Response to Comments

Response to DEQ Comments
Class 3 Permit Modification
Cell 16 ET Cover Design

Responses to Comments on Attachment 9d

1. *Deficiency:*

This attachment contains a large portion of Attachment 9c, and therefore is partially redundant.

Correction:

Revise this attachment by referring to Attachment 9c whenever possible. and only keeping the parts that are specific to Cell 16, such as figures, slope stability calculations, etc.. All sections that are addressed within the Attachment in response to the following comments also need to be included.

Response: In order to avoid redundancy, the Cell 16 design in Attachment 9d makes reference to the soil laboratory test report in Volume 2 of Attachment 9c. This has eliminated the largest area of overlap between the two attachments.

Changes have been made between Attachments 9c and 9d throughout the components, including the design report, construction quality assurance plan (CQA Plan), specifications, and calculations. The attached pdf file provides a comparison between Attachments 9c and 9d with the changes highlighted.

The overlap between Attachments 9c and 9d will be further reduced by eliminating the specifications in Attachment 9d. Instead, references have been added to Attachment 9d to refer to the specifications in Attachment 9c. The differences that exist between the specifications in Attachment 9c (Cells 14 and 15) and Attachment 9d (Cell16) are that two specification sections are not needed for Cell 16 construction:

- 33 24 14 Leachate and Well Riser Modification
- 40 14 49 HDPE Pipe

Nevertheless, the Attachment 9c specifications are otherwise the same and can be used for the Cell 16 cover under Attachment 9d. Statements have been added to the Attachment 9d Construction Quality Assurance Plan to clarify which sections of the specifications are not applicable to Cell 16.

We do not suggest further consolidation of other sections of Attachment 9d for the following reasons:

- The Attachment 9d design report should be clear to a reviewer, without requiring many referrals between two separate documents.

- The Attachment 9d CQA Plan includes revisions throughout the document, not discrete sections where differences occur like the specifications.

- Each calculation in Attachment 9d is new. Some references attached to calculations are duplicated in both Attachments 9c and 9d. However, our standards for engineering calculations call for including applicable references with each calculation.

2. Deficiency:

Section 6.1, page 26, 1st paragraph: The source of the Cell 16 design information is not included.

Correction:

Add that the “Cell 16 Engineering Report” in presented in Attachment 18b.

Response: A reference to Attachment 18b has been added.

3. Deficiency:

Section 6.1, page 27, Table 4: The information presented in this table does not agree with that used for the stability analysis as set forth on page 2/5 of Appendix D1.

Correction:

Revise so that the table and the appendix contain consistent information.

Response: The parameters in Table 4 have been checked for consistency with parameters used in the slope stability calculation in Appendix C1 (previously Appendix D1). Some parameters used in the analysis were not clearly called out in the calculation. The parameters listed in Table 4 have now been added to the calculation.

4. Deficiency:

Section 6.3, page 30, Table 5: No analysis appears to have been done for the West Slope

Correction:

An explanation of this omission is required.

Response: The configuration of the west slope is identical to the east slope, which was analyzed. Text has been added to Section 6.1 to clarify.

5. Deficiency:

Section 6.3, page 30, Table 5: For the East and South Slopes, many of the safety factor numbers shown in the columns do not correspond to the numbers presented in pages 4/5 and 5/5 of Appendix D1.

Correction:

The numbers either need to be the same or an explanation of the discrepancies provided. If the safety factor numbers in Table 5 are correct, then several of the safety factors are below acceptable limits. If the Appendix D1 safety factors are correct, then they are acceptable. Clarification as to which calculated values are correct is required before further comment can be made regarding acceptability.

Response: Corrections have been made to the factors of safety in Table 5. The slope stability calculation in Appendix C1 (previously Appendix D1) has been checked to verify that the calculations are correct. The table has been changed to match the calculation. The correct factors of safety provide acceptable results for slope stability.

6. Deficiency:

Section 7.1, page 30, Table 6: The information presented in this table does not agree with that presented in Appendix D2-1.

Correction:

Clarification is required.

Response: Corrections have been made to variables in Table 6. The table has been changed to match the calculation.

7. Deficiency:

Section 7.2, page 31, Table 7: The information presented in this table does not agree with that presented.in Appendix D2-2.

Correction:

Clarification is required.

Response: Corrections have been made to variables in Table 7. The table has been changed to match the calculation.

8. Deficiency:

Section 7.2, page 31, general comment: Gully formation often initiates at the grade break between a mild slope and a steeper slope. Once a "notch" develops at the grade break, the new gully begins to head-cut into the milder slope. One method to protect against this phenomenon is to protect the edge with a berm, collect the up-slope water, and discharge it across the steeper slope in a culvert or lined channel. Another is to "harden" the grade break edge with more gravel/rock to prevent notching. It is not clear how this issue is addressed.

Correction:

Explain how the calculations and design address this mild to steeper slope issue.

Response: The design calls for the entire cover to be hardened against erosion with the inclusion of 25 to 40 percent by weight of gravel in the upper 6-inch erosion protection soil layer. The cover design reduces the potential for gully formation by providing a configuration that evenly disperses runoff to avoid any areas of concentrated flow.

The runoff from the top deck will be low, due to the arid climate and low maximum precipitation intensity of 1.07 inches per hour from the design 100-year, 1-hour storm event. Also, the gully formation calculations for the gravel armored cover show that the armoring is effective at preventing gully formation. The gravel armor increases the critical distance for gully formation from 250 to 8,300 feet for the top deck and from 20 to 660 feet for the side slopes. The gravel armoring provided by the erosion protection layer will prevent gully formation over the transition between the slopes.

9. Deficiency:

Section 7.2, page 31, second paragraph: Does the critical distance for the top of the cover system stay the same as the one used for Cells 14 and 15?

Correction:

Verify this value and explain why it is the same (5,405 feet).

Response: Changes have been made to the text to include values from the Cell 16 gully formation calculation, replacing incorrect values that had been carried over from the original Cell 14 and 15 text. The critical distance for gully formation differs between the cover designs due to differences in slopes.

10. Deficiency:

Sections 7.2 and 7.3, general comment: For both soil loss and gully formation, the side slope analyses only appear to account for the precipitation falling on the side slope. In fact, the side slope will also have to withstand the effects of runoff coming from the top area. The top area runoff increases (probably substantially) the volume of water flowing over the side slope during a precipitation event. How do the calculations take this additional water into account?

Correction:

Explain how the calculations take this additional water into account.

Response: The top deck and side slope erosion calculations are performed separately for the cover top deck and side slope. The calculation methods use a single slope. This is accounted for by providing substantial factors of safety for the calculated erosion rates and maximum slope lengths. The erosion analysis for Cell 16 uses a conservative approach by designing for the highest runoff intensity from a 100-year, 1-hour storm event.

The runoff from the top deck onto the side slope provides a relatively small additional amount of runoff. The top deck of the cover amounts to 31 percent of the cover area, with 69 percent of the cover on side slopes. Also, the gradual 3.5 percent slope of the top deck will produce low runoff rates in comparison to runoff from the 3:1 side slopes. Because the small top deck area will produce low runoff rates in comparison to the runoff produced on the side slopes, the factors of safety in the erosion calculations provide sufficient protection to account for the top deck runoff contribution.

11. Deficiency:

Section 7.3, page 32, third paragraph: A fourth scenario needs to be evaluated: crust only with no vegetation. This would occur if the cover vegetation was removed due to fire, drought, disease or animal over-grazing.

Correction:

Add this scenario and determine the soil loss due to wind erosion.

Response: The wind erosion calculation in Appendix C3 (previously Appendix D3) has been revised to add a fourth scenario for a soil crust without vegetation. In the event of vegetation loss, the condition will be temporary.

12. Deficiency:

Appendix C, general comment: The Federal Clean Water Action National Pollution Discharge Elimination System appears to apply to this work. The construction documents should address the requirements of the US EPA Construction General Permit and Notice of Intent including compliance with an approved site-specific Storm Water Pollution Prevention Plan. The Owner may already have such a plan in place.

Correction:

Explain how these have been addressed or if they are required.

Response: The construction contractor for final cover construction will be required to address all regulatory requirements. This is addressed in Appendix A on Sheet 2 of the design drawings. Requirements for erosion control, environmental protection, and stormwater pollution prevention plan are addressed.

13. Deficiency:

Appendix D1, page 5/5, last paragraph: Figures 4 through 6 are referenced but not provided. Those figures need to be included with the calculations. Cell 16 needs to be included in all pertinent discussions, such as seismic impact zones.

Correction:

Add figures to this appendix and check that Cell 16 is added to all the descriptions.

Figures 4 through 6 were omitted from Appendix C1 (previously Appendix D1), but the figures have been added to a revised calculation.

Cell 16 is addressed in Appendix C1, which states that "USEI Cell 16 is located in a seismic impact zone."

14. Deficiency:

Appendix D2-1 and D2-2, general comment: The subject calculations need to be adjusted as required to address the previous comments regarding additional water contributed to the side slope from the top slope, notching at the grade break and contribution of snow melt.

Correction:

Adjust calculations as needed.

Response: These issues are addressed in the responses to Comments 8 and 10 above. The erosion and gully formation calculations show that the planned addition of 25 percent gravel to the cover surface soil will provide effective armoring to prevent erosion.

Revised Report

Final Cover Design for Cell 16
Permit Modification for Alternative Evapotranspiration Final Cover
US Ecology Idaho

Prepared for **US Ecology Idaho, Inc.**
Grand View, Idaho

August 19, 2011
Revised
February 24, 2012

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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 Cell 16 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
- Providing superior long-term performance and stability

The ET cover design for Cell 16 mirrors the design and performance evaluation of the approved ET cover design for Cells 14 and 15 and Trenches 10 and 11 in the current permit. 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 the performance of 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, 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 cover proposed for Cell 16 at USEI Site B is consistent with the ET cover designs currently approved for the site. 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. The Cell 16 ET cover provides a similar maximum height and side slopes as the previously approved designs. Slopes range from a minimum of 3.5 percent to a maximum of 33 percent (3:1 [3 horizontal to 1 vertical]).

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.

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

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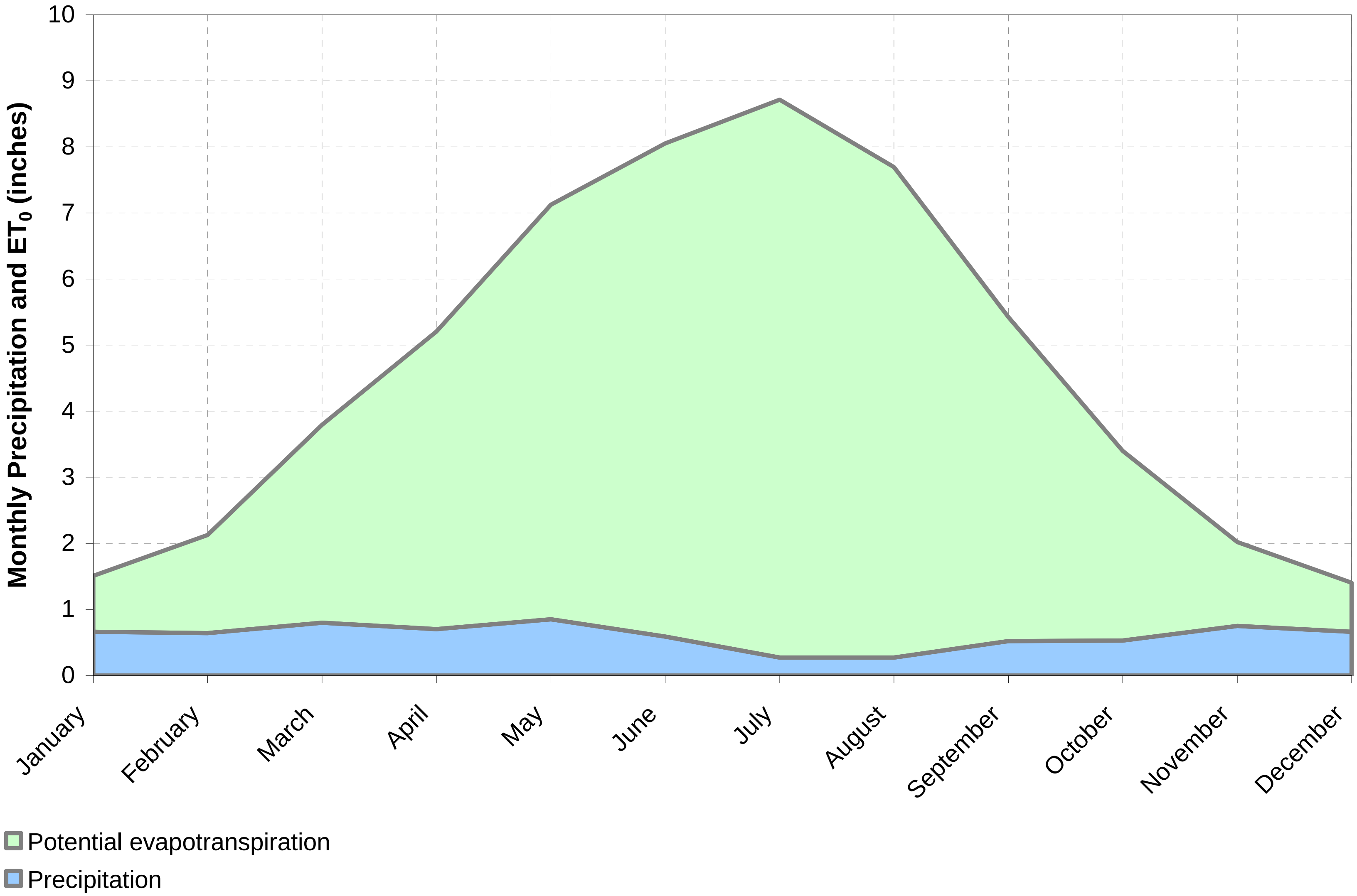


US ECOLOGY IDAHO

Average Monthly Total Precipitation and Potential Evapotranspiration

Daniel B. Stephens & Associates, Inc.

8/19/11

Figure 1

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 ET 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.

To conservatively simulate high-precipitation conditions, 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 Cell 16 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 cover for Cell 16 requires a minimum thickness of 5 feet. 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 in Section 4.
- Information on cover slopes and thickness is provided in Section 5.
- Slope stability is discussed in Section 6.
- Erosion protection is discussed in Section 7.
- Information on the vegetation plan is provided in Section 8.
- Engineering design drawings of the final covers are provided as Appendix A.
- A construction quality assurance (CQA) plan for proper selection and placement of ET cover soil is provided in Appendix B.
- Engineering calculations of slope stability, wind and water erosion, and critical density of soils are included in Appendix C.

Also applicable to this permit modification for the USEI Cell 16 final cover are portions of USEI permit Attachment 9c, which addresses final cover designs for USEI Cells 14 and 15. These applicable sections of USEI permit attachment 9c include:

- Construction specifications in Appendix C
- Complete soil laboratory test results for the soil samples tested in 2008 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 Cell 16 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 ET covers for disposal cells that have been closed and for cells with ET covers to be constructed in the future. The following subsections 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 USEI Site B 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 Section 3.2.

3.2 40 CFR §264.310

As part of 40 CFR §264.111, RCRA cell closure must comply with Section 264.310, which 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 USEI Site B 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 USEI Site B. 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 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 Cell 16 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

In 2008, DBS&A tested soils from the USEI Site B facility to determine their adequacy as a borrow source for construction of ET covers. Adequacy was determined by comparing the results of the 2008 soil 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 soils with characteristics indicative of performing as well as 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.

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 Cell 16, from a soil stockpile located adjacent to Cell 15, and from 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 a lower percentage of 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.

Table 1. Soils and Selected Testing Results from 2008

Sample (compaction)	USCS Classification	Water Holding Capacity (cm^3/cm^3)	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
K_{sat} = Saturated hydraulic conductivity
cm/s = Centimeters per second

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 (cm/s) (ASTM D5084)
- Moisture retention characteristic curve and van Genuchten parameters (ASTM D6836):
  - alpha (α)
  - N
  - residual moisture content (θ_r)
  - saturated moisture content (θ_s)

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 (Table 1). 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) (Appendix C3). 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 soil GLBDs were obtained from the DBS&A laboratory report particle size analysis plots (Appendix E in Volume 2 of USEI permit Attachment 9c for Cells 14 and 15).

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 of 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.

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 in Table 2 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.

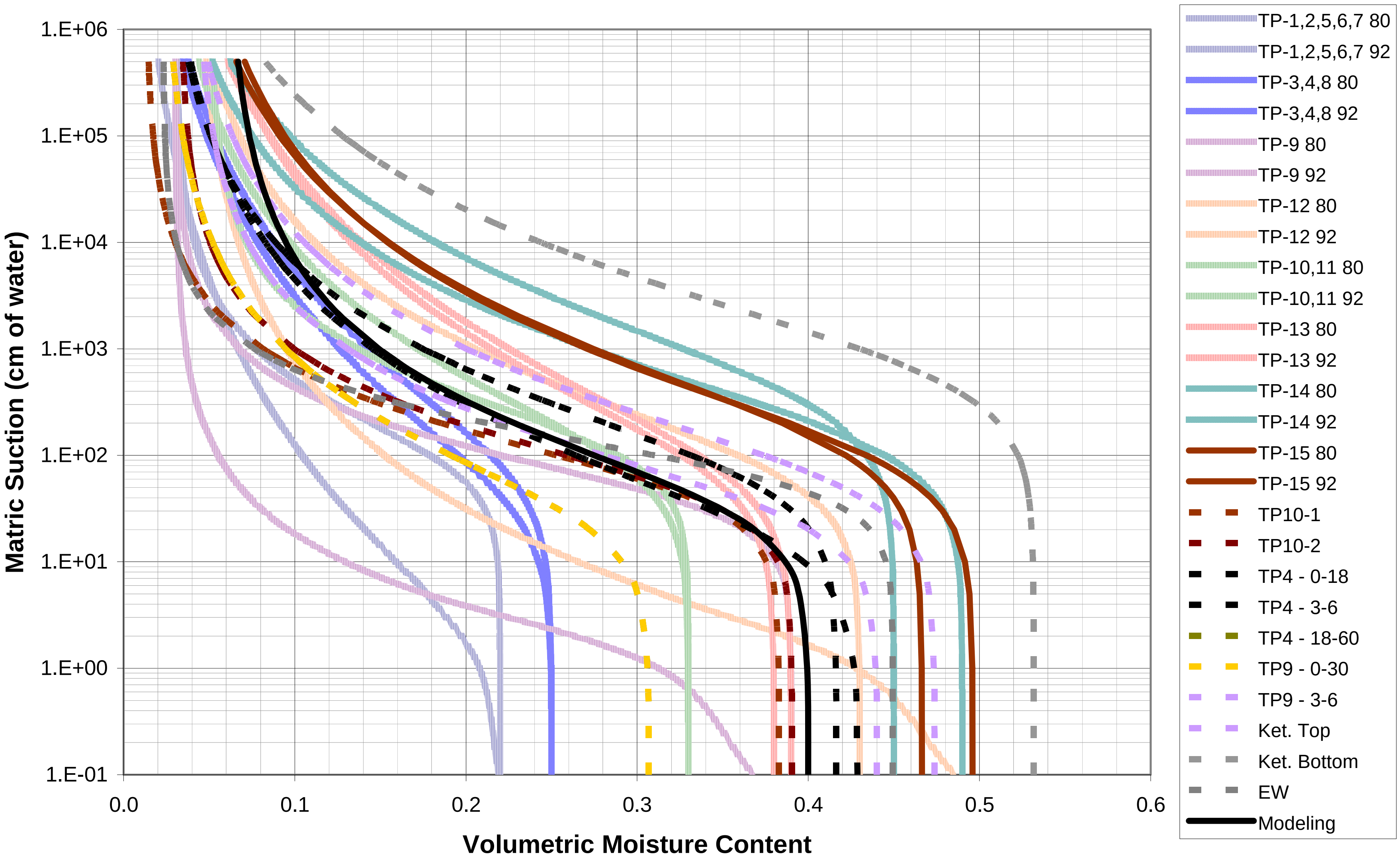
Table 2. Soils and Selected Testing Results from 1998

Sample	USCS Classification	Water Holding Capacity (cm^3/cm^3)	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
K_{sat} = Saturated hydraulic conductivity
cm/s = Centimeters per second

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.

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.



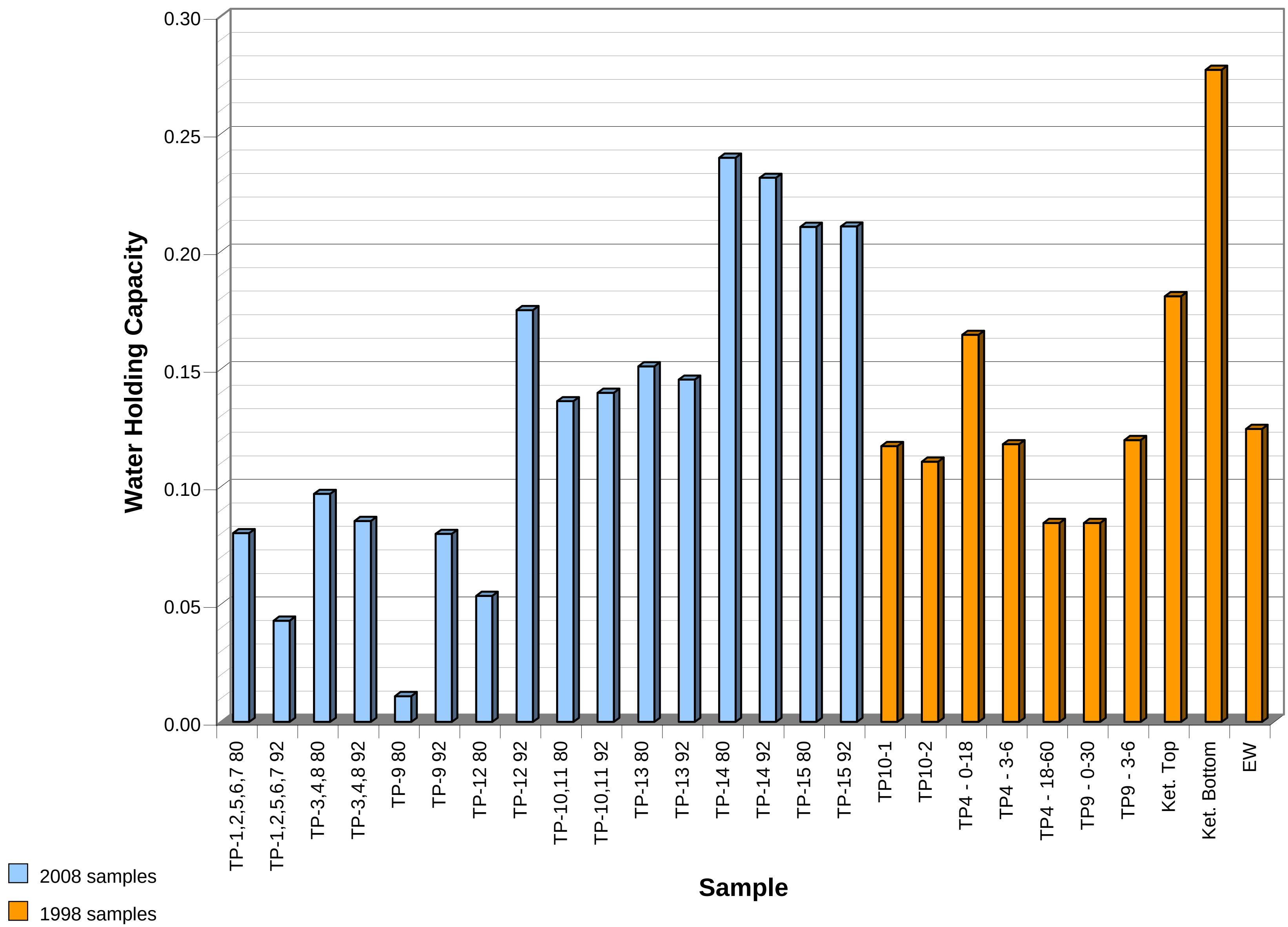
US ECOLOGY IDAHO

Moisture Characteristic Curves for All Soil Samples

Figure 2

Daniel B. Stephens & Associates, Inc.

8/19/11



US ECOLOGY IDAHO

Water Holding Capacities

Figure 3

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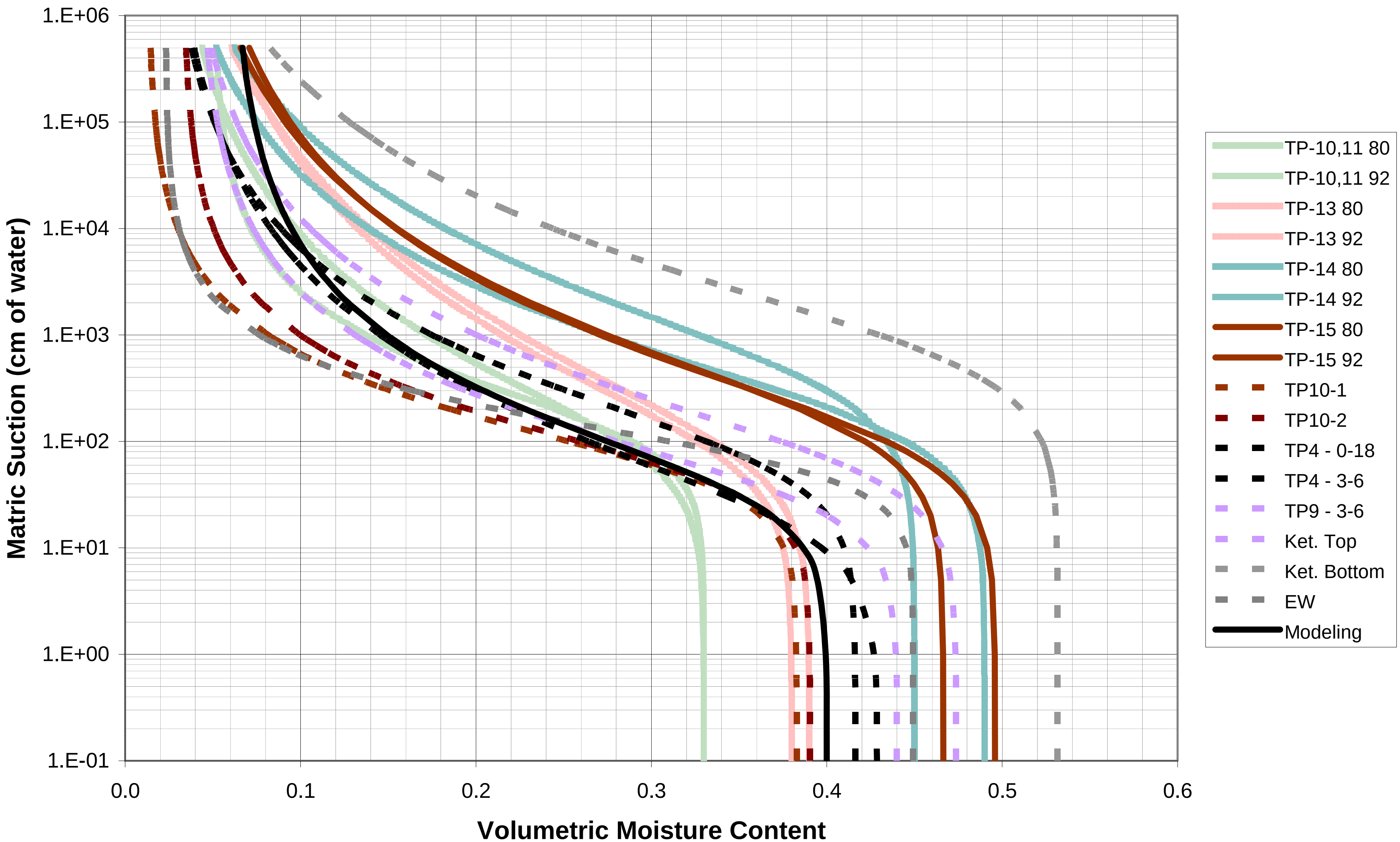
8/19/11



US ECOLOGY IDAHO

Moisture Characteristic Curves for Soils with Acceptable Water Holding Capacity

Daniel B. Stephens & Associates, Inc.

8/19/11

Figure 4

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 conductivities 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.

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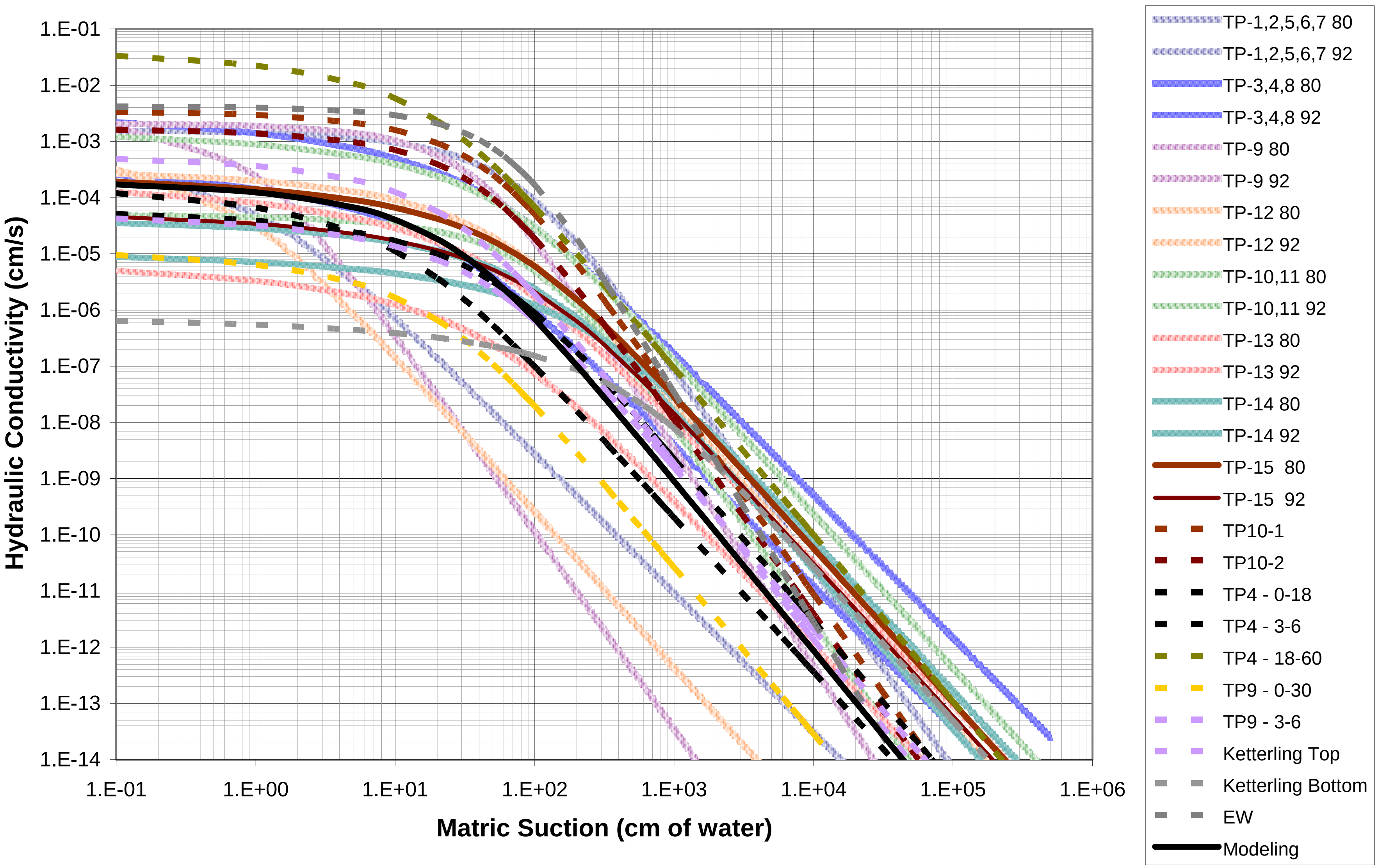

US ECOLOGY IDAHO

Hydraulic Conductivity Curves for All Soil Samples

Figure 5

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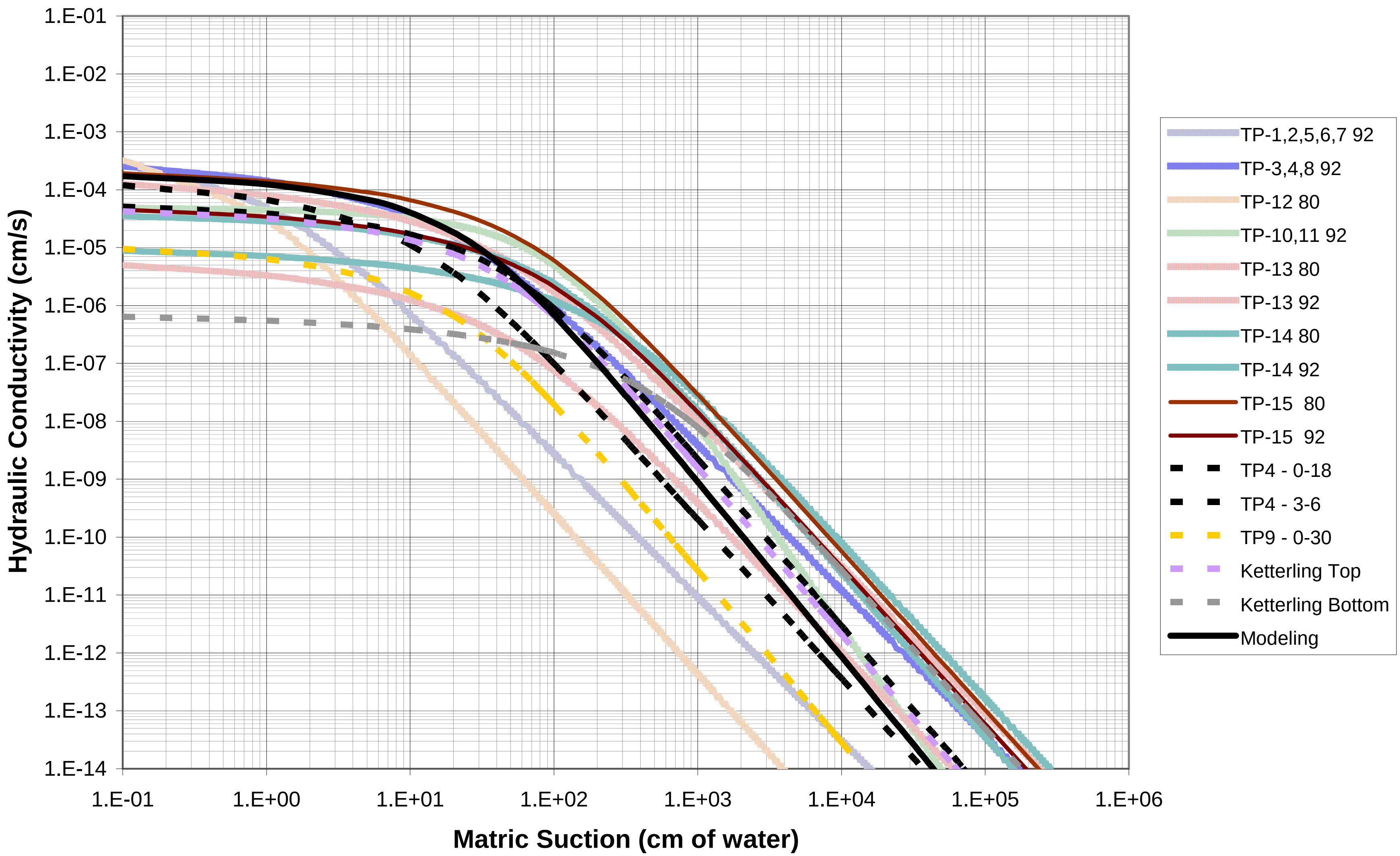

US ECOLOGY IDAHO

Hydraulic Conductivity Curves for Soils with Acceptable Hydraulic Conductivity Values

Figure 6

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8/19/11

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

This section describes the design basis for the Cell 16 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 16 cover are provided in Appendix A. The drawings include details of the cover thickness and slopes, cover grading plan, and cross sections.

Drawing Sheet 8 (Appendix A) provides a typical final cover cross section for Cell 16. 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.

The top deck of the final cover will be graded to drain at a slope of 3.5 percent. The final lift of waste will also be placed on a slope of 3.5 percent, serving as the subgrade for the final cover. Cover side slopes are a maximum of 33 percent (3:1). Near the toe of the side slopes, the slope transitions to a less steep 28.57 percent (3.5:1) slope to extend the side slope over the liner anchor trench with a minimum 5-foot thickness. At the south end of Cell 16, the 5-foot-thick ET cover will extend to the edge of the liner, maintaining a minimum 3.5 percent slope to promote positive drainage away from the cover.

Drawings 16-09-01, -02, and -03 show that the waste limit, projected to the geomembrane liner, is set back 9 feet from the liner crest. Drawing 16-09-01 provides the coordinates of the liner crest. The liner crest serves as the reference point for the location of the cover toe.

Based on the 5-foot minimum cover thickness overlying the waste and lined area, 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. The perimeter bench around Cell 16 is 30 feet wide measured from the liner crest. As designed, the cover extension distance onto the perimeter bench is 21 feet, maintaining a 9-foot-wide perimeter access road.

6. Cover Slope Stability

6.1 Calculation Approach

ET cover slope stability analysis (Appendix C1) was performed on profiles of Cell 16. Global stability of the completed landfill with the cover components and consideration for deep seated failures into the liner system and the foundation materials are addressed in the Cell 16 Engineering Report (Attachment 18b). Extensive laboratory testing and analysis has been performed in identifying the critical shear strength envelopes for the project's geosynthetic liner components.

The cover slope stability analyses were performed on profiles of Cell 16 at locations representing the maximum height of the closed cell. The analyses included cross section profiles through the cover, waste, and liner for the north, east, and south sides of Cell 16, where there are design differences. The east and west sides of Cell 16 represent the same configuration.

Slope stability analyses were performed using Slope/W 2007, GeoStudio Version 7.17 (Geo-Slope, 2007) for static and pseudo-static, limit equilibrium, slope stability analyses. The analyses employed auto-search-generated circular critical surfaces with optimization and block-designated auto-search critical surfaces with optimization. USEI Cell 16 is 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 seismic analyses used the local bedrock acceleration coefficient of 0.11 g, which also represented the ground surface acceleration at the site.

The cover slope stability analyses considered the geometry and strength of the cover material and waste. A liner system was considered in the section geometry for completeness, although the intent of the analyses was stability of the cover components. Parameters representing these materials are presented in Table 4.

The waste characteristics for USEI were described by Washington Group International, Inc. (2002) as stabilized and unstabilized soil-like material. 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.

Table 4. Material Characteristics Used in Slope Stability Analysis

Material	Friction Angle (degrees)	Cohesion (lb/ft^2)	Unit Weight (lb/ft^3)
ET cover [a]	30	0	101.6
Natural subgrade [b]	36	800	115
Waste [b]	30	125	115
Compacted clay liner [b]	22	60	94
Common fill [b]	31	1,000	124.8
Liner	15	292.4	1.0

[a] ET soil strength estimated as an average of friction angles obtained from direct shear tests on borrow source soils from TP-009, TP-035, and TP-143 (DBS&A, 2011).
[b] Properties 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

Static and seismic (pseudo-static) 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. Figure 4.4(a) in U.S. EPA (1995) estimates a maximum acceleration of 0.11 g for a maximum acceleration in rock of 0.11 g, assuming stiff soil conditions and/or deep cohesionless soils. 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.

6.2 Analysis Description

For this analysis, DBS&A used the USGS PGA of 0.11 g. The slope stability analysis used auto-located circular slip surfaces and range-specified block masses. 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 factors of safety for the auto-located circular slip surfaces and range-specified block masses were determined by optimizing the approximated critical slip surface. In Slope/W, optimization is a technique that incrementally alters segments of the approximated critical slip surface to find the shape with the lowest factor of safety.

Block failure analysis was performed in Slope/W by designating the locations for the left and right blocks of potential intersections of the bottoms of the sliding mass. The critical block is determined by the algorithm and then optimized for the lowest factor of safety.

6.3 Results and Discussion

The factors of safety determined from the analyses using various standard solutions for limit equilibrium analysis are presented in Table 5. The complete slope stability results are provided in Appendix C1.

Based on these analyses, DBS&A determined that ET soil cover with a minimum friction angle of 30 degrees and slopes not exceeding 3:1 will maintain proper stability for Cell 16.

Table 5. Slope Stability Factors of Safety

Acceleration Method [a]	Minimum Depth (feet)	Factor of Safety: Static	Factor of Safety: Acceleration Coefficient 0.11 g
North Slope			
Auto Search Circular Failure Planes with Optimization			
Morgenstern-Price	4	1.73	1.29
Ordinary	4	1.73	1.30
Bishop	4	1.77	1.32
Janbu	4	1.73	1.29
Block Failure Planes with Optimization			
Morgenstern-Price	1	1.73	1.29
Ordinary	1	1.73	1.30
Bishop	1	1.78	1.33
Janbu	1	1.73	1.29
East Slope			
Auto Search Circular Failure Planes with Optimization			
Morgenstern-Price	4	1.82	1.34
Ordinary	4	1.81	1.35
Bishop	4	1.85	1.37
Janbu	4	1.82	1.34
Block Failure Planes with Optimization			
Morgenstern-Price	1	1.82	1.34
Ordinary	1	1.82	1.35
Bishop	1	1.84	1.36
Janbu	1	1.81	1.34
South Slope			
Auto Search Circular Failure Planes with Optimization			
Morgenstern-Price	4	1.73	1.29
Ordinary	4	1.73	1.30
Bishop	4	1.77	1.32
Janbu	4	1.73	1.29
Block Failure Planes with Optimization			
Morgenstern-Price	1	1.74	1.31
Ordinary	1	1.73	1.33
Bishop	1	1.77	1.35
Janbu	1	1.73	1.31

[a] Morgenstern-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. Morgenstern-Price satisfies both moment and force equilibrium. For a thorough description, see Geo-Slope International Ltd. (2007).

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 C2. 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 C2-1) 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 0.2 ton per acre per year on the top of cover and 4.18 tons per year on the side slopes with application of 4 tons per acre of mulch, and 0.04 ton per acre per year on the top of cover and 0.79 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

Variable	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 per acre, tacked down (C)	0.05
Cover subfactor 25% gravel amended soil (C_f)	0.55
Conservation support practice factor (not used) (P_c)	1
Organic matter (OM)	0.01
Slope steepness and length factor (LS)	0.58
Slope steepness and length factor (LS_2)	11.96
Mean soil erodibility factor (K)	0.41

7.2 Critical Distance of Gully Formation

The calculation of critical distance of gully formation (Appendix C2-2) 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. 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 420 feet for a 3:1 side slope, exceeding the maximum slope length for the cover design for Cell 16. Table 7 provides input values used in this calculation.

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

Variable	Value
Runoff intensity (q_s)	1.07 inches per 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)	2.0° (3.5 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 660 feet for the gravel-amended soil and 20 feet for the unamended soil. The critical distance for the top of the cover system was determined to be 8,300 feet for the gravel-amended soil and 250 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 C2-3.

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, four 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.
4. Crust has developed, but vegetation is lost.

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, 0.3 ton per acre per year, and 9.1 tons 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 formation of non-erodible materials (desert pavement) on the cover. The fourth value accounts for temporary vegetation loss due to a cause such as a brush fire, with desert pavement still intact.

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 Cell 16 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 lb/acre mulch, 50 lb/acre tackifier, and 400 lb/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 B

CQA Plan

Construction Quality Assurance Plan

US Ecology Idaho

Final Cover Design for Cell 16

August 19, 2011
Revised
February 24, 2012

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Attachment

1. Scope

This Construction Quality Assurance Plan (CQA Plan) is intended for use during construction of the final cover system for Cell 16 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
- Revegetation
- QA/quality control (QC) testing and inspection

The final cover design for Cell 16 includes 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

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 referenced in this document refer to engineering design drawings for construction of the USEI Cell 16 final cover. Project specifications referenced in this document refer to the specifications in Attachment 9c of USEI's permit, which are applicable to final cover construction for USEI Cells 14, 15, and 16. 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

The USEI final covers will consist of soil installed over waste disposal Cell 16. The cover system profile will include the following (from the bottom up):

- Existing subgrade consisting of the following:
  - Waste
  - Intermediate cover
  - Other existing soil
- Select cover subgrade soil (in limited areas at the toe of side slopes)
- 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.

Specifications in USEI permit Attachment 9c applicable to the final cover system for USEI Cell 16 include:

- Section 31 00 00 - Earthwork
- Section 31 10 00 - Site Clearing
- Section 31 32 00 - Cover System Components
- Section 31 38 01 -Surface Rock Durability Requirements
- Section 32 92 19 - Vegetation and Seeding

Specifications in permit Attachment 9c not applicable to the final cover system for USEI Cell 16 include:

- Section 33 24 14 - Leachate and Well Riser Modification
- Section 40 14 49 - HDPE Pipe

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

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. 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.

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.
- 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 Cell 16, 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 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 cover for Cell 16 will be an ET cover 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. 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.

7. 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.

7.1 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

7.2 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)

Attachment 1

Soil Rooting Medium
Sampling and Analysis Plan

Soil Rooting Medium Sampling and Analysis Plan
Soil Characterization for Evapotranspiration Cover
US Ecology Idaho Cell 16

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 Cell 16.

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

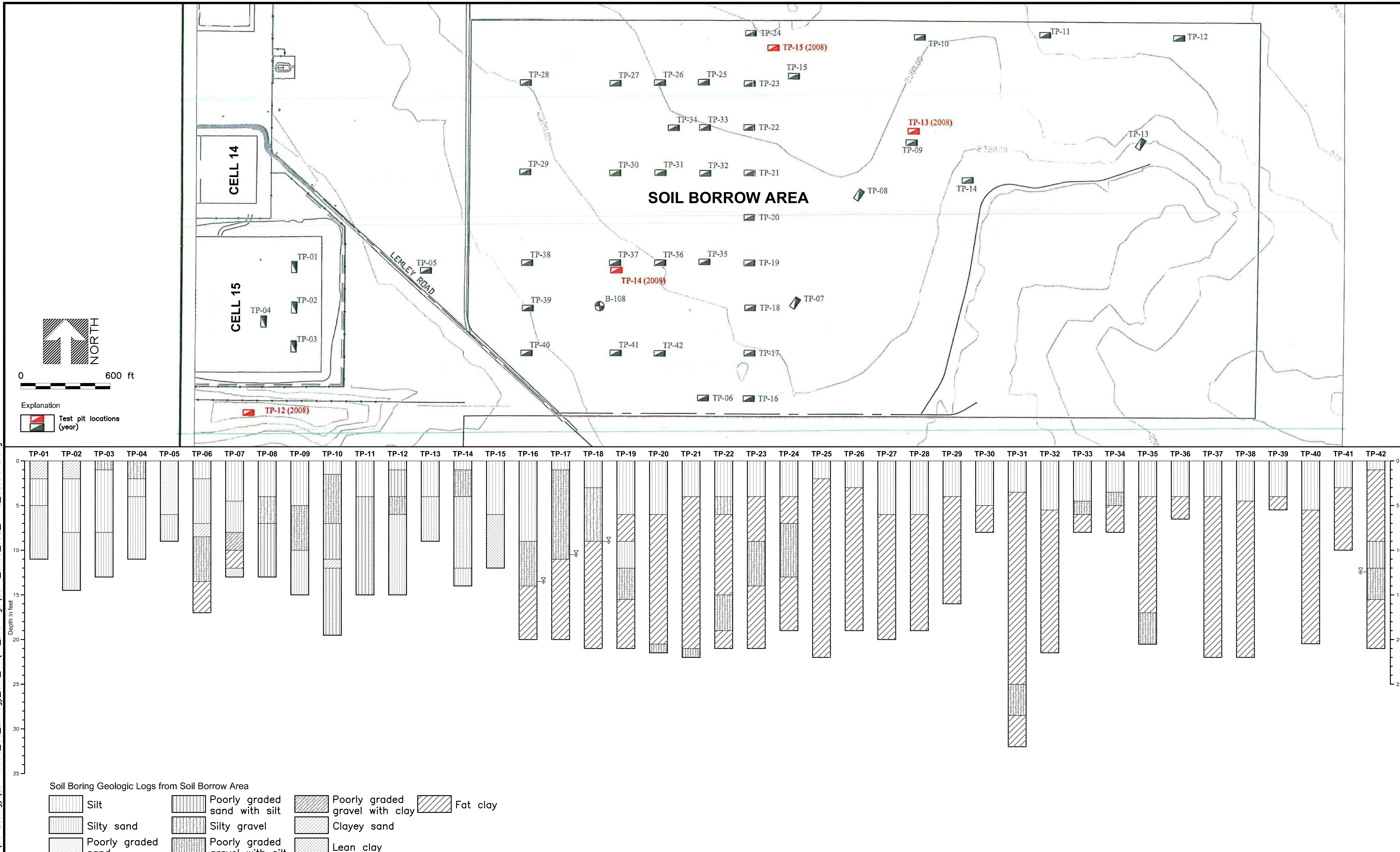
[a] Testing frequencies for saturated hydraulic conductivity and water holding capacity designated at 1 per 10,000 yd^3 are dependent on the variability of the borrow source material. If the borrow source soil shows significant variability, then the testing frequency will be increased to 1 per 5,000 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 700,000 yd^3 of soil will be required to construct covers for Cell 16. The soil rooting medium layer in the final covers requires approximately 630,000 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

A soil borrow area for the Cell 16 cover will be identified to obtain suitable on-site soil from within US Ecology property. The borrow area will be the Steiner property where suitable soil has been identified or another area at US Ecology. The Steiner property soil borrow area illustrated on Figure 1-1 is approximately 318 acres. 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 10-foot depth of excavation, soil rooting medium samples will need to be collected from an area of approximately 40 acres, selected within the proposed borrow area. At a testing rate of 1 per 5,000 yd^3 of soil rooting medium, approximately 126 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 63 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.
8–19–11 JN ES11.0086

Steiner Borrow Area for ET Cover Soil

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 40 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 115-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

Calculations

Appendix C1

Slope Stability Calculations

Daniel B. Stephens and Associates - Calculation Sheet

Project Name: USEI Cell 16
Project Number: ES11.0086.00
Calculation Number: 1
Number of Sheets:

Calculation Performed By: REP ***Date:*** February 19, 2012

Calculation Checked By: ***Date:***

Status (Draft or Final):

Objective of Calculation:

This calculation is performed to determine the stability of the final geometry of USEI cell 16 using the proposed cover design.

Assumptions:

1) Stability of the landfill may analyzed by representative, two-dimensional, cross sections. Stability is predictable by methods of limit equilibrium analysis. Seismic stability may be predicted by pseudo-static analysis.

2) Saturated conditions were not considered in the analysis, due to the nature of the waste and depth to the groundwater.

3) The peak bedrock acceleration was obtained from the USGS National Seismic Hazard Maps, 2008, 2% probability of exceedance in 50 years (reference 1).

4) 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.

References:

1) USGS National Seismic Hazard Map, 2008.

2) Gundle/SLT Environmental, Inc. (GSE). 2006. GSE Technical Note 17. Direct Shear & Friction Angle Testing for GSE Membranes.

3) Koerner, R. M. 1990. *Designing with Geosynthetics.* Second Edition. Prentice Hall, New Jersey.

4) USEPA, 1995. RCRA Subtitle D (258) Seismic design Guidance for Municipal Solid Waste Landfill Facilities. EPA/600/R-95/051. Washington D.C.

5) Washington Group International, Inc. 2002. Engineering Report for Landfill Cell 15 - Grand View Facility. Boise, Idaho.

6) GeoStudio 2007 (Version 7.12 Build 4250). Geoslope International, Ltd., Calgary, Alberta, Canada.

Variables:

$\delta_1 := 26\cdot deg$ 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 3 - 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 3 - 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 cell 16 is 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 4).

$a_{max} := 0.11\cdot g$ $a_{max} = 3.539\cdot\frac{ft}{s^2}$ Peak Ground Acceleration (PGA) value from the USGS National Seismic Hazard Maps, 2008
2% probability of exceedance in 50 years (reference 1)

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 4, 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 0.11g and 0.2g were used in this analysis.

$a_{max} := 0.2\cdot g$ $a_{max} = 6.435\cdot\frac{ft}{s^2}$

Other material properties used in the analysis are listed in the following table (see Reference 5).

Material	Friction Angle (degrees)	Cohesion (lb/ft^2)	Unit Weight (lb/ft^3)
ET cover	30	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
Liner	15	292.4	1.0

Slope Stability Calculations Using Slope/W (reference 6)

Static and seismic slope stability calculations were performed for the cross-sections presented in Figures 1, 2, and 3.

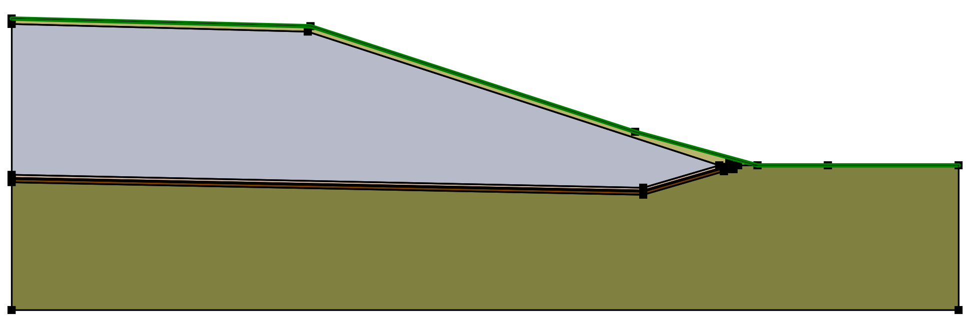


Figure 1. Profile of Cell 16 north slope used for stability analysis.

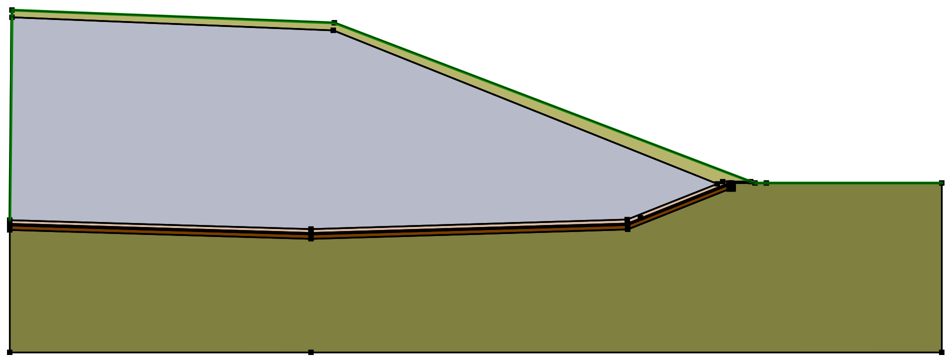


Figure 2. Profile of Cell 16 east slope used for stability analysis.

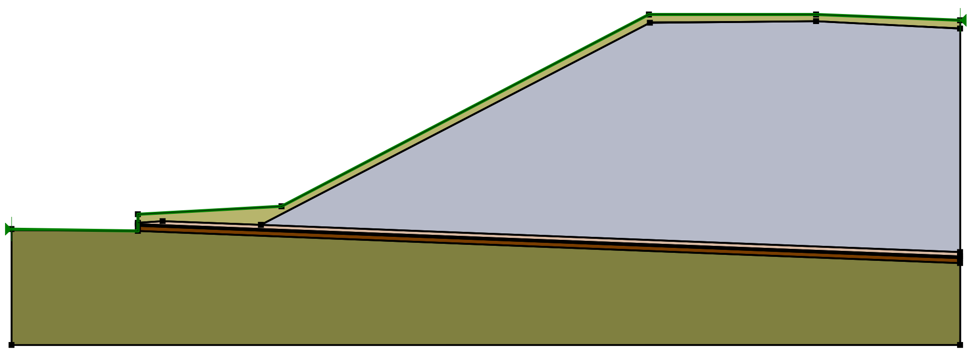


Figure 3. Profile of Cell 16 south slope used for stability analysis.

Summary of Minimum Factors of Safety for North Slope

Method	Static FS	Seismic (0.11g) FS	Seismic (0.20g) FS	Analysis
Morgenstern-Price	1.73	1.29	1.09	Circular/Auto Search
Ordinary	1.73	1.30	1.10	Circular/Auto Search
Bishop	1.77	1.32	1.12	Circular/Auto Search
Janbu	1.73	1.29	1.09	Circular/Auto Search
Morgenstern-Price	1.73	1.29	1.09	Block
Ordinary	1.73	1.30	1.10	Block
Bishop	1.78	1.33	1.13	Block
Janbu	1.73	1.29	1.09	Block

Summary of Minimum Factors of Safety for East Slope

Method	Static FS	Seismic (0.11g) FS	Seismic (0.20g) FS	Analysis
Morgenstern-Price	1.82	1.34	1.13	Circular/Auto Search
Ordinary	1.81	1.35	1.14	Circular/Auto Search
Bishop	1.85	1.37	1.16	Circular/Auto Search
Janbu	1.82	1.34	1.13	Circular/Auto Search
Morgenstern-Price	1.82	1.34	1.13	Block
Ordinary	1.82	1.35	1.13	Block
Bishop	1.84	1.36	1.14	Block
Janbu	1.81	1.34	1.13	Block

Summary of Minimum Factors of Safety for South Slope

Method	Static FS	Seismic (0.11g) FS	Seismic (0.20g) FS	Analysis
Morgenstern-Price	1.73	1.29	1.09	Circular/Auto Search
Ordinary	1.73	1.30	1.10	Circular/Auto Search
Bishop	1.77	1.32	1.12	Circular/Auto Search
Janbu	1.73	1.29	1.09	Circular/Auto Search
Morgenstern-Price	1.74	1.31	1.13	Block
Ordinary	1.73	1.33	1.15	Block
Bishop	1.77	1.35	1.16	Block
Janbu	1.73	1.31	1.15	Block

Conclusion

A 3:1 (horizontal:vertical) sloped ET soil cover will be adequately stable against typical seismic events expected at this site. Selected failure surfaces are displayed in Figures 4 through 6. Specific report analyses are attached to this calculation. An additional discussion is provided in the permit report.

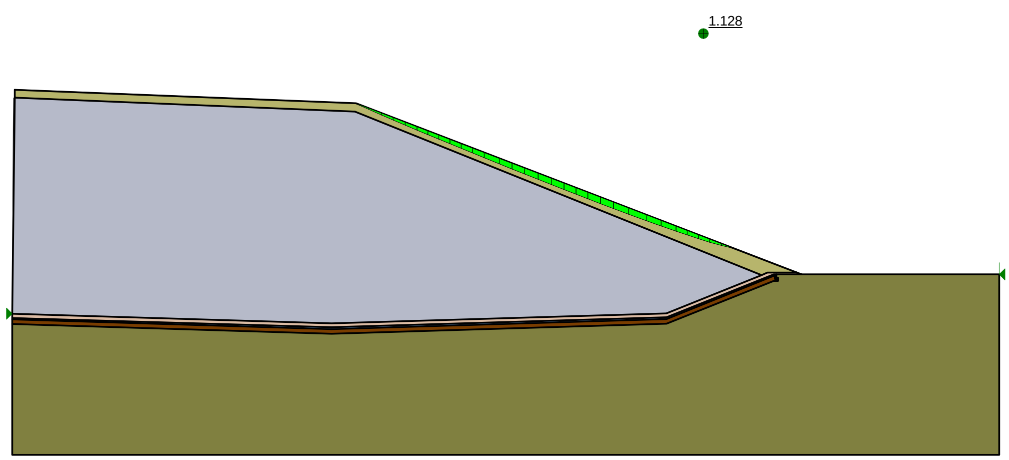


Figure 4. Failure surface and factor of safety for circular seismic (0.20g) analysis of east slope.

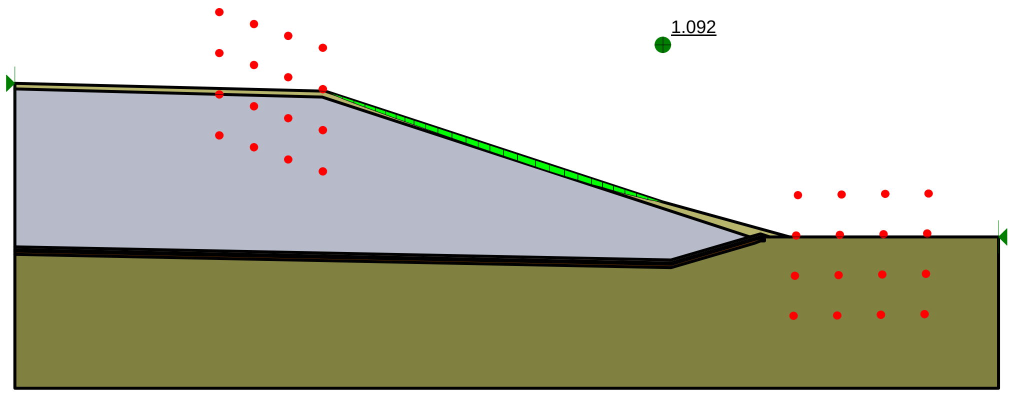


Figure 5. Failure surface and factor of safety for circular seismic (0.20g) analysis of east slope.

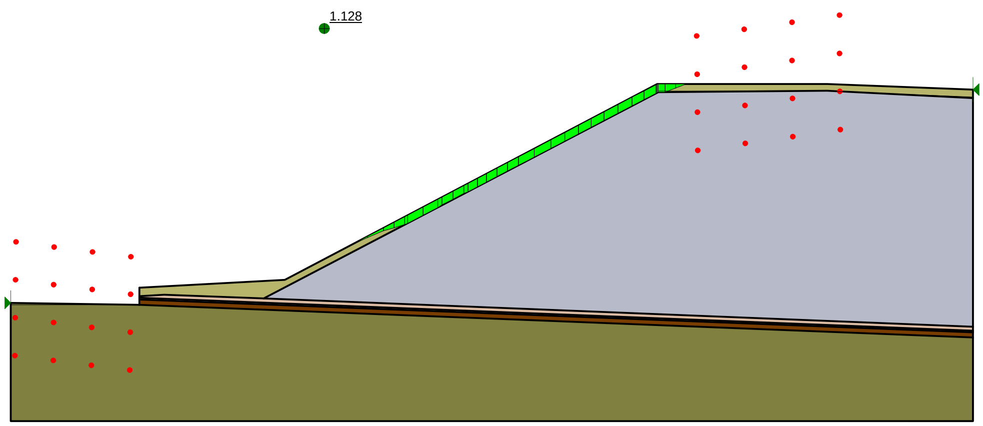
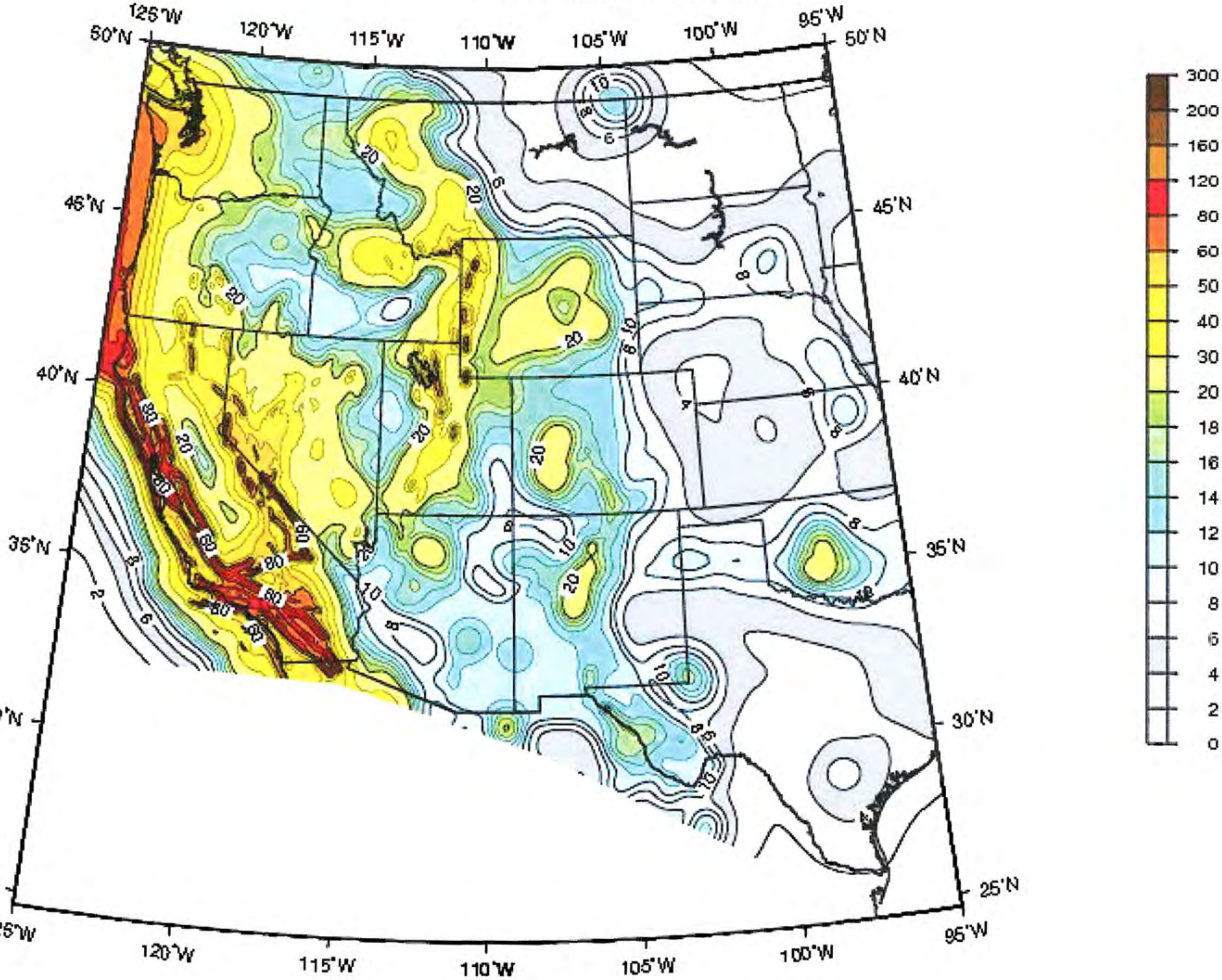


Figure 6. Failure surface and factor of safety for circular seismic (0.20g) analysis of east slope.

Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002rev



REFERENCE 1

REFERENCE 2

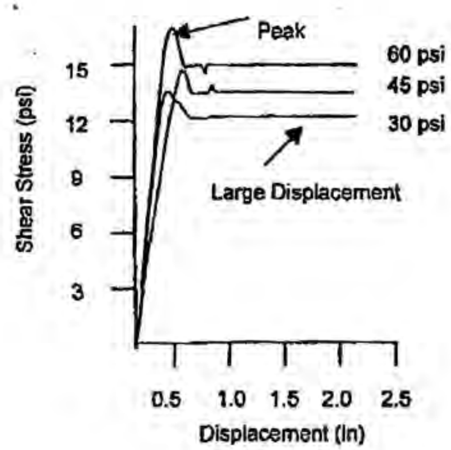
GSE®

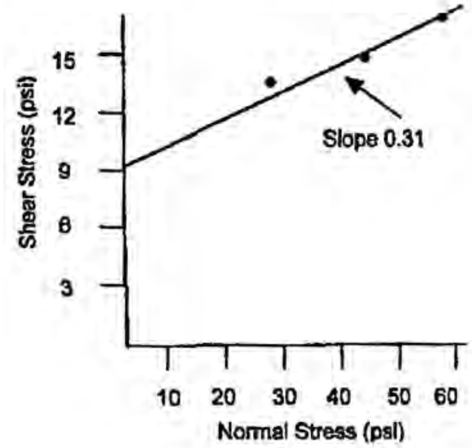
Technical Note

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.

North America	GSE Lining Technology, Inc.	Houston, Texas	800 435 2008	281 443 8564	Fax: 281 230 8650
South America	GSE Lining Technology Chile S.A.	Santiago, Chile		56 2 595 4200	Fax: 56 2 595 4290
Asia Pacific	GSE Lining Technology Company Limited	Bangkok, Thailand		66 2 937 0091	Fax: 66 2 937 0097
Europe & Africa	GSE Lining Technology GmbH	Hamburg, Germany		49 40 767420	Fax: 49 40 7674234
Middle East	GSE Lining Technology-Egypt	The 6th of October City, Egypt		202 2 828 8888	Fax: 202 2 828 8889

www.gseworld.com

SUPPLEMENT TO REFERENCE 2

A recommendation to use peak shear strengths for geosynthetic interface design

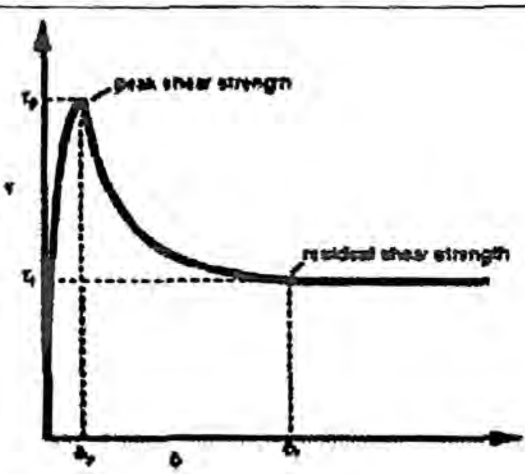
Since many geosynthetic designers are also geotechnical engineers, it is only natural to consider shear stress versus shear strain curves beyond peak strength into large-deformation, or even residual, strength conditions. A. Casagrande in the 1930s defined residual shear strength from triaxial soil testing 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-

By Robert M. Koerner, Ph.D., P.E., NAE, and H. L. Bowman, Ph.D.

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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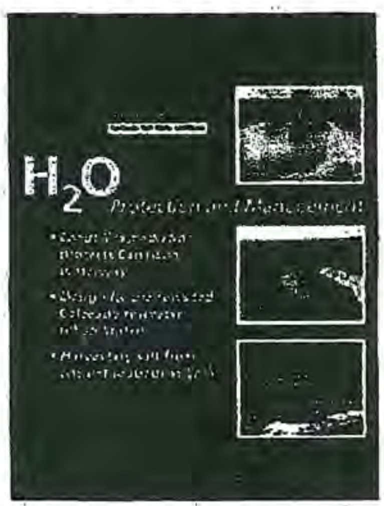

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REFERENCE 3

Designing with Geosynthetics

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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 ($\phi = 30°$)	Ottawa sand ($\phi = 28°$)	Mica schist sand ($\phi = 26°$)
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 ($\phi = 30°$)	Ottawa sand ($\phi = 28°$)	Mica schist sand ($\phi = 26°$)
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 4

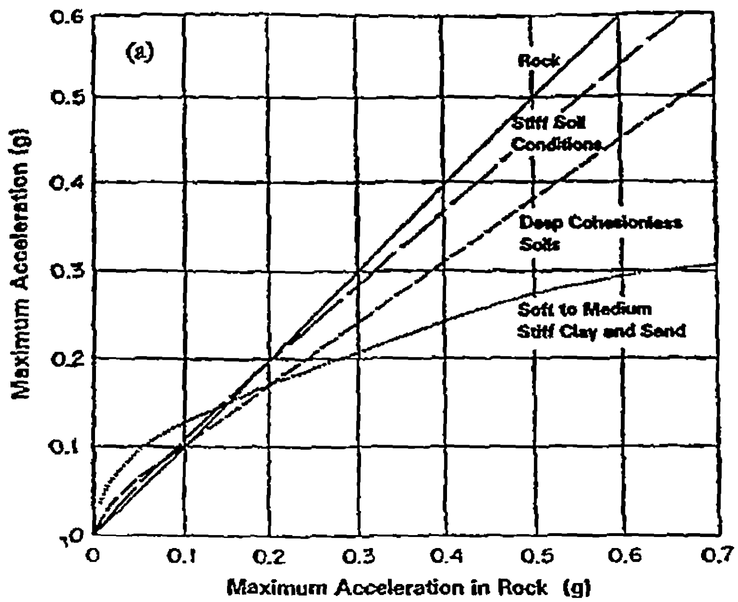
United States Environmental Protection Agency

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



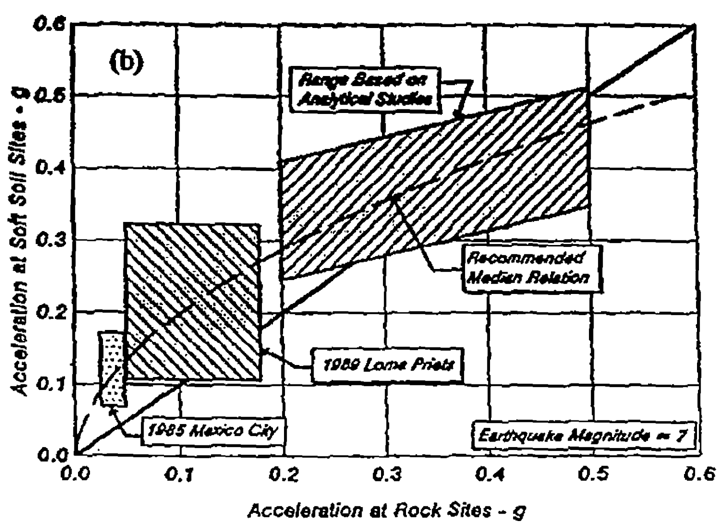


Figure 4.4 Relationship Between Maximum Acceleration on Rock and Other Local Site Conditions: (a) Seed and Idriss (1982); (b) Idriss (1990).

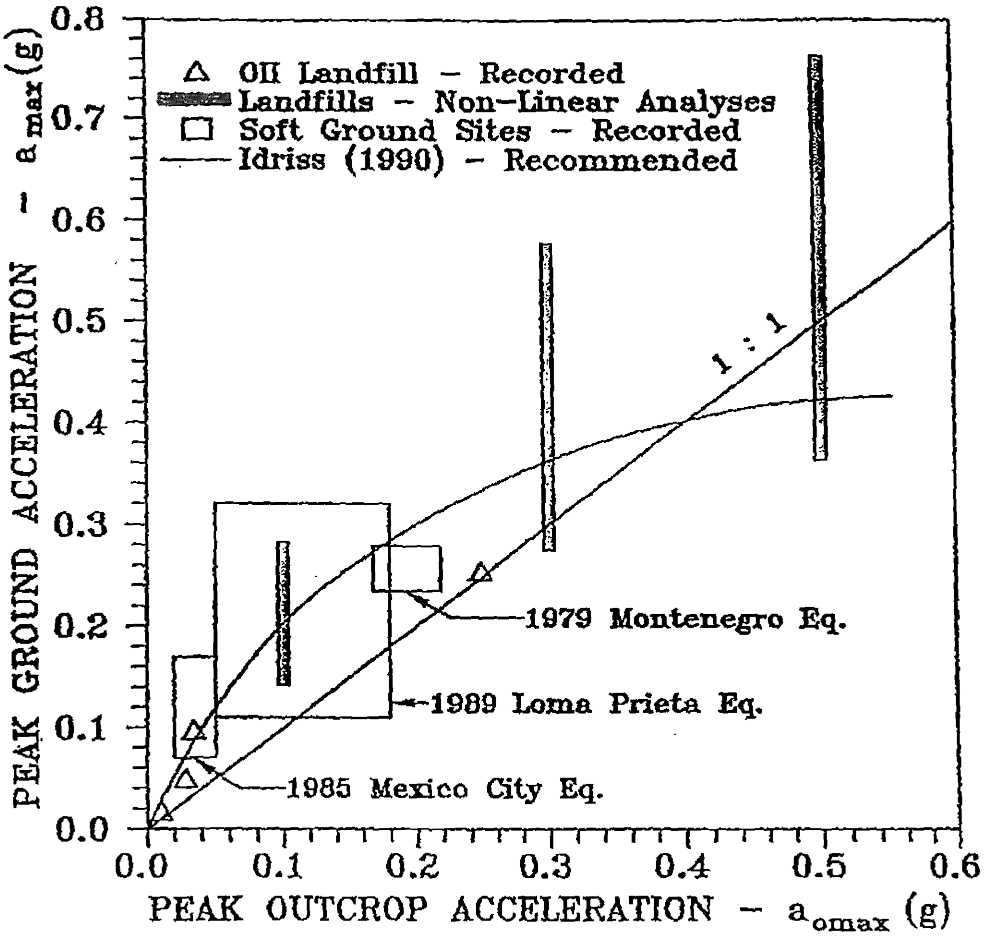


Figure 4.5 Observed Variations of Peak Horizontal Accelerations on Soft Soil and MSW Sites in Comparison to Rock Sites (Kavazanjian and Matasović, 1994).

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) $\emptyset'$ = 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 yd = 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.

Appendix C2

Erosion and Stormwater Protection

Appendix C2-2
Gully Formation

Daniel B. Stephens & Associates, Inc. - Calculation Sheet

Project Name: USEI Cell 16
Project Number: ES11.0086
Calculation Number: 1
Number of Sheets:

Calculation Performed By: S Brady ***Date:*** 2/23/2012

Calculation Checked By: ***Date:***

Status (Draft or Final): Final

Objective of Calculation:

This calculation is performed to determine the critical distance along a slope before gully formation begins. The calculation 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, reference 5.

2) Onsite, loamy sand soil has an allowable shear stress of 0.02, typical of soils with D_{75}<0.05 inches, reference 4, and a manning roughness factor of 0.018, reference 5.

2) The top deck of the cover will have a slope of 3.5%. The sides of the cover will have a slope of 33%.

3) The 100 year - 1 hour storm intensity was used for calculation, 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 (USDA). 1987. Stability Design of Grass-Lined Open Channels. Agriculture Handbook Number 667. Stillwater, OK.

Variables:

$q_s := 1.07$ runoff intensity (inches/hour), reference 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, reference 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, reference 5

$n_2 := 0.025$ roughness factor for amended soil, reference 5

$x_t := 2.0 \cdot deg$ $x_s := 18.4 \cdot deg$

Calculation:

This calculation was performed using the Horton/NRC Method; reference 1.

$$f_{St} := \frac{\sin(x_t)}{\tan(x_t)^{0.3}}$$ slope function value recommended by reference 2, Pg. A-4, Step 3

$f_{St} = 0.095$

$$f_{Ss} := \frac{\sin(x_s)}{\tan(x_s)^{0.3}}$$ 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

$$x_{c3} := \frac{65 \cdot t_a^{\frac{5}{3}}}{q_s \cdot n_2 \cdot f_{St}^{\frac{5}{3}}}$$

$x_{c3} = 8.333 \times 10^3$ critical distance (ft) for amended soil on top deck

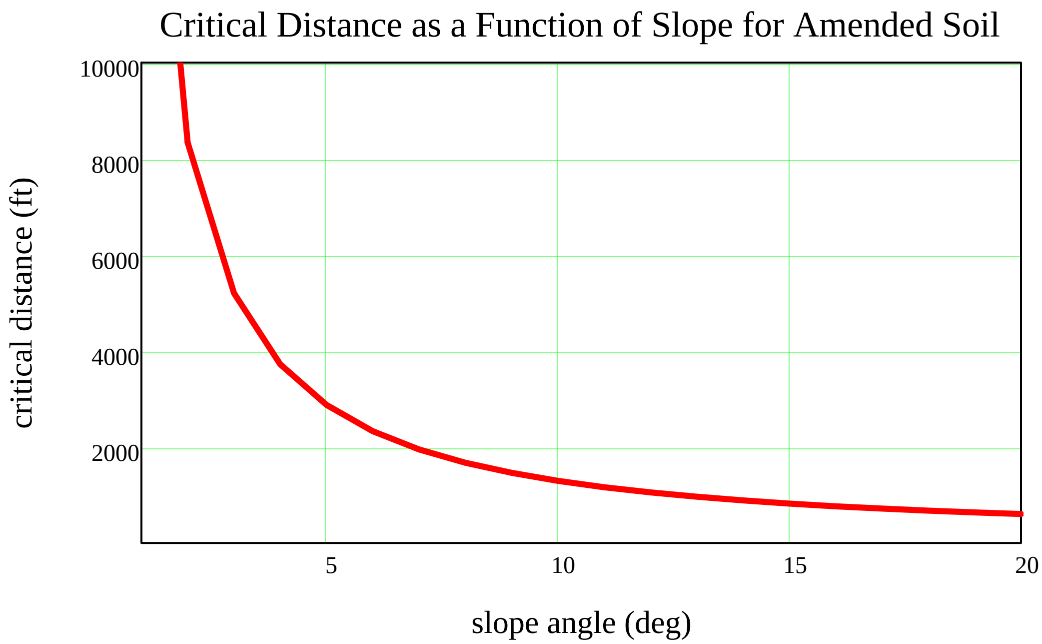
$$x_{c4} := \frac{65 \cdot t_s^{\frac{5}{3}}}{q_s \cdot n_1 \cdot f_{St}^{\frac{5}{3}}}$$

$$x_{c4} = 249.354$$

critical distance (ft) for on-site soil on top deck

$$x_c(x_s) := \frac{65 \cdot t_a^{\frac{5}{3}}}{q_s \cdot n_2 \cdot \left(\frac{\sin(x_s)}{\tan(x_s)^{0.3}} \right)^{\frac{5}{3}}}$$

$$x_s := \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \end{pmatrix} \cdot deg$$


Critical Distance as a Function of Slope for Amended Soil
critical distance (ft)
10000
8000
6000
4000
2000
5
10
15
20
slope angle (deg)

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 <u>Technical Basis</u>

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 originial 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 x 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:

$$V_a = Q/y. \quad \text{(A-4)}$$

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:

$$t_a = t_{ab}\, C_e^2, \quad \text{(A-5)}$$

where t_a = basic allowable shear stress (pounds per square foot),

C_e = void ratio correction factor,

$$C_e = 1.38 - (0.373)(e) = 1.38 - (0.373)(.5) = 1.19 \quad \text{(A-6)}$$

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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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)

NOAA ATLAS 2

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 = 0.457 (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.

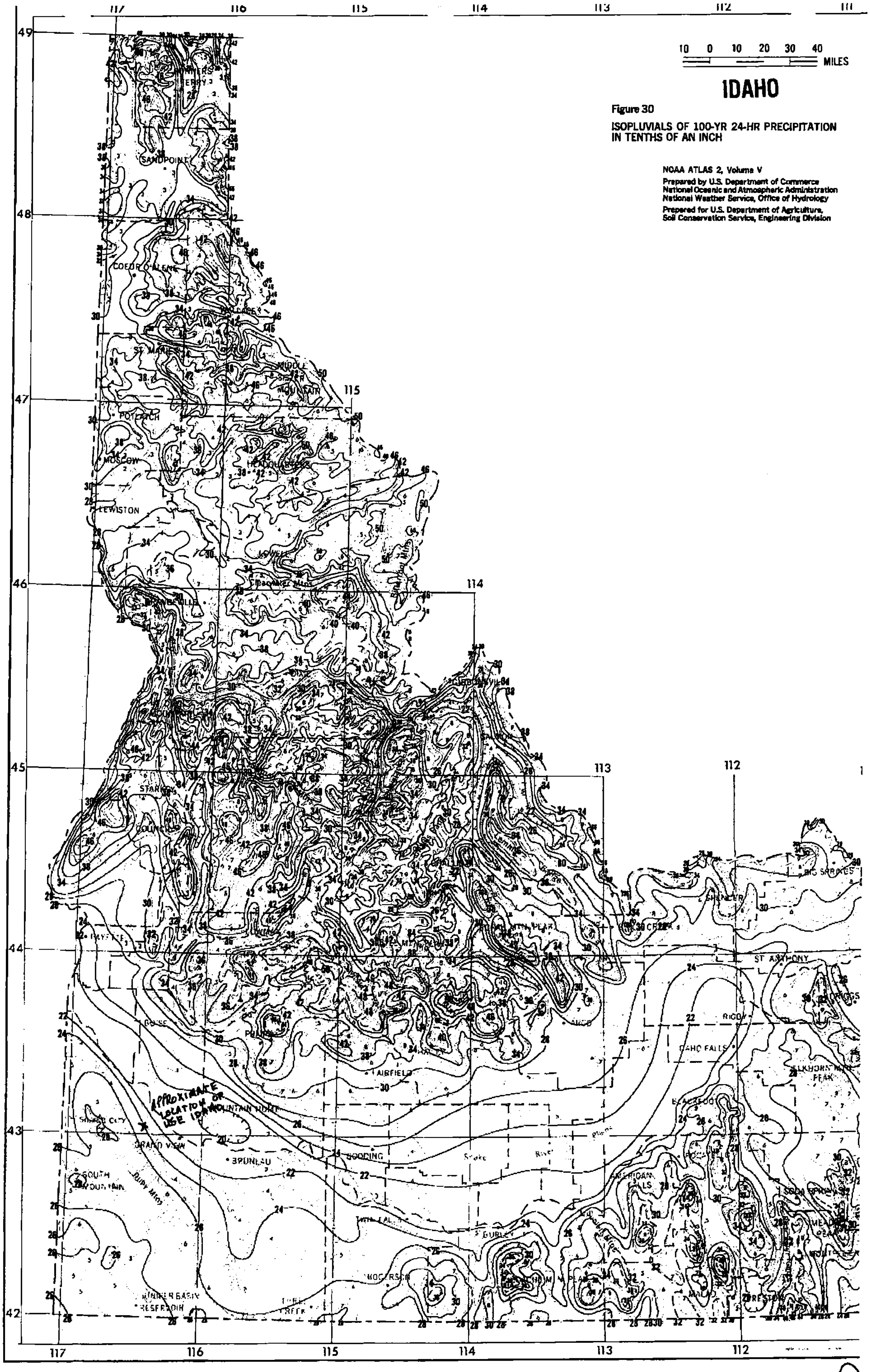
Duration (min)	5	10	15	30
Ratio to 1-hr	0.29	0.45	0.57	0.79

(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**
50-yr				**2.42**	4.42 ~~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.*



IDAHO

Figure 30

ISOPLUVIALS OF 100-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

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National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
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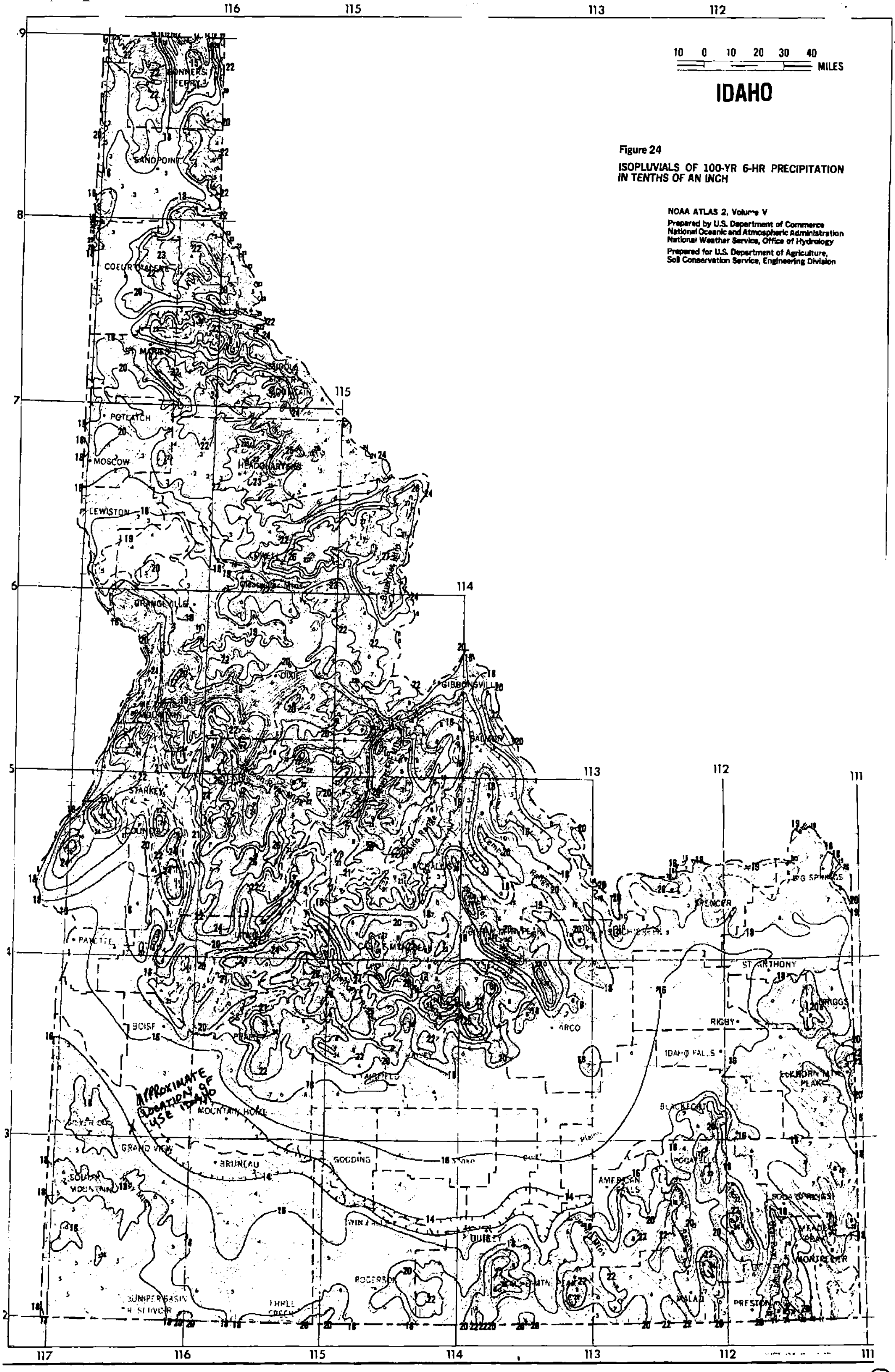

Figure 24

ISOPLUVIALS OF 100-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

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National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
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Stability Design of Grass-Lined Open Channels

D.M. Temple, K.M. Robinson, R.M. Ahring, and A.G. Davis[1]

The research reported in this publication was done in cooperation with the Oklahoma Agricultural Experiment Station.

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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 stress[1]

Soil classification	Applicable range	Equation
Noncohesive soils GW, GP, SW, SP	$I_w < 10$	
	$d_{75} < 0.05$	$n_s = 0.0156$ $\tau_a = 0.02$
	$0.05 \le d_{75}$	$n_s = 0.0256\ d_{75}^{1/6}$ $\tau_a = 0.4\ d_{75}$
Cohesive soils	$10 < I_w$	$n_s = 0.0156$ $\tau_a = \tau_{ab}\ C^2$
GM, SC		$C_e = 1.42 - 0.61\ e$
	$10 \le I_w \le 20$	$\tau_{ab} = (1.07\ I_w^2 + 14.3\ I_w + 47.7) \times 10^{-4}$
	$20 < I_w$	$\tau_{ab} = 0.076$
GC		$C_e = 1.42 - 0.61\ e$
	$10 \le I_w \le 20$	$\tau_{ab} = (0.0477\ I_w^2 + 2.86\ I_w + 42.9) \times 10^{-3}$
	$20 < I_w$	$\tau_{ab} = 0.119$
SM		$C_e = 1.42 - 0.61\ e$
	$10 \le I_w \le 20$	$\tau_{ab} = (1.07\ I_w^2 + 7.15\ I_w + 11.9) \times 10^{-4}$
	$20 < I_w$	$\tau_{ab} = 0.058$

Appendix C2-3
Wind Erosion

Daniel B. Stephens & Associates, Inc. - Calculation Sheet

Project Name: USEI Cell 16
Project Number: ES11.0086
Calculation Number: 1
Number of Sheets:

Calculation Performed By: SB ***Date:*** 02/17/2012

Calculation Checked By: ***Date:***

Status (Draft or Final): Final

Objective of Calculation:

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 crusting with vegetation on the cover system.

Assumptions:

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 3.5% 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.

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.

Variables:

$I = 86$	soil erodibility index, Reference 1 - Exhibit 502-2, page 502-22
$I_{cr\_adj} = 38$	soil erodibility index with crust adjustment factor (gravel admixture), Reference 1, Table 502-2, page 502-8
$K_{rd} = 0.625$	soil surface roughness factor, Reference 1, Fig 502-4, page 502-10
$C = 40$	climate factor, Reference 2, Fig 3, 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

E = function($IK_{rd}CLV$) with no vegetation and crust adjustment

$E = 9.1 \frac{tons}{acre \cdot year}$ Reference 1, Subpart G - Exhibits, I = 38, K = 0.60, C = 40, V = 0

(1)

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 land-forming 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

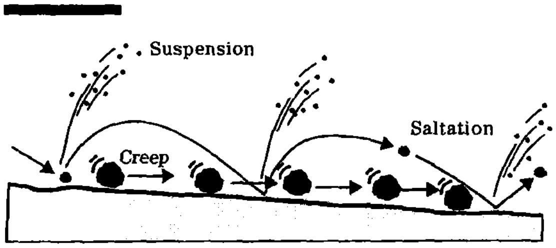
- loose, dry, and finely granulated soil;
- smooth soil surface that has little or no vegetation present;
- sufficiently large area susceptible to erosion; and
- sufficient wind velocity to move soil.

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 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 502–1 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 502-2 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

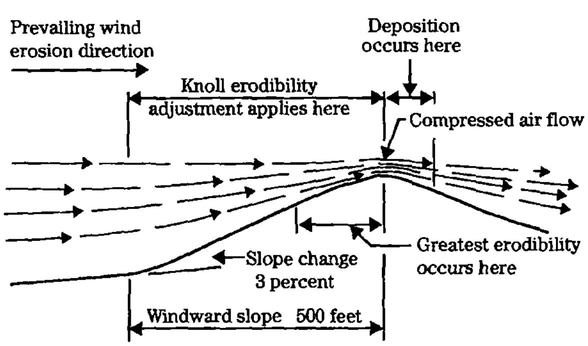
Under erosive conditions, the surface crust and surface clods on fine sands and loamy fine sands tend to break down readily On silt loams and silty clay loams the surface crust and surface clods may be preserved, and the relative erosion may be as little as one-sixth of I Other soils react somewhere 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.

1c

- 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

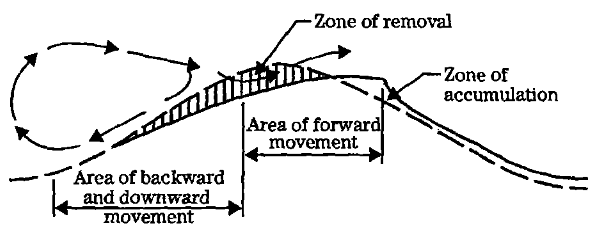
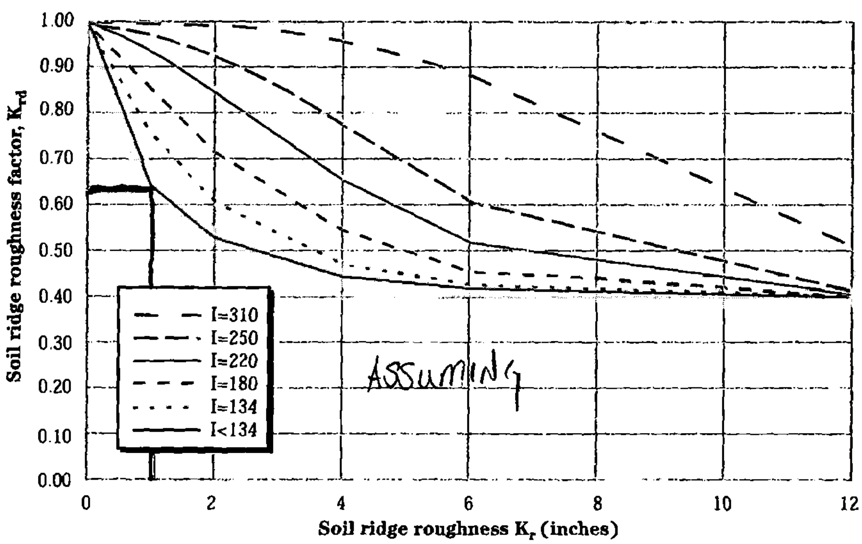


Figure 502–4 Chart to determine soil ridge roughness factor, K_{rd}, from ridge roughness, K_r, (inches). Only this chart, representing an angle of deviation of 0°, will be used for the WEQ **critical period procedure**. When using the **management period procedure**, see exhibit 502–4 for graphs representing 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 horizontal 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

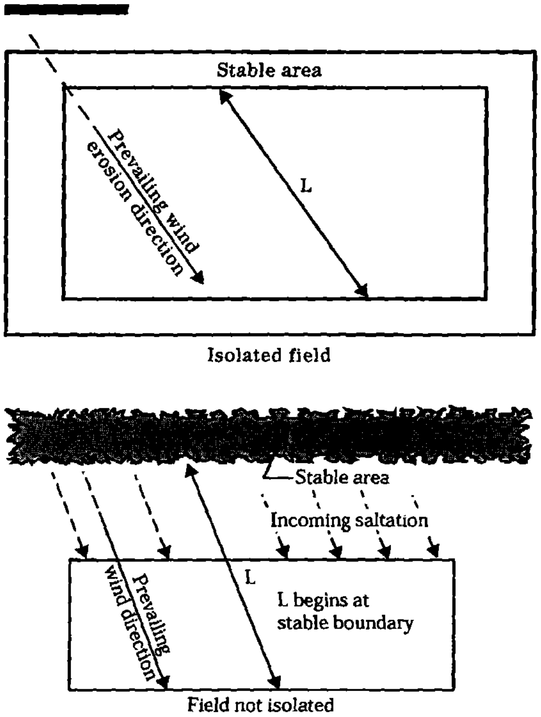
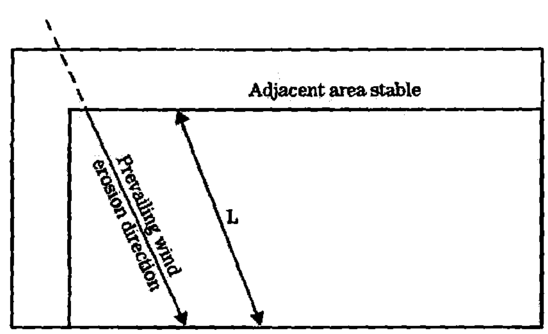
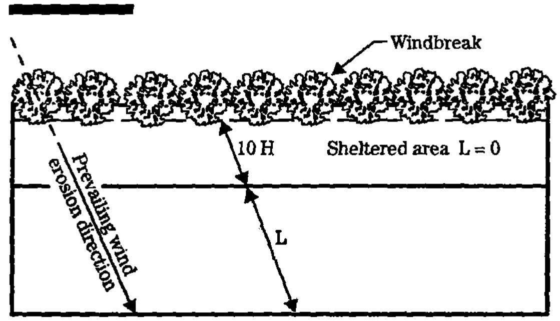


Figure 502–6 Unsheltered distance L, perennial vegetation (pasture or range)



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

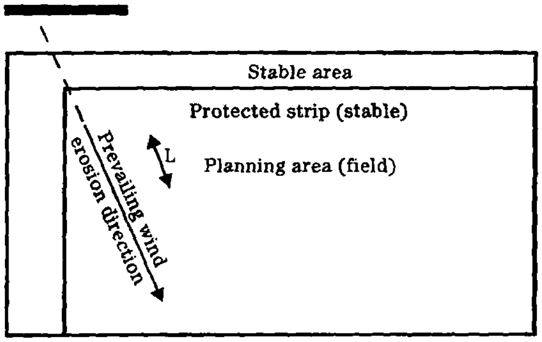


Table 502-3 Wind erosion direction factors 1/

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	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	—	—

AMENDED SOIL

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

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'

(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.

Leon Lyles is research leader with the Agricultural Research Service, U.S. Department of Agriculture, stationed at the Wind Erosion Research Unit, Kansas State University, Manhattan, 66506. *This article is a contribution from ARS, USDA, in cooperation with the Kansas Agricultural Experiment Station. Department of Agronomy Contribution 82-393-J.*

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)

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.

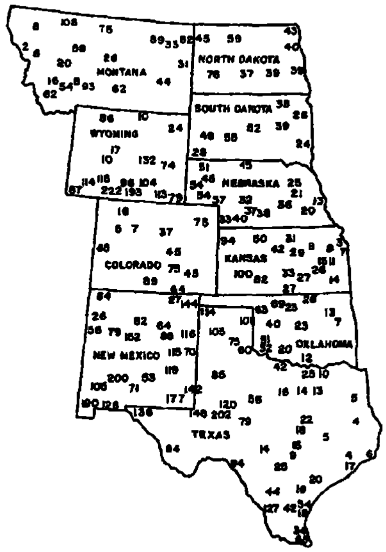

Figure 2. Annual climatic factor (C) in percent for the Great Plains.

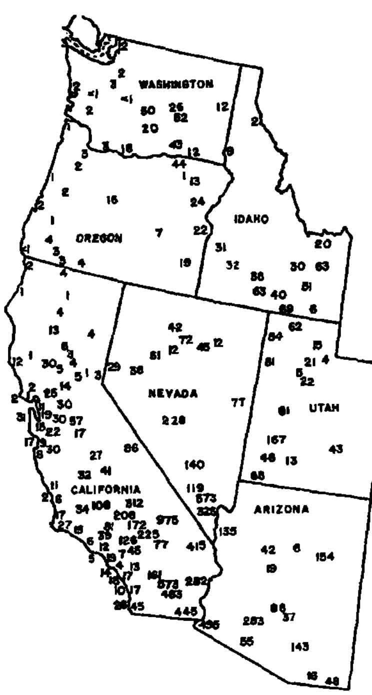

Figure 3. Annual climatic factor (C) in percent for the West.

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

(4)

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

BASIN WILDRYE

	Grass Plants	Pounds per acre of Range Vegetation 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

*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
ADVANCES IN AGRONOMY, VOLUME 15, 1963
ACADEMIC PRESS INC., NEW YORK, N.Y.

(5)

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_o	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_o 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_o 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_o, 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_o 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

$$E = f\,(I,C,K,L,V) \qquad (27)$$

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.