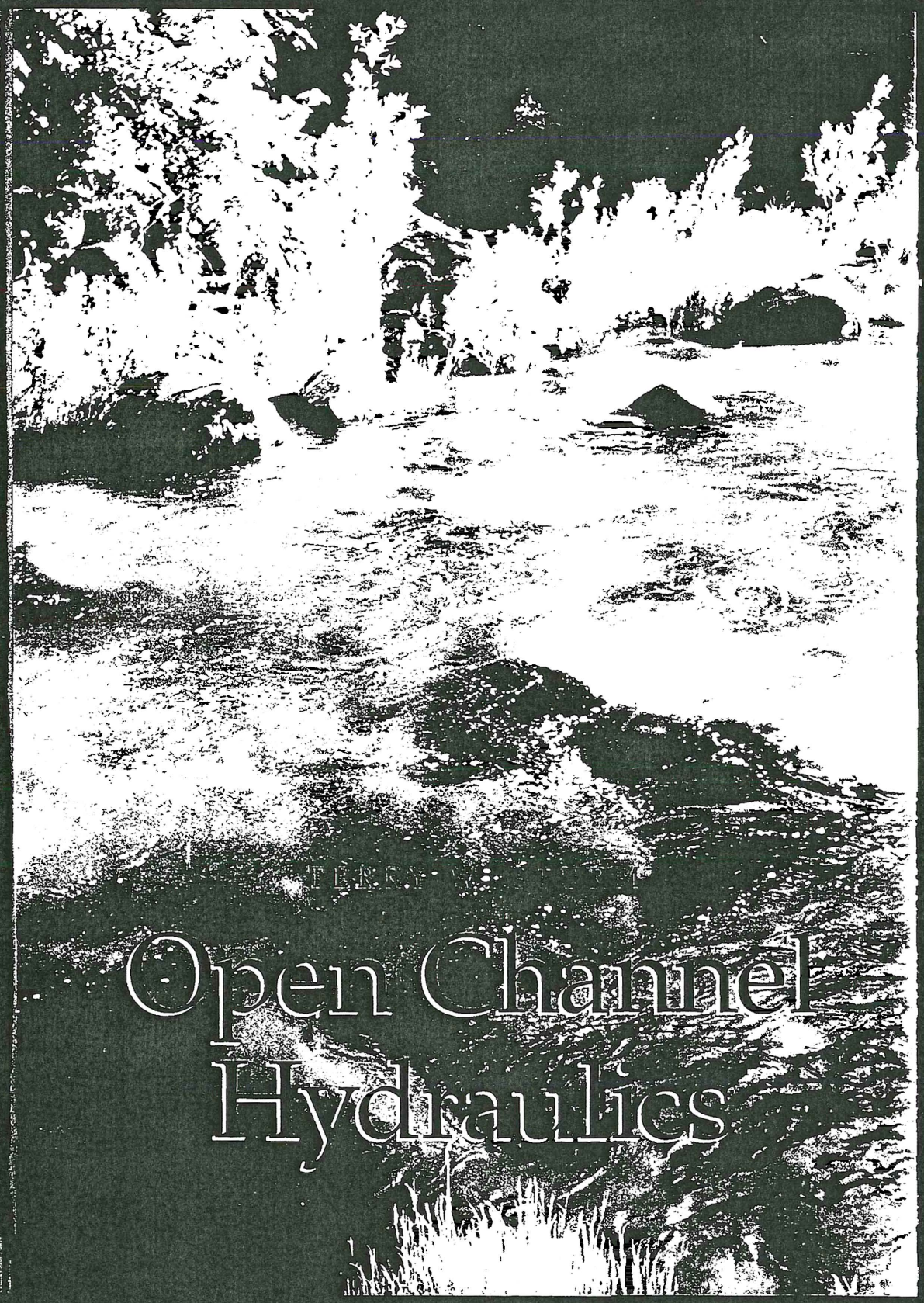

Open Channel Hydraulics

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OPEN CHANNEL HYDRAULICS

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TABLE 4-1 (Continued)

Type of Channel and Description	Minimum	Normal	Maximum
B. Lined or Built-up Channels			
B–1. Metal			
a. Smooth steel surface			
1. Unpainted	0.011	0.012	0.014
2. Painted	0.012	0.013	0.017
b. Corrugated	0.021	0.025	0.030
B–2. Nonmetal			
a. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
b. Wood			
1. Planed, untreated	0.010	0.012	0.014
2. Planed, creosoted	0.011	0.012	0.015
3. Unplaned	0.011	0.013	0.015
4. Plank with battens	0.012	0.015	0.018
5. Lined with roofing paper	0.010	0.014	0.017
c. Concrete			
1. Trowel finish	0.011	0.013	0.015
2. Float finish	0.013	0.015	0.016
3. Finished, with gravel on bottom	0.015	0.017	0.020
4. Unfinished	0.014	0.017	0.020
5. Gunite, good section	0.016	0.019	0.023
6. Gunite, wavy section	0.018	0.022	0.025
7. On good excavated rock	0.017	0.020	
8. On irregular excavated rock	0.022	0.027	
d. Concrete bottom float finished with sides of			
1. Dressed stone in mortar	0.015	0.017	0.020
2. Random stone in mortar	0.017	0.020	0.024
3. Cement rubble masonry, plastered	0.016	0.020	0.024
4. Cement rubble masonry	0.020	0.025	0.030
5. Dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of			
1. Formed concrete	0.017	0.020	0.025
2. Random stone in mortar	0.020	0.023	0.026
3. Dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. Glazed	0.011	0.013	0.015
2. In cement mortar	0.012	0.015	0.018
g. Masonry			
1. Cemented rubble	0.017	0.025	0.030
2. Dry rubble	0.023	0.032	0.035
h. Dressed ashlar	0.013	0.015	0.017
i. Asphalt			
1. Smooth	0.013	0.013	
2. Rough	0.016	0.016	
j. Vegetal lining	0.030	. . .	0.500
C. Excavated or Dredged			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020

Type of Channel and Description	Minimum	Normal	Maximum
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. Natural Streams			
D–1. Minor streams (top width at flood stage < 100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
D–2. Flood plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035

(continued)

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(3)

NOAA ATLAS 2

11

Precipitation-Frequency Atlas of the Western United States

J. F. Miller, R. H. Frederick, and R. J. Tracey

Volume V–Idaho

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Nevada, western Utah, and the southeastern desert areas of California. The portion within Idaho is in the southeastern corner of the State and is south of the southern boundary of the Snake River Basin (Region 3, fig. 18). Equations to provide estimates for the 1-hr duration for 2- and 100-yr return periods are shown in table 12. Also listed are the statistical parameters associated with each equation. In these equations, the variable $[(X_1)(X_1/X_2)]$ or $[(X_3)(X_3/X_4)]$ can be regarded as the 6-hr value times the slope of the line connecting the 6- and 24-hr values for the appropriate return year.

As with any separation into regions, the boundary can only be regarded as the sharpest portion of a zone of transition between regions. These equations have been tested for boundary discontinuities by computing values using equations from both sides of the boundary. Differences were found to be mostly under 15 percent. However, it is sugegsted that when computing estimates along or within a few miles of a regional boundary computations be made using equations applicable to each region and that the average of such computations be adopted.

Estimates of 1-hr precipitation-frequency values for return periods between 2 and 100 yrs. The 1-hr values for the 2- and 100-yr return periods can be plotted on the nomogram of figure 6 to obtain values for return periods greater than 2 yrs or less than 100 yrs. Draw a straight line connecting the 2- and 100-yr values and read the desired return-period value from the nomogram.

Estimates for 2- and 3-hr (120- and 180-min) precipitation-frequency values. To obtain estimates of precipitation-frequency values for 2 or 3 hrs, plot the 1- and the 6-hr values from the Atlas on the appropriate nomogram of figure 15. Draw a straight line connecting the 1- and 6-hr values, and read the 2- and 3-hr values from the nomogram. This nomogram is independent of return period. It was developed using data from the same regions used to develop the 1-hr equations.

The mathematical solution from the data used to develop figure 15 gives the following equations for estimating the 2- and 3-hr values:

For Region 1,	2-hr = 0.278 (6-hr) + 0.722 (1-hr)	(3)
figure 18	3-hr = 0.503 (6-hr) + 0.497 (1-hr)	(4)
For Region 2,	2-hr = 0.250 (6-hr) + 0.750 (1-hr)	(5)
figure 18	3-hr = 0.467 (6-hr) + 0.533 (1-hr)	(6)
For Region 3,	2-hr = 0.299 (6-hr) + 0.701 (1-hr)	(7)
figure 18	3-hr = 0.526 (6-hr) + 0.474 (1-hr)	(8)

Estimates for 12-hr (720-min) precipitation-frequency values. To obtain estimates for the 12-hr duration, plot values from the 6- and 24-hr maps on figure 16. Read the 12-hr estimates at the intersection of the line connecting these points with the 12-hr duration line of the nomogram.

Estimates for less than 1 hr. To obtain estimates for durations of less than 1 hr, apply the values in table 13 to the 1-hr value for the return period of interest.

Table 12. *Equations for estimating 1-hr values in Idaho with statistical parameters for each equation*

Region of applicability*	Equation	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Snake River Valley below 5,000 ft (1)	$Y_2 = 0.077 + 0.715[(X_1)(X_1/X_2)] - 0.0004(X_5)(X_6)$	0.86	30	0.35	0.034
	$Y_{100} = 0.187 + 0.833[(X_3)(X_3/X_4)]$	.87	30	1.08	.161
Mountainous regions of Washington and Oregon east of crest of Cascade Range and of Idaho and Montana west of Continental Divide and north of southern boundary of Snake River Basin—excluding Snake River Valley below a smoothed 5,000-ft contour (2)	$Y_2 = 0.019 + 0.711[(X_1)(X_1/X_2)] + 0.001Z$	.82	98	0.40	.031
	$Y_{100} = 0.338 + 0.670[(X_3)(X_3/X_4)] + 0.001Z$	.80	79	1.04	.141
Western Utah and Nevada except Snake and Virgin River Basins and spillover zone east of Sierra Nevada crest (3)	$Y_2 = 0.005 + 0.852[(X_1)(X_1/X_2)]$	.89	65	0.41	.047
	$Y_{100} = 0.322 + 0.789[(X_3)(X_3/X_4)]$	.87	65	1.25	.196

* Numbers in parentheses refer to geographic regions shown in figure 18. See text for more complete description.

List of variables

Y_2 = 2-yr 1-hr estimated value
Y_{100} = 100-yr 1-hr estimated value
X_1 = 2-yr 6-hr value from precipitation-frequency maps
X_2 = 2-yr 24-hr value from precipitation-frequency maps
X_3 = 100-yr 6-hr value from precipitation-frequency maps
X_4 = 100-yr 24-hr value from precipitation-frequency maps
X_5 = latitude (in decimals) minus 40°
X_6 = longitude (in decimals) minus 100°
Z = point elevation in hundreds of feet

$Y_{100} = 0.187 + 0.833\left(1.6 \times \frac{1.6}{2.4}\right)$

$= 1.07''$ ESTIMATE

Illustration of Use of Precipitation-Frequency Maps, Diagrams, and Equations

To illustrate the use of these maps, values were read from figures 19 to 30 for the point at 44°00′ N. and 115°00′ W. These values are shown in boldface type in table 14. The values read from the maps should be plotted on the return-period diagram of figure 6 because (1) not all points are as easy to locate on a series of maps as are latitude-longitude intersections, (2) there may be some slight registration differences in printing, and (3) precise interpolation between isolines is difficult. This has been done for the 24-hr values in table 14 (fig. 17a) and a line of best fit has been drawn subjectively. On this nomogram, the 50-yr value appears somewhat below the line, so the value read from the maps is corrected (as shown by the strikeout in table 14); such corrected values are adopted in preference to the original readings.

The 2- and 100-yr 1-hr values for the point were computed from the equations applicable to Region 2, figure 18 (table 12) since the point is in the orographic region. The 2-yr 1-hr is estimated at 0.56 in. (using elevation of 9,100 ft and 2-yr 6- and 24-hr values from table 14); the estimated 100-yr 1-hr value is 1.37 in. (100-yr and 24-hr values from table 14). By plotting these 1-hr values on figure 6 and connecting them with a straight line, one can obtain estimates for return periods of 5, 10, 25, and 50 yrs.

The 2- and 3-hr values can be estimated by using the nomogram of figure 15 or equations (5) and (6). The 1- and 6-hr values for the desired return period are obtained as above. Plot these points on the nomogram of figure 15 and connect them with a straight line. Read the estimates for 2 or 3 hrs at the intersections of the connecting line and the 2- and 3-hr vertical lines. An example is shown in figure 17b for the 100-yr return period. The values of the 100-yr 2-hr (1.68 in.) and 100-yr 3-hr (1.95 in.) are in italics on table 14.

Duration (min)	5	10	15	30
Ratio to 1-hr	0.29	0.45	0.57	0.79

(Adopted from *U.S. Weather Bureau Technical Paper* No. 40, 1961.)

Table 13. *Adjustment factors to obtain n-min estimates from 1-hr values*

	1-hr	2-hr	3-hr	6-hr	24-hr
2-yr	*0.56*			**1.24**	**2.44**
5-yr				**1.57**	**3.02**
10-yr				**1.83**	**3.42**
25-yr				**2.20**	**3.90**
					4.42
50-yr				**2.42**	~~**4.34**~~
100-yr	*1.37*	*1.68*	*1.95*	**2.61**	**4.85**

Table 14. *Precipitation data for depth-frequency atlas computation point 44°00′ N., 115°00′ W.*

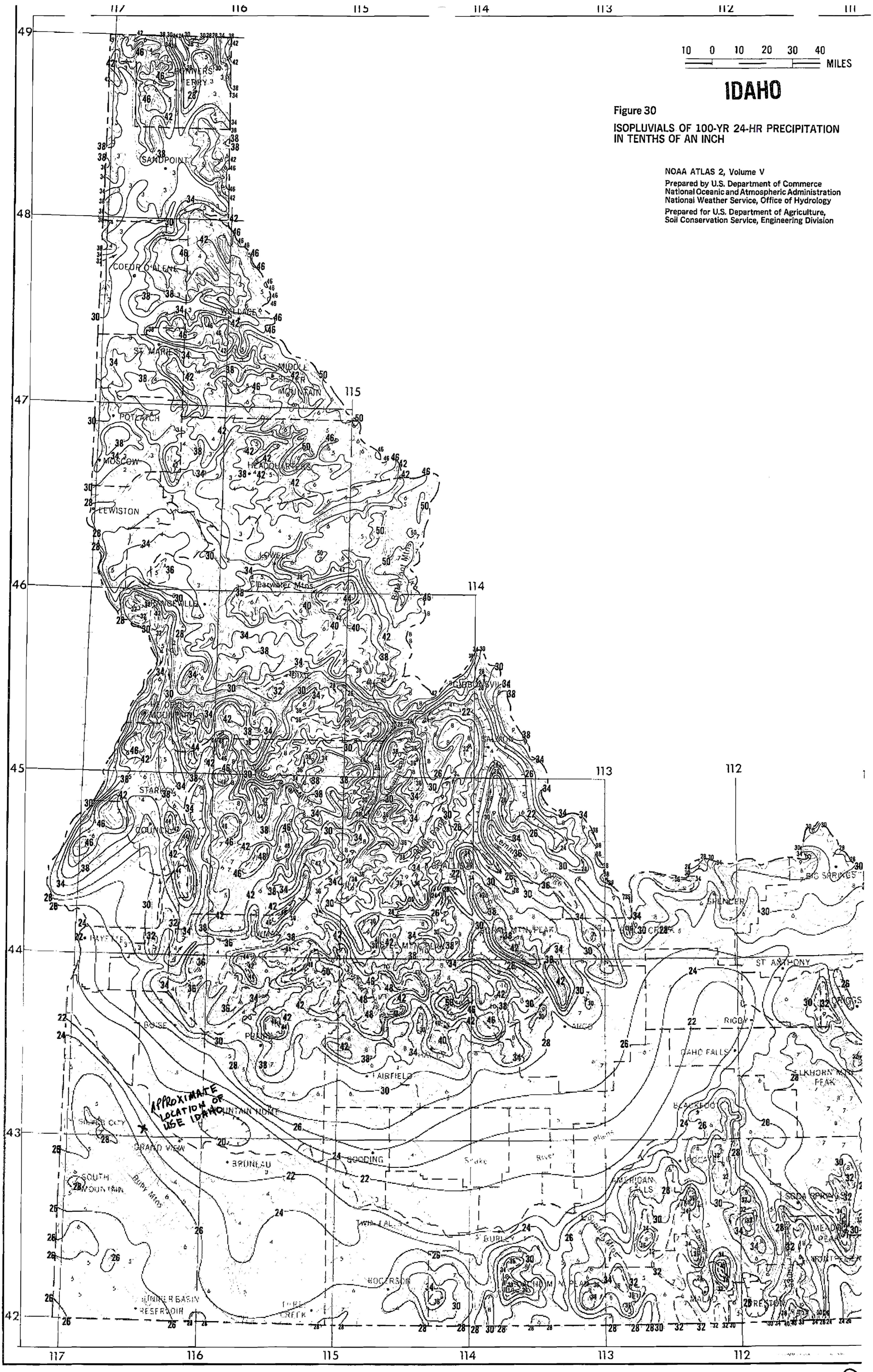

Figure 30

ISOPLUVIALS OF 100-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

NOAA ATLAS 2, Volume V

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

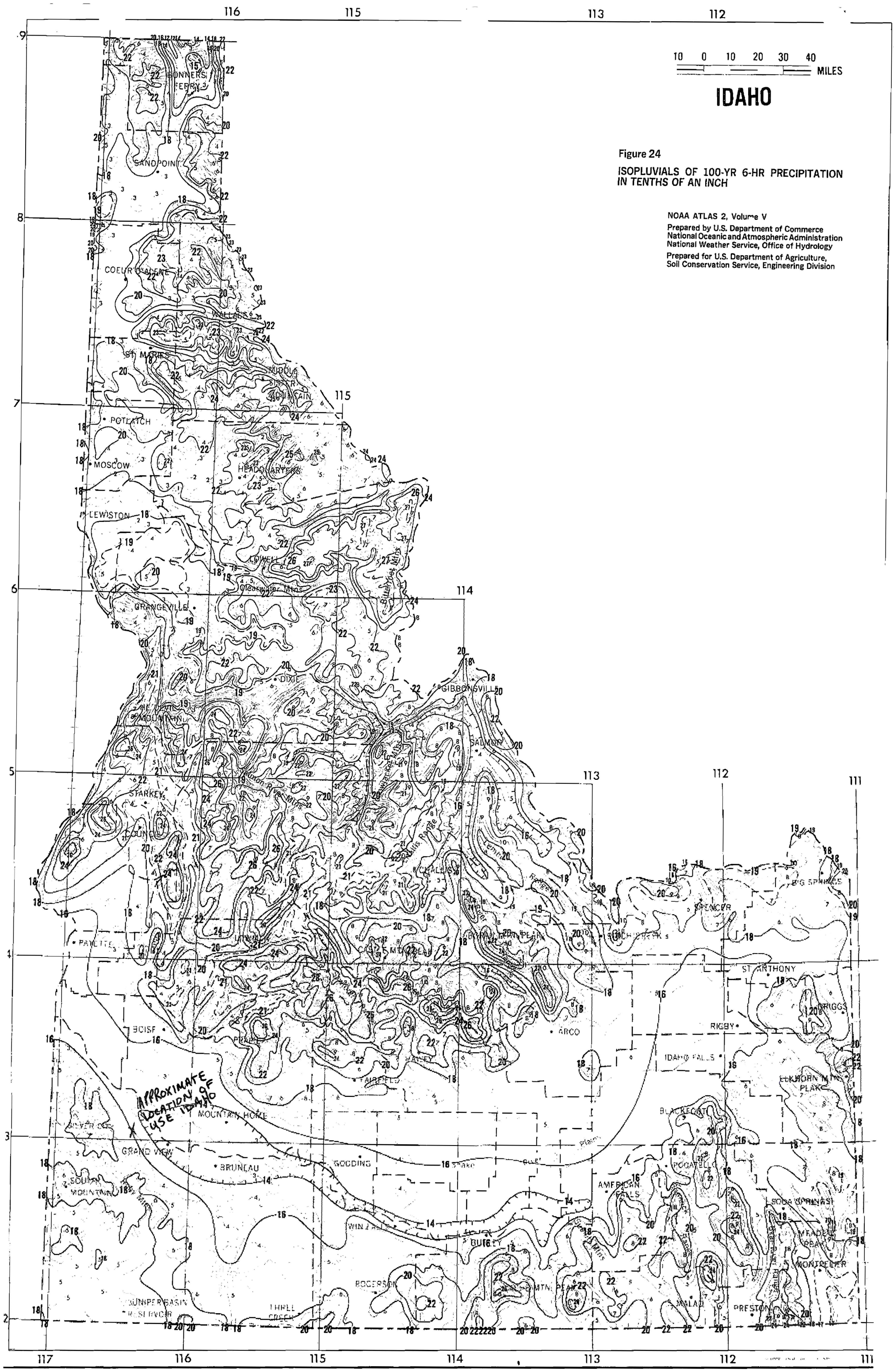

Figure 24

ISOPLUVIALS OF 100-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

NOAA ATLAS 2, Volume V

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

(4)

United States
Department of
Agriculture

Agricultural
Research
Service

Agriculture
Handbook
Number 667

Stability Design of Grass-Lined Open Channels

D.M. Temple, K.M. Robinson, R.M. Ahring, and A.G. Davis'

The research reported in this publication was done in cooperation with the Oklahoma Agricultural Experiment Station.

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For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

ABSTRACT

Temple, D.M., K.M. Robinson, R.M. Ahring, and A.G. Davis. 1987. Stability Design of Grass-Lined Open Channels. U.S. Department Of Agriculture, Agriculture Handbook 667, 175., illus.

This handbook presents the state of the art in grass-lined channel design. It is intended primarily for use by engineers and technicians directly involved in planning, designing, or maintaining open channels where vegetation can be used as a lining for erosion protection. Each of the six chapters is a complete discussion, with reference to other chapters as appropriate. Nomographs and calculator/computer programs are included as design aids. Only those design conditions that have implications unique to the use of grass as a channel lining are discussed in detail, and the design aids focus on stability design under steady, uniform flow conditions.

KEYWORDS: grass linings, open channel hydraulics, agricultural waterways, lined channels erosion

Issued September 1987

Table 3.3
Equations for determining allowable effective stress1

Soil classification	Applicable range	Equation
Noncohesive soils GW,GP,SW,SP	$I_w < 10$	
	$d_{75} < 0.05$	$n_s = 0.0156$ $\tau_a = 0.02$
	$0.05 \leq d_{75}$	$n_s = 0.0256\ d_{75}^{1/6}$ $\tau_a = 0.4\ d_{75}$
Cohesive soils	$10 < I_W$	$n_s = 0.0156$ $\tau_a = \tau_{ab}\ C^2$
GM,SC		$C_e = 1.42 - 0.61\ e$
	$10 \leq I_w \leq 20$	$\tau_{ab} = (1.07\ I_w^2 + 14.3\ I_W + 47.7)x10^{-4}$
	$20 < I_W$	$\tau_{ab} = 0.076$
GC		$C_e = 1.42 - 0.61\ e$
	$10 \leq I_w \leq 20$	$\tau_{ab} = (0.0477\ I_w^2 + 2.86\ I_W + 42.9)x10^{-3}$
	$20 < I_W$	$\tau_{ab} = 0.119$
SM		$C_e = 1.42 - 0.61\ e$
	$10 \leq I_w \leq 20$	$\tau_{ab} = (1.07\ I_w^2 + 7.15\ I_W + 11.9)x10^{-4}$
	$20 < I_W$	$\tau_{ab} = 0.058$

Appendix D2-3
Wind Erosion

Final Cover Design for Low-Level Radioactive Waste Disposal Facility US Ecology, Idaho

Wind Erosion Soil Loss

Objective

The Wind Erosion Soil Loss Equation is a function of multiple charts, graphs and tables. This sheet demonstrates the steps needed in order to determine soil loss due to wind, and provides the values for the required variables, but does not perform the actual calculation. The equation is performed for scenarios of no crusting, and and crusting with vegetation on the cover system.

References

1. National Agronomy Manual, 190-V-NAM, 3rd Ed., October 2002.

2. Journal of Soil and Water Conservation, March-April 1983, Vol. 38, Number 2, Soil Conservation Society of America.

3. Rangeland Productivity and Plant Composition-Elmore Area, Idaho, Parts of Elmore, Owyhee and Ada Counties, Web Soil Survey 2.2, National Cooperative Soil Survey, USDA Conservation Service.

4. Argronomy Technical Note 69 - Wind Erosion Equation (Annual Method) on Rangeland, NM-NRCS, May, 2004.

5. The Physics of Wind Erosion and Its Control, W.S. Chepil and N.P. Woodruff, Advances in Agronomy, Vol 15, 1963, Academic Press Inc., New York, N.Y.

Assumption

1. The top 6 inches of the cover soil will be ammended with 25% by weight gravel. For the purpose of this equation, the more conservative value of 20% has been used to determine values of the Soil Erodibility Index (I).

2. From the design drawings, the maximum slope of 5% along the top deck of the cover used.

3. The maximum unsheltered distance is assumed to be the the greatest value (10,000 ft) provided on the reference tables.

4. In determining the vegetative cover factor, the values provided in Reference 2 are converted into "small grain" equivalents in Reference 4.

Variables

$I = 86$	soil erodibility index (reference 1, Exhibit 502-3, page 502-23 & 24 for 5% slope, 25% (20% used for conservative value) gravel retained the #20 sieve)
$I_{cr_adj} = 38$	soil erodibility index with crust adjustment factor (reference 1, Exhibit 502-2, page 502-22, and Table 502-2, page 502-8, Wind Erodibility Group (WEG), for I=86)
$K_{rd} = 0.625$	soil surface roughness factor (reference 1, Fig 502-4, page 502-10, assuming gravel admixture surface treatment)
$C = 40$	climate factor (reference 2, Fig 3, for worst case assumption used a C of 40)
$L = 10000$	unsheltered distance (worst case assumption)
$V = 1250 \cdot \frac{lbf}{acre}$	vegetative cover factor (reference 3 and 4)

Calculation

$E = function(IK_{rd}CLV)$	with no crust adjustment and no vegetation during the first year
$E = 20.6 \frac{tons}{acre \cdot year}$	reference 1, Subpart G - Exhibits, I = 86, K = 0.60, C = 40, V = 0
$E = function(IK_{rd}CLV)$	with vegetation and no crust adjustment
$E = 1.4 \frac{tons}{acre \cdot year}$	reference 1, Subpart G - Exhibits, I = 86, K = 0.60, C = 40, V = 1250
$E = function(IK_{rd}CLV)$	with vegetation and crust adjustment
$E = 0.3 \frac{tons}{acre \cdot year}$	reference 1, Subpart G - Exhibits, I = 38, K = 0.60, C = 40, V = 1250

Part 502 Wind Erosion

Subpart 502A Introduction

502.00 Overview

Part 502 presents Natural Resources Conservation Service (NRCS) policy and procedures for estimating wind erosion. It explains the Wind Erosion Equation (WEQ) and provides guidance and reference on wind erosion processes, prediction, and control. NRCS technical guidance related to wind erosion conforms to policy and procedures in this part.

This part will be amended as additional research on wind erosion and its control is completed and published. The national agronomist is responsible for updating this chapter and coordinating wind erosion guidance with Agricultural Research Service (ARS).

NRCS cooperating scientists may supplement this manual. However, appropriate supplements prepared by cooperating scientists are to be submitted to the national agronomist for review and concurrence before issuance. State supplements are to be reviewed and approved by the national agronomist before being issued to field offices.

Understanding the erosive forces of wind is essential to the correct use of the Wind Erosion Equation and interpretation of wind erosion data. NRCS predicts erosion rates, assesses potential damage, and plans control systems for wind erosion.

The Agricultural Research Service has primary responsibility for erosion prediction research within the U.S. Department of Agriculture (USDA). Wind erosion research is conducted by the Wind Erosion Research Unit at Manhattan, Kansas, and the Cropping Systems Research Unit at Big Spring, Texas.

Subpart 502B Wind erosion

502.10 The wind erosion problem

Wind is an erosive agent. It detaches and transports soil particles, sorts the finer from the coarser particles, and deposits them unevenly Loss of the fertile topsoil in eroded areas reduces the rooting depth and, in many places, reduces crop yield. Abrasion by airborne soil particles damages plants and constructed structures. Drifting soil causes extensive damage also. Sand and dust in the air can harm animals, humans, and equipment.

Some wind erosion has always occurred as a natural landforming process, but it has become detrimental as a result of human activities. This *accelerated* erosion is primarily caused by improper use and management of the land (Stallings 1951).

Few regions are entirely safe from wind erosion. Wherever the soil surface is loose and dry, vegetation is sparse or absent, and the wind sufficiently strong, erosion will occur unless control measures are applied (1957 Yearbook of Agriculture). Soil erosion by wind in North America is generally most severe in the Great Plains. The NRCS annual report of wind erosion conditions in the Great Plains shows that wind erosion damages from 1 million to more than 15 million acres annually, averaging more than 4 million acres per year in the 10-state area. USDA estimated that nearly 95 percent of the 6 5 million acres put out of production during the 1930's suffered serious wind erosion damage (Woodruff 1975). Other major regions subject to damaging wind erosion are the Columbia River plains; some parts of the Southwest and the Colorado Basin, the muck and sandy areas of the Great Lakes region, and the sands of the Gulf, Pacific, and Atlantic seaboards.

In some areas, the primary problem caused by wind erosion is crop damage. Some crops are tolerant enough to withstand or recover from erosion damage. Other crops, including many vegetables and specialty crops, are especially vulnerable to wind erosion damage. Wind erosion may cause significant short-term economic loss in areas where erosion rates are below the soil loss tolerance (T) when the crops grown in that area are easily damaged by blowing soil (table 502–4).

502.11 The wind erosion process

The wind erosion process is complex. It involves detaching, transporting, sorting, abrading, avalanching, and depositing of soil particles. Turbulent winds blowing over erodible soils cause wind erosion. Field conditions conducive to erosion include

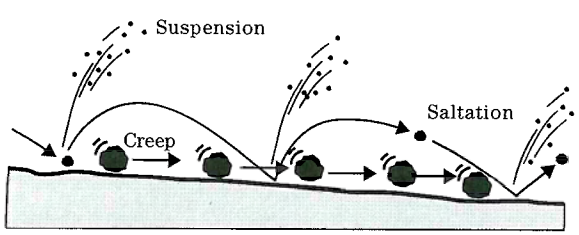
- loose, dry, and finely granulated soil;
- smooth soil surface that has little or no vegetation present;
- sufficiently large area susceptible to erosion; and
- sufficient wind velocity to move soil.

Winds are considered erosive when they reach 13 miles per hour at 1 foot above the ground or about 18 miles per hour at a 30 foot height. This is commonly referred to as the threshold wind velocity (Lyles and Krauss 1971).

The wind transports primary soil particles or stable aggregates, or both, in three ways (fig. 502–1):

Saltation—Individual particles/aggregates ranging from 0.1 to 0.5 millimeter in diameter lift off the surface at a 50- to 90-degree angle and follow distinct trajectories under the influence of air resistance and gravity The particles/aggregates return to the surface at impact angles of 6 to 14 degrees from the horizontal. Whether they rebound or embed themselves, they initiate movement of other particles/aggregates to create the *avalanching* effect. Saltating particles are the abrading *bullets* that remove the protective soil crusts and clods. Most saltation occurs within 12 inches above the soil surface and typically, the length of a saltating particle trajectory is about 10 times the height. From 50 to 80 percent of total transport is by saltation.

Figure 502-1 The wind erosion process



Suspension—The finer particles, less than 0.1 millimeter in diameter, are dislodged from an eroding area by saltation and remain in the air mass for an extended period. Some suspension-sized particles or aggregates are present in the soil, but many are created by abrasion of larger aggregates during erosion. From 20 percent to more than 60 percent of an eroding soil may be carried in suspension, depending on soil texture. As a general rule, suspension increases downwind, and on long fields can easily exceed the amount of soil moved in saltation and creep.

Surface creep—Sand-sized particles/aggregates are set in motion by the impact of saltating particles. Under high winds, the whole soil surface appears to be creeping slowly forward as particles are pushed and rolled by the saltation flow Surface creep may account for 7 to 25 percent of total transport (Chepil 1945 and Lyles 1980).

Saltation and creep particles are deposited in vegetated strips, ditches, or other areas sheltered from the wind, as long as these areas have the capacity to hold the sediment. Particles in suspension, however, may be carried a great distance.

The rate of increase in soil flow along the wind direction varies directly with erodibility of field surfaces. The increase in erosion downwind (avalanching) is associated with the following processes:

- the increased concentration of saltating particles downwind increases the frequency of impacts and the degree of breakdown of clods and crusts, and
- accumulation of erodible particles and breakdown of clods tends to produce a smoother (and more erodible) surface.

The distance required for soil flow to reach a maximum for a given soil is the same for any erosive wind. The more erodible the surface, the shorter the distance in which maximum flow is reached. Any factor that influences the erodibility of the surface influences the increase in soil flow

Subpart 502C Estimating wind erosion

502.20 How, why, and by whom wind erosion is estimated

Using the Wind Erosion Equation (WEQ), NRCS estimates erosion rates to

- provide technical assistance to land users,
- inventory natural resources, and
- evaluate the effectiveness of conservation programs and conservation treatment applied to the land.

Wind erosion is difficult to measure. Wind moves across the land in a turbulent, erratic fashion. Soil may blow into, within, and out of a field in several directions in a single storm. The direction, velocity, duration, and variability of the wind all affect the erosion that occurs from a wind storm. Much of the soil eroding from a field bounces or creeps near the surface; however, some of the soil blown from a field may be high above the ground in a dust cloud by the time it reaches the edge of a field (Chepil 1963).

502.21 Methods of estimating wind erosion

No precise method of measuring wind erosion has been developed. However, various dust collectors, remote and in-place sensors, wind tunnels, sediment samplers, and microtopographic surveys before and after erosion have been used. Each method has its limitations. Research is continuing on new techniques and new devices, on modifications to older ones, and on means to measure wind erosion.

Estimates of wind erosion can be developed by assigning numerical values to the site conditions that govern wind erosion and expressing their relationships mathematically This is the basis of the current Wind Erosion Equation (WEQ) that considers soil erodibility, ridge and random roughness, climate, unsheltered distance, and vegetative cover

502.22 The wind erosion equation

The Wind Erosion Equation (WEQ) erosion model is designed to predict long-term average annual soil losses from a field having specific characteristics. With appropriate selection of factor values, the equation will estimate average annual erosion or erosion for specific time periods.

Development of the wind erosion equation
Drought and wind erosion during the 19th century caused wind erosion to be recognized as an important geologic phenomenon. By the late 1930's, systematic and scientific research into wind erosion was being pioneered in California, South Dakota, Texas, and in Canada and England. This research produced information on the mechanics of soil transport by wind, the influence of cultural treatment on rates of movement, and the influence of windbreaks on windflow patterns. The publication, *The Physics of Blown Sand and Desert Dunes*, (Bagnold 1941), is considered a classic by wind erosion researchers.

In 1947, USDA began the Wind Erosion Research Program at Manhattan, Kansas, in cooperation with Kansas State University. That program was started under the leadership of Austin W. Zingg, who was soon joined by W.S. Chepil, a pioneer in wind erosion research in Canada. The research project's primary purposes were to study the mechanics of wind erosion, delineate major influences on that erosion, and devise and develop methods to control it.

By 1954, Chepil and his coworkers began to publish results of their research in the form of wind erosion prediction equations (Chepil 1954; Chepil 1957; Chepil et al. 1955; Woodruff and Chepil 1956).

In 1959, Chepil released an equation

$$E = IRKFBWD$$

where:

E = quantity of erosion
I = soil cloddiness
R = residue
K = roughness
F = soil abradability
B = wind barrier
W = width of field
D = wind direction

Wind velocity at geographic locations was not addressed in this equation (Chepil 1959).

In 1962, Chepil's group released the equation

$$E = \int(ACKLV)$$

where:

A = percentage of soil fractions greater than 0.84 millimeter

Factors C, K, L, and V were the same as in the present equation although they were not handled the same (Chepil 1962). A C-factor map for the western half of the United States was also published in 1962 (Chepil et al. 1962).

In 1963, the current form of the equation, E= f(ICKLV) was first released (Chepil 1963).

In 1965, the concept of preponderance in assessing wind erosion forces was introduced. See 502.34 for details on preponderance (Skidmore 1965 and Skidmore and Woodruff 1968).

In 1968, monthly climatic factors were published (Woodruff and Armbrust 1968). These are no longer used by NRCS. Instead, NRCS adopted a proposal for computing soil erosion by periods using wind energy distribution which was published in 1980 (Bondy et al. 1980). (See 502.24.) In 1981, the Wind Erosion Research Unit provided NRCS with data on the distribution of erosive wind energy for the United States and in 1982 provided updated annual C factors. (See exhibit 502-8.)

Although the present equation has significant limitations (see 502.23), it is the best tool currently available for making reasonable estimates of wind erosion. Currently, research and development of improved procedures for estimating wind erosion are underway

The present Wind Erosion Equation is expressed as:

$$E = \int(IKCLV)$$

where:

E = estimated average annual soil loss in tons per acre per year
f = indicates relationships that are not straight-line mathematical calculations
I = soil erodibility index
K = soil surface roughness factor
C = climatic factor
L = the unsheltered distance
V = the vegetative cover factor

The **I** factor, expressed as the average annual soil loss in tons per acre per year from a field area, accounts for the inherent soil properties affecting erodibility These properties include texture, organic matter, and calcium carbonate percentage **I** is the potential annual wind erosion for a given soil under a given set of field conditions. The given set of field conditions for which **I** is referenced is that of an isolated, unsheltered, wide, bare, smooth, level, loose, and non-crusted soil surface, and at a location where the climatic factor (C) is equal to 100. (For details on the **I** factor see 502.31).

The K factor is a measure of the effect of ridges and cloddiness made by tillage and planting implements. It is expressed as a decimal from 0.1 to 1.0. (For details on the K factor see 502.32.)

The C factor for any given locality characterizes climatic erosivity, specifically windspeed and surface soil moisture. This factor is expressed as a percentage of the C factor for Garden City, Kansas, which has a value of 100. (For details on the C factor see 502.33.)

The L factor considers the unprotected distance along the prevailing erosive wind direction across the area to be evaluated and the preponderance of the prevailing erosive winds. (For details on the L factor see 502 34.)

The V factor considers the kind, amount, and orientation of vegetation on the surface. The vegetative cover is expressed in pounds per acre of a flat small-grain residue equivalent. (For details on the V factor see 502.35.)

Solving the equation involves five successive steps. Steps 1, 2 and 3 can be solved by multiplying the factor values. Determining the effects of L and V (steps 4 and 5) involves more complex functional relationships.

Step 1 $E_1 = I$

Factor I is established for the specific soil. I may be increased for knolls less than 500 feet long facing into the prevailing wind, or decreased to account for surface soil crusting, and irrigation.

Step 2. $E_2 = IK$

Factor K adjusts E_1 for tillage-induced oriented roughness, K_{rd} (ridges) and random roughness, K_{rr} (cloddiness). The value of K is calculated by multiplying K_{rd} times K_{rr}. ($K = K_{rd} \times K_{rr}$).

Step 3: $E_3 = IKC$
Factor C adjusts E_2 for the local climatic factor

Step 4: $E_4 = IKCL$
Factor L adjusts E_3 for unsheltered distance.

Step 5 $E_5 = IKCLV$
Factor V adjusts E_4 for vegetative cover

502.23 Limitations of the equation

When the unsheltered distance, L, *is sufficiently long, the transport capacity of the wind for saltation and creep is reached.* If the wind is moving all the soil it can carry across a given surface, the inflow into a downwind area of the field is equal to the outflow from that same area of the field, for saltation and creep. The net soil loss from this specific area of the field is then only the suspension component. This does not imply a reduced soil erosion problem because, theoretically, there is still the estimated amount of soil loss in creep, saltation, and suspension leaving the downwind edge of the field.

Surface armoring by nonerodible gravel is not usually addressed in the **I** factor.

The equation does not account for snow cover or seasonal changes in soil erodibility The equation does not estimate erosion from single storm events.

502.24 Alternative procedures for using the WEQ

The WEQ Critical Period Procedure is based on use of the Wind Erosion Equation as described by Woodruff and Siddoway in 1965 (Woodruff and Siddoway 1965). The conditions during the critical wind erosion period are used to derive the estimate of annual wind erosion.

- The Critical Wind Erosion Period is described as the period of the year when the greatest amount of wind erosion can be expected to occur from a field under an identified management system. It is the period when vegetative cover, soil surface conditions, and expected erosive winds result in the greatest potential for wind erosion.
- Erosion estimates developed using the critical period procedure are made using a single set of factor values (IKCL & V) in the equation to describe the critical wind erosion period conditions.
- The critical period procedure is currently used for resource inventories. NRCS usually provides specific instructions on developing wind erosion estimates for resource inventories.

The WEQ Management Period Procedure was published by Bondy, Lyles, and Hayes in 1980. It solves the equation for situations where site conditions have significant variation during the year or planning period where the soil is exposed to soil erosion for short periods, and where crop damage is the foremost conservation conern, rather than the extent of soil loss. The management period procedure is described as being more responsive to changing conditions throughout the cropping year but is not considered more accurate than the critical period procedure.

Comparisons should not be made between the soil erosion predictions made by the management period procedure and the critical period procedure. In other words, where a conservation system has been determined to be acceptable by the management period procedure and placed in a conservation plan or the FOTG, then only the management period procedure will be used to determine if other conservation systems, planned or applied, provide equivalent treatment.

Factor values are selected to describe management periods when cover and management effects are approximately uniform. The cropping system is divided into as many management periods as is necessary to describe the year or planning period accurately. Erosive wind energy (EWE) distribution is used to derive a weighted estimate of soil loss for the period. The general procedure is as follows:

- Solve for E in the basic equation ($E = f(IKCLV)$) using management period values for I, K, L, and V, and the local annual value for C.
- Multiply the annual soil loss rate E obtained from management period values by the percentage of annual erosive wind energy that occurs during the management period to estimate average erosion for that management period.
- Add the management period amounts for the crop year, or add the period amounts for a total crop sequence and divide by the number of years in the sequence to estimate average annual wind erosion.

Exhibit 502–7a is an example of tables showing the expected monthly distribution of erosive wind energy at specific locations. The complete table is available for downloading at

http://www.weru.ksu.edu/nrcs/windparm.doc

Exhibit 502–7b shows how these values are used in the management period method computations. Erosive wind energy values are entered on the form in the column identified **% EWE**.

Estimates for management periods less than 1 year in duration are often useful in conservation planning. Examples include

- When crop damage (crop tolerance) during sensitive growth stages is the major concern.
- When a system or practice is evaluated for short-term effects.

States will use critical period or the management period procedure, within published guidelines, for conservation planning. The management period procedure will not be used for resource inventories unless specifically stated in instructions. Refer to individual program manuals for more specific instructions pertaining to the use of the Wind Erosion Equation.

Adjustments to the WEQ soil erodibility factor, **I**, can be made for temporary conditions that include irrigation or crusts, but such adjustments are to be used only with the management period procedure. The use of monthly preponderance data to determine equivalent field width is also applicable only to the management period procedure.

502.25 Data to support the WEQ

ARS has developed benchmark values for each of the factors in the WEQ. However, the NRCS is responsible for developing procedures and additional factor values for use of the equation. Field Office Technical Guides will include the local data needed to make wind erosion estimates.

ARS has computed benchmark C factors for locations where adequate weather data are available (Lyles 1983). C factors used in the field office are to reflect local conditions as they relate to benchmark C factors. Knowledge of local terrain features and local climate is needed to determine how point data can be extended and how interpolation between points should be done. See 502.33 for guidance.

ARS has developed soil erodibility **I** values based on size distribution of soil aggregates. Soils have been grouped by texture classes into wind erodibility groups. Wind erodibility group numbers are included in the soil survey data base in NASIS.

For further discussion of benchmark data supporting factor values, refer to subpart 502D, WEQ factors.

502.26 Using WEQ estimates with USLE or RUSLE calculations

The WEQ provides an estimate of average annual wind erosion from the field width along the prevailing wind erosion direction (L) entered in the calculation, USLE or RUSLE provide an estimate of average annual sheet and rill erosion from the slope length (L) entered into the model. Although both wind and water erosion estimates are in tons per acre per year, they are not additive unless the two equations represent identical flow paths across identical areas.

502.27 Tools for using the WEQ

Graphs and tables for determining factor values are in Subpart 502G Exhibits.

E tables

The ARS WEROS (Wind Erosion) computer program has produced tables that give estimated erosion (E values) for most of the possible combinations of I, K, C, L, and V Exhibit 502–1 is an example. See 502.30 for procedures to download E tables.

Use of the management period procedure can be simplified through the use of worksheets on which information for each management period is documented. Subpart 502F is to include sample wind erosion computations using the Management Period Procedure.

An acceptable WEQ calculator has been developed in Microsoft Excel, and is being adapted for use in many states. A copy of this spreadsheet can be obtained from the NRCS state agronomist in Albuquerque, New Mexico. Exhibit 502.7B shows an example of this spread sheet.

Trade names mentioned are for specific information and do not constitute a guarantee or warranty of the product by the Department of Agriculture or an endorsement by the Department over other products not mentioned.

Subpart 502D WEQ Factors

502.30 The wind erosion estimate, E

The wind erosion estimate, E, is the estimate of average annual tons of soil per acre that the wind will erode from an area represented by an unsheltered distance L and for the soil, climate, and site conditions represented by I, K, C, and V The equation is an empirical formula. It was initially developed by relating wind tunnel data to observed field erosion for 3 years in the mid 1950's (Woodruff et al. 1976). The field data was normalized to reflect long-term average annual erosion assuming given conditions during the critical period without reference to change in those conditions through the year The estimate arrived at by using the critical period procedure for estimating wind erosion does not track specific changes brought about by management and crop development; nor does it assume that critical period conditions exist all year The calibration procedure accounted for minor changes expected to occur during a normal crop year at that time in history The WEQ annual E is based on an annual C and field conditions during the critical wind erosion period of the year. This procedure does not account for all the effects of management.

The management period procedure for estimating wind erosion involves assigning factor values to represent field conditions expected to occur during specified time periods. Using annual wind energy distribution data, erosion can be estimated for each period of time being evaluated. The period estimates are summed to arrive at an annual estimate. Cropping sequences involving more than 1 year can be evaluated using this procedure. It also allows for a more thorough analysis of a management system and how management techniques affect the erosion estimate.

The new E tables can be downloaded from the WERU server, Manhattan, Kansas. These tables can be accessed in two ways:

- Through your WWW browser To view, direct your web browser to: **http://www.weru.ksu.edu/nrcs**

  Download the Adobe Acrobat Reader (if not already installed on your computer) by clicking on the icon and installing per the installation instructions. (Trade names mentioned are for specific information and do not constitute a guarantee or warranty of the product by the Department of Agriculture or an endorsement by the Department over other products not mentioned.) When the Adobe Acrobat Reader is running on your browser you can click the PDF icon to view and print the table. When on the WERU Web page, copies of the files can be downloaded by clicking on the hypertext for the following:

  etab.pdf for PDF or
  etab.wpd (for WordPerfect) or
  etab.ps for Postscript

- Through FTP—For those without a web browser but have FTP access, FTP to: **ftp.weru.ksu.edu**
  go to the appropriate directory, for example
  cd pub/nrcs/etables
  Be sure that you are in binary mode

To download the table format of your choice, type:
get etab.pdf for PDF or
get etab.wpd for WordPerfect or
get etab.ps for Postscript

The appropriate E table will download to your computer Exhibit 502-1 shows an example of an E table.

502.31 Soil erodibility index, I

I is the erodibility factor for the soil on the site. It is expressed as the average annual soil loss in tons per acre that would occur from wind erosion, when the site is:

- **Isolated** – incoming saltation is absent
- **Level** – knolls are absent
- **Smooth** – ridge roughness effects are absent and cloddiness is minimal
- **Unsheltered** – barriers are absent.
- At a location where the **C factor is 100**
- **Bare** – vegetative cover is absent
- **Wide** – the distance at which the flow of eroding soil reaches its maximum and does not increase with field size
- **Loose** – and non-crusted, aggregates not bound together, and surface not sealed.

The **I** factor is related to the percentage of nonerodible surface soil aggregates larger than 0.84 millimeters in diameter. For most NRCS uses, the **I** value is assigned for named soils based on wind erodibility groups (WEG). The WEG is included in the soil survey data base in NASIS. If the soil name is not known, exhibit 502–2 can be used to determine the WEG from the surface soil texture

To determine erodibility for field conditions during various management periods throughout the year, follow the sieving instructions in exhibit 502–3 (Do not use this procedure to determine average annual **I** values.)

A soil erodibility index based solely on the percentage of aggregates larger than 0.84 millimeters has several potential sources of error. Some of these follow:

- Relative erodibility of widely different soils may change with a change in wind velocity over the surface of the soil.
- Calibration of the equation is based on the volume of soil removed, but the erodibility index is based on weight.
- Differences in size of aggregates have considerable influence on erodibility but no distinction for this influence is made in table 1, exhibit 502–3
- Stability of surface aggregates influences erodibility, large durable aggregates can become a *surface armor*; less stable aggregates can be abraded into smaller, more erodible particles.
- Surface crusting may greatly reduce erodibility; erodibility may increase again as the crust deteriorates (Chepil 1958).

Knoll erodibility—Knolls are topographic features characterized by short, abrupt windward slopes. Wind erosion potential is greater on knoll slopes than on level or gently rolling terrain because wind flowlines are compressed and wind velocity increases near the crest of the knolls. Erosion that begins on knolls often affects field areas downwind.

Adjustments of the Soil Erodibility Index (**I**) are used where windward-facing slopes are less than 500 feet long and the increase in slope gradient from the adjacent landscape is 3 percent or greater. Both slope length and slope gradient change are determined along the direction of the prevailing erosive wind (fig. 502–2).

Table 502–1 Knoll erodibility adjustment factor for **I**

Percent slope change in prevailing wind erosion direction	A Knoll adjustment of **I**	B Increase at crest area where erosion is most severe
3	1.3	1.5
4	1.6	1.9
5	1.9	2.5
6	2.3	3.2
8	3.0	4.8
10 and greater	3.6	6.8

Table 502-1 contains knoll erodibility adjustment factors for the Soil Erodibility Index **I**. The **I** value for the Wind Erodibility Group is multiplied by the factor shown in column A. This adjustment expresses the average increase in erodibility along the knoll slope. For comparison, column B shows the increased erodibility near the crest (about the upper 1/3 of the slope), where the effect is most severe.

No adjustment of **I** for knoll erodibility is made on level fields, or on rolling terrain where slopes are longer and slope changes are less abrupt. Where these situations occur, the wind flow pattern tends to conform to the surface and does not exhibit the flow constriction typical of knolls.

Surface crusting—Erodibility of surface soil varies with changing tillage practices and environmental conditions (Chepil 1958). A surface crust forms when a bare soil is wetted and dried. Although the crust may be so weak that it has virtually no influence on the size distribution of dry aggregates determined by sieving, it can make the soil less erodible. The resistance of the crust to erosion depends on the nature of the soil, intensity of rainfall, and the kind and amount of cover on the soil surface. A fully crusted soil may erode only one-sixth as much as non-crusted soil. However, a smooth crusted soil with loose sand grains on the surface is more erodible than the same field with a cloddy or ridged surface.

Table 502-2 **I** adjustment guidelines for crusts

WEG	**I**	Max adj mgt prd factor 1/	Calculated **I**	Rounded **I**
1	310	.7	217	220
1	250	.7	175	180
1	220	.7	154	160
1	180	.7	126	134
1	160	.7	112	134
2	134	.7	67	86
3	86	.4	34	38
4	86	.4	34	38
4L	86	.4	34	38
5	56	.3	17	21
6	48	.3	14	21
7	38	.3	11	12

1/ The management period adjustment to **I** has not been validated by research and is based on NRCS judgment

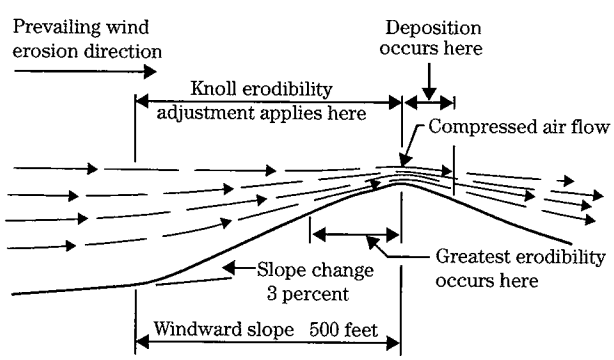
Under erosive conditions, the surface crust and surface clods on fine sands and loamy fine sands tend to break down readily On silt loams and silty clay loams the surface crust and surface clods may be preserved, and the relative erosion may be as little as one-sixth of **I** Other soils react somewhere between these two extremes (Chepil 1959).

Because of the temporary nature of crusts, no adjustment for crusting is made for annual estimates based on the critical wind erosion period method (Woodruff and Siddoway 1973). However, crust characteristics may be estimated and adjustment to **I** may be made for management period estimates when no traffic, tillage, or other breaking of crusts is anticipated. Such adjustments may be up to, but may not exceed the percentages shown in table 502–2.

Irrigation adjustments—The **I** values for irrigated soils, as shown in exhibit 502–2, are applicable throughout the year **I** adjustments for irrigation are applicable only where assigned **I** values are 180 or less.

Adjustments based on dry sieving—Temporal changes in the surface fraction > 0.84 millimeter may be measured by dry sieving. These measurements may be used to establish a basis for adjusting **I** for conservation planning when sieving has been performed for each management period and for 3 years or more. The adjustment to **I** applies only to the respective time periods when the soil surface is influenced by changes in the nonerodible fraction. Therefore, the adjustment is used only with the management period procedure of estimating wind erosion. The procedure does expand the applicability of the equation to a management effect not previously addressed. When the **I** factor is adjusted based on the results of sieving, no additional adjustment to **I** will be made for irrigated fields. Adjustments to **I**, based on sieving, should not be used without adequate supporting data. These adjustments reflect specific soil and management conditions and are only applicable in the area(s) from which samples were obtained and in areas that have similar soil and management conditions.

Figure 502–2 Graphic of knoll erodibility



Use of adjusted soil erodibility **I** factor, arrived at by using standard rotary sieving procedures, is warranted provided it represents soil surface conditions during the appropriate management period. Adjustments may be made up to, but should not exceed, limits assigned for crusting in table 502-2.

The **I** factor adjustment may be used where applicable in determining whether an adequate conservation system is being followed. However, **I** factor adjustments are not to be used in the erodibility index (CI/T) when determining highly erodible land because this index is the potential erodibility and not an estimate of actual erosion.

Current instructions for the National Resources Inventory (NRI) are to be followed. These instructions do not allow for any adjustment of the **I** factor This ensures uniformity between States and allows for trend analysis.

Studies to adjust **I** should be made systematically and include all related soil in a given area. Multiple-year soil sieving data is required before adjustments are to be considered.

The National Soil Survey Center must review and concur in any proposal to adjust **I** and arrange for laboratory assistance. Adjustments to **I** must also be approved by the National Soil Survey Center and correlated across state and regional boundaries before implementation. Any adjustment to **I** must be within the framework of the existing E tables.

Surface stability—A significant limitation of the **I** factor is that it does not account for changes in the soil surface over time that are caused by the dynamics of wind erosion The erodibility of a bare soil surface is based on the interaction of the following:

- Soils that have both erodible and nonerodible particles on the surface tend to stabilize if there is no incoming saltation. As the wind direction changes, the surface is disturbed, or the wind velocity increases, erosion may begin again
- Saltation destroys crusts, clods, and ridges by abrasion.

- Fields tend to become more erodible as finer soil particles, which provide bonding for aggregation, are carried off in suspension.
- If the surface soil contains a high percentage of gravel or other nonerodible particles that are resistant to abrasion, the surface will become increasingly armored as the erodible particles are carried away. Desert pavement is the classic example of surface armoring. A surface with only nonerodible aggregates exposed to the wind will not erode further except as the aggregates are abraded.
- A surface may be virtually nonerodible and yet allow saltation and creep to cross unabated. A paved highway is an example. Other surfaces may be relatively stable and trap some, or all, of zthe incoming soil flow Examples of this type of stability usually relate to some roughness, sheltering, or vegetative cover. A ridged field may trap a significant portion of the incoming soil flow until the furrows are filled and the surface loses its trapping capability. A vegetated barrier will provide a sheltered area downwind until the barrier is filled with sediment.

502.32 Soil roughness factor K, ridge and random roughness

K_{rd} is a measure of the effect of ridges made by tillage and planting implements. Ridges absorb and deflect wind energy and trap moving soil particles (fig. 502–3).

The K_r value is based on a standard ridge height to ridge spacing ratio of 1:4. Because of the difficulty of determining surface roughness by measuring surface obstructions, a standard roughness calibration using nonerodible gravel ridges in a wind tunnel was developed. This calibration led to the development of curves (fig. 502–4 and exhibit 502–

Figure 502–3 Detachment, transport, and deposition on ridges and furrows

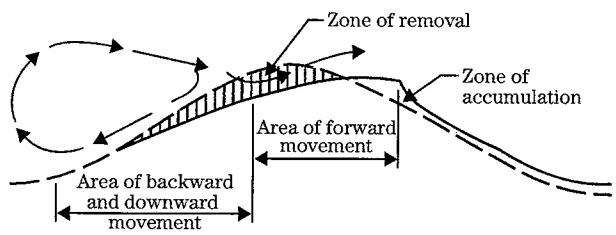
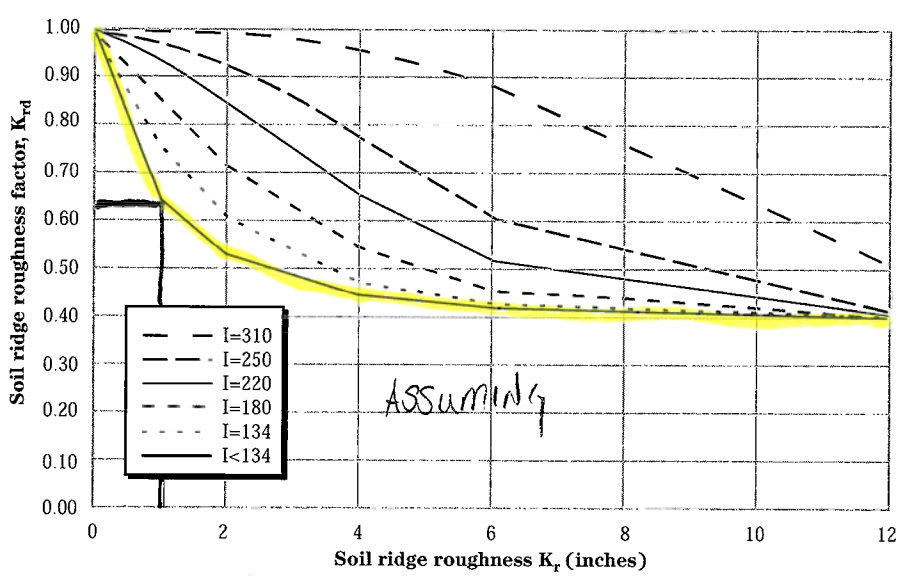


Figure 502–4 Chart to determine soil ridge roughness factor, K_{rd}, from ridge roughness, K_r, (inches). Only this chart, representing an angle of deviation of 0°, will be used for the WEQ **critical period procedure**. When using the **management period procedure**, see exhibit 502–4 for graphs representing additional angles of deviation. Note: This graph represents erosive wind energy 60% parallel and 40% perpendicular to the prevailing erosive wind. —Hagen 1996



Kr=4(hxh)/s h=ridge height in inches s=ridge spacing in inches

$$K_r = \frac{4(h \times h)}{s}$$

where:
h = ridge height in inches
s = ridge spacing in inches

4) that relate ridge roughness, K_r, to a soil ridge roughness factor, K_{rd}, (Skidmore 1965; Skidmore and Woodruff 1968; Woodruff and Siddoway 1965, and Hagen 1996).

The K_r curves are the basis for charts and tables used to determine K_{rd} factor values in the field (exhibits 502–4 and 502–5). The effect of ridges varies as the wind direction and erodibility of the soil change. To take into account the change in wind directions across a field, we consider the angle of deviation. The angle of deviation is the angle between the prevailing wind erosion direction and a line perpendicular to the row direction. The angle of deviation is 0 (zero) degrees when the wind is perpendicular to the row and is 90 degrees when the wind is parallel to the row Following is an example of how the angle of deviation affects K_{rd} values. when evaluating a soil with an assigned **I** value of <134, and the prevailing erosive wind direction is perpendicular to ridges 4 inches high and 30 inches apart, then K_{rd} is 0.5 But when the prevailing erosive wind direction is parallel to those ridges, the K_{rd} value is 0 7 Random roughness, particularly in the furrows, significantly reduces wind erosion occurring from erosive winds blowing parallel to the ridges.

In 1996, ARS scientists provided a method for adjusting the WEQ K_{rd} factor with consideration for preponderance (erosive wind energy 60% parallel and 40% perpendicular to prevailing erosive wind direction) when using the Management Period Procedure. The use of preponderence recognizes that during the periods when the prevailing erosive winds are parallel to ridges, there are other erosive winds during the same period which are not parallel, thus making ridges effective during part of each period. Preponderance keeps the K factor value less than 1.0, when the **I** factor values are 134 or less. When estimating wind erosion rates by management periods, without the aid of a computer model, the prevailing wind erosion direction and a *default* preponderance are used for each period. This procedure more adequately addresses the effects of the ridges in wind erosion control since erosive wind directions may vary within each management period

Note: When using the WEQ Excel spreadsheet model, the actual preponderance, up to and including a value of 4, for the period will be used, rather than a default value.

The WEQ K_{rr} factor accounts for random roughness. Random roughness is the nonoriented surface roughness that is sometimes referred to as cloddiness. Random roughness is usually created by the action of tillage implements. It is described as the standard deviation (in inches) of the soil surface elevations, measured at regular intervals from a fixed, arbitrary plane above a tilled soil surface, after oriented (ridge) roughness has been accounted for Random roughness can reduce erosion significantly. Note: The random roughness factor will only be used with the WEQ management period procedure.

Random roughness values have been developed for various levels of WEQ **I** factor values and surface random roughness (exhibit 502–6). Random roughness curves only adjust the K factors of a soil that has an **I** factor value of 134 and less.

The random roughness values used in the WEQ are the same random roughness values used in RUSLE. Random roughness (inches) from the machine operations data base in RUSLE can be used to determine WEQ random roughness values (table 502–7). However, keep in mind that these RUSLE random roughness values were determined for medium textured soils tilled at optimum moisture conditions for creating random roughness. Under most circumstances random roughness is determined by comparing a field surface to the random roughness (standard deviation) photos in the RUSLE handbook (Agriculture Handbook 703, appendix C).

The photos in Agriculture Handbook 703, appendix C, may be downloaded from.

http://www.nrcs.usda.gov/technical/ECS/agronomy/roughness.html

State agronomists should download, reproduce, and distribute the photographs to field offices.

When both random roughness and ridge roughness are present in the field, they are complimentary When both are present, the K_{rd} factor for ridges and K_{rr} factor for random roughness will be multiplied together to obtain the total roughness K-factor

Example problem. Take into consideration just one WEQ management period. The soil in the field being evaluated has an **I** value of 86. The field has just been fertilized with anhydrous ammonia using a knife applicator Considering the height and spacing of the oriented roughness, the ridge roughness K_{rd} factor was determined to be 0.8. Using table 502–7, under random roughness (inches), the anhydrous applicator has a core value of 0.6 Going into the random roughness (inches) graph (exhibit 502–6), on the hori-

zontal axis to 0.6, and then vertically to the line representing an **I** factor of 86, the K_{rr} factor is rounded to 0.8. The total roughness value (K factor) is 0.8 x 0.8 = 0.64, then rounded to 0.6.

The major effects of random roughness on wind erosion are to raise the threshold wind speed at which erosion begins and to provide some sheltered area among the clods where moving soil can be trapped. Hence, when the effectiveness of random roughness increases the total K-value decreases.

Random roughness, particularly in the furrows, significantly reduces wind erosion occurring from erosive winds blowing parallel to the ridges.

Random roughness is subject to much faster degradation by rain or wind erosion than large tillage ridges. Therefore the WEQ management period, where random roughness is effective, may be of short duration.

For fields being broken out of sod, such as CRP, random roughness will be credited for erosion control. The field surface is usually covered with the crowns of plants, their associated roots, and adhering soil. The total random roughness of the field should be compared to the photos in the RUSLE handbook and credited appropriately

Surface roughening (emergency tillage)—In some situations, there is a need to control erosion on bare fields where the surface crust has been destroyed or where loose grains are on the surface and can abrade an existing crust. One method to reduce the erosion hazard on such fields is emergency or planned tillage to roughen the surface or increase nonerodible clods on the surface (random roughness). This may be accomplished by one or more of the following.

- Soil that characteristically forms a crust with loose sand grains on the surface may be worked to create clods. The loose grains fall into the crevices between clods. This is the principle of sand fighting used in some emergency tillage.
- The soil may be deep tilled to bring up finer textured soil material that will form more persistent clods.
- Irrigation increases the nonerodible fraction of a soil (exhibit 502–2).
- The surface may be worked into a ridge-furrow configuration that will trap loose, moving soil.
- The soil may be tilled in strips or in widely spaced rows to provide some degree of ridge and random roughness to break the flow of saltation and creep.

502.33 Climatic factor, C

The C factor is an index of climatic erosivity, specifically windspeed and surface soil moisture. The factor for any given location is based on long-term climatic data and is expressed as a percentage of the C factor for Garden City, Kansas, which has been assigned a value of 100 (Lyles 1983). In an area with a C factor of 50, for example, the IKC value would be only half of the IKC for Garden City, Kansas.

The climatic factor equation is expressed as:

$$C = 34.48 \times \frac{v^3}{(PE)^2}$$

where:

C = annual climatic factor
V = average annual wind velocity
PE = precipitation-effectiveness index of Thornthwaite
34.48 = constant used to adjust local values to a common base (Garden City, Kansas)

The basis for the windspeed term of the climatic factor is that the rate of soil movement is proportional to windspeed cubed. Several researchers have reported that when windspeed exceeds threshold velocity, the soil movement is directly proportional to friction velocity cubed which, in turn, is related to mean windspeed cubed (Skidmore 1976).

The basis for the soil moisture term of the climatic factor is that the rate of soil movement varies inversely with the equivalent surface soil moisture. Effective surface soil moisture is assumed to be proportional to the Thornthwaite precipitation-effective- ness index (PE) (Thornthwaite 1931). The annual PE index is the sum of the 12 monthly precipitation effectiveness indices. The formula is expressed as follows:

$$PE = \sum^{12} 115 \times \left[\frac{P}{(T-10)}\right]^{\frac{10}{9}}$$

where:

PE = the annual precipitation effectiveness index
P = average monthly precipitation
T = average monthly temperature

The C factor isoline map developed by NRCS in 1987 can accessed at:

http://data4.ftw.nrcs.usda.gov/website/c-values

Complete instructions for viewing the map are given in exhibit 502-8. The map displays C factors for all areas of the conterminous United States and Alaska. The isolines were drafted to conform with local C factors calculated from 1951–80 weather data and were correlated across state and regional boundaries. Procedures for developing local C factors are explained in exhibit 502–9

1. Interpolation of WEQ climatic factors (C)— States may interpolate between county assigned C values to the nearest 5 units based on the National C Factor Isoline Map or the state C Factor Isoline Map in the Field Office Technical Guide (FOTG). When interpolating between values, knowledge of the local climatic and topographic conditions is extremely useful since climatic conditions can vary disproportionately between C factor value isolines.

2. Where WEQ soil loss (E) tables have been developed with C factor increments greater than 5 units, a straight line interpolation to the nearest C factor value of 5 may be made from existing E tables. Straight line interpolations can also be made from the soil losses (E) calculated with approved WEQ computer software, when C factors programmed into the model are in increments greater than 5 units.

3. C factor interpolations are for the purpose of conservation planning only and are NOT to be used in determining or adjusting previous highly erodible land (HEL) designations. However, they may be used during status reviews to determine if an individual is actively applying a conservation system. Previous national policy, regarding the changing of prior HEL designations, remains in effect.

Effects of irrigation water on the C factor—When irrigation water is applied to a dry soil surface, a reduction in wind erosion can be expected. A specific procedure to directly adjust the climatic factor C for irrigation is not available. However, a procedure has been developed by researchers to adjust the Erosive Wind Energy (EWE) by the fraction of time during which the soil is considered wet and nonerodible because of irrigation. See 502.31 and exhibit 502–2.

The procedures that follow adjust the Erosive Wind Energy (EWE) value which planners are to use when estimating wind erosion on irrigated fields. This adjustment is for the WEQ Management Period Procedure. States where wind erosion is a concern should replace previous methods used to adjust for the effects of irrigation and utilize this procedure and the procedure for adjusting the **I** factor, for all plan revisions or new planning activities. This new procedure, however, does not impact designated highly erodible lands (HEL) or new determinations since management practices are not considered in the HEL formula.

Note· Irrigation adjustments to EWE and to the **I** factor, apply to fully irrigated fields and to fields that receive *supplemental* irrigation water.

- Research scientists have developed an Irrigation Factor (IF) that adjusts the EWE or period erosion loss to account for the effect of irrigation wetting the soil surface and making it less erodible. The IF takes into account the number of days in a management period, number of irrigation events during a management period, and a Texture Wetness Factor (TWF).
- To account for the *nonerodible wet* condition of various soil textures after irrigation, a TWF of 1, 2, or 3 is assigned to coarse, medium, and fine textured soil, respectively See exhibit 502 2 for values assigned to the various soil groups.
- The IF is calculated with the following equation:
  IF = number of days in period minus (–) nonerodible wet days in period (NEWD), divided by the number of days in period.
  Nonerodible Wet Days (NEWD) are equal to the Texture Wetness Factor (TWF) times the number of irrigation events in the period.
- When using the WEQ to account for the effects of irrigation, multiply the EWE for the period by the IF
- Example: A fine textured soil was irrigated three times during 45 days. Twelve percent of the annual EWE occurs during this period. Therefore:
  TWF = 3 for fine textured soil
  Number of irrigations during the period = 3
  NEWD = (3)(3) = 9
  IF = (45 days – 9)/45 = 0.80

  The adjusted EWE for 45 days is then determined by multiplying IF times the percentage of annual erosion wind energy during the period being evaluated.
  Adjusted EWE = (.80)(12%) = 9.6 %

  Note: The EWE shall not be adjusted for any management period where irrigation does not occur
- The WEQ factors (C & I) used to determine the Erodibility Index (EI), will not be adjusted when determining highly erodible land (HEL) on cropland that is irrigated.

502.34 Unsheltered distance, L

The L factor represents the unsheltered distance along the prevailing wind erosion direction for the field or area to be evaluated. Its place in the equation is to relate the *isolated, unsheltered, and wide* field condition of **I** to the size and shape of the field for which the erosion estimate is being prepared. Because V is considered after L in the 5-step solution of the equation (502.22), the unsheltered distance is always considered as if the field were bare except for vegetative barriers.

1 L begins at a point upwind where no saltation or surface creep occurs and ends at the downwind edge of the area being evaluated (figure 502–5). The point may be at a field border or stable area where vegetation is sufficient to eliminate the erosion process. An area should be considered stable only if it is able to trap or hold virtually all expected saltation and surface creep from upwind. If vegetative barriers, grassed waterways, or other stable areas divide an agricultural field being evaluated, each subdivision will be *isolated* and shall be evaluated as a separate *field*. Refer to the appropriate NRCS Conservation Practice Standards to determine when practices are of adequate width, height, spacing, and density to create a stable area.

2. When erosion estimates are being calculated for cropland or other relatively unstable conditions, upwind pasture or rangeland should be considered a stable border. However, if the estimate is being made for a pasture or range area, L should be determined by measuring from the nearest stable point upwind of the area or field in question (figure 502–6). The only case where L is equal to zero is where the area is fully sheltered by a barrier.

3. When a barrier is present on the upwind side of a field, measure L across the field along the prevailing wind erosion direction and subtract the distance sheltered by the barrier. Use 10 times the barrier height for the sheltered distance (figure 502–7).

Figure 502–5 Unsheltered distance L

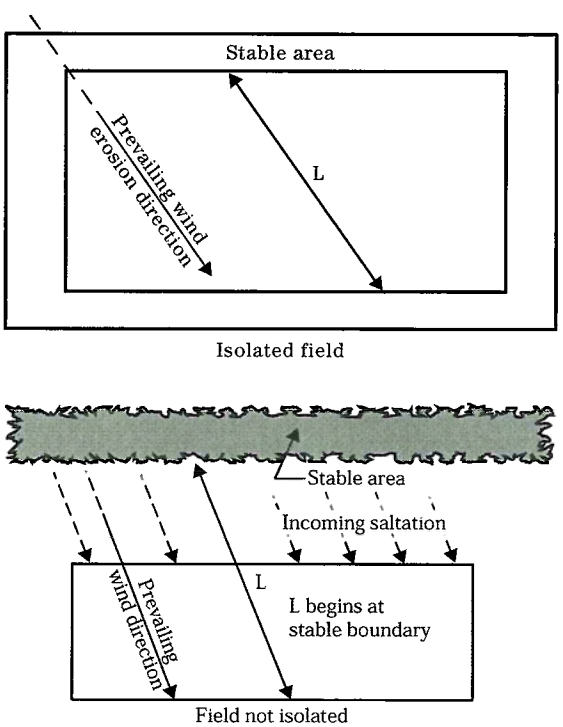
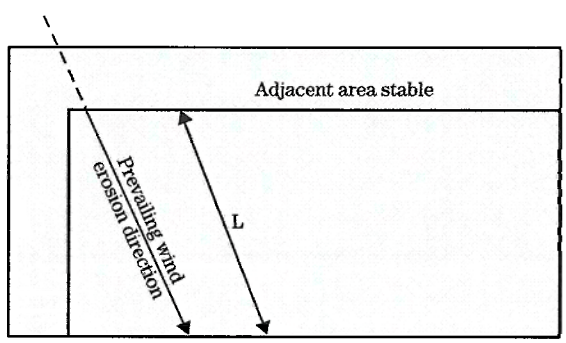
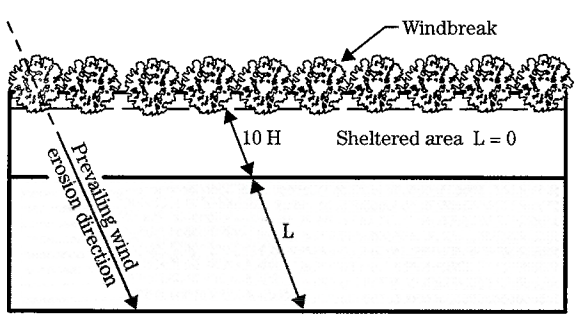


Figure 502–6 Unsheltered distance L, perennial vegetation (pasture or range)



Unsheltered distance "L" perennial vegetation (pasture or range)

Figure 502-7 Unsheltered distaqnce L – windbreak or barrier



4. When a properly designed wind stripcropping system is applied, alternate strips are protected during critical wind erosion periods by a growing crop or by crop residue. These strips are considered stable. L is measured across each erosion-susceptible strip, along the prevailing wind erosion direction (figure 502–8).

The prevailing wind erosion direction is the direction from which the greatest amount of erosion occurs during the critical wind erosion period. The direction is usually expressed as one of the 16 compass points. When predicting erosion by management periods, the prevailing wind erosion direction may be different for each period (exhibit 502–7a).

Preponderance is a ratio between wind erosion forces parallel and perpendicular to the prevailing wind erosion direction Wind forces parallel to the prevailing wind erosion direction include those coming from the exact opposite direction (180°). A preponderance of 1.0 indicates that as much wind erosion force is exerted perpendicular to the prevailing direction as along that direction. A higher preponderance indicates that more of the force is along the prevailing wind erosion direction. Wind patterns are complex; low preponderance indicates high complexity and as a result, less wind will be from the prevailing erosive wind direction than locations that have a high preponderance.

L can be measured directly on a map or calculated using a wind erosion direction factor·

- For uses of the Wind Erosion Equation involving a single annual calculation, L should be the measured distance across the area in the prevailing wind erosion direction from the stable upwind edge of the field to the downwind edge of the field. When the prevailing wind erosion direction is at an angle that is not perpendicular to the long side of the field, L can be determined by multiplying the width of the field by the appropriate conversion factor obtained from table 502-3.

- For management period calculations, wind erosion direction factors based on preponderance are to be used instead of a measured distance to determine L except
  - Where irregular fields cannot be adequately represented by a circle, square, or rectangle.
  - Where preponderance data are not available.

Steps to determine L for management period estimates:

1. Obtain local values for prevailing the wind erosion direction and preponderance (exhibit 502–7a).
2. Measure actual length and width of the field and determine the ratio of length to width.
3. Determine angle of deviation between prevailing wind erosion direction and an imaginary line perpendicular to the long side of the field.

Using data from steps 1 through 3, determine the wind erosion direction factor from wind erosion direction factor tables, tables 502–81a-e. These are adjustment factors that account for prevailing wind erosion direction, preponderance of wind erosion forces, and size and shape of the field.

Multiply the width of the field by the wind erosion direction factor This is the L for the field.

If a barrier is on the upwind side of the field, reduce L by a distance equal to 10 times the height of the barrier

For circular fields, **L** = 0.915 times the diameter, regardless of the prevailing wind erosion direction or preponderance.

Figure 502–8 Unsheltered distance L, stripcropping system

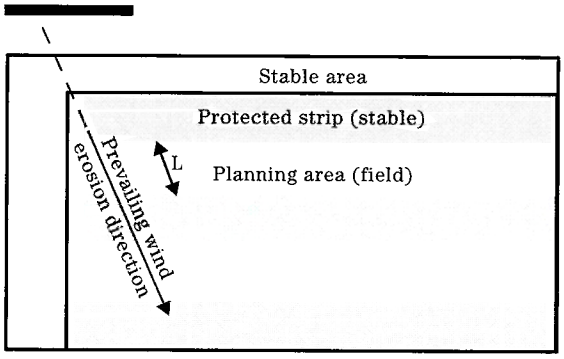


Table 502-3 Wind erosion direction factors [1/]

Angle of deviation [2/]	Adjustment factor
0	1.00
22.5°	1.08
45°	1.41
67.5°	2.61
90°	L = Length of field

1/ These adjustment factors are applicable when preponderance is not considered. L cannot exceed the longest possible measured distance across the field.

2/ Angle of deviation of the prevailing erosive wind from a direction perpendicular to the long side of the field.

502.35 Vegetative cover factor, V

The effect of vegetative cover in the Wind Erosion Equation is expressed by relating the kind, amount, and orientation of vegetative material to its equivalent in pounds per acre of small grain residue in reference condition Small Grain Equivalent (SGe). This condition is defined as 10 inch long stalks of small grain, parallel to the wind, lying flat in rows spaced 10 inches apart, perpendicular to the wind. Several crops have been tested in the wind tunnel to determine their SGe. For other crops, small grain equivalency has been computed using various regression techniques (Armbrust and Lyles 1985; Lyles and Allison 1980; Lyles 1981, Woodruff et al. 1974; Woodruff and Siddoway 1965). NRCS personnel have estimated SGe curves for other crops. SGe curves are in exhibit 502–10.

Position and anchoring of residue is important. In general, the finer and more upright the residue, the more effective it is for reducing wind erosion. Knowledge of these and other relationships can be used with benchmark values to estimate additional SGe values.

Research is underway to develop a method of estimating the relative erosion control value of short woody plants and other growing crops.

Several methods are used to estimate the kind, amount, and orientation of vegetation in the field. Often the task is to predict what will be in the field in some future season or seasons. Amounts of vegetation may be predicted from production records or estimates and these amounts are then reduced by the expected or planned tillage. It may be desirable to sample and measure existing residue to determine quantity of residue. Local data should be developed to estimate surface residue per unit of crop yield and crop residue losses caused by tillage.

The crown of a plant, its associated roots, and adhering soil should also be credited when doing transects to determine residue cover Employees will need to use their best judgment when deciding which crop curve to use when converting from percent ground cover to mass and then selecting a curve to convert the residue mass to SGe.

If you encounter a crop, residue, or a type of vegetation for which an SGe curve has not been developed. exhibits 502–11 and 502–12 give procedures to develop an interim SGe curve. Any SGe curve developed in this way must be submitted to the National Agronomists or the Cooperating Scientist for wind erosion for approval.

Subpart 502E Principles of wind erosion control

502.40 General

Five principles of wind erosion control have been identified (Lyles and Swanson 1976; Woodruff et al. 1972; and Woodruff and Siddoway 1965). These are as follows:

- Establish and maintain adequate vegetation or other land cover
- Reduce unsheltered distance along wind erosion direction.
- Produce and maintain stable clods or aggregates on the land surface
- Roughen the land with ridge and/or random roughness.
- Reshape the land to reduce erosion on knolls where converging windflow causes increased velocity and shear stress.

The *cardinal rule* of wind erosion control is to strive to keep the land covered with vegetation or crop residue at all times (Chepil 1956). This leads to several principles that should be paramount as alternative controls are considered:

- Return all land unsuited to cultivation to permanent cover
- Maintain maximum possible cover on the surface during wind erosion periods.
- Maintain stable field borders or boundaries at all times.

502.41 Relation of control to WEQ factors

The Wind Erosion Equation (WEQ) was developed to relate specific field conditions to estimated annual soil loss. Of the five factors, two (I and C) are often considered to be *fixed* while the other three (K, L, and V) are generally considered *variable* or management factors. This is not precisely true.

The **I** factor is related to the percentage of dry surface soil fractions greater than 0.84 millimeters. Its derivation is usually based on the Wind Erodibility Group.

However, if a special management condition is going to be maintained, such as crusts or irrigation, a modification of **I** is appropriate. Also, **I** is increased by a knoll erodibility factor where appropriate. See 502.31. This adjustment is not appropriate if the knoll condition is modified through landforming or use of barriers to protect the knoll.

Knoll erodibility adjustments to **I** relate to wind direction; low preponderance indicates that knoll erodibility will vary widely as wind direction changes.

Total K reflects the tilled ridge roughness and random roughness in a field. This is a management factor Stability of tilled roughness is related, however, to soil erodibility, climate, and the other erosion factors.

Ridge roughness relates to ridge spacing in the wind erosion direction. Even with optimum orientation of rows, some of the winds will be blowing parallel to the rows when preponderance is low

Random roughness relates to the nonoriented surface roughness that is often referred to as cloddiness. Random roughness is described as the standard deviation of elevation from a plane across a tilled area after taking into account oriented (ridge) roughness.

The C factor is based on long-term weather records. Conservation treatment should be planned to address the critical climatic conditions when high seasonal erosive wind energy is coupled with highly erodible field conditions.

The unsheltered distance L is a management factor that can be changed by altering field arrangement, stripcropping, or establishing windbreaks or other barriers. L is a function of field layout as it relates to prevailing wind direction and preponderance of erosive winds in the prevailing direction.

When preponderance values are high (more than 2.5 and approaching 4.0), conservation treatment should be concentrated on addressing potential erosion from the prevailing wind erosion direction.

When preponderance values are low (approaching 1.0), knowledge of local seasonal wind patterns becomes more important in planning treatment. Conservation treatment should be planned to allow for the effect of seasonal changes in the prevailing wind erosion direction.

A stable strip across an agricultural field divides the area into separate fields. Examples of stable areas include grass waterways, hedges and their sheltered area, brushy draws or ravines, roadways with grass borders, grass strips, and drainage or irrigation ditches.

To be considered stable, an area must be able to stop and hold virtually all of the expected saltation and surface creep. Be aware that an area may be stable during one crop stage, but not stable in other seasons.

V is the equivalent vegetative cover maintained on the soil surface. It is directly related to the management functions of crop establishment, tillage, harvesting, grazing, mowing, or burning.

502.42 Tolerances in wind erosion control

In both planning and inventory activities, NRCS compares estimated erosion to soil loss tolerance (T). T is expressed as the average annual soil erosion rate (tons/acre/year) that can occur in a field with little or no long-term degradation of the soil resource, thus permitting crop productivity to be sustained for an indefinite period.

Soil loss tolerances for a named soil are recorded in the soil survey data base in NASIS.

The normal planning objective is to reduce soil loss by wind or water to T or lower In situations where treatment for both wind and water erosion is needed, soil loss estimates using the WEQ and USLE or RUSLE are not added together to compare to T

Additional impacts of wind erosion that should be considered are potential offsite damages, such as air and water pollution and the deposition of soil particles.

Crop tolerance to soil blowing may also be an important consideration in wind erosion control. Wind or blowing soil, or both, can have an adverse effect on growing crops. Most crops are more susceptible to abrasion or other wind damage at certain growth stages than at others. Damage can result from desiccation and twisting of plants by the wind.

Crop tolerance can be defined as the maximum wind erosion that a growing crop can tolerate, from crop emergence to field stabilization, without an economic loss to crop stand, crop yield, or crop quality

(a) Blowing soil effects on crops

Some of the adverse effects of soil erosion and blowing soil on crops include:

- Excessive wind erosion that removes planted seeds, tubers, or seedlings.
- Exposure of plant root systems.
- Sand blasting and plant abrasion resulting in
  - crop injury
  - crop mortality
  - lower crop yields
  - lower crop quality
  - wind damage to seedlings, vegetables, and orchard crops.
- Burial of plants by drifting soil.

(b) Crop tolerance to blowing soil or wind

Many common crops have been categorized based on their tolerance to blowing soil. These categories of some typical crops are listed in table 502-4 Crops may tolerate greater amounts of blowing soil than shown in table 502–4, but yield and quality will be adversely affected.

(c) The effects of wind erosion on water quality

Some of the adverse effects of wind erosion on water quiality include:

- Deposition of phosphorus (P) into surface water
- Increased Biochemical Oxygen Demand (BOD) in surface water
- Reduced stream conveyance capacity because of deposited sediment in streams and drainage canals

Local water quality guidelines under Total Maximum Daily Loads (TDML) for nutrients may require that wind erosion losses be less than the soil loss tolerance (T) in order to achieve local phosphorus (P) or other pollutant reduction goals.

For a phosphorus (P) intrapment estimation procedure, see the Core 4 manual, chapter 3C, Cross Wind Trap Strips.

1b

Exhibit 502–2 Wind erodibility groups and wind erodibility index

Soil texture [1]	EWE texture wetness factor [2]	Predominant soil texture class of surface layer	Wind Erodibility Group (WEG) [3]	Soil Erodibility Index (I) (ton/ac/yr) [4, 5]	Soil Erodibility Index (I) for irrigated soils (ton/ac/yr) [4]
C	1	Very fine sand, fine sand, sand, or coarse sand	1	310 [4] 250 220 180 160	310 250 220 160 134
C	1	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, sapric organic soil materials, and all horizons that meet andic [6] soil properties as per Criteria 2 in Soil Taxonomy, regardless of the fine earth texture	2	134	104
C	1	Very fine sandy loam, fine sandy loam, sandy loam, coarse sandy loam, and noncalcareous silt loam with 35 to 50% very fine sand and <10% clay	3 AMENDED SOIL	86	56
F	3	Clay, silty clay, non-calcareous clay loam, or silty clay loam with more than 35% clay	4	86	56
M	2	Calcareous [7] loam and silt loam or calcareous clay loam and silty clay loam	4L	86	56
M	2	Non-calcareous loam and silt loam with more than 20% clay (but does not meet WEG 3 criteria), or sandy clay loam, sandy clay, and hemic organic soil materials	5	56	38
M	2	Non-calcareous loam and silt loam with more than 20% clay, or non-calcareous clay loam with less than 35% clay or silty clay loam with less than 35% clay	6	48	21
M	2	Silt and fibric organic soil material	7	38	21
—	—	Soils not susceptible to wind erosion because of surface rock and pararock fragments or wetness	8	—	—

1/ Soil texture, C = Coarse; M = Medium; F = Fine
2/ Texture wetness factor for adjustment of Erosive Wind Energy (EWE) for the period (Irrigated fields only)
3/ For all WEGs except sand and loamy sand textures, if percent rock and pararock fragments (>2mm) by volume is 15-35, reduce **I** value by one group with more favorable rating If percent rock and pararock fragments by volume is 35-60, reduce **I** value by two favorable groups except for sands and loamy sand textures which are reduced by one group with more favorable rating If percent rock and pararock fragments by volume is more than 60, use **I** value of zero for all textures except sands and loamy sand textures which are reduced by three groups with more favorable rating.
4/ The wind erodibility index is based on the relationship of dry soil aggregates greater than 0.84 millimeters to potential soil erosion. Value for irrigated soils is applicable throughout the year Values for irrigated soils determined by Dr. E L Skidmore, USDA, ARS, Wind Erosion Research Unit, Manhattan, Kansas.
5/ The **I** factor for WEG 1 vary from 160 for coarse sands to 310 for very fine sands Use an **I** value of 220 as an average figure.
6/ Vitrandic, Vitritorrandic, and Vitrxerandic Subgroups with ashy textural modifiers move one group with less favorable rating
7/ Calcareous is a strongly or violently effervescent reaction of the fine-earth fraction to cold dilute (IN) HCL

1a

Exhibit 502–3 Sieving instructions

Soil sieving has become increasingly important because of USDA's emphasis on advancing erosion prediction technology Soil samples can be sieved using either a flat or a rotary sieve. The flat sieve method is useful in making onsite field determinations. However, the results are not as consistent as those achieved by the electric motor-driven rotary sieve. If the objective is to gather scientific data, consistency is important, and rotary sieving should be the chosen method

(a) Equipment needs

- A standard number 20 flat sieve or access to a properly designed rotary sieve.
- A device for weighing samples.
- A square-nosed scoop or shovel.
- Worksheet for sieving of dry aggregates (example follows).

(b) Procedure

1. Take samples only when the soil is reasonably dry If the soil sticks to the scoop, postpone the sampling until the soil dries sufficiently. If sieving is being done to verify the **I** factor assigned to a soil, samples should be taken during the normal wind erosion period in an area that is smooth, bare, not crusted, not sheltered by windbreaks or barriers, and at a location in the field far enough downwind for avalanching to occur If the objective is to estimate erodibility for a specific field condition, select a smooth, bare, unsheltered area with the desired conditions. In all cases, avoid compacted or vegetated areas.

2. Use the square-nosed scoop to collect a sample from the soil surface. Try to avoid sampling more deeply than approximately 1 inch Several small scoops may be more representatives than one larger scoop of soil

3. Gently place the sample (about 2 lb) into a padded container for transporting to a sieving location. Fill in the appropriate blanks on the form to specify field conditions and other data. If the soil sample will be done in the field with a flat sieve, proceed.

4. Weigh the sieve (including receiver) and record for later use. Place about 2 pounds of the sample on the No. 20 sieve. Remove loose vegetation without fracturing soil aggregates.

5. Determine gross weight of the sample and sieve. Subtract the weight of the sieve to determine net weight of the sample.

6. Remove the receiver and shake the sieve 50 times using moderate force. Do not bounce the sample or shake so hard that you break down the clods. Place the sieve over the receiver and shake again 50 times. If more than 0.5 ounce collects in the receiver, empty the receiver and repeat the process. If more than 0.5 ounce is again in the receiver, repeat the process again. Do not exceed a total of 200 shakes. Discard material in the receiver and weigh the sieve, receiver, and remaining aggregates in the sieve. Determine the weight of soil aggregates greater than 0.84 millimeter in diameter. Divide the weight of the sieved sample by the total weight of the soil sample to determine percentage of aggregates that exceed 0.84 millimeter.

7. Refer to table that follows to arrive at soil erodibility when using the percentage of nonerodible aggregates. *

1a

Exhibit 502–3 Sieving instructions–continued

Soil erodibility Index I in tons/acre determined by percentage of nonerodible fractions

% units—>	0	1	2	3	4	5	6	7	8	9
Tens	ton/ac	ton/ac	ton/ac	ton/ac	ton/ac	ton/ac	ton/ac	ton/ac	ton/ac	ton/ac
0	—	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86 *	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	—	—	—	—	—	—	—	—	—

(TP-13)

USING SITE SOIL AMENDED WITH 25% GRAVEL. ROUNDING DOWN TO 20% TO BE CONSERVATIVE.

SLOPE = 5%

(E)* SOIL LOSS FROM WIND EROSION IN TONS PER ACRE PER YEAR — JANUARY, 1998

C = 40
I = 86

SURFACE - K =0.60

(V)** - FLAT SMALL GRAIN RESIDUE IN POUNDS PER ACRE

(L) UNSHELTERED DISTANCE IN FEET	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
10000	20.6	17.1	12.3	7.8	3.7	1.4	0.5						
8000	20.6	17.1	12.3	7.8	3.7	1.4	0.5						
6000	20.6	17.1	12.3	7.8	3.7	1.4	0.5						
4000	19.7	16.3	11.6	7.4	3.4	1.3							
3000	18.8	15.5	11.1	7.0	3.2	1.2							
2000	17.5	14.4	10.2	6.4	2.9	1.1							
1000	14.4	11.8	8.2	5.0	2.2	0.8							
800	13.4	10.9	7.5	4.6	2.0	0.7							
600	11.8	9.5	6.5	3.9	1.7	0.4							
400	9.9	8.0	5.4	3.1	1.3	0.3							
300	8.3	6.7	4.4	2.5	1.0	0.2							
200	5.6	4.4	2.8	1.5	0.5								
150	4.2	3.3	2.1	1.1	0.4								
100	3.1	2.4	1.5	0.7									
80	2.4	1.8	1.1	0.5									
60	1.6	1.2	0.6										
50	1.3	1.0	0.5										
40	1.0	0.5											
30	0.7	0.4											
20													
10													

(E)* SOIL LOSS FROM WIND EROSION IN TONS PER ACRE PER YEAR — JANUARY, 1998

C = 40
I = 86

SURFACE - K =0 50

(V)** - FLAT SMALL GRAIN RESIDUE IN POUNDS PER ACRE

(L) UNSHELTERED DISTANCE IN FEET	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
10000	17.2	14.1	10.0	6.2	2.8	1.1							
8000	17.2	14.1	10.0	6.2	2.8	1.1							
6000	17.2	14.1	10.0	6.2	2.8	1.1							
4000	16.0	13.1	9.2	5.7	2.6	0.9							
3000	15.1	12.4	8.6	5.3	2.4	0.8							
2000	13.8	11.3	7.8	4.8	2.1	0.7							
1000	11.5	9.3	6.3	3.8	1.6	0.3							
800	10.4	8.4	5.7	3.3	1.4	0.3							
600	8.9	7.1	4.8	2.7	1.1	0.2							
400	6.7	5.3	3.5	1.9	0.6								
300	5.1	4.0	2.6	1.4	0.5								
200	3.8	3.0	1.9	0.9									
150	2.8	2.1	1.3	0.6									
100	1.9	1.4	0.8										
80	1.5	1.1	0.6										
60	1.0	0.5											
50	0.8	0.5											
40	0.6	0.4											
30													
20													
10													

* NOTE: SOIL LOSS FOR VALUES WHERE 'E' IS LESS THAN 0 1 OR GREATER THAN 440 0 ARE NOT SHOWN; OTHER VALUES NOT SHOWN ARE INVALID

** NOTE: VALUES SHOWN ARE FLAT SMALL GRAIN EQUIVALENT, NOT 'V'

1d

(E)* SOIL LOSS FROM WIND EROSION IN TONS PER ACRE PER YEAR

JANUARY, 1998
C = 40
I = 38

SURFACE - K =0.60

(V)** - FLAT SMALL GRAIN RESIDUE IN POUNDS PER ACRE

(L) UNSHELTERED DISTANCE IN FEET	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
10000	9.1	7.3	4.9	2.8	1.2	0.3							
8000	9.1	7.3	4.9	2.8	1.2	0 3							
6000	8.5	6.8	4.5	2.6	1.0	0 2							
4000	7.6	6.1	4.0	2.3	0.8								
3000	6.5	5.1	3.4	1.8	0.6								
2000	5.4	4.3	2.8	1.5	0.5								
1000	3.8	2.9	1.8	0.9									
800	3.3	2.5	1.6	0.7									
600	2.4	1.8	1.1	0.5									
400	1.7	1.3	0.7										
300	1.2	0.9	0.5										
200	0.8	0.4											
150													
100													
80													
60													
50													
40													
30													
20													
10													

(E)* SOIL LOSS FROM WIND EROSION IN TONS PER ACRE PER YEAR

JANUARY, 1998
C = 40
I = 38

SURFACE · K =0 50

(V)** - FLAT SMALL GRAIN RESIDUE IN POUNDS PER ACRE

(L) UNSHELTERED DISTANCE IN FEET	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
10000	7.6	6.1	4.0	2.3	0.8								
8000	7.5	6.0	4.0	2.2	0.7								
6000	6.8	5.4	3.5	2.0	0.7								
4000	6.0	4.7	3.1	1.7	0.6								
3000	5.0	3.9	2.5	1.3	0.4								
2000	4.4	3.5	2.2	1.2	0.4								
1000	2.9	2.2	1.4	0.6									
800	2.3	1.8	1.1	0.5									
600	1.8	1.3	0.7										
400	1.2	0.9	0.5										
300	0.9	0.5											
200													
150													
100													
80													
60													
50													
40													
30													
20													
10													

* NOTE· SOIL LOSS FOR VALUES WHERE ˙E˙ IS LESS THAN 0 1 OR GREATER THAN 440 0 ARE NOT SHOWN; OTHER VALUES NOT SHOWN ARE INVALID

** NOTE· VALUES SHOWN ARE FLAT SMALL GRAIN EQUIVALENT, NOT 'V˙

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2

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Erosive wind energy distributions and climatic factors for the West

Leon Lyles

ABSTRACT: Erosive wind energy (EWE) distributions were determined for the 7 western states and Alaska. Wind erosion equation climatic factors (C) were determined for the 10 Great Plains States, the 7 western states, and Alaska. Both EWE and C should be useful in improving design and evaluation of wind erosion control systems and data quality from future national erosion inventories.

CONSERVATIONISTS presently use a wind erosion equation (*8*) to design erosion control systems and to estimate soil loss by wind. Recently, Bondy and associates (*1*) outlined a procedure for computing soil erosion by periods using erosive wind energy distributions. They presented erosive wind energy distributions only for the 10 Great Plains States. Consequently, additional data are needed, especially for the other western states where wind erosion is a serious problem.

Annual climatic factors (C), one of the independent variables in the wind erosion equation, were published in 1962 (*2*) However, only general ranges of values were given. Subsequent maps were prepared for some states (areas), generally by request of the Soil Conservation Service (SCS), and may be found in various SCS Technical Guides or Notes (for example, *4*) Updated maps are needed using more recent climatological data and containing more locations.

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Method of evaluation

Erosive wind energy distribution. I determined erosive wind energy distributions for specific sites in the states west of the Great Plains using methods described previously (*1*) Erosive wind energy is defined by months as the sum of the cube of windspeeds between 8 and 20 meters per second (18-45 miles/hour) in 1-meter-per-second (2.2-mile/hour) increments. I included only locations with 5 years or more of wind data.

Annual climatic factors. The local wind erosion climatic factor (C) is used to characterize the erosive potential of climate (windspeed and surface soil moisture) at a particular location relative to Garden City, Kansas, which has an annual C value of 100 percent based on long-term climatic

data (except for Alaska) are related to the key map in figure 1 Individual locations show extremes of 40.4 percent (Barrow, Alaska) and 99.8 percent (Roseburg, Oregon) of annual erosive wind energy occurring in the first six months. Of the states evaluated, Arizona shows the most erosive wind energy occurring during the first six months while Alaska shows the least (Table 1)

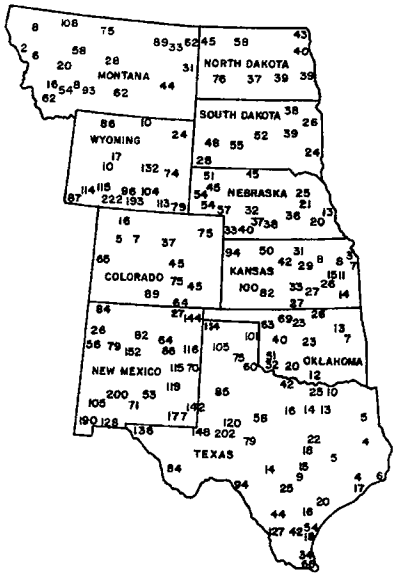

Figure 2. Annual climatic factor (C) in percent for the Great Plains.

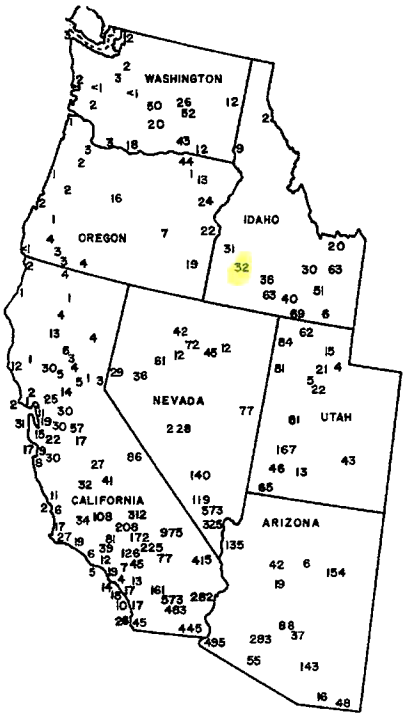

Figure 3. Annual climatic factor (C) in percent for the West.

Data in table 1 would be used according to the equation:

$$(E)_p = (EWE)_p\,(E)_a \qquad [3]$$

where $(E)_p$ is the estimated erosion during a given period, $(EWE)_p$ is the proportion of erosive wind energy occurring during the period at a particular location, and $(E)_a$ is the estimated annual erosion obtained from solving the wind erosion equation using period input data for all factors except the climatic factor For example, assume the location is Big Delta, Alaska, and the period is January through March. Then $(EWE)_p$ equals 0.43 (Table 1), that is, 43 percent of the erosive wind energy occurs during that period.

Figures 2 and 3 show all the C-factor data (Alaska C-factors are given in table 2) I made no attempt to draw isolines on the maps. Knowledge of terrain features and local climate would be needed to make judgments about how far the point data can be extended areawise.

To illustrate how the monthly precipitation limit of 1.27 centimeters (0.5 inch) influences C-factors in dry climates, I chose Daggett, El Centro, and Thermal, California, and calculated the following C-factors using actual monthly precipitation normals: 2,222, 2,856, and 2,446, respectively. Those values correspond to 975, 445, and 483 using the 1.27 centimeters (0.5 inch) limit (Figure 3) The lower values appear more reasonable for those locations.

Both erosive wind energy and C factors should be useful in improving design and evaluation of wind erosion control systems. These data should also be useful in future national erosion inventories and as input to a wind erosion component of an erosion-productivity model now under development by the Agricultural Research Service.

Table 2. Annual C factors for Alaska.

Location	*C-factor (%)*
Anchorage	9
Aniak	4
Annette	1
Barrow	89
Barter Island	84
Bethel	42
Bettles	6
Big Delta	32
Cold Bay	16
Cordova	<1
Elmdorf	2*
Fairbanks	14
Galena	4
Gulkana	11
Homer	2
Juneau	1
Kenai	5
King Salmon	15
Kodiak	1
Kotzebue	87
McGrath	2
Minchumina	4
Nenana	9
Nome	17
Northway	3
Petersburg	<1
St. Paul Island	20*
Shemya	40
Sitka	<1
Summit	7
Talkeetna	1
Tanana	5
Unalakleet	40
Yukutat	<1

*Less than 5 years of wind data.

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Rangeland Productivity and Plant Composition

In areas that have similar climate and topography, differences in the kind and amount of rangeland or forest understory vegetation are closely related to the kind of soil. Effective management is based on the relationship between the soils and vegetation and water

This table shows, for each soil that supports vegetation suitable for grazing, the ecological site; the total annual production of vegetation in favorable, normal, and unfavorable years; the characteristic vegetation, and the average percentage of each species. An explanation of the column headings in the table follows.

An *ecological site* is the product of all the environmental factors responsible for its development. It has characteristic soils that have developed over time throughout the soil development process; a characteristic hydrology, particularly infiltration and runoff that has developed over time; and a characteristic plant community (kind and amount of vegetation). The hydrology of the site is influenced by development of the soil and plant community The vegetation, soils, and hydrology are all interrelated. Each is influenced by the others and influences the development of the others. The plant community on an ecological site is typified by an association of species that differs from that of other ecological sites in the kind and/or proportion of species or in total production. Descriptions of ecological sites are provided in the Field Office Technical Guide, which is available in local offices of the Natural Resources Conservation Service (NRCS)

Total dry-weight production is the amount of vegetation that can be expected to grow annually in a well managed area that is supporting the potential natural plant community. It includes all vegetation, whether or not it is palatable to grazing animals. It includes the current year's growth of leaves, twigs, and fruits of woody plants. It does not include the increase in stem diameter of trees and shrubs. It is expressed in pounds per acre of air-dry vegetation for favorable, normal, and unfavorable years. In a favorable year, the amount and distribution of precipitation and the temperatures make growing conditions substantially better than average. In a normal year. growing conditions are about average. In an unfavorable year, growing conditions are well below average, generally because of low available soil moisture. Yields are adjusted to a common percent of air-dry moisture content.

Characteristic vegetation (the grasses, forbs, and shrubs that make up most of the potential natural plant community on each soil) is listed by common name. Under *rangeland composition*, the expected percentage of the total annual production is given for each species making up the characteristic vegetation The amount that can be used as forage depends on the kinds of grazing animals and on the grazing season.

Range management requires knowledge of the kinds of soil and of the potential natural plant community It also requires an evaluation of the present range similarity index and rangeland trend. Range similarity index is determined by comparing the present plant community with the potential natural plant community on a particular rangeland ecological site. The more closely the existing community resembles the potential community, the higher the range similarity index. Rangeland trend is defined as the direction of change in an existing plant community relative to the potential natural plant community Further information about the range similarity index and rangeland trend is available in the "National Range and Pasture Handbook," which is available in local offices of NRCS or on the Internet

The objective in range management is to control grazing so that the plants growing on a site are about the same in kind and amount as the potential natural plant community for that site. Such management generally results in the optimum production of vegetation, control of undesirable brush species, conservation of water, and control of erosion. Sometimes, however, an area with a range similarity index somewhat below the potential meets grazing needs, provides wildlife habitat, and protects soil and water resources.

Reference:
United States Department of Agriculture, Natural Resources Conservation Service, National range and pasture handbook.

Report—Rangeland Productivity and Plant Composition

Rangeland Productivity and Plant Composition– Elmore Area, Idaho, Parts of Elmore, Owyhee and Ada Counties						
Map unit symbol and soil name	**Ecological site**	**Total dry-weight production**			**Characteristic vegetation**	**Rangeland composition**
		Favorable year	**Normal year**	**Unfavorable year**		
		Lb/ac	*Lb/ac*	*Lb/ac*		*Pct*
47—Davey-Mazuma complex, 12 to 40 percent slopes						
Davey	Sandy Loam 8-12 Artrw8/achy	1,000	600	350	Wyoming big sagebrush	35
					Indian ricegrass	20
					Thurber needlegrass	15
					Miscellaneous perennial forbs	10
					Miscellaneous shrubs	10
					Bottlebrush squirreltail	5
					Sandberg bluegrass	5
Mazuma	Saline Bottom 8-12 Save4/leci4	1,200	900	600	Black greasewood	40
					Basin wildrye	35
					Inland saltgrass	10
					Bottlebrush squirreltail	5
					Miscellaneous perennial grasses	5
					Miscellaneous shrubs	5
50—Dors fine sandy loam, 0 to 4 percent slopes						
Dors	Calcareous Loam 7-10 Atco-pide4/ achy-acth7	700	500	250	Shadscale saltbush	25
					Bud sagebrush	20
					Indian ricegrass	15
					Miscellaneous shrubs	10
					Thurber needlegrass	10

Rangeland Productivity and Plant Composition– Elmore Area, Idaho, Parts of Elmore, Owyhee and Ada Counties						
Map unit symbol and soil name	**Ecological site**	**Total dry-weight production**			**Characteristic vegetation**	**Rangeland composition**
		Favorable year	**Normal year**	**Unfavorable year**		
		Lb/ac	*Lb/ac*	*Lb/ac*		*Pct*
					Sandberg bluegrass	5
					Miscellaneous perennial forbs	5
					Bottlebrush squirreltail	5
51—Dors gravelly fine sandy loam, 4 to 12 percent slopes						
Dors	Calcareous Loam 7-10 Atco-pide4/ achy-acth7	700	500	250	Shadscale saltbush	25
					Bud sagebrush	20
					Indian ricegrass	15
					Miscellaneous shrubs	10
					Thurber needlegrass	10
					Miscellaneous perennial forbs	5
					Sandberg bluegrass	5
					Bottlebrush squirreltail	5
164—Typic Torriorthents-Badland complex, 20 to 70 percent slopes						
Typic torriorthents	Calcareous Loam 7-10 Atco-pide4/ achy-acth7	700	500	250	Shadscale saltbush	25
					Bud sagebrush	20
					Indian ricegrass	15
					Miscellaneous shrubs	10
					Thurber needlegrass	10
					Sandberg bluegrass	5
					Miscellaneous perennial forbs	5
					Bottlebrush squirreltail	5
Badland	—	—	—	—	—	—

Rangeland Productivity and Plant Composition– Elmore Area, Idaho, Parts of Elmore, Owyhee and Ada Counties						
Map unit symbol and soil name	**Ecological site**	**Total dry-weight production**			**Characteristic vegetation**	**Rangeland composition**
		Favorable year	**Normal year**	**Unfavorable year**		
		Lb/ac	*Lb/ac*	*Lb/ac*		*Pct*
169—Vanderhoff-Buko-Loray complex, 2 to 20 percent slopes						
Vanderhoff	Calcareous Loam 7-10 Atco-pide4/ achy-acth7	700	500	250	Shadscale saltbush	25
					Bud sagebrush	20
					Indian ricegrass	15
					Miscellaneous shrubs	10
					Thurber needlegrass	10
					Miscellaneous perennial forbs	5
					Bottlebrush squirreltail	5
					Sandberg bluegrass	5
Buko	Sandy Loam 8-12 Artrw8/achy	1,000	600	350	Wyoming big sagebrush	35
					Indian ricegrass	20
					Thurber needlegrass	15
					Miscellaneous perennial forbs	10
					Miscellaneous shrubs	10
					Sandberg bluegrass	5
					Bottlebrush squirreltail	5
Loray	Calcareous Loam 7-10 Atco-pide4/ achy-acth7	700	500	250	Shadscale saltbush	25
					Bud sagebrush	20
					Indian ricegrass	15
					Thurber needlegrass	10
					Bottlebrush squirreltail	5
					Sandberg bluegrass	5

Data Source Information

Soil Survey Area Elmore Area, Idaho, Parts of Elmore, Owyhee and Ada Counties
Survey Area Data. Version 9, Jan 31, 2008

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Agronomy Technical Note 69 - Wind Erosion Equation (Annual Method) on Rangeland

NM-NRCS May, 2004 Mike Sporcic, State Agronomist

This note is to be used to estimate annual wind erosion annual method using the WEQ NAM part 502 method where native vegetation is in the field. It is **not** to be **used for RMS planning on rangeland**. It can be used when sodbusting land to estimate a before erosion rate and can be used to see if current vegetation meets T.

TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE
West Technical Services Center Portland Oregon

June 1981

A GUIDE FOR CONVERTING RANGELAND VEGETATION TO SMALL GRAIN EQUIVALENTS

This technical note is to be used as a supplement to the National Resources Inventory (NRI 1981-82) instruction Section N, Wind Erosion, Data.

In using the wind erosion equation (WEE) to determine the soil loss by wind on rangelands, the vegetative cover must be converted to small grain equivalents. When western rangelands are properly managed, vegetation is generally adequate to control wind erosion. Areas receiving 12 inches or more of average annual precipitation and those range sites producing more than 1,000 pounds of average annual air dry vegetation per acre generally will not have a wind erosion problem if they are properly managed.

Natural plant communities produce various proportions of grass, forbs, and shrubs. A variety of species complement each other and, when properly managed, generally curtail wind erosion. In areas of less than 12 inches average annual precipitation and where vegetation is not properly managed, wind erosion can become a serious problem.

Vegetative communities in the western states which may require the use of the WEE are the Great Basin sagebrush areas, saltbush-greasewood, creosote bush, cactus-shrub, grama-tobosa-creosote bush, and other areas which have sparse plant cover and have not been properly managed.

To use the following table, estimate the total vegetation produced per acre and, determine the percent composition by species, then convert to flat small grain equivalent. Mixtures of species generally have a combined effect greater than the sum of the individual effects (see reference). As a rule of thumb, 75 to 125 pounds of plant growth can be expected for each inch of water available in the soil even though the site may be in a low ecological condition. If a conversion is needed for a plant not listed on the table, use a similar species.

The figures in the table are based on the current total production of leaves and twig growth. The Woody materials (trunks, branches, and stems) are not included in the table. Wood material of deciduous species such as shimery oak and mesquite may have a significant effect on wind erosion, depending density and height. Fallen leaves provide some mulch cover which provides some protection from wind erosion. Until we have better data, use a direct ratio for litter to flat small grain; i.e. 200 pounds of litter equals 200 pounds small grain residue.

The effect of rock fragments (stones and desert pavement) is provided for in the "I" factor of the equation.

Other than those grass plants indicated, the conversion equivalents are estimates by the author and are intended to be used to attain an approximation of potential wind erosion under average conditions. Field testing and research are needed to improve these estimates so that the conversion guide will be more reliable. As field use is made of this table, suggestions for improvement should be sent to the range conservationist at the technical service center

Prepared by Donald H. Fulton, Range Conservationist, West TSC, Portland Oregon.

Guide for Converting Range Vegetation to Equivalent Quantity of Flat Small Grain Residue

		Pounds per acre of Range Vegetation										
	Grass Plants	**50**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
1	*Buffalograss, burrograss Inland saltgrass	320	720	1630	2630							
2	*Big bluestem	45	110	280	480	705	950	1215	1495	1785	2090	2410
3	*Western wheatgrass, creeping wildrye & sideoats grama	155	245	775	1240	1740	2260	2795	3345			
4	*Little bluestem	45	110	285	495	735	995	1280	1580	1900	2230	2575
5	*Blue grams, threadleaf sedge & perennial threeawn	110	235	490	760	1040	1325	1610	1905			
6	Galleta & tobosa	150	300	800	1200	1700	2600					
7	Bottlebrush squirreltail, needleandthread, & thurber needlegrass	70	150	300	600	800	1200					
8	Alkali sacaton	60	150	400	800	1400	2200	2800	3600			
9	Bluebunch wheatgrasa	50	120	300	550	850	1150	1500	1900	2300	2600	3000
10	Idaho fescue	100	200	400	900	1500	2300					
11	Indian ricegrass	100	175	300	600	900	1400					
12	Crested wheatgrass	130	300	600	900	1300	1800	2400	3100	4000		
13	Cheatgrass	100	200	300	600	800	1000	1200	1600	2000	2500	3000

BASIN WILDRYE

*Lyles Leon and Bruce E. Allison, "Range Grasses and Their Small Grain Equivalents for Wind Erosion Control," Journal of Range Management, Vol. 33 No. 2, March 1980, pp. 143-146.

NOTE. Other grass species equivalents were estimated by comparing the growth characteristics with the tested species.

		Pounds per acre of Range Vegetation [1/]										
	Forbs	**50**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
1	Perennial forbs	50	100	300	500							
2	Annual forbs	50	100	200	300	500	800	1000				
	Shrubs											
1	Big sagebrush	30	70	300	750	1100	1500	2000	2600	3200	4000	
2	Low sagebrush	50	150	450	900	1600	2200	2900	3600			
3	Greasewood & 4-wing saltbush	20	60	250	450	800	1250	1800	2400	3000		
4	Tall and low rabbitbrush	30	70	350	800	1200	1700	2200	2800	3400		
5	Shadscale	30	70	300	500	850	1300					
6	Creosote bush	20	70	250	400	600	800	1000				
7	Mesquite	20	80	200	300	500	700	800	1000	1500	2000	3000
8	Juniper	40	90	180	300	450	800	950	1300	2000	2700	36050
9	Cholla 2/	0	50	100	250	350	500	700	950	1300		
10	Yucca 2/	0	70	150	250	400	600	750	000	1400	1800	
11	Winterfat	40	100	300	500	800	1400	1800	2300	3000		
12	Litter 3/	50	100	200	300	400	509	600	700	300	900	1000

[1/] Total leaf and twig growth-air dry weight. Woody production not included in these weight figures,
[2/] Include all leaf and fibrous material.
[3/] Litter should, include leaves, twigs and seems up to 1/2 inch in diameter
For deciduous shrub" estimate foliage production at time of wind erosion hazard.
The forb and shrub small grain equivalents are personal judgment only No research data is available to support these figures.

Examples of determining "v" for use in the wind erosion equation.

Range site: Loamy – 8-10" p.z. fair condition

Bluebunch wheatgrass	-	50#/acre	=	80
Cheatgrass	-	100#/acre	=	200
Annual forbs	-	50#/acre	=	50
Big sagebrush	-	500#/acre	=	1500
Litter	-	300#/acre	=	300
		v	=	2130

Range site: Basalt hills 2-7"" p.z. fair condition

Perennial threeawn	-	20#/acre	=	28	
Sixweeks grama	-	80#/acre	=	160	(use cheatgrass)
Annual forbs	-	20#/acre	=	20	
Creosote bush*	-	250#/acre	=	325	
Litter	-	50#/acre	=	50	
		v	=	583	

*current and accumulated production

Range site: Loamy 12-16" p.z. [1/] poor condition

Cheatgrass	-	300#/acre	=	600
Big sagebrush	-	700#/acre	=	2600
Litter	-	400#/acre	=	400
		v	=	3600

[1/] Little if any wind erosion should occur on this site.

W. S. CHEPIL and N. P. WOODRUFF
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cotton is grown, some special forms of wind strip cropping are employed wherein cotton in two to four rows is alternated with various numbers and sequences of rows of sorghum or of other high-residue yielding crops (Burnett *al at.*, unpublished data, 1962).

In conclusion, the chief benefit from strip cropping for wind erosion control is realized because the strips control soil avalanching and the serious damage which can result from it. Strip cropping alone will not fully control wind erosion; it must be supplemented with other practices, such as stubble mulching, to be fully effective. In combination with strip cropping, the supplementary practices need not be as intensive as they would have to be for large fields.

2. *Crop Rows*

The relative effectiveness of different row spacings for wind erosion control has not been fully evaluated. Generally speaking, the closer the row spacing, the more effective will be the crop. Most close-spaced crops, i.e., those planted with drills with spacing ranging from 7 to 14 inches, are erosion resistant once they are established. Sorghum, corn, cotton, and other crops normally planted in 40- to 42-inch rows are not so resistant. Recent experiments have shown that some of these crops can be grown in closer-spaced rows without detrimental effects on yields.

The direction of crop rows with reference to prevailing erosive winds has some effect on erosion. Siddoway (unpublished data, 1962) has shown that the relative amount of erosion from soil planted to wheat in 10-inch rows is about six times greater when the wind is blowing parallel to the rows than when the wind is perpendicular to the rows. Zingg *et al.* (1952) working with a portable wind tunnel with 9-inch high sorghum stubble in 40-inch rows showed soil losses three times greater with rows parallel to the wind than with rows perpendicular to the wind.

VII. The Wind Erosion Equation

A. General Framework

A wind erosion equation, with all its accompanying charts and tables, has been developed to indicate the relationships between the amount of wind erosion and the various field and climatic factors that influence erosion (Agricultural Research Service, 1961; Chepil, 1962a). The equation is being modified continually as new data become available. It is designed to serve a twofold purpose:

(1) As a tool for determining the potential amount of wind erosion on any field under existing local climatic conditions.

(2) As a guide for determining the conditions of surface roughness, soil cloddiness, vegetative cover, sheltering, or width and orientation of field necessary to reduce the potential wind erosion to an insignificant amount.

The equation embodies the major primary factors that govern wind erodibility of land surfaces. These primary factors influence wind erosion directly. They have been recognized during the course of many years of accumulation of experimental data on the problem. Some of them may be grouped or converted for convenience into equivalent factors, or may be disregarded, as follows:

Individual Primary Factors	*Equivalent Factors*
Per cent soil fractions > 0.84 mm. as determined by standard dry sieving, A	Soil erodibility, I
Mechanical stability of the surface crust, F_s	Transient, and therefore generally disregarded
Average wind velocity, v Average moisture of soil surface, M	Local climatic factor, C
Soil surface roughness, K	Same
Distance (along prevailing wind erosion direction across field, D_f) Distance (along prevailing wind erosion direction protected by barrier, D_b)	Equivalent width of field, L
Quantity of vegetative cover, R Kind of vegetative cover, S Orientation of vegetative cover, K_0	Equivalent quantity of vegetative cover, V

The percentage of nonerodible dry soil fractions > 0.84 mm., A, as determined by standard dry sieving is an equivalent of their true percentage and of their stability against breakdown by tillage and abrasion from wind erosion. Sieving breaks a portion of the nonerodible clods to smaller, erodible ones. The problem is to sieve the soil with such vigor or for such period of time to neither overemphasize nor underemphasize the influence of one of these factors in relation to the other. Therefore, the method of dry sieving is standardized (Chepil, 1962a). The percentage of nonerodible dry soil fractions > 0.84 mm. in diameter as determined by standard method of dry sieving is directly related to *soil erodibility I*. This relation was derived from three major studies:

(1) Wind tunnel experiments on the relation between soil cloddiness and wind erodibility (Chepil, 1950b; Chepil and Woodruff, 1954, 1959).

(2) Field measurements in the vicinity of Garden City, Kansas, during 1954-1956 on the relation between wind tunnel erodibility and natural field erodibility (Chepil. 1960b).
(3) Analysis of intensity-frequency of occurrence of climatic conditions in the vicinity of Garden City, Kansas, during 1954-1956 (Chepil *et al.*, 1962).

The mechanical stability of the surface crust, F_s, if the crust is present, is of little consequence in the long run. It is disintegrated readily under the action of abrasion after wind erosion has started. It is a transitory condition and has some significance only if we desire to determine erodibility of the field at the moment the estimation is made. If we are interested in average erodibility for the entire soil-drifting season or year, as we ordinarily are, this condition should be disregarded.

The rate of soil movement by wind varies directly as the cube of wind velocity, v, and inversely as the cube of average soil surface moisture M. It is convenient to consider these two factors together as a *local wind erosion climatic factor*, C. A map has been prepared indicating the approximate value of this factor for any location in the United States and the agricultural areas of Canada (Chepil *et al.*, 1962).

The *soil surface roughness*, K, is expressed in terms of height of standard soil ridges (the same as ridge roughness equivalent of Zingg and Woodruff, 1951) and means that the surface, other factors being equal, will resist the wind as much as the standard soil ridges in which nonerodible clods do not exceed ¼ inch in diameter and which have a height-spacing ratio of 1:4. For example, a ridge roughness equivalent of 2 inches for a given soil surface means that the wind drag against the surface will be as great as against the surface composed of standard ridges 2 inches high and 8 inches apart running at right angles to wind direction, composed of the same proportion of erodible and nonerodible fractions as the soil, and exposed to the same drag velocity of the wind as the soil.

Width of field or field strip alone does not determine how erodible it is unless the prevailing wind direction and the presence or absence of adjoining wind barriers are taken into account too. No matter how narrow the field strip might be, if wind direction is parallel to its length, the strip would be almost as erodible as a large field of a width equal to the length of the strip. Furthermore, if any barrier is present on the windward side of the field, the distance D_b (along the prevailing wind erosion direction) which it fully shelters from the wind must be subtracted from the total distance D_f (along the prevailing wind erosion direction) across the field to determine the unsheltered distance across

the field along the prevailing wind erosion direction. This is the distance L that directly determines the quantity of erosion. It may be termed the *equivalent width of field.*

The quantity R, kind S, and orientation K_0 of vegetation or vegetative cover can be expressed together in terms of equivalent pounds per acre. The equivalent vegetative material is small grain stubble to which S has been assigned the value of 1. The equivalent orientation is the absolutely flat, small-grain stubble with straw aligned parallel with wind direction, for which K_0 has been assigned the value of 1. The *kind of vegetative cover factor,* S, denotes the total cross-sectional surface area of the vegetative material. The finer the material, the greater its surface area, the more it slows down the wind velocity, and the more it reduces wind erosion. The *orientation of vegetative cover factor,* K_0, is in effect the vegetative surface roughness factor and the two terms mean the same thing. The more erect the vegetative matter, the higher it stands above the ground, the more it slows down the wind velocity near the ground, and the lower the rate of erosion. The factors R, S, and K_0 are multiplied together to give what is termed the *equivalent quantity of vegetative cover,* V (Chepil, 1962a). The wind erosion equation then may be expressed as

$$E = f\,(I,C,K,L,V) \tag{27}$$

which says that the potential average annual quantity of erosion, or soil loss, E, expressed in tons per acre is a function of the following factors:

I = soil erodibility,

C = local wind erosion climatic factor,

K = soil surface roughness,

L = equivalent width of field (the maximum unsheltered distance across the field along the prevailing wind erosion direction),

V = equivalent quantity of vegetative cover.

The mathematical relationships among the factors in the wind erosion equation are complicated, but charts and tables have been prepared from which the quantity of erosion (soil loss), as influenced by each of these factors, can be read at a glance (Chepil, 1962a). Moreover, the charts and tables can be used in reverse to determine what conditions are necessary to reduce wind erosion to any degree. Space is too limited here to include these charts and tables and to indicate how they can be used to estimate the potential soil loss of a field or the conditions needed to reduce the soil loss to an insignificant amount.

B. Data Needed to Estimate Potential Soil Loss

Each of the individual primary factors that influence wind erosion must be determined before the potential soil loss can be estimated. They are as follows:

Datum 1. *Soil erodibility I* in tons per acre per annum, determined from percentage of nonerodible soil fractions > 0.84 mm. in diameter. The percentage of nonerodible fractions is determined by standard dry sieving (Chepil, 1962b) or from reference tables of known average cloddiness of different soils during the wind erosion season.

Datum 2. *Local wind erosion climatic factor C*, in per cent, estimated for a particular geographic location from the wind erosion climatic map (Chepil *et al.*, 1962).

Datum 3. *Soil surface ridge roughness equivalent, K*, in inches. Usually K is equal to the average height of clods or ridges of which the soil surface is composed (Zingg and Woodruff, 1951; Chepil, 1962a). Several measurements can be made with a ruler and averaged. Widely spaced ridges, such as those used in emergency tillage for wind erosion control, have a ridge roughness equivalent less than their height. Usually, if the distance between them is increased beyond the 1:4 ratio, their ridge roughness equivalent is decreased proportionately. Thus, if the ridges are 6 inches high and the distance between them, measured along the prevailing wind erosion direction, is 48 inches, their height spacing ratio is 1:8, as compared to 1:4 for standard ridges, so that their ridge roughness equivalent is 4/8 of 6 inches, or 3 inches, if soil cloddiness remains the same as for standard ridges.

Datum 4. *Distance D_f*, in feet across the field (along prevailing wind erosion direction). This distance can be measured or computed from the width of field if the prevailing wind erosion direction is known (Chepil, 1959a). No adequate published data on the prevailing wind erosion direction at various geographic locations are available at present (1962).

Datum 5. *Distance D_b*, in feet (along prevailing wind erosion direction) of full protection from wind erosion afforded by a barrier, if any, adjoining the field. This distance for standard pervious continuous barrier is about 10 times the height of the barrier (Woodruff and Zingg, 1952). Data on the effectiveness of different kinds of barriers in shielding the soil surface from

erosion are meager. If height of barrier is no greater than normal height of stubble, the influence is negligible and no evaluation is made.

Datum 6. *Quantity of vegetative cover, R,* above the ground in pounds per acre. This is estimated by sampling, cleaning, drying, weighing, and computing on a pounds per acre basis in accordance with standard procedure (Chepil and Woodruff, 1959). For some types of standing stubble, such as sorghum or corn, the quantity can be estimated roughly from height of stubble and number of stalks per unit area. Unpublished supplementary charts and tables are available to facilitate this type of estimation. All quantities of R presented in this review are based on washed, oven-dry material multiplied by 1.20. This represents approximately the average thoroughly cleaned, air-dry weights.

Datum 7. *Kind of vegetative cover factor,* S (dimensionless), obtainable from supplementary tables (Chepil, 1962a).

Datum 8. *Orientation of vegetative cover factor,* K_o (dimensionless), obtainable from supplementary charts (Chepil, 1962a).

VIII. Needed Research

Field and supplemental wind tunnel studies on the basic causes, effects, and remedies of wind erosion began in the severe dust storm period of the 1930's. Data have been collected and recorded continuously till the present time. The first attempt to apply some of this information as part of the wind erosion equation was published by Chepil and Woodruff in 1954. From then, general wind erosion research and research as applied to the wind erosion equation have been continued simultaneously. One is not and could not be separated from the other.

Considerable information still is required on air flow, temperature, evaporation, and crop yields in the vicinity of windbreaks and other types of surface barriers such as snowfences, hedges, crop strips, crop rows, ridges, and soil clods. Part of this study is expected to be applied to classification standards for shelterbelts presently in existence in the Great Plains. Ultimately it is hoped that greater clarification may be made of the principles governing air flow patterns and soil erodibility in the vicinity of barriers ranging from the size of clods to field shelterbelts. Experiments on models in a wind tunnel are being initiated to speed up attainment of basic information on this subject.

Much damage to soils and crops could be avoided if severe wind erosion conditions could be predicted a few months to a year ahead

of their occurrence. Such predictions might be possible in view of the fact that severe wind erosion conditions tend to occur in cycles. A prediction of severe conditions one growth season ahead of their occurrence should give farmers ample opportunity to establish special tillage and cropping practices that would be effective.

Although it is known at present what soil structure approaches an ideal condition for resisting wind, little information is available on how best to create such a condition and at the same time permit the soil to absorb water freely and serve as a good medium for crop growth. None of the present cropping systems, including grasses, are entirely suitable, and some are detrimental. Studies are needed on new techniques of developing a suitable soil structure. More information is needed on the influence of moisture on soil structure as influenced by different types of tillage action. Possibilities of finding new methods and materials to develop desirable sizes of stable soil aggregates should be explored further.

It is recognized that vegetative covers, alive or dead, offer one of the most effective conditions for controlling wind and water erosion. However, better implements and probably more extensive education on how best to use the present implements are needed to maintain protective crop residues on the surface, to control wind and water erosion, runoff, and evaporation, and to maintain high level of crop yields.

One of the problems associated with present methods of maintaining vegetative covers is that they tend to leave the surface soil loose, fine, and highly erodible by wind. When drought occurs and vegetative covers become depleted, serious erosion sometimes occurs. Implements that improve structure of the surface soil and at the same time maintain vegetative residues on the surface need to be improved. Information on how to preserve vegetative matter above the ground or how to develop vegetative matter resistant to decomposition also is needed. Recognition, selection, and development of plant species suited for reclaiming eroding sand dune land is needed urgently.

The general framework of the wind erosion equation has been developed, but many details are still lacking. These details may be filled with accessory charts and tables as more research information becomes available.

Information is needed on the average soil surface roughness K for soil surfaces tilled with different implements on different soil classes, with different soil moisture contents. This information is important to determine the nature of the implements and methods of tillage that might be more suited than the present ones for permanent and emergency tillage programs for wind erosion control.

Information is needed on the average distance D_b of full protection from wind erosion afforded by barriers of various degrees of air penetrability in various geographic regions and for various soils. This type of information for windbreaks and other barriers is presently almost completely lacking.

Information is needed on the prevailing wind erosion direction for various locations. Available data needed to determine the prevailing wind erosion direction include: (a) average hourly wind velocity from each of the 16 points of the compass, and (b) per cent duration of wind from each of the 16 points of the compass. The prevailing wind erosion direction needs to be computed from the above data. A map then can be prepared for estimating the prevailing wind erosion direction on individual farms. This type of information would be valuable in determining factors D_f and D_b and, inversely, in determining how wide crop strips running in a certain direction should be to control wind erosion in various regions.

Soil erodibility I, based on standard dry sieving procedure, needs to be determined for various soil types wherever wind erosion is a problem.

Information on the values of kind of vegetative cover factor S and orientation of vegetative cover factor K_o is needed for cultivated and grass crops other than those already investigated.

It is expected that the wind erosion equation will become more useful as more specific information on the influence of the major primary factors I, C, K, D_f, D_b, R, S, and K_o becomes available.

IX. Conclusion

This review has been devoted to discussion of progress made in obtaining new information on wind erosion and its control. However, the solution of the problem is dependent on the overall progress made in research, testing, and extension.

It is beyond the scope of this review to discuss the overall progress made in the solution of the wind erosion problem. Substantial progress apparently has been made. Probably the best evidence of this is the fact that the severity of dust storms in the Great Plains during the 1950's was considerably less than during a period of similar climatic conditions in the 1930's (Chepil and Woodruff, 1957; Chepil *et al.*, 1962; unpublished data by Chepil *et al.*) This difference is believed to be due to better techniques, more favorable financial resources, and more earnest desire on the part of everyone to conserve the soil.

Appendix D3

Critical Density Calculations

Final Cover Design for Low-Level Radioactive Waste Disposal Facility US Ecology, Idaho

Soil Densities

Objective

This calculation is performed to estimate the soil densities of the cover material.

References

1) DBS&A Laboratory Report, August 13, 2008

Calculation

$gf := 0.001 \cdot kgf$

Maximum dry densities of Steiner soils — Critical Density

Steiner 13

$\rho_{maxS13} := 1.75 \cdot \frac{gf}{cm^3}$ $\rho_{maxS13} = 109.249 \cdot \frac{lbf}{ft^3}$

$\rho_{minS13} := 0.80 \cdot \rho_{maxS13}$ $\rho_{minS13} = 87.399 \cdot \frac{lbf}{ft^3}$

$\rho_{mxS13} := 0.92 \cdot \rho_{maxS13}$ $\rho_{mxS13} = 100.509 \cdot \frac{lbf}{ft^3}$

104.3 lbf/ft^3

Steiner 14

$\rho_{maxS14} := 1.58 \cdot \frac{gf}{cm^3}$ $\rho_{maxS14} = 98.636 \cdot \frac{lbf}{ft^3}$

$\rho_{minS14} := 0.80 \cdot \rho_{maxS14}$ $\rho_{minS14} = 78.909 \cdot \frac{lbf}{ft^3}$

$\rho_{mxS14} := 0.92 \cdot \rho_{maxS14}$ $\rho_{mxS14} = 90.745 \cdot \frac{lbf}{ft^3}$

93.6 lbf/ft^3

Steiner 15

$\rho_{maxS15} := 1.57 \cdot \frac{gf}{cm^3}$ $\rho_{maxS15} = 98.012 \cdot \frac{lbf}{ft^3}$

$\rho_{minS15} := 0.80 \cdot \rho_{maxS15}$ $\rho_{minS15} = 78.41 \cdot \frac{lbf}{ft^3}$

$\rho_{mxS15} := 0.92 \cdot \rho_{maxS15}$ $\rho_{mxS15} = 90.171 \cdot \frac{lbf}{ft^3}$

95.5 lbf/ft^3

Subject: US Ecology Idaho (USEI) Site B - IDD073114654
Alternative Evapotranspiration Final Cover Design for Cells 14 and 15
Response to Comments from State of Idaho Department of Environmental Quality (DEQ) dated June 7, 2010

Date: June 23, 2010

The following calculations are submitted as a response to comments from the State of Idaho Department of Environmental Quality, dated June 7, 2010, and the USEPA Region 10, dated May 10, 2010. The calculations were originally submitted in *Final Cover Design for Cells 14 and 15, Permit Modification for Alternative Evapotranspiration Final Cover, US Ecology Idaho, Volume 1: Report, Figures, Tables, Appendices A-C, July 20, 2009, Revised November 25, 2009*, by Daniel B. Stephens & Associates, Inc.

The specific comment being addressed is:

EPA Region 10

2. Item number 4, on page 2: Maximum soil density is an important criterion for proper root growth and must be specified in the report.

DEQ

Soil density requirements will be noted in the Specifications and the CQA Plan. Revise these documents, where necessary, so these are included.

DBS&A

Soil density has been specified as values of relative compaction according to ASTM D698. Relative compaction values of 80% to 92% of the standard, maximum dry density have been specified. For the Steiner soils, these equate to the following ranges:

Steiner TP-13	*87.4 to 100.5 lbf/ft^3*
Steiner TP-14	*78.9 to 90.7 lbf/ft^3*
Steiner TP-15	*78.4 to 90.2 lbf/ft^3*

Goldsmith et. al. (2001) discuss the growth limiting bulk density (GLBD) for different soil types. They reference a GLBD textural triangle which was modified from Daddow and Warrington (1983). Plotting the Steiner soils on the GLBD textural triangle allowed a GLBD to be determined for Steiner TP-13, Steiner TP-14, and Steiner TP-15. Data used to plot the soils was obtained from the DBS&A Laboratory Report, dated August 13, 2008, particle size analysis plots.

The soils yielded the following values of GLBD:

Steiner TP-13	*104.3 lbf/ft^3*
Steiner TP-14	*93.6 lbf/ft^3*
Steiner TP-15	*95.5 lbf/ft^3*

The maximum densities for each soil sample, representing 92% of the standard, maximum dry density, are all less than the corresponding GLBD values.

It must be noted that specifying a relative compaction range is standard practice, as this value will remain a constant throughout construction. The specified relative compaction range remains the same but is based on different borrow areas and thus, different maximum dry bulk densities. DBS&A is of the opinion that specifying density would add unnecessary complication to the project. We recommend staying with relative compaction of the maximum dry density for each accepted borrow source.

Daddow, R. L. and G. E. Warrington. 1983. *Growth-Limiting Soil Bulk Densities as Influenced by Soil Texture*. Watershed Systems Development Group (WSDG), USDA Forest Service. Fort Collins, CO. WSDG-TN-00005.

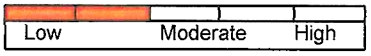
Goldsmith, W., M. Silva, and C. Fischenich. 2001. *Determining Optimal Degree of Soil Compaction for Balancing Mechanical Stability and Plant Growth Capacity.* The U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) Ecosystem Management and Restoration Research Program (EMRRP), Vicksburg, MS. ERDC TN-EMRRP-SR-26.

Determining Optimal Degree of Soil Compaction for Balancing Mechanical Stability and Plant Growth Capacity

by Wendi Goldsmith[1], Marvin Silva[1], and Craig Fischenich[2]

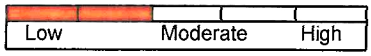
May 2001

Complexity



Benefit

Cost



OVERVIEW

Few standards exist for determining ideal design parameters for soil compaction when applying vegetation for stabilization and erosion control of slopes and banks. Geotechnical engineers regularly recommend the highest practical soil compaction based on data correlating soil density with increased mechanical strength. Agronomists, on the other hand, recommend minimal soil compaction because compacted soils are widely understood to impede the growth and development of crops, forests, and native plant communities. Those who design treatments utilizing vegetation for structural performance, generally known as bioengineering, tend to borrow from various fields with a range of outcomes as a result (Figure 1) Therefore, the purpose of this technical note is to present information that can help designers and natural resource managers make decisions regarding soil compaction so as to balance agronomic and mechanical considerations related to the installation and maintenance of bioengineered stabilization treatments.

INFLUENCE OF COMPACTION ON SOIL STABILITY

Soils are compacted to improve the stability of fills – reducing the likelihood of failures and enhancing safety. Soil fills settle and compress over time. The amount of settlement depends upon the initial compaction rate, among other

Figure 1. Soil is compacted after installing a brushlayer lift. Correct compaction is needed after material installation to close voids and to provide suitable soil density for appropriate plant growth

things. Foundations of heavy buildings, highway roadbeds, and airport runways all require considerable levels of soil compaction for satisfactory performance. Construction of earth-fill dams also involves heavy compaction to provide stable slope faces as well as a uniform and controlled rate of seepage through

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[2] US Army ERDC EL, 3909 Halls Ferry Rd, Vicksburg, MS 39180

the dam core. The degree of necessary compaction is less clear in earth fills along streambanks because of conflicting project objectives and allowable factors of safety that differ from the examples above.

The effects of soil compaction on the soil strength, compressibility, hydraulic conductivity, and structure have been well-studied (Assouline et al 1997, Bowles 1992, Lambe and Whitman 1969, Seed and Chan 1959) and a series of standardized testing procedures have become widely adopted by professionals (Hunt 1986) One of the original and most popular tests, the standard compaction test, was developed by R. R. Proctor in the 1930's. The procedure involves compacting three sequential layers of soil in a 4-in-diameter mold with a volume of 1/30 ft^3, using a 5-1/2-lb hammer dropped 25 times from a height of 12 in.

The density that can be achieved using this fixed energy of compaction is dependent upon both the textural composition of the soil and its moisture content at the time of the test (Table 1) The density of the soil is achieved through the close packing of the particles. The lubrication effect of an optimal moisture level allows soil particles to become more easily realigned during the compaction procedure, leading to the highest degrees of compaction. For any given textural composition of soil, there is a maximum dry density that can be achieved at the optimal moisture level using the standard Proctor test (Figure 2).

Table 1. Type of Soil

No.	Description	Sand %	Silt %	Clay %	w_L	I_P
1	Well-Graded Sand	88	10	2	16	
2	Well-Graded Sandy Marl	72	15	13	16	
3	Medium Sandy Marl	73	9	18	22	4
4	Sandy Clay	32	33	35	28	9
5	Silty Clay	5	64	31	36	15
6	Loess Silt	5	85	10	26	2
7	Clay	6	22	72	67	40
8	Poorly Graded Sand	94	6	-		-

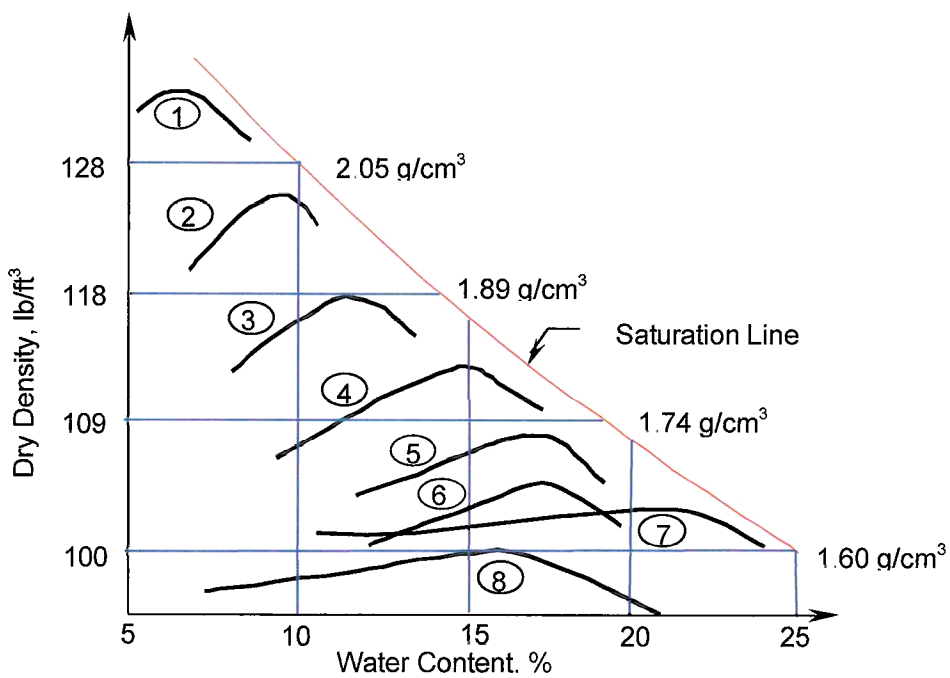

Figure 2. Compaction curves for eight different soils using the standard (AASHTO) Proctor test (modified after Abramson et al. (1995))

In general, compacted granular soils will have higher dry densities in the range of 115 to 135 lb/ft^3 (1.84 to 2 16 g/cm^3) than those of clayey to silty soils, which are in the range of 85 to 115 lb/ft^3 (1.36 to 1.84 g/cm^3). The corresponding optimum moisture contents for the granular and silty to clayey soils are generally on the order of 5 to 15 percent and 20 to 35 percent, respectively (Abramson et al 1995)

Maximum density does not represent a soil condition with no voids remaining, rather one where the tightest possible packing arrangement is achieved given compaction conditions. The point of 100-percent saturation is called the saturation line (Figure 2), which is never reached since some air (pore space) always remains trapped in the soil

As a general practice, fills that are part of site grading not related to load bearing, are specified to be compacted to 90-92 percent of standard Proctor maximum dry density Load-bearing soils and other specialized fill applications call for higher compaction levels, including compactions that exceed the values achieved by the standard Proctor test Once compacted to the selected degree, various parameters of soil strength, including saturated and suction cohesion as well as effective stress envelope, vary with soil type, but all are considerably improved over the uncompacted state (Hunt 1986).

HOW SOIL COMPACTION INFLUENCES PLANT GROWTH

Soil compaction influences plant growth in a variety of ways, both negatively and positively, depending to a large extent on degree and context. These impacts have been studied extensively by agronomists who are concerned with the decline in soil productivity associated with modern agriculture and forestry practices and equipment, which tend to compact soils over time. Observation by the authors of the performance of bioengineering projects throughout the United States provides additional insight into effects of compaction upon plants.

Densities typically sought out by geotechnical engineers for mechanical strength have been shown to reduce or effectively stop the development of roots. When soil compaction levels are high, there appears to be a threshold soil bulk density value beyond which roots are unable to penetrate due to the high mechanical resistance of soils (Figure 3) Review of data for various crops and forest stands growing on a wide range of soil textures reveals limiting bulk densities, which may be used as a predictive tool. Depending on the plant species and the soil conditions, evidence of limits to plant growth range from restriction in root growth, to severe reduction in length of all roots and/or primary root, to no root penetration of compacted soils.

Figure 3. Root penetration of a ponderosa pine (*Pinus ponderosa*) limited by an old compacted roadbed. (Courtesy of Lolo National Forest)

It has been suggested that a growth-limiting bulk density (GLBD) might exist for each given soil texture. Daddow and Warrington (1983) show that it is possible to calculate the average pore radius for a given soil by simulating the packing of soil particles into defined geometric arrangements based on particle size distribution and that GLBD values correlate well with calculated average pore radius. The GLBDs for 80 different soil textures were computed using a regression equation. Daddow and Warrington then plotted on a USDA soil textural triangle in order to locate the growth-limiting isodensity lines shown in Figure 4 These isodensity lines represent equal

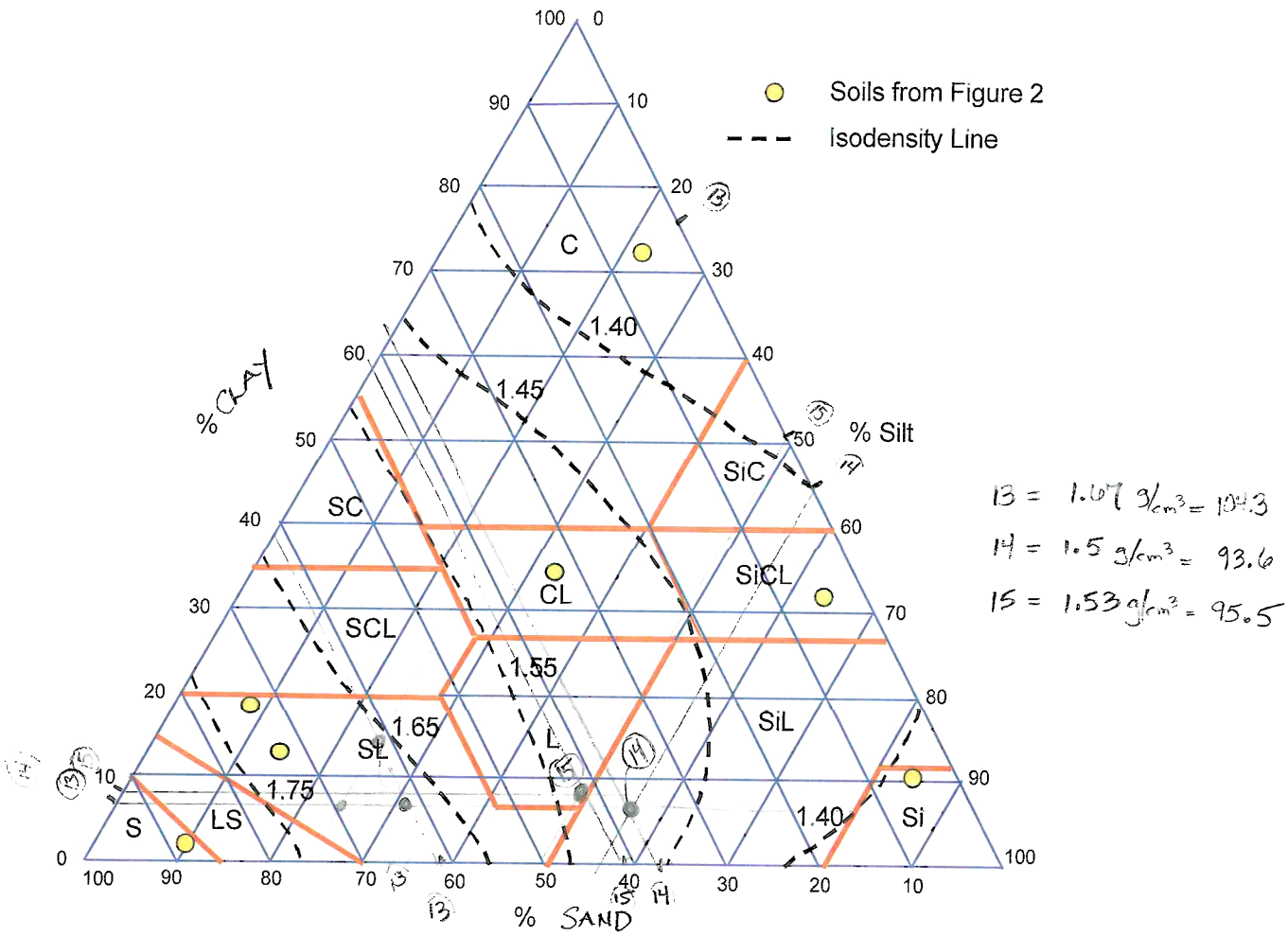

Figure 4. Growth-limiting bulk density textural triangle (Modified from Daddow and Warrington (1983))

GLBD values and are used to estimate the GLBD of a soil.

Some researchers have tried to relate bulk density to factors such as root penetration, soil strength, and compaction (Table 1) These data lead to the conclusion that, in general, non-cohesive soils reach higher maximum dry densities than cohesive soils (Figure 2). Additionally, non-cohesive soils exhibit higher critical dry density than cohesive soils (Figure 4 and Table 1). Sandy soils have large continuous pores, while clays have small pores, which transmit water slowly Clays, however, contain more pore space than sandy soils.

For growing plants, pore sizes are more important than total pore space. Therefore, plants will have a better environment in sandy soils if porosity is low because of the increase in water retention The converse is true for clays. High porosity clays have a high macro-movement, which provides high infiltration and more water available for plants.

Coppin and Richards (1990) agree that the critical dry density depends on the soil texture and suggest values of about 87 lb/ft^3 (1.4 g/cm^3) for clay soils and 106 lb/ft^3 (1 7 g/cm^3) for sandy soils. These threshold values are within the intervals presented in Table 2

Table 2. Approximate Bulk Densities That Restrict Root Penetration (from *Handbook of Soil Science* (1999))

Texture	Critical bulk density (g/cm^3) for soil resistance	
	High	Low
Sandy	1.85	1.60
Coarse-loamy	1.80	1.40
Fine-loamy	1 70	1.40
Coarse, Fine-silty	1.60	1.30
Clayey	(Depends on both clay percent and structure)	

lb/ft³
115.5 - 99.9
112.4 - 87.4
106.1 - 87.4
99.9 - 81.2

It is widely understood that the rooting pattern, including length, areal extent, and internal morphology, are principally controlled by plant genetics, and that soil conditions, as well as other environmental factors, exert a formative influence on the expression of the ideal pattern.

Jaramillo-C et al (1992) studied the development of moisture-conducting tissues in the new roots of bean plants under varying compaction regimes. Results showed that soil compaction not only limited the length of roots, but the roots failed to properly develop the usual size and shape of metaxylem in high soil bulk densities, resulting in severely reduced transport capacity for water and nutrients. Compacted soils limit capillary radius of roots, which according to Poisseuille's law are able to transport water as a function of the fourth power of the radius. This effect is clearly an issue with new seedlings, and results suggest that problems in early development may persist as plants mature

Gale, Grigal, and Harding (1991) used a soil productivity index to predict white spruce growth. Their study suggested that soil compaction limits root development and hence nutrient and moisture uptake for younger trees, but that the forest floor becomes the dominant source of nutrients and intercepted rainfall provides moisture as trees mature. Landhaeuser et al. (1996) studied the effects of soil compaction on the depth and lateral spread of marsh reed grass. They concluded that soil compaction is so effective at controlling the growth of this species that superficial soil compaction might be a valuable control technique to prevent the species from dominating new tree plantations. In summary, compaction to a higher degree than the growth-limiting bulk density for the particular soil can severely limit the short- and long-term growth and development of plants.

The preponderance of information in the literature, supported by the authors' observations, suggests that a compaction between 80 and 85 percent of the standard Proctor maximum dry density provides many of the stabilizing benefits of soil compaction without jeopardizing the viability of vegetation development and growth

Growth-limiting bulk densities or critical dry bulk densities can readily be compared to standard Proctor maximum dry densities. The critical dry density for each type of soil presented in Figure 2 can be determined by plotting the soils in Figure 4. The degree of compaction suitable for root growth is calculated by dividing the critical dry density by the maximum dry density for each type of soil Compaction rates thus calculated corresponding to growth-limiting bulk densities vary from 81.9 to 91.0 percent of standard Proctor densities, with an average of 84 1 percent.

INFLUENCE OF VEGETATION ON SOIL STABILITY

Vegetation, both directly and indirectly, influences a variety of processes that lead to increased reinforcement and strength of soils. Under certain circumstances, vegetation can also adversely influence soil stability Soil compaction affects interactions of water within the soil as well as the growth rate and rooting characteristics of vegetation. These, along with the increased tensile strength from the root systems and the armoring effect of plant components against erosion, are the primary influences of vegetation on soil stability Growing plants constantly remove water from the soil, increasing the matric suction and, thus, compacting the soil. This process can be visualized using the constitutive surface from soil mechanics (Figure 4). In Figure 4 the vertical axis represents the void ratio (e), the right axis is the matric suction ($u_a - u_w$), and the left axis is the net normal stress ($\sigma_n - u_a$) A soil compacted to 85 percent Proctor will have an

initial void ratio e_0. The plant roots will be extracting water from the soil, increasing the matric suction up to the wilting point. During this process the soil is said to be consolidating, reducing its void ratio from e_0 to e_f This means that plants will be creating a suitable soil density environment. When plants remove water from the soil through evapotranspiration, the associated matric suction increases the soil shear strength

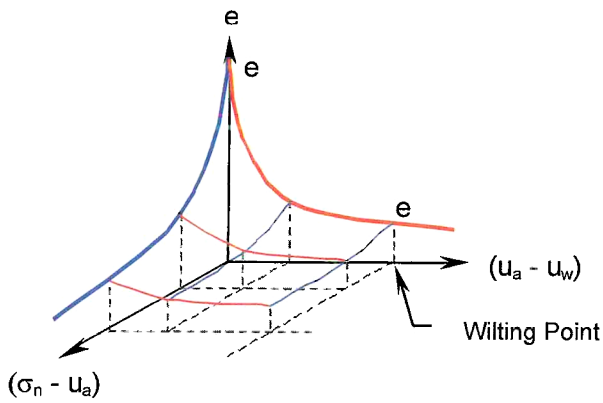

Figure 4. Constitutive surface of soils

Shear strength is also increased through root cohesion. The density of roots within the soil matrix, as well as their orientation, tensile strength, and length, affect the ability of soils to resist shear stress. As deformation begins to occur within a mass of soil, any roots that extend across the zone or plane of movement are placed under tension. Assuming that roots are well-anchored and do not pull out, the shear force is resisted by the tensile properties of the roots (Greenway 1987). In practice, the presence of roots often serves to significantly increase the strength of soils, in some cases by more than an order of magnitude.

The shear strength of unsaturated soils can be assessed within conventional slope analyses by using the total cohesion method. The total cohesion (c_T) includes three components effective cohesion (c'), suction cohesion (c_ψ) and root cohesion (c_R) (Silva 1999). The shear strength (τ) of the unsaturated soil may be written as

$$\tau = c' + c_\psi + c_R + (\sigma - u_a)\tan\phi$$

where $(\sigma - u_a)$ is the net normal stress and ϕ is the angle shearing resistance. This equation suggests that the soil shear strength is enhanced by evapotranspiration and the root biomass. The suction cohesion varies with changes in the soil moisture, making it difficult to predict. However, soils become stronger and the effective cohesion tends to increase due to the hysteresis phenomenon caused by the wetting and drying cycles. Specific plant communities can sometimes be designed and managed for a net export of water from a site.

Vegetation on slopes generally helps to promote infiltration of water into soils. This process commences when raindrops are intercepted by plants, funneling rainfall gently down stems, or allowing it to drip slowly off leaves rather than directly striking the soil surface, which often leads to crust formation due to compaction and reworking of exposed soil surfaces. Accumulated organic litter, combined with the roughness derived from living plant stems and foliage, helps to detain water, which might otherwise leave the area as runoff, thus increasing infiltration Organic matter that becomes incorporated into the soils also improves the capillarity of soils and enhances water retention.

Water is a limiting factor on many sites with erosion problems, and processes that help to increase the availability of water generally improve the survival and recruitment of vegetation. Root channels and biopores increase the conductivity of soils to allow efficient infiltration and drainage. While increased moisture levels almost always lead to an improvement in surface erosion problems, excess soil moisture is often the cause of deeper-seated soil instability Evaluation of this problem is complex, but under many circumstances the presence of vegetation can improve conditions by enhancing internal drainage of soils through root channels and biopores. At higher soil compaction rates, the increase of infiltration and conductivity rates of soil by vegetation becomes more pronounced, until the point when plants cease to develop effectively

A common best management practice, especially for slopes, is to establish and

maintain vegetative cover, typically of turf-forming grasses, in order to prevent surface erosion. Vegetation shields soils from rain splash and helps to prevent sheet and rill erosion. Vegetation-lined swales and vegetated riverbank and lakeshore treatments demonstrate similar benefits in more highly erosive settings. Roots that develop into dense mats perform as a separating filter layer to prevent fine particles from being removed by forces of traction and suction. Leaves and stems dissipate wave energy and slow flow in the zone nearest the soil surface, thus providing a localized reduction in forces. Vegetation can provide protection against surface erosion even in settings with highly compacted lower soil horizons, provided rooting can occur in the upper horizon.

Depending on the geomorphic context, roots can penetrate through discontinuities in soil and bedrock strata in order to provide special slope-stabilizing functions (Greenway 1987). An individual deeply rooted tree can reinforce a column of soils and anchor weaker mantle soils to more stable bedrock or compacted soils below The region of soils positioned upslope from the tree can also be stabilized through buttressing. When two or more points on a slope are similarly anchored, an additional zone upslope and between the two anchored columns of soil is stabilized by virtue of arching, which develops within the mantle soils. These effects are only noteworthy if roots are capable of penetrating from a less stable soil mantle to a more stable layer below Compaction that limits root penetration may prevent the attainment of these benefits.

The mass and leverage of vegetation, especially large trees, can also promote soil instability Surcharge loading associated with heavy trees can increase the likelihood of deep-seated failures in some cases. Trees that are wind-thrown or uprooted by flowing water can generate local turbulence that increases erosion and scour.

Generally, data show that vegetated soil slopes are more stable than unvegetated soil slopes in terms of geomorphic processes, and without consistent intervention most slopes naturally vegetate over time. Much of this stability is derived from soil structure, which is promoted by biological activity, rather than the attributes readily analyzed through conventional testing (Burmister 1965). Soil systems that are well-vegetated and maintain fundamental physical properties including normal ranges of bulk density can perform biogeochemical functions which poorly managed soils cannot (Parr et al 1992). Although these functions may not be a recognized priority in all current design considerations, they are becoming more widely understood. In river corridor and lakeshore settings, the role of healthy soil and vegetation buffers is well-appreciated and soil stability and erosion control functions have been successfully combined with water quality functions through bioengineering design.

PRACTICAL CONSIDERATIONS OF SOIL COMPACTION SPECIFICATIONS IN BIOENGINEERING

In general, a compaction between 80 and 85 percent of the standard Proctor maximum dry density optimizes slope stability with vegetation development and growth. If superficial erosion control is the only need; for example, when the angle of repose for unconsolidated soils can easily be met, then soil compaction may be a needless expense that is readily omitted from the design. In many situations, it may be appropriate to compact base soils over bedrock to a high degree for mass stability, and plant upper soil mantle layers for superficial erosion control. However, compacted soils should not inhibit lateral movement of water In all cases, soils that fail to be compacted to at least typical field bulk densities are vulnerable to considerable settlement and slumping as well as surface erosion, all of which pose short- and long-term problems for plant development.

There is some delay between the introduction of vegetation and the start of its active role. If the slope is in a critical condition at this stage, a high degree of compaction may protect the slope against failure, but root growth will be restricted. In this situation, the geotechnical requirements should be addressed using some initial safeguard against failure such as biodegradable and synthetic geotextiles, live or

dead wooden stakes, metal pins or spikes, soil nails, or a retaining structure. This will provide a temporary engineering function until vegetation takes root and grows. Stability analyses should be conducted on the short- and long-term slope condition, with and without the vegetation effects.

A soil compacted to 85 percent Proctor will not provide a significant engineering function to the stability of slopes, but it will provide a suitable environment for roots to grow However, the initial loose condition of the soil is only temporary

Achieving desired soil compaction rates always requires careful attention in the field, as exact soil textural characteristics and daily moisture levels are highly variable It is essential to test soils, using sufficient samples to adequately reflect the variability of the site in order to develop meaningful criteria for soil compaction. Tests of both particle size distribution and standard Proctor densities are helpful additions to standard agronomic tests. The adequacy of compaction procedures should be evaluated on a daily basis during construction (Figure 5). Otherwise, even the best-conceived specifications are unlikely to be consistently followed (Burmister 1965) Both the testing and inspection requirements should be identified in the specifications. Unwanted soil compaction, for instance on haul roads and staging areas, should also be addressed in the design and specifications.

CONCLUSIONS

In conclusion, vegetation measures and soil compaction standards are compatible provided that suitable densities are maintained to allow for root penetration. Design approaches must suitably account for site-specific geomorphic conditions as well as short- and long-term goals. When thoughtfully integrated, vegetation and soil compaction can serve as complementary design elements to provide highly effective treatments that function synergistically

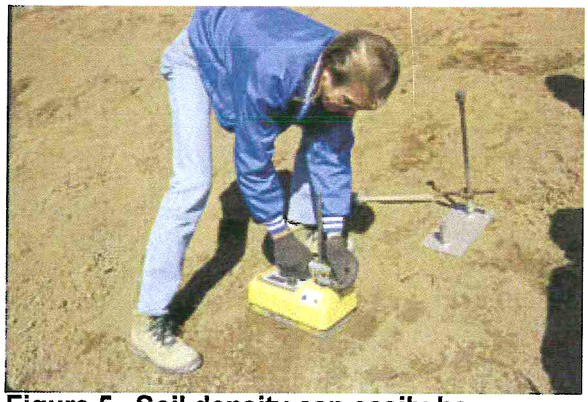

Figure 5. Soil density can easily be checked in the field using portable equipment such as a gamma probe

The wide range of ancillary attributes (water and air quality benefits, improved aesthetics, habitat functions, self-maintenance, and self-repair), and cost-effectiveness make bioengineering an attractive choice over standard geotechnical engineering. The knowledgeable specification and proper execution of soil compaction can greatly enhance the outcome of a range of bioengineering projects.

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> Goldsmith, W., Silva, M., and Fischenich, C (2001). "Determining optimal degree of soil compaction for balancing mechanical stability and plant growth capacity," ERDC TN-EMRRP-SR-26), U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/emrrp

GROWTH-LIMITING SOIL BULK DENSITIES AS INFLUENCED BY SOIL TEXTURE

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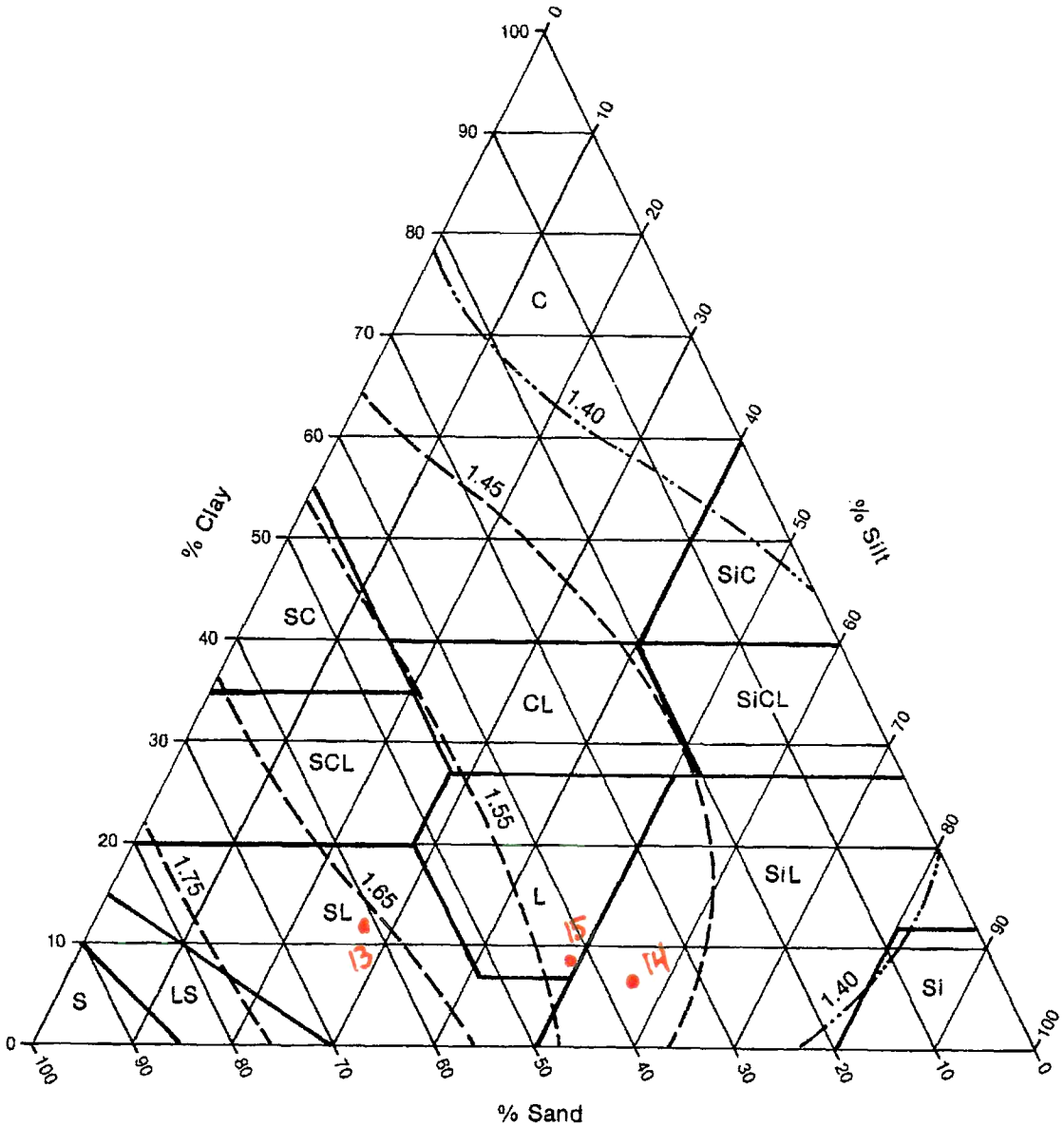

STEINER 13 1.67 g/cm³ = 104.3 lb/ft³
STEINER 14 1.50 g/cm³ = 93.6 lb/ft³
STEINER 15 1.53 g/cm³ = 95.5 lb/ft³

Figure 3.--Growth-limiting bulk density textural triangle.