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ENGINEERING STUDY FOR THE TRENCH AND ENGINEERED BARRIER CONFIGURATION FOR THE ENVIRONMENTAL RESTORATION STORAGE AND DISPOSAL FACILITY

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The U.S. Department of Energy (DOE) has tasked the U.S. Army Corps of Engineers (USACE) to perform detailed planning for the development of the conceptual design for the Environmental Restoration Storage and Disposal Facility (ERSDF) at the Hanford site near Richland, Washington. The production of plutonium and related activities since 1943 have resulted in significant environmental (primarily soil) contamination on the Hanford site. The ERSDF will serve as the disposal facility for the majority of wastes excavated during remediation of waste management sites in the 100 and 300 areas of the Hanford facility. The overall project has been designated by Westinghouse Hanford Company (WHC) as project W-296, and is defined as the design, construction, and operation of the facility through the year 2001. The operation of the facility after the year 2001 will be performed under another project. The USACE has tasked Montgomery Watson to conduct this engineering study under Delivery Order No. 0017, under the indefinite delivery order (IDO) contract number DACW68-92-D-0001, with the Walla Walla District.

This report presents analyses of several factors related to the waste disposal trenches at the proposed ERSDF. The purpose of these analyses is to select the most suitable approaches for input to the Conceptual Design of the ERSDF. The evaluations presented here are pre-conceptual and are intended to provide an initial screening only. More detailed analyses suitable for specifying materials and designs of ERSDF subsystem components will be performed at later stages of the project design.

The factors that are evaluated in the subsequent sections of this study include the following:

- Use of excavated soils for liner and cover material.
- Effectiveness of interim covers on the waste.
- Mitigation of dust emissions.
- Surface water management.
- Settlement of the waste.

Where needed for volume estimates, it is assumed that the trenches are double-lined in accordance with RCRA Minimum Technology Requirements (MTRs). However, one strategy for permitting the ERSDF involves classifying it as a Corrective Action Management Unit (CAMU), in which case MTRs may not apply. Hence, unlined trenches are also being considered, although they are not evaluated in this study because they are less complex and costly. The need for a double lining system is being determined by ongoing modelling studies and regulatory negotiations. Hence, resolution of the liner issue is beyond the scope this study. Although the presence of a liner system will affect the trench geometry, required land area, cost, monitoring requirements, etc., the factors evaluated in this study, with the exception of the materials evaluation presented in Section 2, are not affected by the presence or absence of a liner system.

1.2 ASSUMPTIONS

1.2.1 Location and Layout

The ERSDF will be located between and slightly to the south of the 200 East and 200 West Areas, as shown on Figure 1-1 (Trost and Roeck 1993). The main site has an area of about 10 km^2. Approximately 5 km^2 has been reserved for future expansion if the volumes of waste are greater than expected. In the main area, the northwest corner is reserved for site facilities such as administration buildings, unloading facilities, maintenance shops, etc. The remainder of the main area will be used for disposal trenches. Other layouts are being considered to optimize waste transportation and handling. These alternatives, however, are not expected to significantly change the conclusions of this study.

1.2.2 Trench Design

The liner system for the ERSDF trenches is shown on Figure 1-2. From the bottom up, the liner consists of:

- A 3-foot-thick layer of low-permeability soil having a hydraulic conductivity of 1×10^{-7} cm/sec or less.

- A 60-mil-thick high-density polyethylene (HDPE) geomembrane (the secondary liner), textured (roughened) to provide a high-friction interface with adjacent components and thus prevent slipping. HDPE was chosen because of its high resistance to chemical deterioration.

- On the sideslopes, a geocomposite leak detection layer consisting of a nonwoven geotextile thermally bonded to each side of an HDPE geonet. This composite material has a high internal shear strength and will interlock with the texturing on the geomembranes to provide high resistance to sliding.

- A primary HDPE geomembrane similar to the secondary liner described above.

- On the sideslopes, a geocomposite drainage layer similar to the leak detection layer described above.

- On the floor of the trench, granular drainage layers. The primary layer may include pipes to accommodate large volumes of potentially contaminated water, primarily from storm events.

- A 3-foot-thick operations layer to prevent mechanical damage from hauling and placing equipment and to protect the low-permeability soil layer from frost damage.

This liner system is based on RCRA MTRs, considerations of slope stability, and protection from damage.

A cross section of a single disposal trench is shown on Figure 1-3. The width across the top is 300 feet, which was chosen to provide a large enough trench for efficient operations given the high rate of waste receipt (on the order of 5000 cubic yards per day), yet small enough so that initial costs would be reasonable, and partial closure could be accomplished within a few years. The side slopes of 3H:1V (horizontal:vertical) are the steepest at which it is feasible to place and compact low-permeability soil in an efficient and economical manner. In addition, these slopes are the steepest that are likely to be accepted by the regulators, based on experience during the permitting process for the Project W-025 Radioactive Mixed Waste Landfill. The floor width of 100 feet is the minimum required for hauling and compacting equipment.

The lengths of the trenches will be determined by the space available in the particular location in the ERSDF, but will generally be several thousand feet.

1.2.3 Hanford Barrier Design

The Hanford Barrier will be used as a permanent closure cover for the trenches. This is a separate project from project W-296 and is being conducted by WHC. The following description is included to provide a context for the evaluations performed as part of this study. A complete description of the Barrier and its function is given by Duranceau et al. (1993).

The Hanford Barrier is a multiple-layer system designed to minimize infiltration, prevent biointrusion, and resist erosion. The barrier has been in the design process since 1985, and is intended to isolate wastes for at least 1,000 years.

A cross section of the Hanford Barrier is shown on Figure 1-4. The major components of this system are as follows:

- The top 2 m consists of silt/gravel admix and silt. The purpose of this upper section of the Barrier is to promote runoff, minimize infiltration, and provide near-surface storage capacity for infiltration so that it can be removed by evapotranspiration. Field lysimeter tests on this material indicate no measurable recharge (Gee et al. 1992). The silt will also provide a suitable medium to support shallow-rooted vegetation, which in turn will enhance evapotranspiration and resist erosion. The gravel mixed into the upper meter of the barrier is intended to resist erosion and burrowing animals.

- The next approximately 2 m consists of a graded soil filter overlying a layer of crushed basalt fragments. This section will form a capillary break. Provided that unsaturated conditions are maintained above the crushed basalt layer (which is expected on the basis of highly effective evapotranspiration; see preceding discussion), moisture will be transmitted across this zone only via vapor transport. The volumes from this mechanism are expected to be very small. The crushed basalt layer is also expected to deter deep-rooted vegetation. The geotextile filter at the top of this section is intended to facilitate construction by preventing mixing of soil types. It is not necessary for barrier performance once the construction has been completed.

- The lower portion of the barrier, consisting of drainage rock and asphaltic concrete, is designed to function as a low-permeability moisture barrier. Any moisture which passes through the upper layers would be stopped by the asphalt and would drain laterally to discharge at the cover margins. The layer of asphalt is also expected to discourage intrusion by insects (such as ants) and indicate to human intruders that this is a manmade structure.

2.0 EXCAVATED SOILS AS LINER AND COVER MATERIALS

The volume of waste to be disposed of in the ERSDF is estimated to be about 30,000,000 cubic yards (Trost and Roeck 1993). To accommodate this amount of waste, a substantial amount of excavation will be required for the disposal trenches. It may be economical to process this excavated soil by screening to produce size fractions that can be used in the trench liner or Hanford Barrier. For the liner system (see Figure 1-2), required soil materials include soil for admixing with bentonite to form the low-permeability soil barrier. For the Hanford Barrier (see Figure 1-4), the following soil materials are required:

- Silt
- Pea gravel
- Filter sand
- Filter rock
- Capillary break material
- Drainage rock

This section of the study will determine if usable volumes of suitable material are available from the required excavation and what the costs associated with processing the excavated soils might be. These costs will be compared to the costs for importing the soil to the ERSDF site. Material which cannot be economically processed into usable products can be made available for other uses such as daily cover, interim cover, or restoring the operable unit cleanup sites. This study is limited to the specific liner and cover components listed above; a complete soil balance evaluation is contained in the ERSDF Design Memorandum (COE 1993a).

2.1 SITE GEOLOGY AND SOILS CHARACTERISTICS

Geologic information for the ERSDF has been developed from geologic descriptions of the adjacent 200 East and 200 West Areas (Lindsey et al. 1991 and 1992). Additional information was obtained from logs of wells located on the proposed site (Fecht and Lillie 1982), as shown on Figure 1-1. The regional geology and the local geology below the bottom of the trenches are described in the previously cited references and will not be repeated here.

The trenches at the ERSDF site will be excavated in unconsolidated sediments of the Hanford Formation. An east-west cross section through the northern portion of the ERSDF is shown on Figure 2-1. Assuming an excavation depth of about 40 feet (33 feet of airspace plus 7 feet of liner), the trenches in this area will encounter the upper gravel and the sandy sequences of the Hanford Formation. As shown on Figure 2-2, the upper gravel is present only in the northern third of the main site. Based on borehole logs and inspection of large open trenches at the U.S. Ecology site, there do not appear to be any gravels in the southern portion of the main site or in the expansion area.

Grain-size data were obtained from two sources. First, data for existing hydrologic monitoring wells were obtained from the Rockwell Hanford Sieve Analysis (ROCKSAN) database through WHC personnel. These data include grain-size analyses at 5-foot intervals and are shown on Figures 2-3 through 2-7 to a depth of 50 feet for monitoring wells within the ERSDF footprint (see Figure 2-2). The second source of data is laboratory sieve analyses of samples collected on May 18, 1993. These results are shown on Figures 2-8 through 2-11. Figure 2-8 represents a sand sample taken about 15 feet below ground surface from the sidewall of an open disposal trench at the U.S. Ecology facility (see Figure 2-2). Figures 2-9 and 2-10 represent samples of the upper gravel of the Hanford formation obtained from gravel pit B, immediately north of the ERSDF site (see Figure 2-2). Figure 2-11 shows a gravel sample from pit A, somewhat further north of the site (see Figure 1-1) but considered representative of the upper gravel sequence.

2.2 MATERIAL COSTS AND VOLUMES

2.2.1 General

Two factors were evaluated to determine the feasibility of using excavated materials for liner or cover construction. First, the cost to process the material at the ERSDF site was estimated. The unit cost will depend on (1) the amount of material that must be screened to obtain the required volume of a particular size product and (2) the cost of screening. The cost model developed for this study is shown on Figure 2-12; the detailed calculations are included in Appendix A. Unit costs for screening are based on estimates provided by local contractors. The unit cost for dry screening is $2.00 per cubic yard of material processed (i.e., input into the screening plant). The unit cost for wet screening, including the cost of hauling water to the ERSDF site in trucks, is $3.00 per cubic yard. Wet screening is generally required when it is important to remove fine-grained materials such as silt and clay or to obtain as much fine-grained material as possible. As would be expected, Figure 2-12 shows that unit costs for the final product increase substantially if the source soil does not contain a large fraction of the required size.

The second factor is the amount of material available from the trench excavations. As noted above, the upper gravel of the Hanford formation is present only in the northern portion of the ERSDF site. The available area was reduced to allow for that portion of the site which will be set aside for handling and administration facilities and, therefore, not available for trenches. The available area was also reduced because not all of the surface will be developed as trenches. Although the entire area could be developed as a borrow source, the cost of excavating and then replacing the gravel with compacted fill would increase unit costs above acceptable levels. The average thickness of usable gravel is estimated to be 20 feet on the basis of hydrologic monitoring well logs.

The results of the cost and volume analysis are presented in Table 2-1. For each soil material, a cost for importing the material to the ERSDF site is included. This cost is based on estimates provided by the WHC aggregate area barrier development group for obtaining and transporting material to the 200-BP-1 operable unit (OU). This OU is located in the northern part of the 200 East Area, and is considered to be an equivalent distance from the borrow source areas as the ERSDF.

On-site processing costs assume that only one specific material is being processed. If two or more materials can be processed simultaneously, the costs will be less because a major portion of the effort is in loading the screening plant and hauling the wash water. The addition of a second set of screens and conveyor is a minimal cost for large volumes of material, and wash water would be recycled through each subsequent set of screens.

Required and available volumes are based on the entire volume of waste. For purposes of this evaluation, a total excavation volume of 35,000,000 cubic yards has been assumed. This includes 28,000,000 cubic yards for waste, based on estimates provided by WHC, increased by 25% to allow for overexcavation for the liner, loss of airspace due to daily and interim cover, and other factors. In most cases, soil material size requirements do not overlap. In the few cases where they do overlap, the available volume has been reduced to account for this. It should be noted that available volumes are proportional to the volume excavated, and that developing less of the ERSDF will not alleviate material shortfalls. For example, because of the low silt content of the sandy sequence, there is simply not enough silt per unit length of trench to meet the needs of the Hanford Barrier.

2.2.2 Admixing Soil

Bentonite will be added to the local soil to form the low-permeability soil component of the trench liner system (see Figure 1-2). The soil used to prepare the admixture (admix) should be relatively fine grained. The grain-size distribution for a satisfactory material is shown on Figure 2-13. This soil is a silty fine sand identified for use in the Project W-025 Landfill. When mixed with 10-percent to 12-percent bentonite, the resulting material had a permeability in the range of $1x10^{-8}$ to $1x10^{-7}$ cm/sec and satisfied regulatory requirements.

As shown on Figures 2-3 through 2-8, the grain-size distributions of the sandy material at the ERSDF site are similar to the soil used to prepare the admix for the Project W-025 Landfill. On this basis, it is expected that the sandy material will be suitable for the ERSDF liner. Based on geologic data (Figures 2-1 and 2-2), it appears that the sandy sequence of the Hanford formation is the predominant material that will be encountered by the trench excavation. No processing will be required. Therefore, all the required material can easily be obtained from trench excavation. Because screening will not be required, no processing costs will be incurred.

2.2.3 Silt

Silt will be required for the upper two layers of the Hanford Barrier (see Figure 1-4). For purposes of this evaluation, it has been assumed that all material passing the U.S. #200 sieve will be suitable. Although this assumption is reasonable, testing should be performed prior to final design to verify that silt from the ERSDF will perform satisfactorily. Based on visual inspection of the grain-size distribution curves shown on Figures 2-3 through 2-8, it appears that the sandy sequence of the Hanford formation contains an average of 25% silt. With wet screening, this results in a unit cost of about $12 per cubic yard. This is substantially higher than the $8 per cubic yard estimated by WHC for McGee Ranch silt. However, it is not known if sufficient material exists at the McGee Ranch site. If material needs to be imported from outside the Hanford site, costs could be higher, and on-site processing would become economically attractive.

A more fundamental limitation is that considerably more material is required than is available from the excavated soils. About three times the volume actually required for waste would need to be excavated to supply a sufficient quantity of silt for the Hanford Barrier. Hence, it appears that considerable quantities of silt will need to be imported. The sandy sequence appears to be widespread to the south and east of the ERSDF area, and it may be feasible to develop borrow areas for screening soils within this area. The problem may be partially resolved if slightly coarser material can be included with the silt, for example all material passing the U.S. #100 sieve. However, testing and analysis to evaluate this approach was beyond the scope of this study.

2.2.4 Filter Sand

Filter sand is used in the Hanford Barrier to separate the overlying silt layers from the underlying rock filter and, ultimately, the capillary break material (see Figure 1-4). The required gradation for the filter sand (provided by WHC) is shown on Figure 2-14. This curve indicates that material screened between the U.S. #10 and U.S. #100 sieves will be satisfactory. Based on visual inspection of the grain-size distribution curves shown on Figures 2-3 through 2-8, it appears that the sandy sequence of the Hanford formation contains an average of about 52% within this size interval. Because of this high percentage, the cost is relatively low, and the available volume is much greater than the required volume.

2.2.5 Pea Gravel

Pea gravel will be mixed with silt to form the upper layer of the Hanford Barrier. Based on specifications provided by WHC, pea gravel will comprise 15 percent of this layer and must have a size ranging from slightly less than the U.S. #4 sieve to 3/8 inch. Based on visual inspection of Figures 2-9 through 2-11, it appears that the upper gravel sequence of the Hanford formation contains only about 12% within this size interval. Screening costs are therefore much higher than for imported material, and the available volume is not quite sufficient. Because the required size range of the pea gravel overlaps the range of the filter and drain rock (see below), the volume of the latter material has been removed from the total gravel volume potentially available for pea gravel.

2.2.6 Filter and Drain Rock

Filter rock will be used in the Hanford Barrier to prevent the overlying sand filter from washing into the underlying capillary break material (see Figure 1-4), and thereby reducing its effectiveness. Coarse drain rock will also be used above the asphalt layer. Specifications provided by WHC indicate that the majority of this material will need to fall between the U.S. #10 sieve and 1 inch in dimension, as shown on Figure 2-15. Based on visual inspection of Figures 2-9 through 2-11, it appears that the distribution in the upper gravel sequence of the Hanford formation is similar to the required curve, and that this material contains about 48% within the required size interval. Screening costs are comparable to importing costs, and sufficient material is available.

2.2.7 Capillary Break Material

This material consists of coarse gravel to cobbles. Based on conversations with WHC personnel, the lower size limit has not been formally established, but it should be sufficiently coarse to provide an abrupt break with the overlying material. Because the upper size limit of the filter rock is about 1 inch, a lower limit for the capillary break material of 2 inches has been assumed for this analysis. This is expected to be sufficient to prevent piping of overlying soils into the coarse zone and should also be sufficiently open to prevent moisture migration through capillary tension.

Based on visual inspection of Figures 2-9 through 2-11, it appears that the upper gravel layer contains about 18% material that is 2 inches or larger in dimension. Costs for screening this material, although high, are substantially less than for importing crushed basalt. The amount of available material, however, is far less than required.

Unlike the other soil materials, the proposed gravel does not satisfy all the requirements of the material currently specified (crushed basalt) for this component of the Hanford Barrier. Consequently, several issues related to use of on-site gravels in the Hanford Barrier need to be resolved. First, the hydrologic performance characteristics discussed above should be verified. Second, the ability to resist human intrusion (a DOE requirement) relative to larger, more angular crushed basalt fragments should be evaluated. Finally, because the gravels are rounded, they may have different strength properties in mass than crushed basalt. Steep perimeter slopes may be more difficult to achieve, and crushed rock may still be required for this part of the cover.

2.3 CONCLUSIONS

The material volumes calculated for this study were limited to relatively high-cost components of the liner system and the Hanford Barrier; a comprehensive material balance study is presented elsewhere (COE 1993a).

It appears that some of the materials required for the Hanford Barrier and trench liner can be economically obtained by screening soils excavated from the disposal trenches, and that sufficient volumes are available. These include admixing soil, filter sand, and filter and drain rock. On the other hand, silt and pea gravel are more expensive to process than to import, and sufficient quantities would not be available from excavated materials. The latter is particularly true for silt, one of the main components of the Hanford Barrier, where only about 35% of the required material is actually present. Coarse rock for the capillary break in the Hanford Barrier is economical to process on-site, but existing gravel deposits appear to be too limited to provide more than about 20% of the total required material. For some materials, on-site screening may be useful to supplement off-site sources, particularly with respect to silt if the low-cost McGee Ranch soil is not available.

While this initial evaluation of on-site materials indicates that they generally appear to be suitable, the ability of such materials to satisfy design and performance requirements should be verified.

Based upon the cost and volume estimates presented in Table 2-1, the potential savings from on-site processing of filter sand, filter and drain rock, and capillary break material is about $30,000,000. Consequently, on-site processing is recommended as part of ERSDF operations. However, the data used in evaluating the volume of upper Hanford gravel was relatively limited, and additional field studies should be performed prior to mobilizing a screening plant to verify that adequate volumes of this source material are actually available.

3.0 INTERIM COVERS

3.1 PURPOSE OF INTERIM COVERS

This section evaluates different types of interim covers based on permeability, traffic, cost, regulatory, and other performance requirements. Although a specific type of cover will be recommended, regulatory issues may dictate that another type of cover would ultimately be used. Hence, a number of potential cover systems are analyzed in detail so that alternative designs can be selected if necessary.

Interim covers would be placed over the waste periodically to provide enhanced containment, particularly under heavy traffic conditions, and in some cases to reduce infiltration. Examples of situations where an interim cover may be appropriate include:

- when operations will be suspended for several months because a particular type of waste being disposed of in the trench is not being received,
- every 15 to 20 vertical feet as the waste level in the trench increases, if the filling sequence requires placement in lifts to provide stability, or
- if waste types change significantly, such as from low-activity to high-activity.

The second situation is shown on Figure 3-1.

An interim cover does not eliminate the need for daily cover to prevent dispersion of contaminated materials, primarily via fugitive dust. Daily cover will most likely consist of clean soil, removable fabric or plastic sheets, dust suppressants, etc. and will be employed whether interim covers are used or not. Dust suppressants for daily cover use are discussed in Section 4.2.5; some of these materials may be suitable for interim cover provided that traffic is excluded from the treated areas and that low permeability is not required.

No specific regulatory design requirements for interim covers at hazardous waste landfills were identified during this study. RCRA Subtitle C regulations for hazardous waste landfills state:

> "If the landfill contains any particulate matter which is subject to wind dispersal, the owner or operator must cover or otherwise manage the landfill to control wind dispersal." (40 CFR 264.302)

Identical language is incorporated in the Washington State regulations (WAC 173-303-665).

Regulatory requirements do exist for daily cover at municipal waste landfills. RCRA Subtitle D regulations state:

> "...the owners or operators of all MSWLF [municipal solid waste landfill] units must cover disposed solid waste with six inches of earthen material at the end of each operating day, or at more frequent intervals if necessary, to control disease vectors,

fires, odors, blowing litter, and scavenging....Alternative materials of an alternative thickness ... may be approved ... if ... the alternative material and thickness can control disease vectors, fires, odors, blowing litter, and scavenging..." (40 CFR 258.21)

Washington state also requires six inches of daily cover for municipal waste landfills (WAC 173-304-460).

The type of waste that will be disposed of at the ERSDF will not be subject to the problems that are of concern in the municipal landfill regulations. Therefore, the need for a specific type or thickness of daily cover is not considered relevant. The need to prevent wind dispersal is an appropriate requirement. However, the method for accomplishing this is not specified, and in no case are permeability requirements established. Consequently, a wide variety of interim covers are potentially suitable, provided that they can control dust emissions.

There are a number of possible designs for an interim cover, depending on the traffic and infiltration requirements. Potential materials include clean soil from the trench excavations, soil/silt admixtures, geosynthetic materials, and stabilized waste. Typical designs are described and evaluated below. These designs are classified as low-permeability or permeable, and intended or not intended for traffic conditions. All of the proposed designs are considered adequate to control fugitive dust; hence, the primary evaluation criteria for purposes of this study are cost, reduction of landfill capacity, and worker exposure during installation.

3.2 WATER BALANCE

The U.S. Army Corps of Engineers, Walla Walla District, performed water balance studies on several interim cover configurations (see Appendix B). The analyses used the Hydrologic Evaluation of Landfill Performance (HELP) computer model (Schroeder et al. 1989), together with simulated precipitation data based on historical records for the Hanford Site. The model considered different waste thicknesses, different numbers of interim cover layers, and different time periods until the final cover (the lower layers of the Hanford Barrier) were installed. Only compacted silt was modelled as an interim cover; no geosynthetics or other materials discussed below were evaluated.

Model input parameters and results are summarized in Table 3-1. In all cases, the maximum drainage through the bottom of the waste was about 1 inch per year. This result is consistent with estimated recharge rates for granular soils on the Hanford Site (Gee et al. 1992). However, the time at which this maximum drainage occurs is delayed with a greater number of interim covers. This result is not unreasonable. As long as the interim cover is at the surface, it will promote runoff and provide storage capacity for evapotranspiration. However, once a few feet of soil is placed over the cover, it is below the evaporative zone, and percolation will be slowed, but not prevented. Thus, if the interim cover is at the ground surface for only a short time, it may be effective in preventing infiltration, but the overall reduction of long-term infiltration will be small. In all scenarios evaluated, leachate drainage from the waste continued at progressively decreasing rates over the period of the simulation (78 years). Consequently, there does not appear to be an advantage in using low-permeability material for interim covers.

The leachate generation rates predicted by this model should be used with caution. Although reasonable values were used for hydraulic properties of waste and soils, there will be considerable variability in actual materials. In addition, the sequence in which the waste and interim cover are placed will be more complex than the HELP model can accommodate. The model itself has limitations on its ability to simulate moisture transport in the unsaturated zone. For these reasons, the HELP analysis is more useful for comparing different alternatives rather than as a design tool.

3.3 LOW-PERMEABILITY COVERS INTENDED FOR TRAFFIC CONDITIONS

3.3.1 Description

Four different types of interim covers that would limit infiltration and withstand traffic are shown on Figure 3-2. The requirements for these covers are: (1) to reduce infiltration relative to a layer of local soil, (2) to prevent wind dispersion of contaminated material, and (3) to withstand the effects of hauling, spreading, and compaction equipment.

As shown on Figure 3-2, Section A-1 consists of 3 feet of operations layer over a geomembrane. The operations layer would be clean soil from the trench excavation. The thickness of 3 feet was selected for two reasons: (1) to provide adequate protection against puncture of the underlying geomembrane from vehicles and (2) to prevent damage if the wheel of a large vehicle became embedded and spun. A very-low density polyethylene (VLDPE) geomembrane was selected because it has high chemical resistance and mechanical toughness. The geomembrane would be textured (roughened) on each side to provide a high-friction interface strong enough to resist sliding. A geotextile layer would be placed on each side of the geomembrane as a cushion to prevent puncture by rocks in the waste or operations layer.

Section A-2 is similar to Section A-1, except that a geosynthetic clay liner (GCL) would be used instead of a geomembrane. A GCL consists of a thin (1/4 inch) layer of bentonite clay between two sheets of geotextile. These layers are stitched together like a quilt to provide internal shear strength. Bentonite swells when hydrated and has a very low permeability ($1x10^{-9}$ to $1x10^{-10}$ cm/sec), thus forming an effective moisture barrier.

Section A-3 incorporates silt into the operations layer to provide high evapotranspiration and reduced permeability. No separate moisture barrier is included. Because there does not appear to be sufficient fine-grained soil on site (see Section 2), the silt would need to be imported. For purposes of this study, it is assumed that the silt is hauled from the McGee Ranch site, about 20 road miles from the ERSDF.

Section A-4 consists of a 1.5-foot-thick layer of waste which has been stabilized with cement as part of the treatment process. This process has not yet been designed, so details such as permeability and flexural strength of the final product are unknown. Hence, this approach should be considered more uncertain than the others.

3.3.2 Cost

The unit costs for each of the low-permeability covers that can support traffic are summarized in Table 3-2. Details of the cost calculations are included in Appendix C.

3.3.3 Evaluation

Those interim covers which utilize geomembranes or GCLs are expected to prevent essentially all infiltration over the few months or years that the interim cover is exposed. The thickness of the cover will provide adequate containment of contaminated material. Cover construction will utilize well-proven technologies, and should proceed rapidly and efficiently. Costs are relatively high, particularly for the cover which uses a geomembrane. A major disadvantage is radiation exposure to the workers installing the geosynthetic layers. The decision of which type of geosynthetic to use will depend on non-technical factors at the time of covering, such as cost, availability, and capabilities of the work force (GCLs are generally easier to install).

The interim cover utilizing a silt and gravel admixture will theoretically allow more infiltration than a geosynthetic cover. However, arid conditions at the Hanford Site can allow fine-grained soils to prevent essentially all infiltration (Gee et al. 1992), provided that the interim cover is sufficiently thick, so this difference may not be significant. Worker exposure will be lower than for the covers utilizing geosynthetic layers, because the admix can be placed with construction equipment. The primary disadvantage of this cover is relatively high cost due to the need to import the McGee Ranch soil to make the admixture.

One of the primary advantages of using cement stabilized waste as an interim cover is that no airspace is lost. Assuming one interim cover for a trench depth of 33 feet, about 10% of the airspace would be lost using interim cover sections A-1, A-2, or A-3. Another advantage is low cost. Because the waste would need to be placed in any case, the only added costs are associated with a higher degree of thickness control and are relatively low. Radiation exposure to workers is also expected to be low with this alternative. The potential disadvantages of using cement-stabilized waste relate to uncertainties about its performance. Although the intact material is expected to have a low permeability, it may be brittle and tend to crack, particularly under repeated traffic loading. This could allow considerably more moisture to enter the underlying waste. In addition, traffic is expected to wear down the surface, producing dust which would contain contaminated material.

3.4 LOW-PERMEABILITY COVERS NOT INTENDED FOR TRAFFIC CONDITIONS

3.4.1 Description

Four potential interim covers that will reduce infiltration but not support traffic are shown on Figure 3-3. The approaches are similar to those discussed immediately above, but the surface layers are substantially thinner because less mechanical protection is required. The primary requirements of these covers are (1) to reduce infiltration relative to a layer of local soil and (2) prevent wind dispersion of waste.

Section B-1 utilizes a 20-mil-thick polyvinyl chloride (PVC) geomembrane placed directly over the waste. This membrane would be weighted (for example, with sandbags) to prevent it blowing away. PVC was selected because it is generally less expensive than VLDPE and, because there is no overlying soil or traffic, the toughness of VLDPE is not required.

Section B-2 utilizes the same GCL used in Section A-2. Six inches of clean soil is placed over the GCL because a minimum load is required to resist swelling during hydration and thereby maintain the mechanical integrity of the material.

In Section B-3, a one-foot-thick layer of silt and gravel admix is placed over the waste. To function effectively as a low-permeability layer, it is desirable to have the layer thickness at least two times larger than the maximum stone size, so that water cannot pass entirely through the layer by running along the interface between the stone and the surrounding matrix. Consequently, if relatively fine-grained soil is used for the admix, the thickness can possibly be decreased to six inches (the practical limit for spreading over large areas). However, with the coarse pebbles and cobbles that may be present at this site, the one-foot-thick layer was conservatively chosen for this evaluation.

Section B-4 consists of a 6-inch-thick layer of cement-stabilized waste.

3.4.2 Cost

The unit costs for each of the low-permeability covers that can support traffic are summarized in Table 3-2. Details of the cost calculations are included in Appendix C.

3.4.3 Evaluation

The advantages and disadvantages of these interim [illegible] covers are similar to those discussed in Section 3.3.3 above. The costs are in all cases lower, with the silt and gravel admix being most expensive. The disadvantages associated with cement-stabilized waste noted previously as cracking and dust generation are probably not significant if vehicular traffic is excluded from the cover.

3.5 PERMEABLE COVERS INTENDED FOR TRAFFIC CONDITIONS

3.5.1 Description

Permeable covers would be used if there is no concern about infiltration into the waste. Consequently, the requirements for such covers are (1) to prevent wind dispersion of contaminated material, and (2) to withstand the effects of hauling, spreading, and compaction equipment.

The single reasonable alternative in this cover group is shown on Figure 3-4. This cover consists of 3 feet of clean soil from the trench excavation placed on top of the compacted waste. The 3-foot thickness was chosen primarily to prevent waste from being brought to the surface if the wheels of large trucks or other earthmoving equipment became stuck and started spinning. In areas where the waste is similar in appearance to the overlying clean soil, a thin geotextile layer would be placed under the clean soil layer. This geotextile would serve as a marker to facilitate construction, to verify that three feet of clean soil have actually been placed, and to indicate whether waste was dispersed if the cover were to be damaged.

3.5.2 Cost

The unit cost for this interim cover alternative is shown in Table 3-2. Details of the cost calculations are included in Appendix C.

3.5.3 Evaluation

The 3-foot-thick clean soil layer is expected to adequately prevent exposure of the underlying waste even under heavy traffic conditions. Some worker exposure would probably occur during geotextile deployment, although it is expected to be less than for installing geomembranes.

3.6 PERMEABLE COVERS NOT INTENDED FOR TRAFFIC CONDITIONS

3.6.1 Description

The only requirement for this type of interim cover is preventing wind dispersion of contaminated material. Neither reduced permeability nor mechanical strength to support traffic are performance issues here.

Two such cover alternatives are shown on Figure 3-5. Section D-1 uses a geotextile placed directly over the waste. This textile would be weighted (for example, with sandbags) to prevent it blowing away. A variety of geotextile materials are available and could be used; for purposes of this evaluation, a 7.5 oz/yd^2 nonwoven polyester has been assumed.

Section D-2 shows a 6-inch-thick layer of clean soil from the trench excavation placed on top of the compacted waste. This thickness is considered the minimum for reasonably accurate spreading by large construction equipment. As in the soil cover intended for traffic conditions, a geotextile marker layer is included.

3.6.2 Cost

The unit costs for these cover alternatives are summarized in Table 3-2. Details of the cost calculations are included in Appendix C.

3.6.3 Evaluation

Both alternatives are expected to adequately contain the underlying waste. The costs are relatively low. However, geotextiles can experience significant deterioration if exposed to sunlight, high temperatures, and other adverse environmental conditions for periods of several months. Therefore, use of geotextiles for long-term applications in Section D-1 might require periodic maintenance or replacement. This would not be a problem with Section D-2. Some worker exposure would probably occur with both alternatives during geotextile deployment, although less than is expected for installing geomembranes.

3.7 CONCLUSIONS

A number of alternative cover designs were evaluated. Covers that reduce infiltration are generally more expensive than corresponding designs which do not. The potential for exposure of installation workers to radiation from the underlying waste is higher where geosynthetics are used as moisture barriers. In addition, water balance studies on silt covers suggest that the benefit of reducing infiltration is not significant because of the short time that the interim cover is in use. For these reasons, use of low-permeability interim covers is not justified and is not recommended.

The other main consideration for interim covers was their ability to withstand traffic from hauling, spreading, and compaction equipment. Covers that are not intended to support traffic are thinner and therefore less expensive than the corresponding traffic-resistant designs. To use the thinner covers, traffic within the trench would need to be carefully managed and restricted to thicker sections of roadway. This approach could severely limit operational flexibility, and restrictions might be breached, both accidentally and deliberately, with resulting damage to the cover. Therefore, covers which cannot support traffic are not considered practical and are not recommended.

For interim cover within the trench, Section C-1 appears to be the most suitable design. If any areas are identified that clearly will not experience traffic, cover Section D-2 could be considered.

4.0 FUGITIVE DUST CONTROL

4.1 WINDS AT ERSDF SITE

The major concern related to fugitive dust is release of contaminated material. The potential for dust release depends both on wind speed and on the susceptibility of the waste to wind dispersal.

Emission limits for airborne releases are governed under the National Emissions Standards for Hazardous and Particulate Sources (NESHAPS, 40 CFR 61). Limits for radionuclide releases are governed by the allowable exposure limit for an offsite individual of 10 mrem/yr.

Wind data for the ERSDF site are shown on Figure 4-1. These data represent average values for the month of June, the month with the highest average wind speeds, and were obtained over the years 1955 to 1980 at the Hanford Meteorological Station, located about 2 miles north of the ERSDF site (Stone et al. 1983). The predominant wind direction is from the northwest, with lesser frequencies from the southwest to west. These directions are typical throughout the year. Average wind speeds range up to 30 mph. Maximum gusts are typically in the range of 60 to 70 mph, but these represent isolated incidents and are not expected on a routine basis.

The susceptibility of the waste to dust release will depend on the amount of fine material which it contains. As shown on Figure 4-2 (EPA 1979), erosion potential increases rapidly as the percentage of fine material increases. In this very generalized relationship, used (together with other factors) for estimating soil loss due to wind erosion, the critical particle size is about 0.84 mm, a medium sand corresponding to the U.S. #20 sieve. The validity of this size criterion at the Hanford Site is supported by Figure 2-13, which shows the grain-size distribution for soil that is considered an eolian (airborne) deposit. Although the grain size characteristics of the soils that will be disposed of in the ERSDF have not been established, most Hanford Site soils contain some material less than 0.84 mm. On this basis, fugitive dust must be considered a possibility.

The following subsections of this study discuss potential methods for reducing fugitive dust emissions.

4.2 POTENTIAL MITIGATING MEASURES

4.2.1 Trench Orientation

Because the waste trench is a depression in the ground surface, this configuration is expected to provide some reduction of wind velocity, hence dust entrainment, at the bottom. Typical guidance suggests orienting the long dimension of a landfill perpendicular to the prevailing wind (EPA 1979). Because the ERSDF trenches are relatively wide (300 feet at the top) in comparison to their depth (33 feet maximum), the reduction of wind velocity is not expected to be substantial. Hence, this approach is not considered promising, although detailed quantitative analysis or simulated testing have not been performed. In any case, it is currently planned to orient the ERSDF trenches with the long axes in a north-south direction, which is generally perpendicular to the prevailing wind direction (see Figure 4-1).

4.2.2 Limiting Trench Operations

Curtailing trench operations on windy days would reduce those fugitive dust emissions caused by dumping, spreading, and compaction operations. It is understood that current practice in the low-level burial grounds curtails operations when the wind speed is greater than 15 mph. At wind speeds of 10 mph, Hanford health physics technicians have the option of stopping work if safety issues are a concern. These restrictions apply to trench disposal of containerized waste, and it is likely that limitations on disposal of bulk contaminated soil would be at least as restrictive. Based on Figure 4-3, operations would be curtailed about 25% of the time under a 10 mph restriction and about 10% of the time under a 15 mph restriction. The magnitude of dust reduction would depend on the waste characteristics and operational procedures; the threshold for stopping work is difficult to predict beforehand and would need to be determined based on actual experience.

Dust which is simply entrained by wind blowing over in-place waste would not be reduced by this approach. If this source of dust is a problem, another dust mitigation method would be needed.

4.2.3 Wind Screens

Wind screens are vertical barriers intended to reduce wind velocity on the downwind side. EPA has sponsored several studies on the use of wind screens to reduce dust emissions from material storage piles (Carnes and Drehmel 1982; Zimmer et al. 1986). A brief review of these studies indicates that while, in general, wind screens are effective in reducing downstream wind velocities, the aerodynamics are complicated and sometimes difficult to predict. The effects of geometry are considerable.

Field measurements have indicated that a vertical windscreen installed on flat ground can reduce downstream velocities appreciably. An example is shown in Figure 4-4 (EPA 1982). Wind velocities at the ground surface have been reduced by 50% or more to a distance of about 12 screen heights downstream. This agrees with the rule-of-thumb that barrier protection extends 10 times the barrier height (EPA 1979). It should be noted that the landfill would form a depression downstream of a wind screen, and the effects on wind velocities are unknown.

Wind screens may prove to be an effective dust control measure, but additional analysis, modelling, or possibly field testing is required to demonstrate their feasibility and to develop effective designs. Given the complexity of detailed analysis and modelling, the most useful approach is probably to observe several different windscreen configurations during initial project operations.

4.2.4 Leachate Recirculation

EPA studies have found a strong correlation between dust emissions and the moisture content of a storage pile (Zimmer et al. 1986). This may be attributed to surface tension of the water which effectively agglomerates smaller particles into larger aggregates which are more resistant to wind dispersion. Water application is one of the most common dust control methods routinely used in the construction industry. Water from the decontamination facility, leachate collection system, or other sources could potentially be used to control dust at the ERSDF.

However, it is undesirable to add water to the waste because of the potential for increasing contaminant transport over the long term. Hence, conventional watering or adding decontamination wastewater to control dust is not considered a viable approach. One potential alternative involves recirculating leachate collected from the primary drainage system in the liner. The leachate would be sprayed on the waste surface in a conventional manner to control dust. However, several problems are associated with this alternative. First, given the arid climate and expected dry condition of the incoming waste, it is not certain that any leachate will be generated. On the other hand, if there is sufficient moisture to freely drain out of the waste, long-term performance objectives may be adversely affected if this volume of moisture is reintroduced into the system. Finally, the leachate may contain concentrated contaminants which could be dispersed from the spray or waste surface as dust is produced by traffic or other causes. For these reasons, leachate recirculation is not considered a viable method of dust control.

4.2.5 Dust Suppressants

Like water, these liquid materials function by penetrating a thin surface layer of soil and binding the particles together so that they will not be entrained by the wind. Types of dust control sprays and surfactants include salts, oils, polymers, etc. Wind tunnel tests on coal dusts indicated that threshold entrainment velocities could be increased by 40% to 125% depending on the concentration of surfactant used (Drehmel and Carnes 1981).

A list of commercially-available dust suppressants is presented in Table 4-1. This list is not complete, but is intended to illustrate typical products and costs. Manufacturers were generally unable to provide specific data on the performance of their products, stating that performance depended on rates of application, soil types, climate, and similar site-specific factors. For these reasons, the costs presented in Table 4-1 should be considered approximate, and the most suitable materials in terms of performance and economy will need to be determined by field testing prior to operation of the ERSDF.

For comparison purposes, the cost of installing a type D-2 interim cover (see Section 3.6) is about $18,000 per acre (see Appendix D). Dust suppression agents are generally much less expensive (see Table 4-1) and do not use landfill airspace. The longevity of these agents, however, should be evaluated if they are used for areas that will not receive waste for extended periods of time.

4.3 CONCLUSIONS

Dust suppressants appear to be the best alternative for controlling fugitive dust emissions. These materials are commercially available and can be less expensive than soil covers. No airspace is lost with dust suppressants. Site-specific testing should be conducted to determine optimum application rates and expected performance characteristics.

Curtailing landfill operations during windy periods will reduce fugitive dust. However, emissions from waste already in the trenches still must be controlled.

Wind screens may have potential for reducing wind velocities and therefore dust emissions in the trenches. However, predicting wind screen performance beforehand is difficult and complex. Therefore, field tests during operations on a full scale trench would be required to evaluate wind screen effectiveness. Because of the uncertainty of this method, such testing should be performed only if other approaches do not work satisfactorily or prove uneconomical.

5.0 SURFACE WATER MANAGEMENT

5.1 BACKGROUND

Surface water, i.e., precipitation runoff, will need to be effectively managed at the ERSDF for a number of reasons. First, it is desirable to prevent as much water as possible from entering the waste disposal trenches; any water that contacts the waste must be assumed to be contaminated and treated accordingly. Substantial volumes of such "contact water" can result in significant treatment costs. Second, runoff from areas adjacent to the waste trenches may become contaminated by minor amounts of fugitive dust that escape during transport and disposal operations. Third, it is necessary to prevent excessive erosion of soil stockpiles, roadways, waste container handling areas, and other facility areas that are critical to operations. Finally, the long-term performance of the ERSDF site with respect to contaminant release may be altered depending on how runoff from the closure cover (the Hanford Barrier) and other surface infiltration is managed.

Runon into landfills is routinely prevented by the use of berms or interceptor ditches. Similarly, erosion is typically controlled by limiting slope grades and/or lengths, diverting surface water into ditches or culverts, planting vegetation to bind soil and reduce overland flow velocities, placing coarse erosion-resistant soil where possible, and similar methods. The best approaches depend on details of site and facility layout, which have not yet been finalized at the ERSDF. Because these methods of surface water management utilize standard, well-proven approaches and components, their selection can be deferred until detailed design without concern for their feasibility. In accordance with existing Hanford Site practice, the ground surface adjacent to the waste trenches will be regularly monitored. Any contaminated material will be removed and disposed of in the trenches.

The major question at this stage of design is the effect of surface water infiltration on long-term performance. Although the Barrier is designed to limit infiltration to very low levels, some moisture will reach the waste to form leachate. Consequently, some leachate is likely to be generated, particularly at times thousands of years in the future, despite the presence of the Hanford Barrier. For this analysis, a long-term infiltration rate of 0.03 cm/year was assumed for the Barrier. If runoff from the Barrier is allowed to infiltrate into the soil between waste trenches, it may increase the concentration of contaminants reaching groundwater or substantially reduce the travel time to groundwater. If this is the case, runoff would need to be channeled in lined ditches or pipes to a discharge area sufficiently remote from the trenches. Considerable regrading would be required, and ERSDF facilities would need to be arranged to accommodate the specific requirements of surface water drainage. To determine whether such measures are necessary, the effects of infiltration were evaluated.

5.2 INFILTRATION ANALYSIS

The effect of infiltration into the soil between the trenches was evaluated using the ERSDF Performance Assessment (PA) Screening Model. This computer model was developed by Golder Associates Inc. of Redmond, Washington, to determine the effects of waste treatment, closure covers, and liner systems upon the isolation characteristics of the ERSDF. The modelling work is currently being performed for WHC, and a final report is expected by the end of FY 1993. Because the PA model is in the process of being verified, the results presented here should be considered preliminary.

The PA model considers the following characteristics of the disposal system:

- the contaminant concentrations in the waste,
- the solubilities of the contaminants,
- other physical and transport characteristics of the waste,
- waste disposal trench dimensions,
- liner system properties,
- infiltration rate through the cover, and
- physical, transport, and hydrologic characteristics of the unsaturated zone.

The PA model incorporates waste dissolution, diffusion transport, and unsaturated flow through the vadose zone. Mixing with clean infiltration can be modelled at various depths below the ground surface, and varying degrees of mixing can be assumed. The model calculates contaminant concentrations at several locations; for this analysis, the top of the saturated zone (the groundwater table) at a depth of about 260 feet was selected. The liner and cover systems described in Section 1.2 were assumed.

The results of the infiltration analysis are shown in Table 5-1. The infiltration rate into the soil between the berms is modelled at 5 mm/yr to represent normal precipitation or at 100 mm/yr to model the increase in recharge due to runoff from the closure covers. The vadose zone mixing factor describes the mixing of clean infiltration water with leachate from the waste. The mixing factor ranges from 0 for no mixing to 1 for complete mixing; a factor of 0.25 is considered reasonable. The vadose zone mixing depth is the distance below ground surface at which mixing occurs (note that the landfill depth with liner is about 12 m).

The PA model can evaluate a number of contaminants. For this study, uranium and chromium were selected as indicators because they are among the longest-lived and most mobile of the contaminants of concern. For uranium, the performance parameters are risk (lifetime incremental cancer risk) and travel time to the water table. For chromium, the performance parameters are the hazard quotient and travel time to the water table. [A simple definition of hazard quotient is the ratio of the expected dose to the toxic threshold dose; a hazard quotient greater than 1 indicates potential toxic effects.]

Cases 1, 2, and 3 evaluate the effects of the mixing depth. Greater recharge is expected to decrease the mixing depth. The modelling results indicate that this would also decrease the travel times. This reflects the larger volume of water that increases the driving force for downward flow. The ultimate concentrations of contaminants (expressed by the risk and hazard quotients) are not affected, however.

Cases 4 and 5 evaluate the effects of the mixing factor. Complete mixing reduces the concentrations of contaminants, while no mixing increases the concentrations. This illustrates the effects of diluting the leachate with clean recharge water. Travel times are not affected.

Cases 6 and 7 show the results of increasing the amount of clean recharge water. For a given mixing depth, the travel time is decreased slightly. However, the contaminant concentrations are decreased by a factor of about 20 relative to the base case. This results from the dilution effect of the large volume of clean water.

5.3 CONCLUSIONS

Methods to prevent surface water from entering the landfill and to minimize erosion are well-developed and will be selected during the detailed facility design. Performance assessment modelling indicates that, because of mixing and dilution, increased infiltration may reduce the concentrations of contaminants in groundwater. For this reason, runoff from the covers will be allowed to infiltrate into the soil between the waste trenches. This approach also avoids the need to regrade the site and install lined ditches or piping systems. *

6.0 SETTLEMENT

6.1 NEED TO CONTROL SETTLEMENT

Excessive settlement of the waste in the trenches could cause subsidence at the ground surface, which in turn would damage the cover used for permanent closure (the Hanford Barrier). Two types of settlement are potentially serious. The first is differential settlement over a relatively short distance. The most extreme example of this would be vertical shearing through the cover above the edges of a collapsed void. Based on the design of the Hanford Barrier (see Figure 1-4) and discussions with WHC personnel, it appears that the asphalt layer is the most sensitive component. Shear offsets or flexural cracking could form preferential pathways for infiltration. The magnitude of differential settlements that would cause this type of damage is material-specific and difficult to model. However, it is intuitively reasonable to expect that differential settlements should be limited to 1 or 2 inches at most.

The other type of settlement damage is subsidence over a broad area. While this would not introduce sufficient strain at any given location to damage the cover, it would reduce the slope of the cover between the edges and the center of the trench (see Figure 6-1). Such changes could decrease the ability of water to drain from the cover, both at the surface and internally. In the extreme case, water could pond within the cover (for example, on top of the asphalt layer) and produce a permanent hydrostatic head on the moisture barrier, thereby increasing the amount of infiltration. As presently designed, the slope of the Hanford Barrier is 2%. Discussions with WHC personnel indicate that although the upper layers of the cover have sufficient water storage and evapotranspiration capabilities to function with a 0% slope, some slope is required so that moisture on top of the internal asphalt layer can drain. Given the irregularities that are expected from construction, a slope of 1% is considered a minimum to provide adequate overall drainage. Using the simplified geometry shown on Figure 6-1, a reduction in slope from 2% to 1% corresponds to a uniform settlement in the waste of about 3% (see Appendix E).

Because the waste is granular and unsaturated, much of the settlement is expected to occur instantaneously as the trench is filled. The only settlements of concern are those that occur after the Hanford Barrier is installed. These secondary settlements occur over time and are caused by particle rearrangement, changes in moisture content, etc. They are generally smaller than the instantaneous, or primary, settlements. In clayey soils, secondary settlement (or consolidation) occurs as the water is squeezed from the pores and the soil matrix collapses. In these materials, secondary settlement can be relatively large. In granular soils, however, any pore water can drain essentially completely at the time of loading. Thus, little long-term settlement is expected in the types of soils that will be disposed of in the ERSDF. Whether the magnitudes of such settlements are sufficiently low to avoid unacceptable loss of cover slope will be evaluated below.

6.2 WASTE TYPES AND SETTLEMENT POTENTIAL

The ERSDF will accept waste from various remediation sites throughout the Hanford site. Consequently, a number of waste types are anticipated, including bulk soils, landfill debris, containerized waste, the fine soil residue from soil washing (the Volume Reduction

System), piping, demolition debris, and other materials. The vast majority (80 to 90%) of waste to be received at the ERSDF is expected to be soils contaminated with low levels of radionuclides.

If the ERSDF is regulated under RCRA, land disposal restrictions (LDRs) will apply. These restrictions essentially prohibit disposal of organic materials, free liquids, or unstabilized toxic metals in the landfill. Thus, many of the waste types that could decompose would be excluded. On the other hand, if the ERSDF is regulated as a Corrective Action Management Unit (CAMU), then LDRs would not strictly apply. Although the type of permitting for the ERSDF has not been finalized, it appears that LDRs will be followed in either case, as discussed in the pre-design guidance document for remediation of the 100 B and C areas (Moore 1993). The discussion in the remainder of this section is based on this assumption.

Waste materials from the 100 B/C Area remediation are expected to be typical of much of the waste received at the ERSDF. These waste types and the processing that will be performed prior to shipment to the ERSDF are as follow (Moore 1993):

- Organic waste constituents will be processed to meet LDR limits (wastes containing more than 10% organic materials must be incinerated as a minimum; Ecology 1990).
- All free liquids will be removed, stabilized, or otherwise eliminated (Ecology 1990).
- Compactible wastes (including pipe) will be volume reduced.
- The contents of intact drums will be analyzed and combined with bulk waste of the same type as appropriate.

Waste which contains leachable inorganic waste (e.g., metals) must be stabilized (solidified) or containerized in order to meet LDRs (Ecology 1990). The 100 B/C area pre-design guidance document states that such waste will not be treated at the remediation site, but will be shipped to the ERSDF. The ERSDF will include a system for mixing these wastes with cement grout in order to satisfy LDRs.

Assuming that these approaches to waste treatment are typical, they will eliminate those waste forms that are most highly susceptible to settlement, particularly containers of free liquids, containers with large void spaces, and organic materials that could decompose. In addition, non-soil wastes can be dispersed throughout the bulk soil mass to avoid concentrated zones that might be more susceptible to settlement. Consequently, it is expected that waste settlement will be controlled by settlement of the bulk soils.

6.3 POTENTIAL MITIGATING MEASURES

6.3.1 Mechanical

6.3.1.1 Conventional. Because most of the waste placed in the ERSDF trenches will be bulk soil, compaction techniques used for conventional earthfill projects are expected to be useful. Mechanical compaction of the soils will reduce the magnitude of both the immediate or distortional settlement and the long term or secondary settlement. Two scenarios were considered: 1) limiting the mechanical compaction to spreading the waste in 2- to 3-foot-thick lifts with bulldozers, and 2) compacting the waste in 1-foot-thick lifts with vibratory rollers. The first scenario would provide minimal compaction, resulting in placement of the waste in a loose condition (about 4 blows per foot in the Standard Penetration Test). The second scenario would generally result in the waste being placed in a medium-dense condition (about 15 blows per foot in the Standard Penetration Test).

For purposes of this evaluation, the waste within the ERSDF was considered to be a compacted fill of coarse granular soil. Most of the settlement will occur immediately as the waste trench is filled (Holtz 1991) and is not a concern because the Hanford Barrier will not yet be in place. However, some post-construction settlement will occur. Post-construction settlements depend in large part on the soil properties and loading conditions, and therefore little guidance for predicting settlements was found in a limited literature review except for general qualitative statements. The most useful analogues are earth and rockfill dams. Numerous studies of rockfill dams show that post-construction settlements of fill do occur. Studies of 15 rockfill dams sited on bedrock, with various degrees of compaction, showed post construction settlements of less than 1% of the total dam height (Dascal 1987). In another study, instrumented rock fills, placed in 2-foot-thick lifts and compacted with six passes of a vibrating drum compactor, yielded average post construction settlements of less then 0.2% of the fill height (Matheson and Parent 1988). It has also been documented that rockfills composed of well-graded, rounded-to-subrounded particles, such as ERSDF waste, generally settle less than angular rock fill materials (Casagrande, 1965). Therefore, estimates based on rock dam experience are probably conservative (too high) for ERSDF waste. In any case, post-construction settlements of less than 1% can reasonably be expected with only minimal compaction. If the waste is compacted in lifts with vibratory rollers as in the second scenario, the post-construction settlement could be substantially less. Such settlements are well below the limit of 3% required for maintaining drainage within the Hanford Barrier.

Additional settlement will occur when the 15-foot-thick Hanford Barrier is constructed. This settlement will probably have a significant immediate component which will affect the slope of the Barrier as it is constructed. Assuming that the waste is in a loose condition as described in scenario 1, settlements on the order of 3% of the fill height were calculated using one-dimensional elastic theory (Schmertmann 1970). The calculations are presented in Appendix E. If the waste is compacted to a medium dense condition, such as described in scenario 2, the settlement of the waste is estimated to be 1% of the waste thickness. On this basis, some compaction of the waste should be performed to limit settlements to acceptably low levels when the Hanford Barrier is constructed.

6.3.1.2 Dynamic Compaction. This approach works by densifying the soil mass with vibrational energy. One type of dynamic compaction is mass impact, which involves dropping a large concrete block onto the waste. Typical equipment utilizes a 30-ton block dropped from a height of 65 feet. The weight is dropped several times at each location, and the process is applied on a regular pattern over the waste trench. Tests at the Hanford site have been performed to evaluate mass impact for treating existing waste burial grounds (Phillips and Gilbert 1985). The results indicated that mass impact could produce accelerations of 1 g or higher to a distance of about 12 feet from the impact point. This level of acceleration is considered most effective for consolidating loose granular materials (Abeele 1985). However, mass impact is difficult to control and could either be ineffective or else damage the liner system in the trenches. Dust control is also a potential problem. For these reasons, mass impact is not considered a desirable method for use at the ERSDF.

A second type of dynamic compaction is dynamic consolidation, which involves driving a beam or pile into the ground. The driving action densifies the soil in the immediate vicinity of the beam. Field tests of this technique have been performed at the Hanford site, and the most effective type of equipment was found to be a vibratory hammer-extractor (Phillips and Hinschberger 1989). The tests indicated that accelerations of 1 g or higher were produced within a 10-foot radius of the beam. This method has the control necessary to consolidate the waste at depth while avoiding damage to the liner. It could be performed through a clean soil cover to control dust. Therefore, it is considered potentially applicable to the ERSDF waste, although field tests would be required to determine its actual effectiveness.

6.3.2 Blending

Waste may be blended with Portland cement, fly ash, or other types of additives to increase its strength and reduce settlement. The most practical way of accomplishing this is probably to spread cement over the waste in the trench and mix it in with a harrow, bulldozer, or similar equipment. Some addition of water may be required if the waste is dry. Blending with cement is discussed in some detail the VRS Dewatering and Stabilization Study (COE 1993b). The advantages of this method are increased strength, reduction of free moisture in the waste, and possible binding of radionuclides, depending on the cement content. The disadvantages include increased cost and fugitive dust emissions during the mixing process.

6.3.3 Containerization

Rather than dumping, spreading, and compacting the bulk soil waste, the transport containers could be placed directly into the landfill. If sufficiently heavy, the container walls could provide some structural support and thereby resist settlement. However, in reality, the potential for settlement would probably increase with this approach unless additional mitigating measures were taken. Some settlement of the waste would likely occur during transport, and a void would form under the top of the container. These voids would need to be grouted so that the containers were full. Other voids would exist between adjacent containers in the landfill. These would need to be backfilled with soil, where compaction would be difficult, or a sufficiently fluid grout. Although technically feasible, the increased operational complexity and cost of containerizing the waste is not considered worth the uncertain benefit.

It should be noted that some waste disposed of in the ERSDF will arrive in containers such as drums or burial boxes. These containers will be required to have all voids filled so that long-term decomposition and collapse is not a problem.

6.3.4 Preloading

Preloading would consist of placing a layer of soil over the filled trench for a period of time, then removing it prior to constructing the Hanford Barrier. The weight of the preload would simulate the weight of the Barrier and induce settlement. If a weight greater than the expected weight of the Barrier is used, the process would be referred to as surcharging. EPA studies suggest that preloading can essentially eliminate immediate settlement and significantly reduce long-term settlement under the landfill cover (Gilbert and Murphy 1987). Swiger (1974) suggested that secondary settlement of granular soils can be neglected when the preload is greater than the loads imposed by the structure. When a preload is removed, some rebound of the underlying soil can be expected; however, much of the initial settlement is inelastic and non-recoverable. For example, settlement monitoring of large tanks built on granular deposits indicated a soil rebound of less than 10% of the total settlement one year after the tanks were drained (Davisson and Salley 1972). The rebound would be the expected settlement when the Hanford Barrier is subsequently constructed. Using the settlement values estimated in Section 6.3.1 for loose fill and assuming a rebound of 10%, the settlement under the Hanford Barrier would be about 0.3% if the waste were preloaded. This is well below the allowable value of 3%. The actual effectiveness of preloading will of course depend on the properties of the ERSDF waste and should be determined by laboratory testing if this approach is used.

Field experience indicates that in relatively dry granular materials, settlement occurs rapidly. For the ERSDF waste, preloading or surcharging is expected to be effective over time periods of a few weeks. Settlement monitoring can be performed when preloading is first used to determine the time requirements more precisely. Portions of the landfill can be loaded at different times using a "rolling" surcharge that moved progressively along the waste trench.

6.3.5 Shredding

Shredding would involving tearing or breaking large pieces of debris into small sizes. The object of shredding would be to eliminate any closed or partially closed voids. Suitably shredded material would then be disposed of with bulk soils to form a waste mass without voids and therefore resistant to settlement. Examples of materials that would be appropriate for shredding include drums, pipes, and boxes.

Shredding requires relatively large, heavy equipment that is expected to need a high level of maintenance, which would be complicated by the need to decontaminate the equipment prior to repair. In addition, dust control would be required during normal operations. Material suitable for shredding would need to be handled at least twice. While these drawbacks are not insurmountable, they do add considerable complexity to the processing operations at the ERSDF. Therefore, shredding is not considered a desirable method for reducing settlement. As noted above, the compactible waste will already have been compacted, satisfying to some extent the intent of shredding. Large irregularly-shaped objects with unacceptable voids could be handled by placing them in a depression in the waste and flood-grouting to fill the voids.

6.4 CONCLUSIONS

Differential settlement will be minimized by controlling the waste forms that are disposed of in the ERSDF trenches. Containers will be grouted if necessary to fill voids. Irregularly shaped objects will be placed in depressions in the bulk soil waste and flood grouted.

Areal settlement of the waste is not expected to be a concern if moderate compaction is achieved using conventional equipment. Secondary settlements in granular materials such as ERSDF waste soils are expected to be well below allowable limits. Primary settlements will occur as the waste is placed. The other major concern is settlement when the Hanford Barrier is constructed. Moderate compaction of the waste (for example, by several passes of a heavy vibrating drum roller) should limit such settlements to acceptable levels. Laboratory tests should be performed on soils having the same particle-size distribution as the waste soils to determine compaction characteristics. The results should be used to specify placement methods such as lift thickness, number of passes by compacting equipment, and related factors.

Another potentially effective approach is surcharging waste with an equivalent mass of soil prior to constructing the Barrier. The disadvantage of this method is the need to handle the surcharging soil twice. The need for surcharging should be determined on the basis of the laboratory test results on the waste fill.

7.0 SUMMARY AND RECOMMENDATIONS

This study has evaluated a number of factors related to waste trench operations. Based on these evaluations, the following approaches are recommended for ERSDF operations:

- Excavated soils can be used for several components of the liner and cover systems. Cost savings of about $30,000,000 could potentially be realized. The suitability of materials derived in this way should be verified. The amount of gravelly material should be determined more precisely by field investigations. If no adverse results are encountered, a screening plant should be incorporated into ERSDF operations.

- An interim cover consisting of 3 feet of clean soil over a geotextile layer is recommended.

- Dust suppressants are recommended as the preferred method to control fugitive dust. Field tests should be performed on several dust suppressants to determine the most suitable product with respect to cost, longevity, ease of application, and overall performance. Windscreens should be evaluated by field testing if dust suppressants do not perform satisfactorily.

- Conventional surface water management techniques are recommended to control runon and runoff and minimize erosion at ERSDF facilities. Runoff from permanently closed areas should be allowed to infiltrate the areas between waste trenches.

- To minimize settlement, bulk soils should be spread in lifts of limited thickness (for example, 12 inches maximum) and compacted with conventional equipment such as vibrating drum rollers. Laboratory tests on bulk soils should be performed to determine compaction requirements such as number of equipment passes, lift thickness, etc.

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Table 2-1. Material Cost and Volume Estimates

Material	Source	Fraction Suitable	Screening Process	Unit Cost, per yd^3		Volume, yd^3	
				Imported	On-Site Processing	Required	Available
Admixing Soil (Liner)	Sandy Sequence	100%	None	N/A	$0.00	4,800,000	22,300,000
Silt (Hanford Barrier)	Sandy Sequence	25%	Wet	$8.00	$12.00	12,700,000	4,400,000
Filter Sand (Hanford Barrier)	Sandy Sequence	52%	Wet	$10.00	$6.00	1,100,000	9,100,000
Pea Gravel (Hanford Barrier)	Upper Gravel	12%	Dry	$6.50	$16.00	1,100,000	1,000,000
Filter & Drain Rock (Hanford Barrier)	Upper Gravel	48%	Wet	$6.50	$6.00	4,200,000	6,100,000
Capillary Break (Hanford Barrier)	Upper Gravel	18%	Wet	$26.00	$16.00	12,400,000	2,300,000

Table 3-1. HELP Modelling Results - Interim Covers

Scenario	Waste Thickness	Number of Interim Covers	Time to Final Cover	Maximum Drainage	Time of Maximum Drainage
A	3 @ 20 feet each	2	4 years	1.0 in/yr	10 years
B	15 and 20 feet	1	3 years	1.0 in/yr	5 years
C	66 feet	0	2 years	1.0 in/yr	2 years
D	32 feet	0	2 years	1.1 in/yr	2 years
E	66 feet	0	6 years	0.8 in/yr	6 years

Table 3-2. Interim Cover Cost Estimates

Component	Cost per Sq Ft	Sect. A-1	Sect. A-2	Sect. A-3	Sect. A-4	Sect. B-1	Sect. B-2	Sect. B-3	Sect. B-4	Sect. C-1	Sect. D-1	Sect. D-2
Proof Roll Waste Surface	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
Geotextile Cushion (7.5 oz/sq yd)	$0.20	$0.40									$0.20	
Geotextile Marker Layer (3.5 oz/sq yd)	$0.14									$0.14		$0.14
30 mil Textured VLDPE	$1.00	$1.00										
High Shear Strength GCL	$0.70		$0.70				$0.70					
Operations layer (3 ft)	$0.46	$0.46	$0.46							$0.46		
Clean Soil (0.5 ft)	$0.13						$0.13					$0.13
Silt and Gravel Admixture (3 ft)	$1.12			$1.12								
Silt and Gravel Admixture (1 ft)	$0.41							$0.41				
20 mil PVC Geomembrane	$0.34					$0.34						
Cement Stabilized Waste (1.5 ft)	$0.03				$0.03							
Cement Stabilized Waste (0.5 ft)	$0.01								$0.01			
Construction Cost per Square Foot		**$1.89**	**$1.19**	**$1.15**	**$0.06**	**$0.37**	**$0.86**	**$0.44**	**$0.04**	**$0.63**	**$0.23**	**$0.30**
On-Site Indirect Costs at 14% of CC (includes QA/QC, H & S Mon., etc.)		$0.26	$0.17	$0.16	$0.01	$0.05	$0.12	$0.06	$0.01	$0.09	$0.03	$0.04
Construction Management at 10% of CC		$0.19	$0.12	$0.12	$0.01	$0.04	$0.09	$0.04	$0.00	$0.06	$0.02	$0.03
Total Cover Cost per Square Foot:		**$2.34**	**$1.48**	**$1.43**	**$0.07**	**$0.46**	**$1.07**	**$0.55**	**$0.05**	**$0.78**	**$0.29**	**$0.37**

Table 4-1. Dust Suppression Agents

Company	Product Type/ Produce Name	Cost	Cost/Acre	Application Rates
Dow Chemical	Calcium Chloride/			
	Pelledow	$325/ton	$1,040	1.32 lbs/sy
	Dowflake	$329/ton	$1,200	1.5 lbs/sy
Witco Chemical Co.	Petroleum based/			
	SC250	$150.85/ton	$1,170	0.35 - 0.40 gal/sy
	SC800	$135.85/ton	$2,640	0.75 - 1.00 gal/sy
Johnson & March	Surfactant/			
	MR	$6/gal	na	No suggested application rates
	MR2040	$7.25/gal	na	
WRR Industries	Magnesium Chloride/			
	Dust Guard	$620/ton	$1,000	1.6 ton/acre
Chemstar Lime Co.	Lime based/			
	Poz-o-Cap	$180/ton	$180	1 ton/acre
Georgia-Pacific	Lignin Sulfonate/			
	Lignosite	$0.19/gal	$226	1,200 gal/acre
American Cyanamid	Polyvinyl Emulsion/			
	Aerospray 70A	$0.63/lb	$51,000	0.25 gal/sy - 2 gal/sy
Rusmar Inc.	Aqueous Anionic Surfactant (Foam)/			
	AC-645	$0.90/lb	$4,800	2 tons/acre
	AC-904	$0.46/lb	$14,000 - $17,000	10 - 17 tons/acre

Table 5-1. PA Screening Model Infiltration Analysis Preliminary Results

Case No.	Infiltration Rate (mm/yr)	Vadose Zone Mixing Factor	Vadose Zone Mixing Depth (m)	Uranium		Chromium	
				Risk	Travel Time (years)	Hazard Quotient	Travel Time (years)
1	5	0.25	50	9×10^{-4}	250,000	54	7,000
2	5	0.25	25	9×10^{-4}	120,000	54	3,500
3	5	0.25	80	9×10^{-4}	400,000	54	11,500
4	5	1	25	3×10^{-4}	120,000	15	3,500
5	5	0	25	5×10^{-3}	120,000	305	3,500
6	100	0.25	50	5×10^{-5}	240,000	3	6,500
7	100	0.25	25	5×10^{-5}	120,000	3	2,500

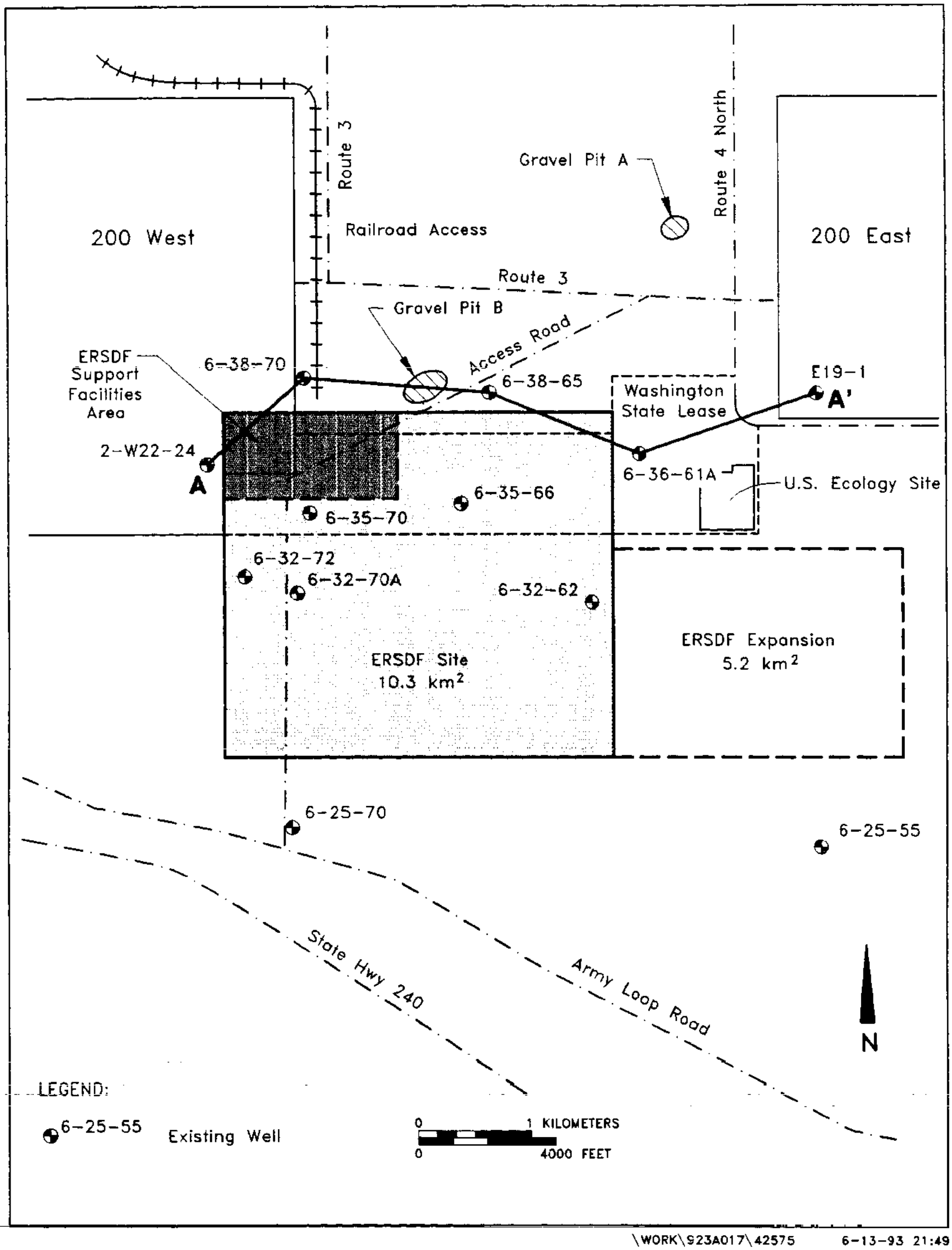

Figure 1-1. ERSDF Site

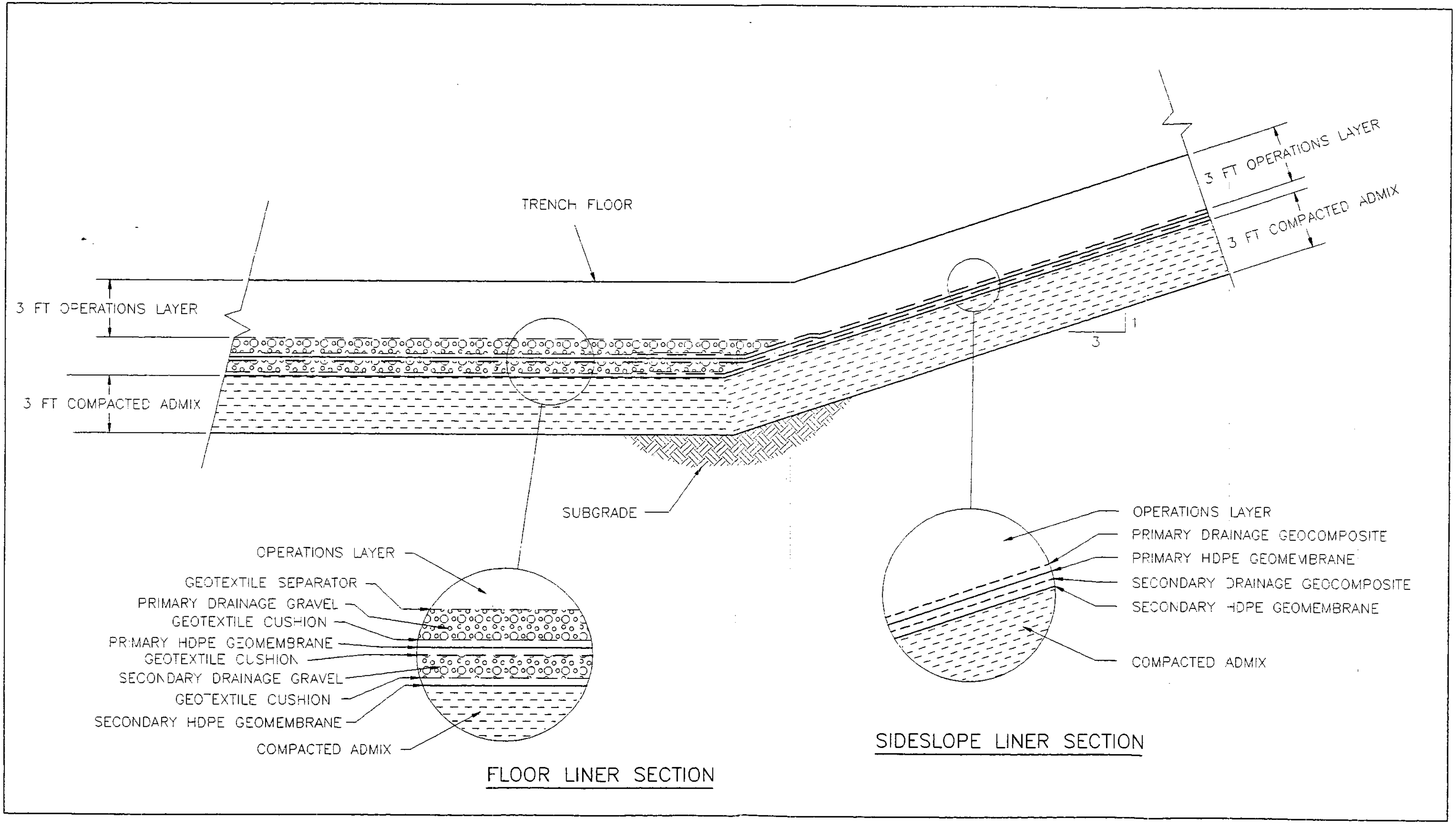

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Figure 1-2. Liner System Section

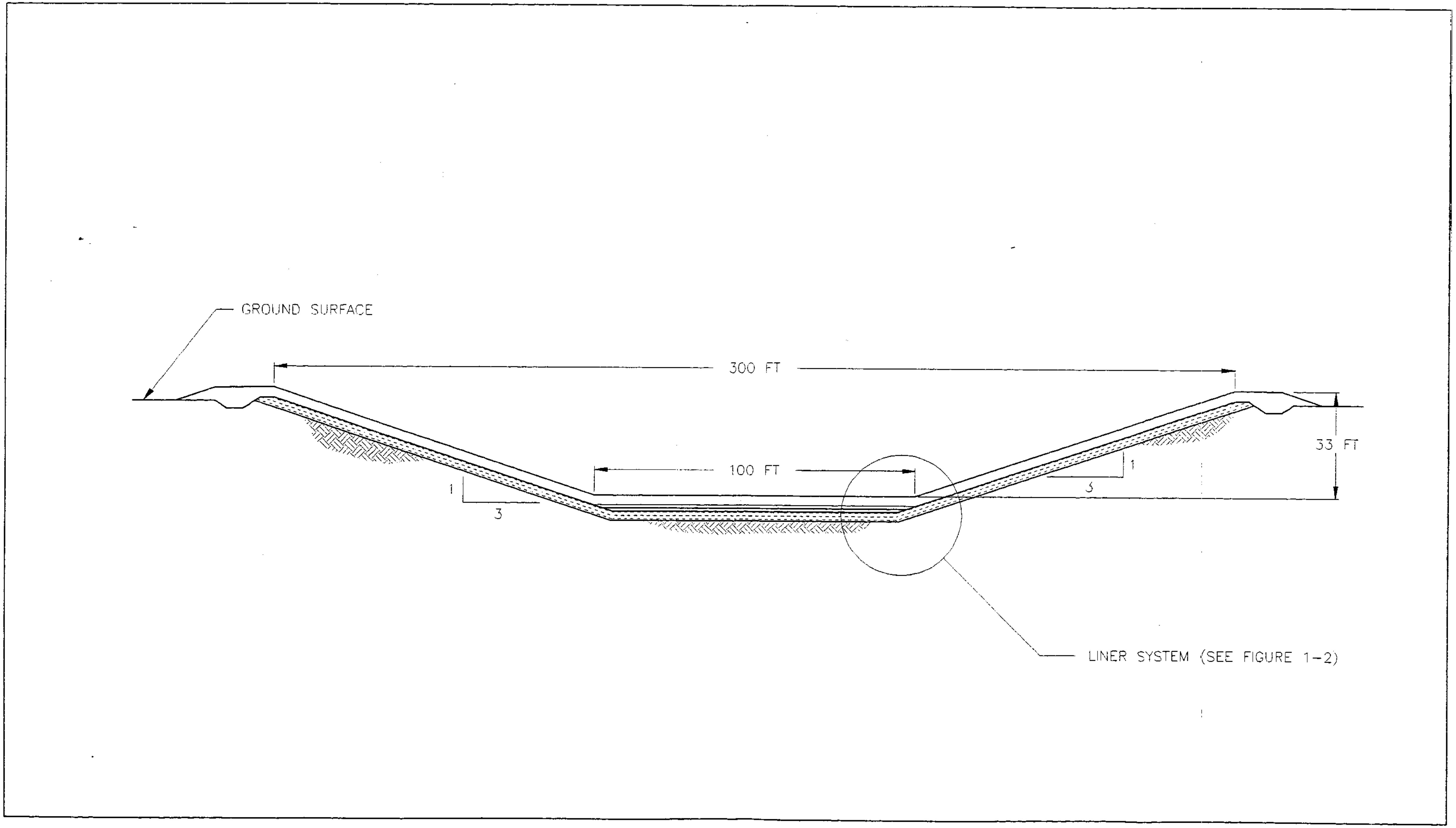

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Figure 1-3. Trench Cross Section

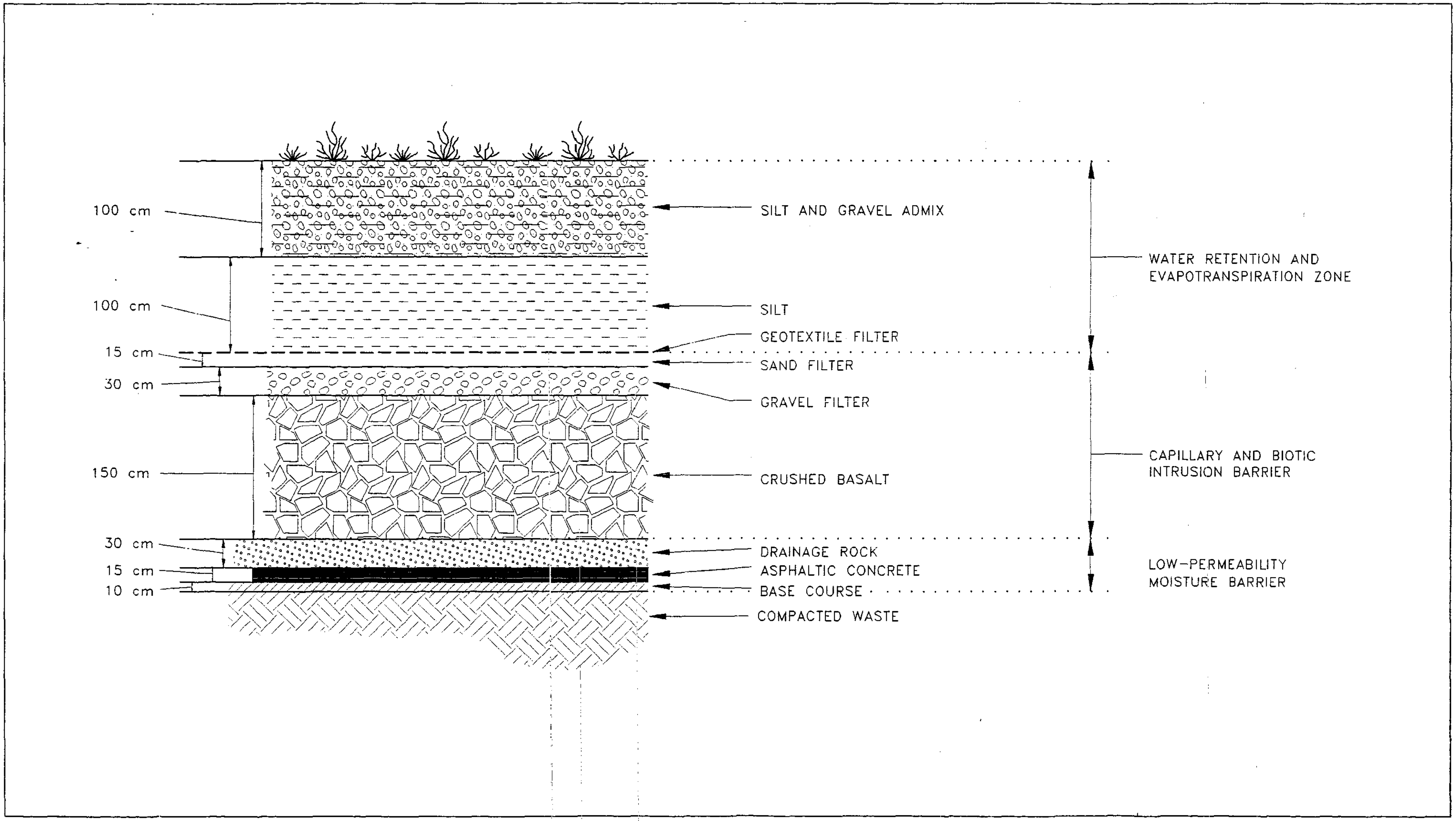

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Figure 1-4. Hanford Barrier Section.

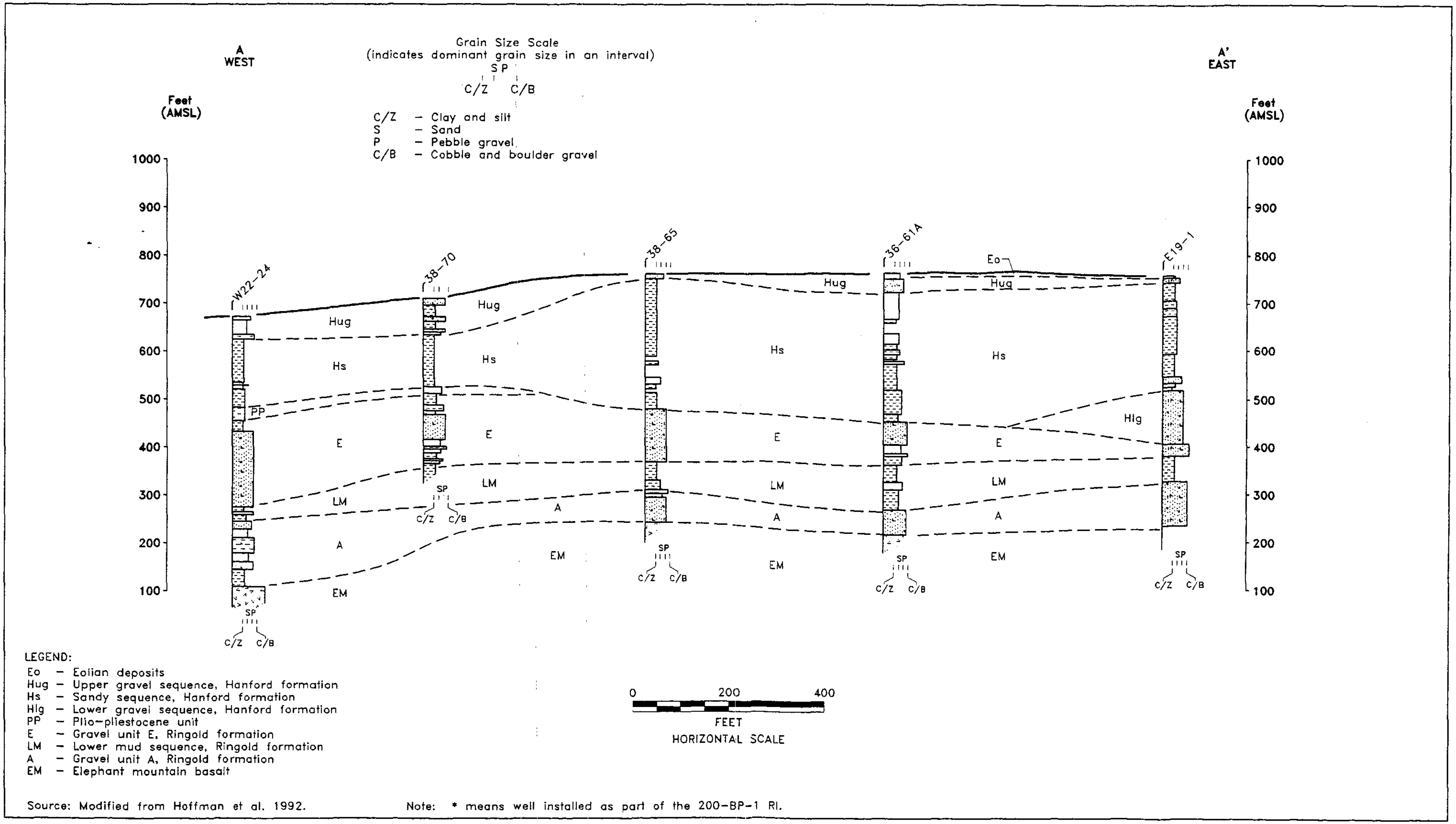

Figure 2-1. Geologic Cross Section A-A'.

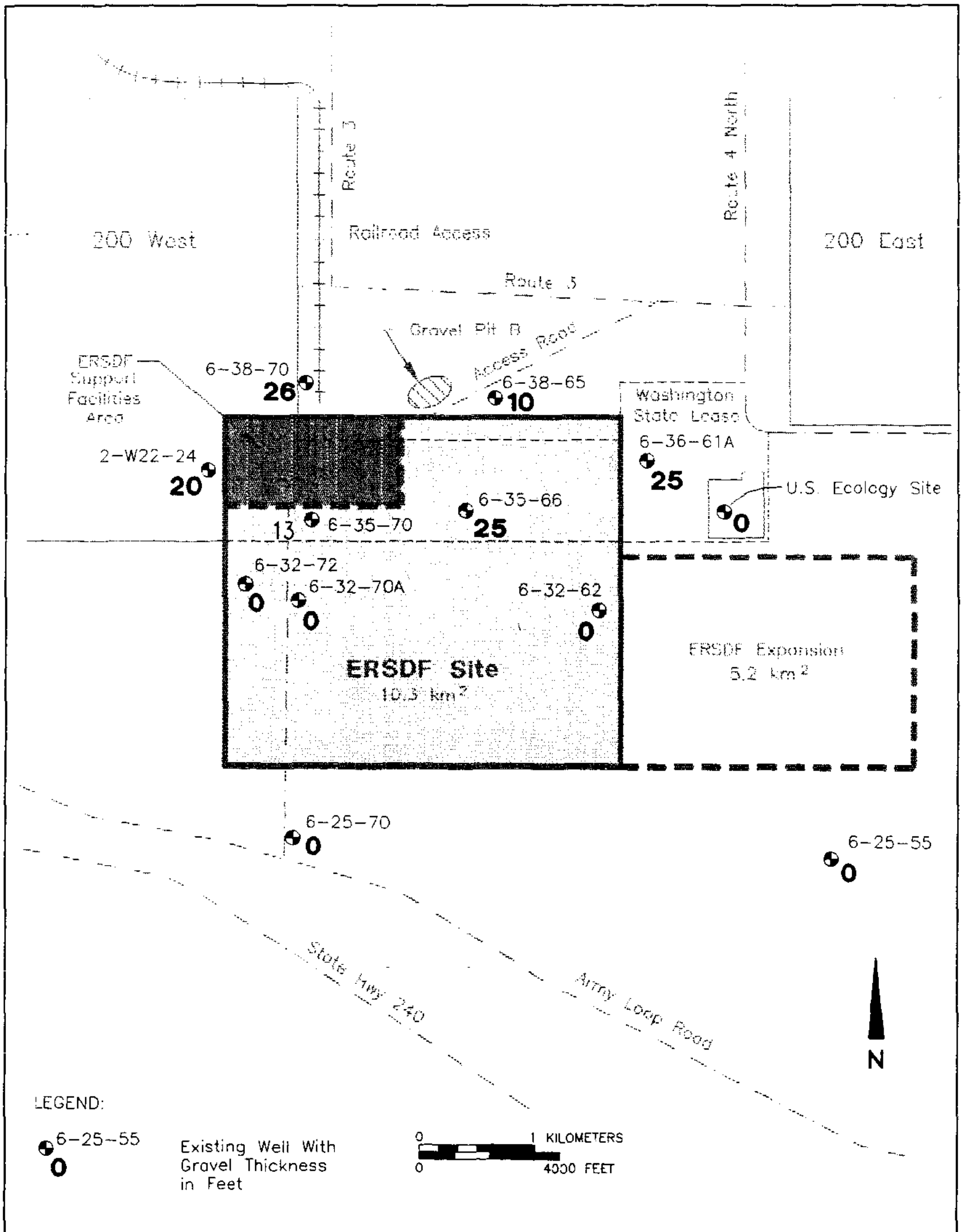

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Figure 2-2. Thickness of Upper Gravel Sequence, Hanford Formation.

GRAIN SIZE DISTRIBUTION

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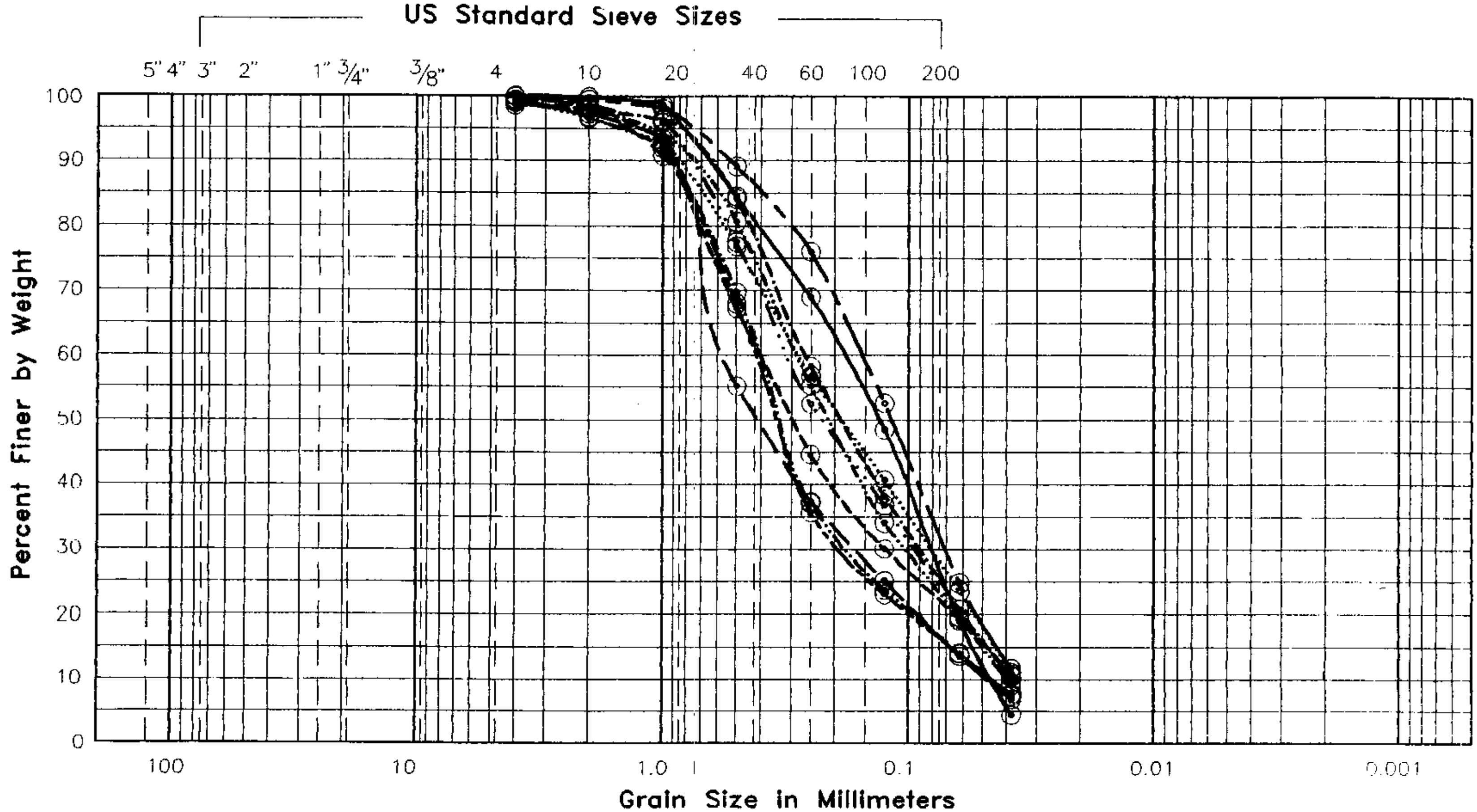

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-035-070	0, 5, 10, 20, 25, 30, 35, 40, 45, 50		—	—	—	

Figure 2-3. Grain Size Distribution - Well 6-35-70.

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GRAIN SIZE DISTRIBUTION

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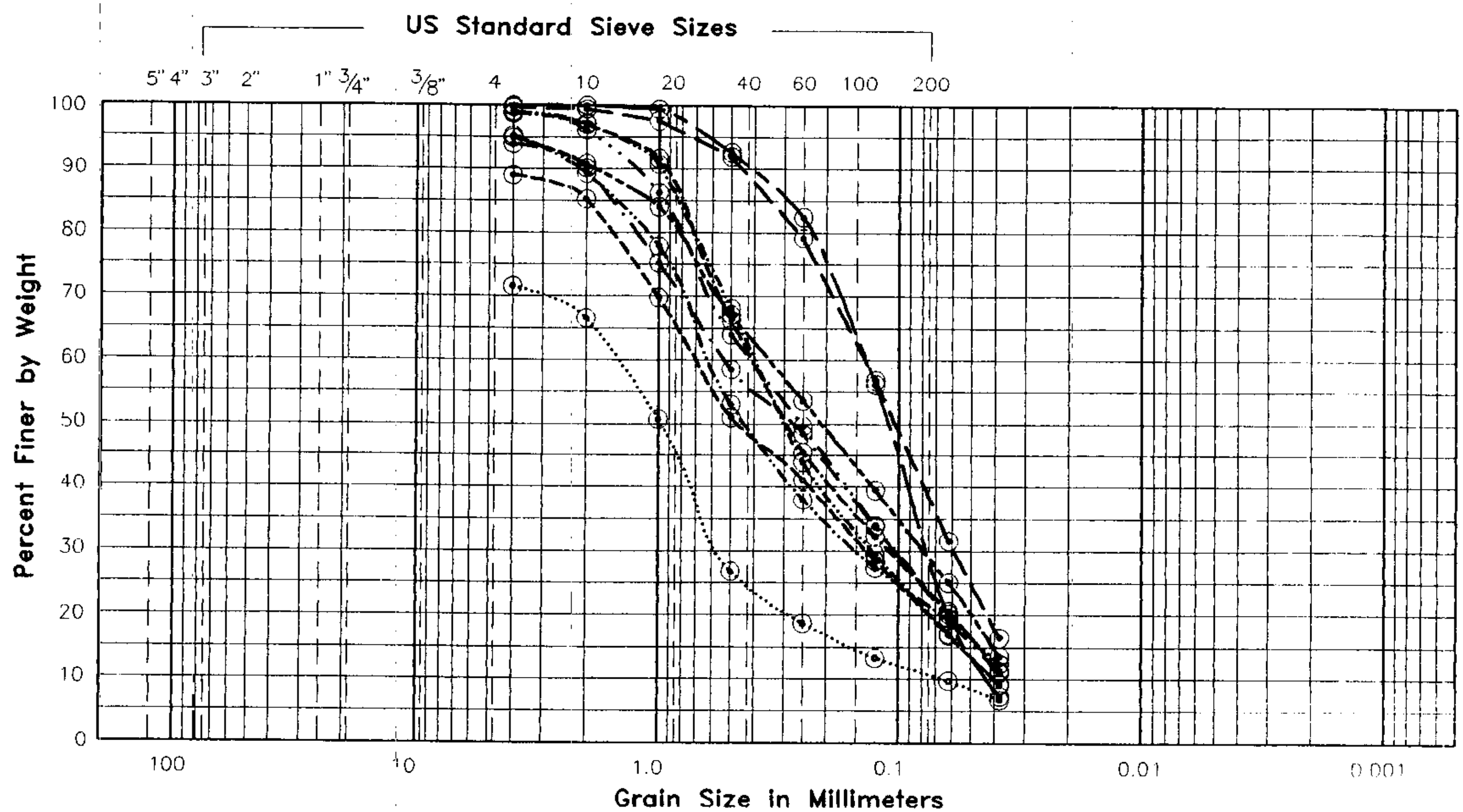

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-035-066	5 10 15 20 25 30 35 40 45 50	–	–	–	–	

Figure 2-4. Grain Size Distribution - Well 6-35-66.

GRAIN SIZE DISTRIBUTION

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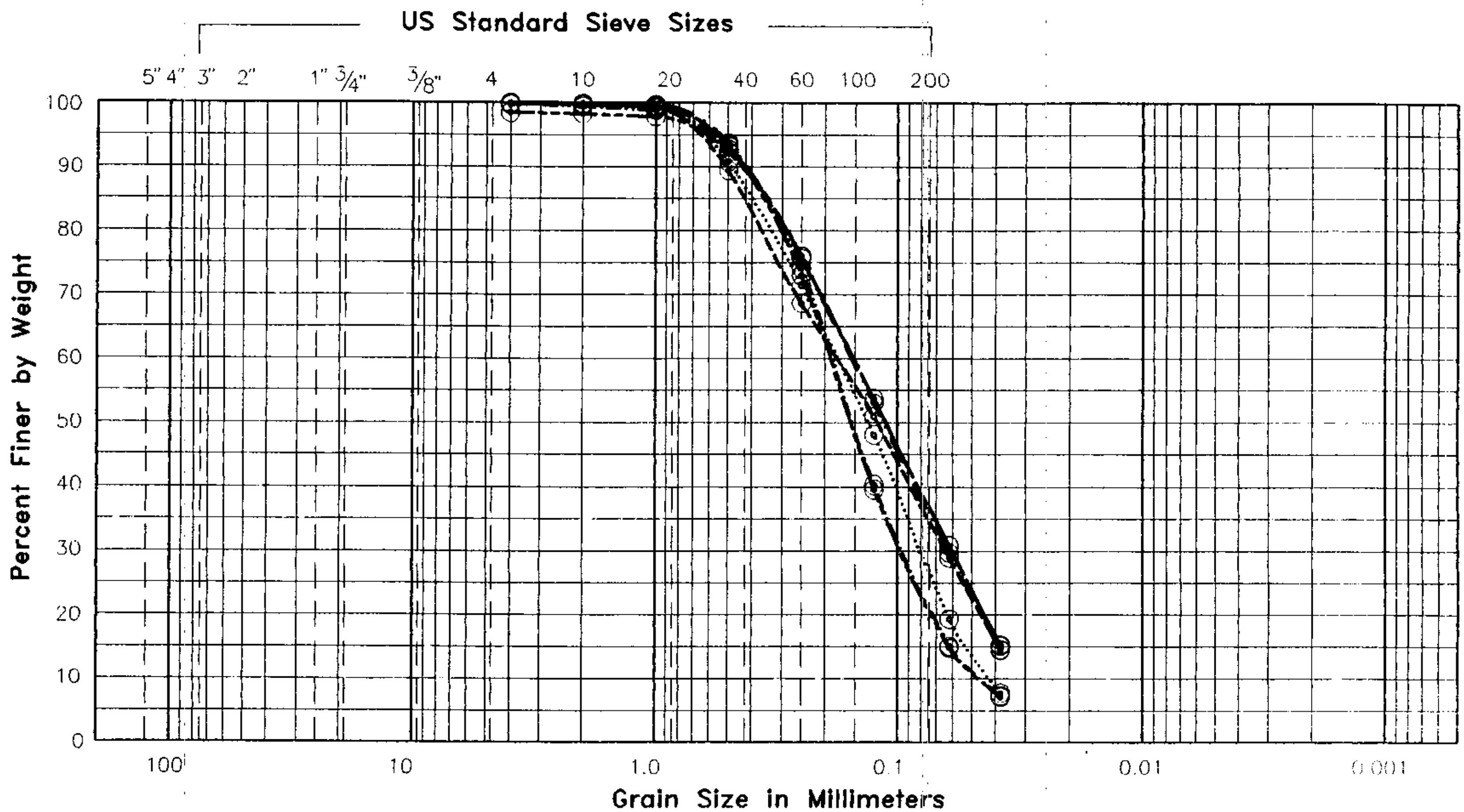

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-032-072	5 10 15 20 25 30 35	–	–	–	–	

Figure 2-5. Grain Size Distribution - Well 6-32-72.

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GRAIN SIZE DISTRIBUTION

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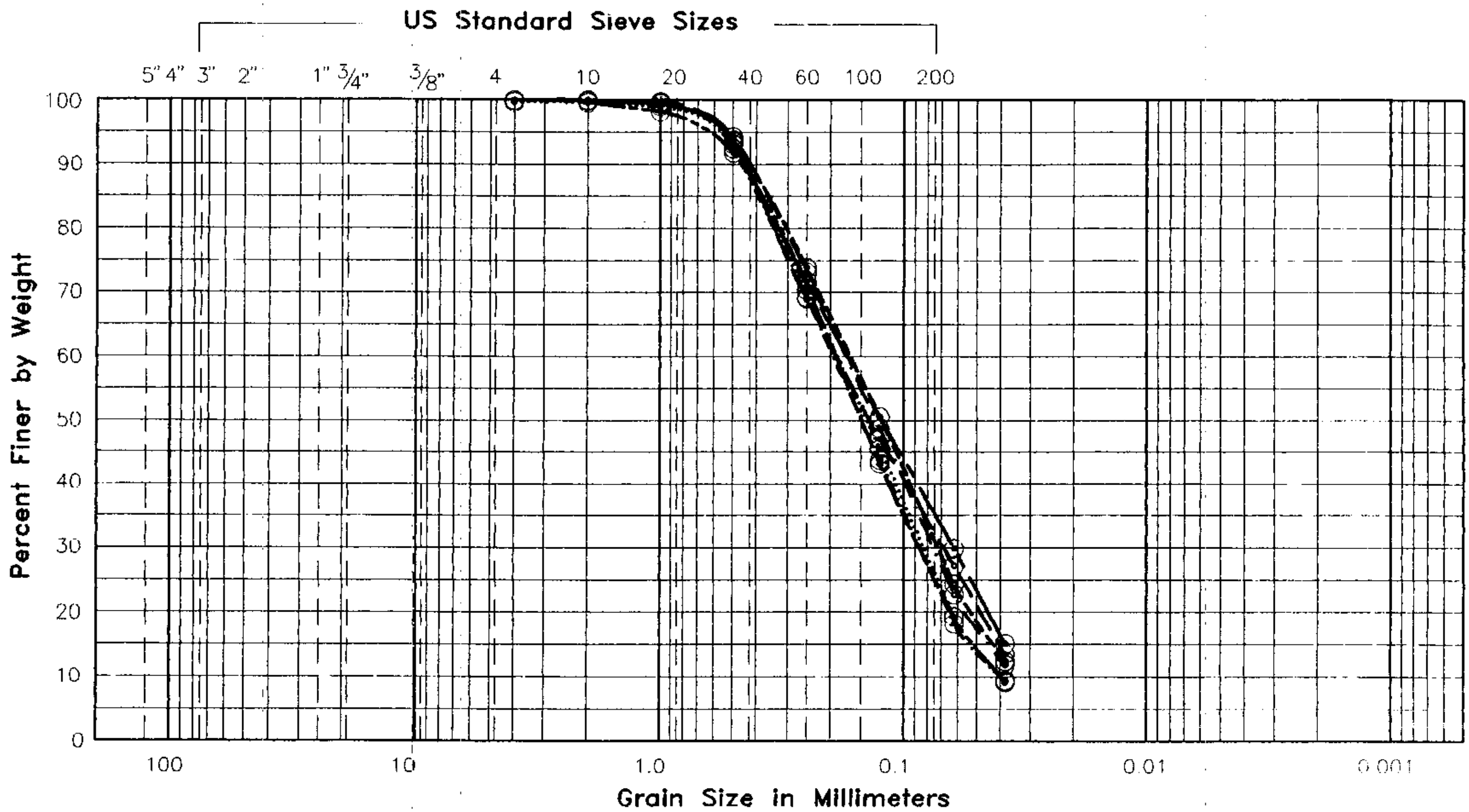

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-032-070A	5 10 15 20 25 30 35	–	–	–	–	

Figure 2-6. Grain Size Distribution - Well 6-32-70A.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
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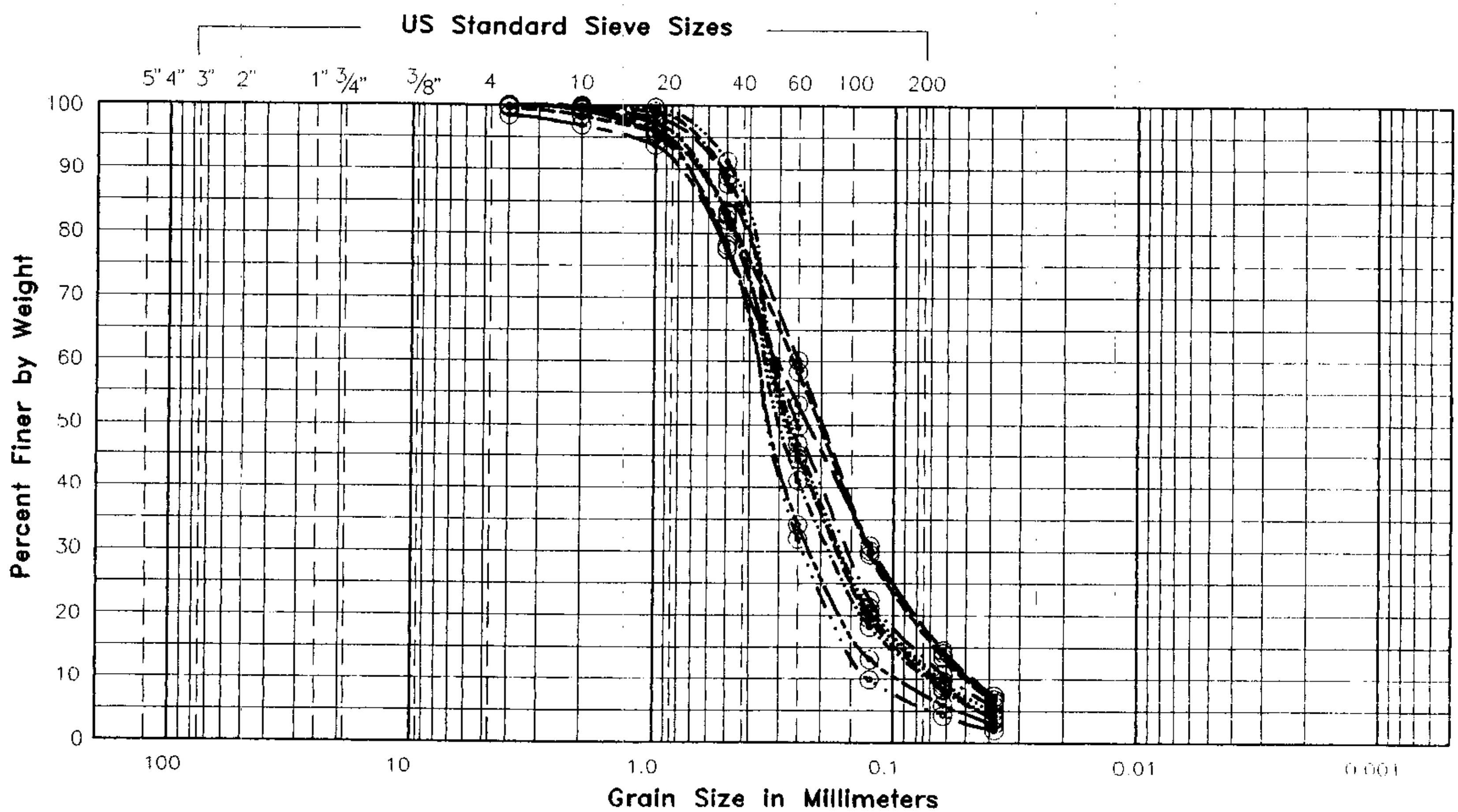


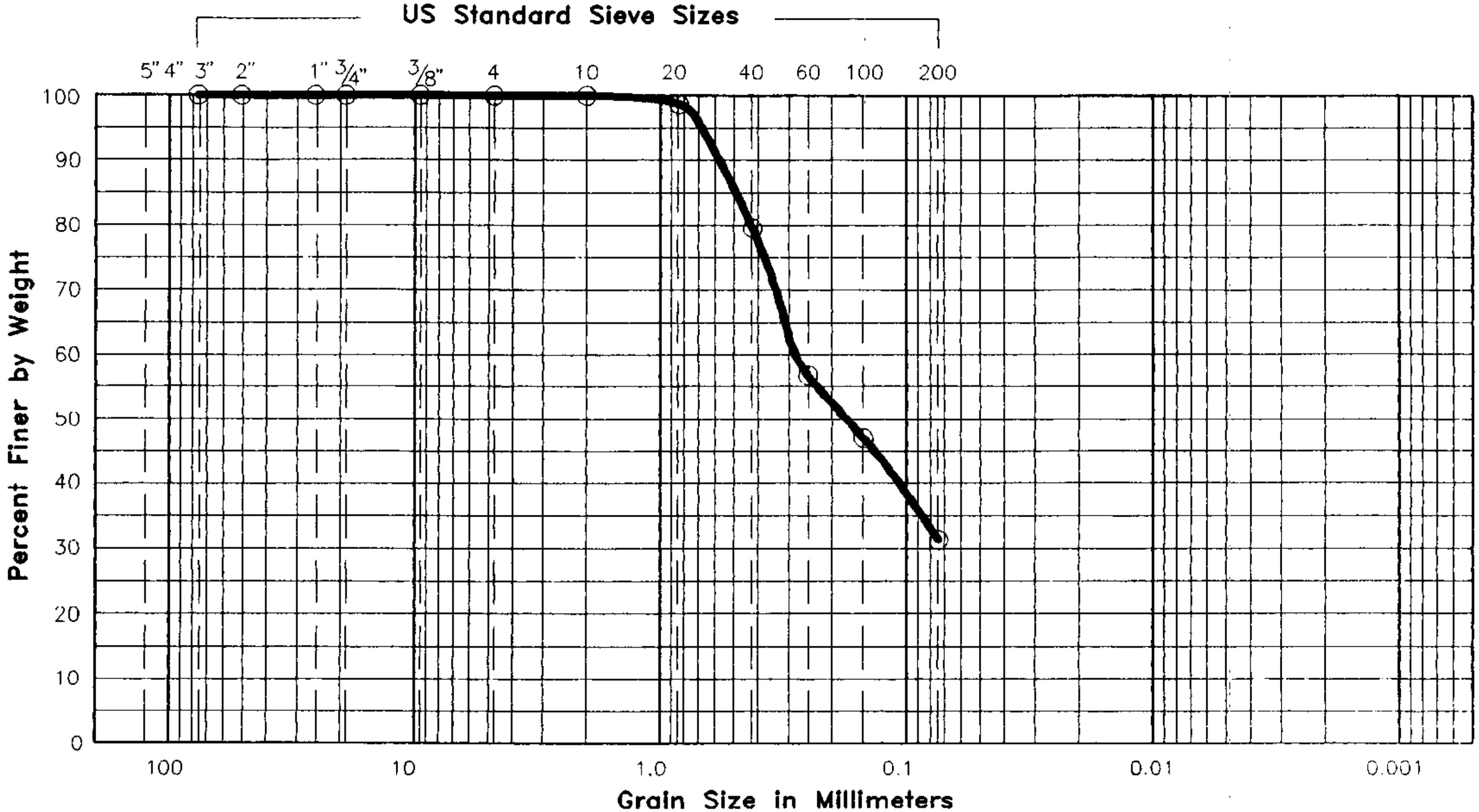
Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-032-062	5 ——— — —— 10 ——— — — — 15 ——·——·—— 20 ---------- 25 ·············· 30 ——··——··—— 35 —————— 40 —···——···— 45 —·——·——·— 50 ···——···——	–	–	–	–	

Figure 2-7. Grain Size Distribution - Well 6-32-62.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-14-93 Tested By MF Reviewed By DPO



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
4	15 FT	1.8	–	–	–	Light olive gray (5Y6/1), m–f SAND and SILT, (SM).

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Figure 2-8. Grain Size Distribution - U.S. Ecology Sand Sample.

GRAIN SIZE DISTRIBUTION

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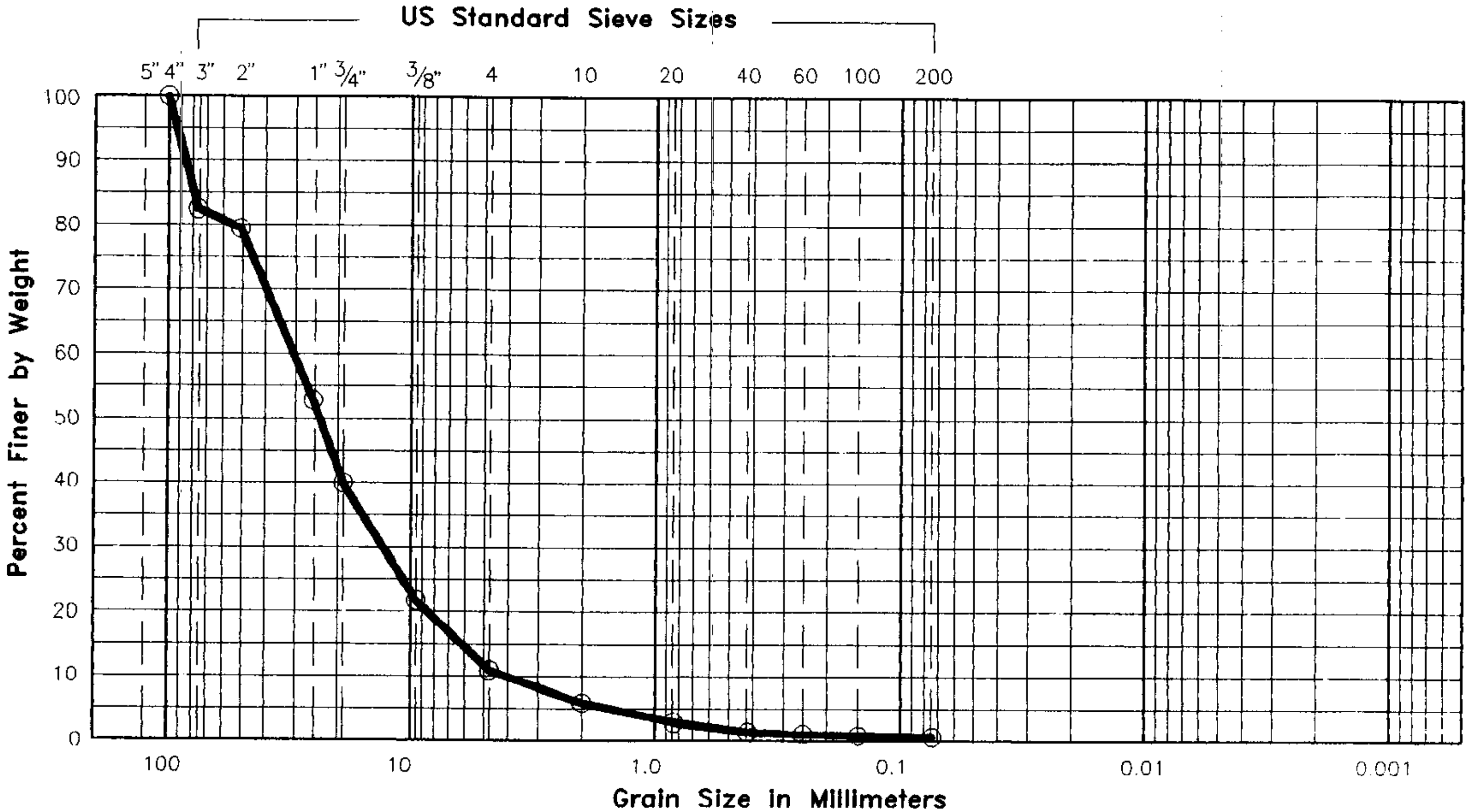

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
1	5 ft	0.5	–	–	–	Yellowish gray (5Y7/2), c–f GRAVEL, some cobbles, little c–m sand, trace silt, (GW)

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Figure 2-9. Grain Size Distribution - Gravel Pit B Sample 1.

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GRAIN SIZE DISTRIBUTION

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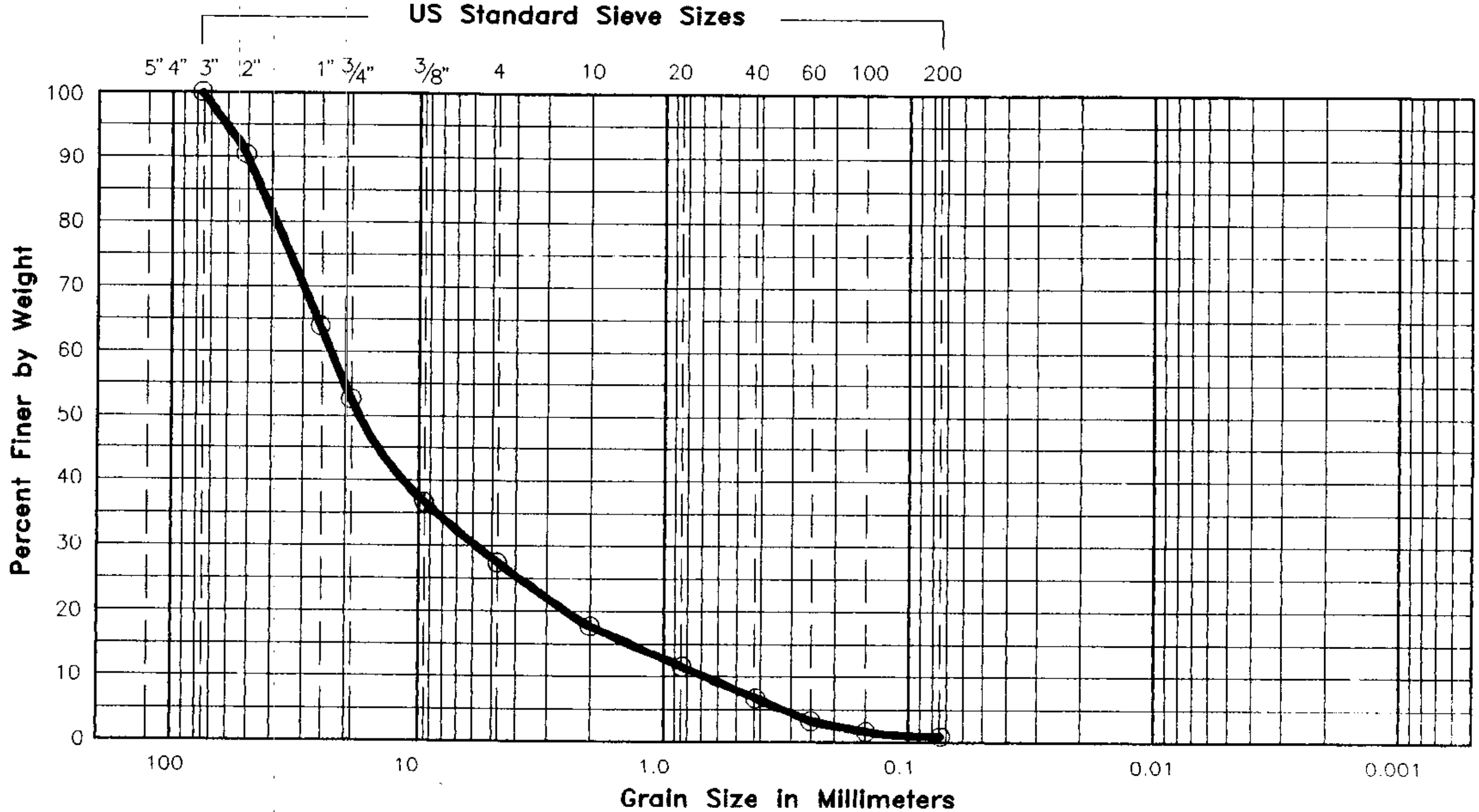


Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

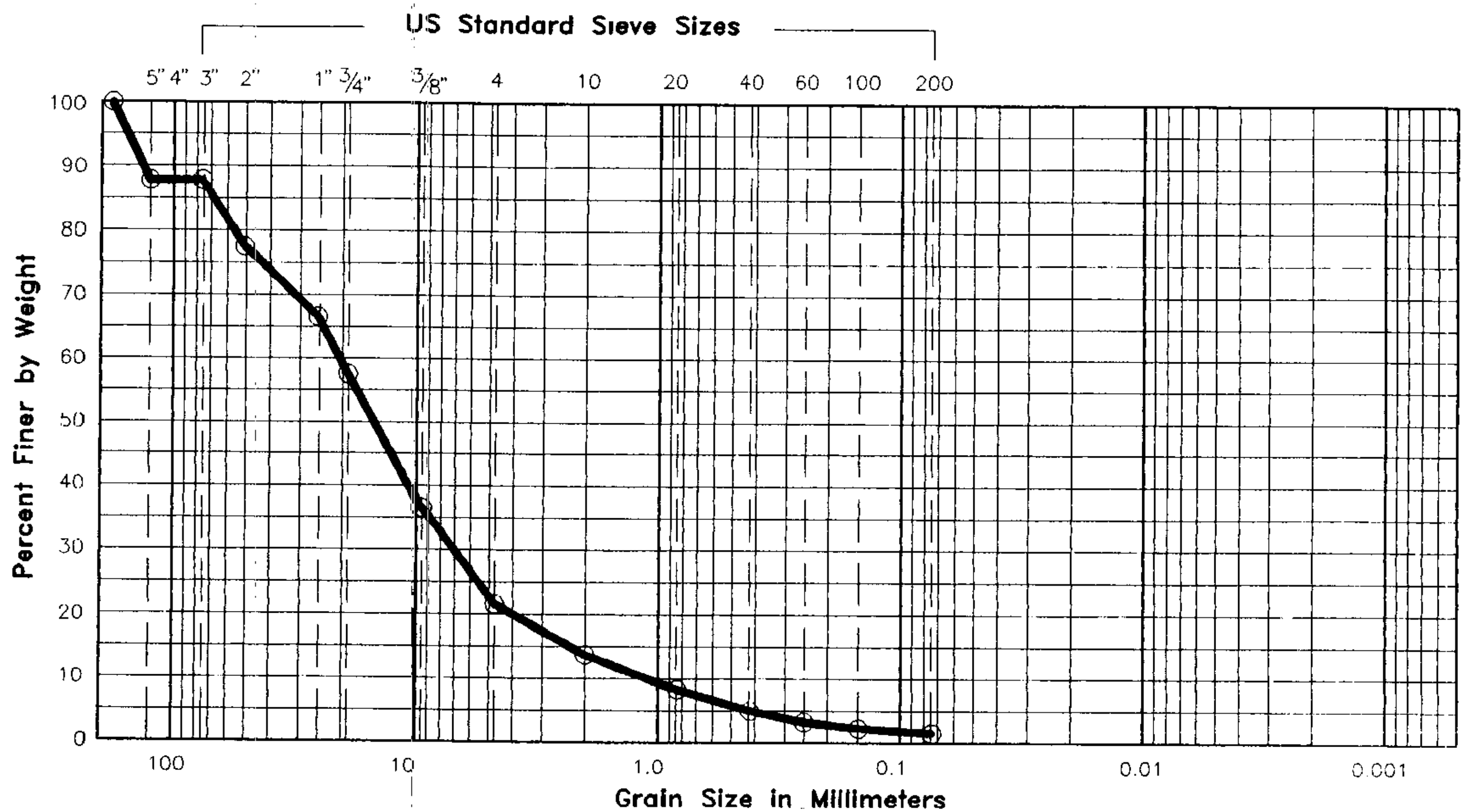
Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
3	7 ft	0.9	–	–	–	Medium light gray (N6), c–f GRAVEL, some c–f sand, trace silt, (GW).

Figure 2-10. Grain Size Distribution - Gravel Pit B Sample 3.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-14-93 Tested By MF Reviewed By DPO

Golder Associates

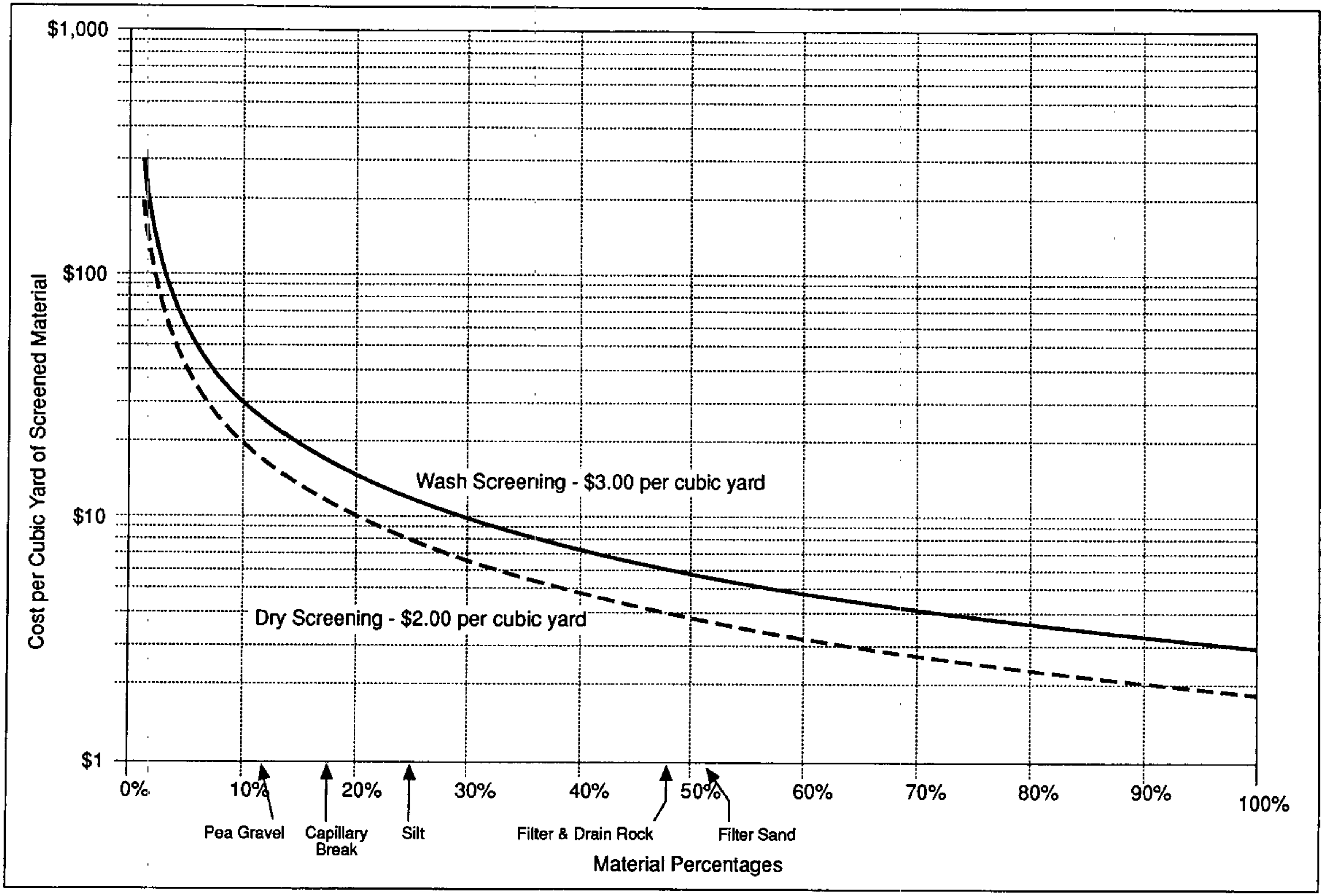


Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
5	–	0.8	–	–	–	Yellowish gray (5Y7/2), c–f GRAVEL, some c–f sand, some cobbles, trace silt, (GW).

6-14-93 7:09 \ERSDF\40045

Figure 2-11. Grain Size Distribution - Gravel Pit A Sample.



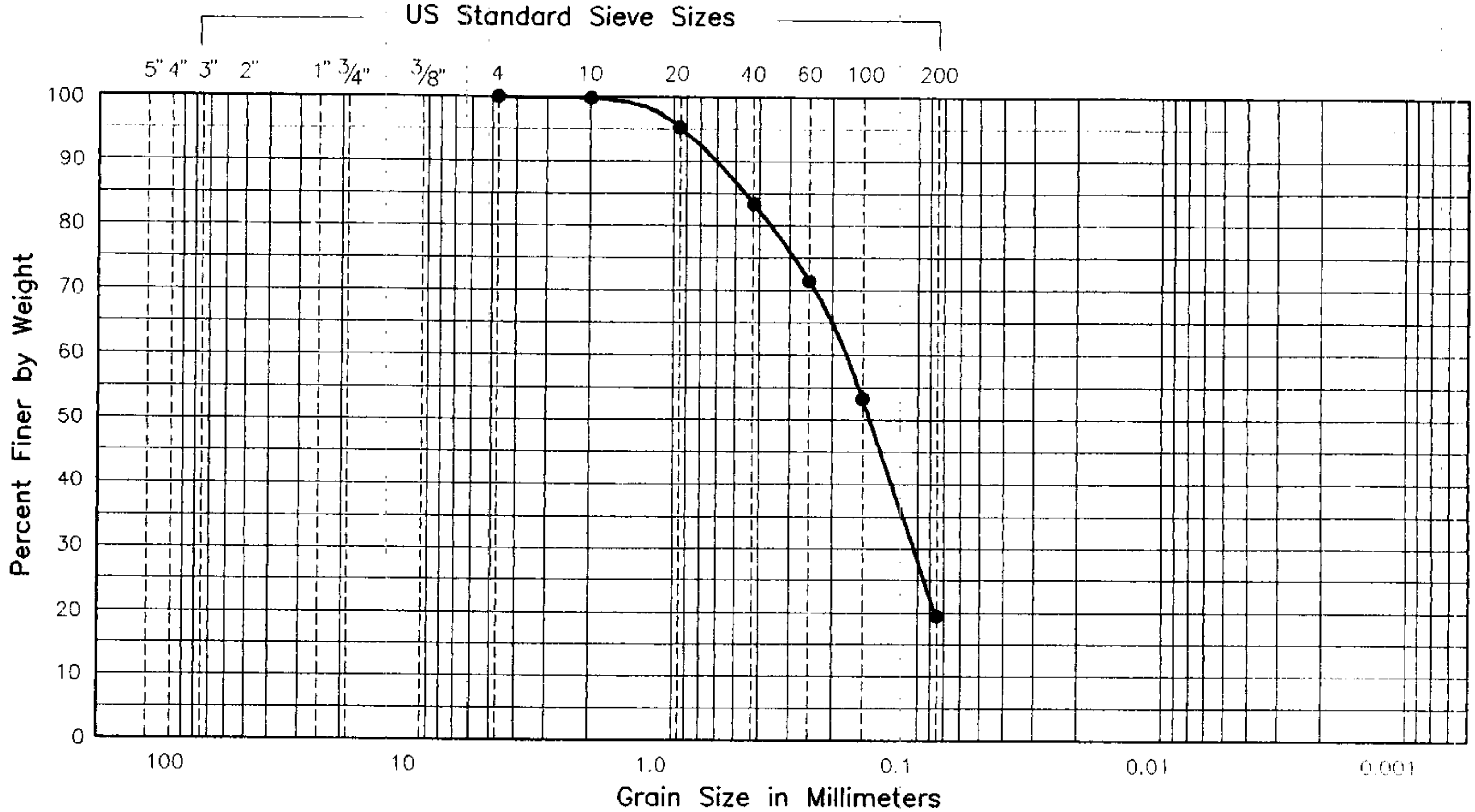
923-A017/45819/7-8-93

Figure 2-12. ERSDF Material Screening Costs.

GRAIN SIZE DISTRIBUTION

Project DOR RL/NCN-DRAG OFF/SEATTLE
Project No. 893-1186.031 Date 11/06/89 Tested By RLM Approved By KRB

Golder Associates

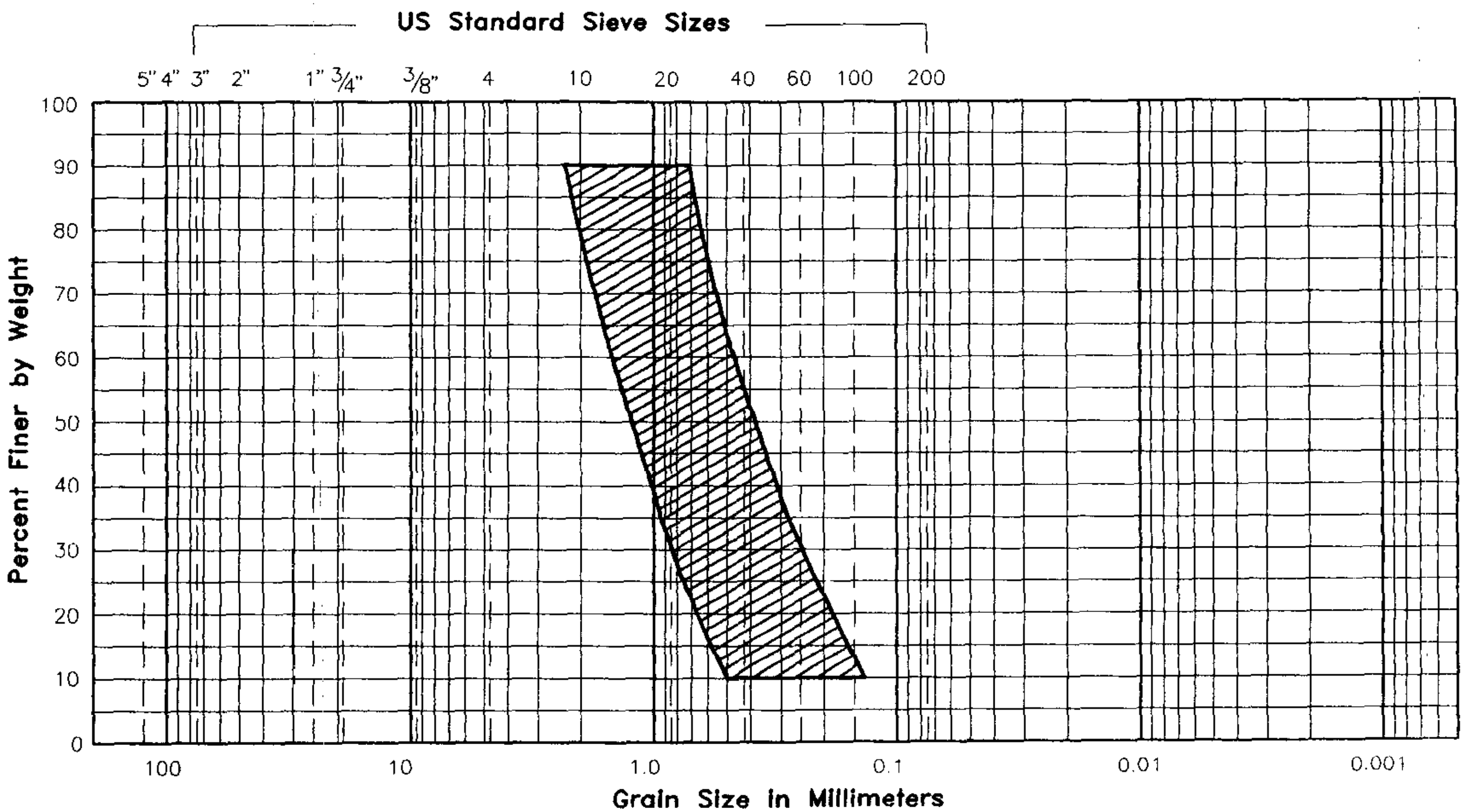


Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
GTP 1-7	Composite	2.6				Olive gray, silty fine to medium SAND, (SM).

923A017\4C041

Figure 2-13. Liner Admixing Soil - Project W-025 Landfill.

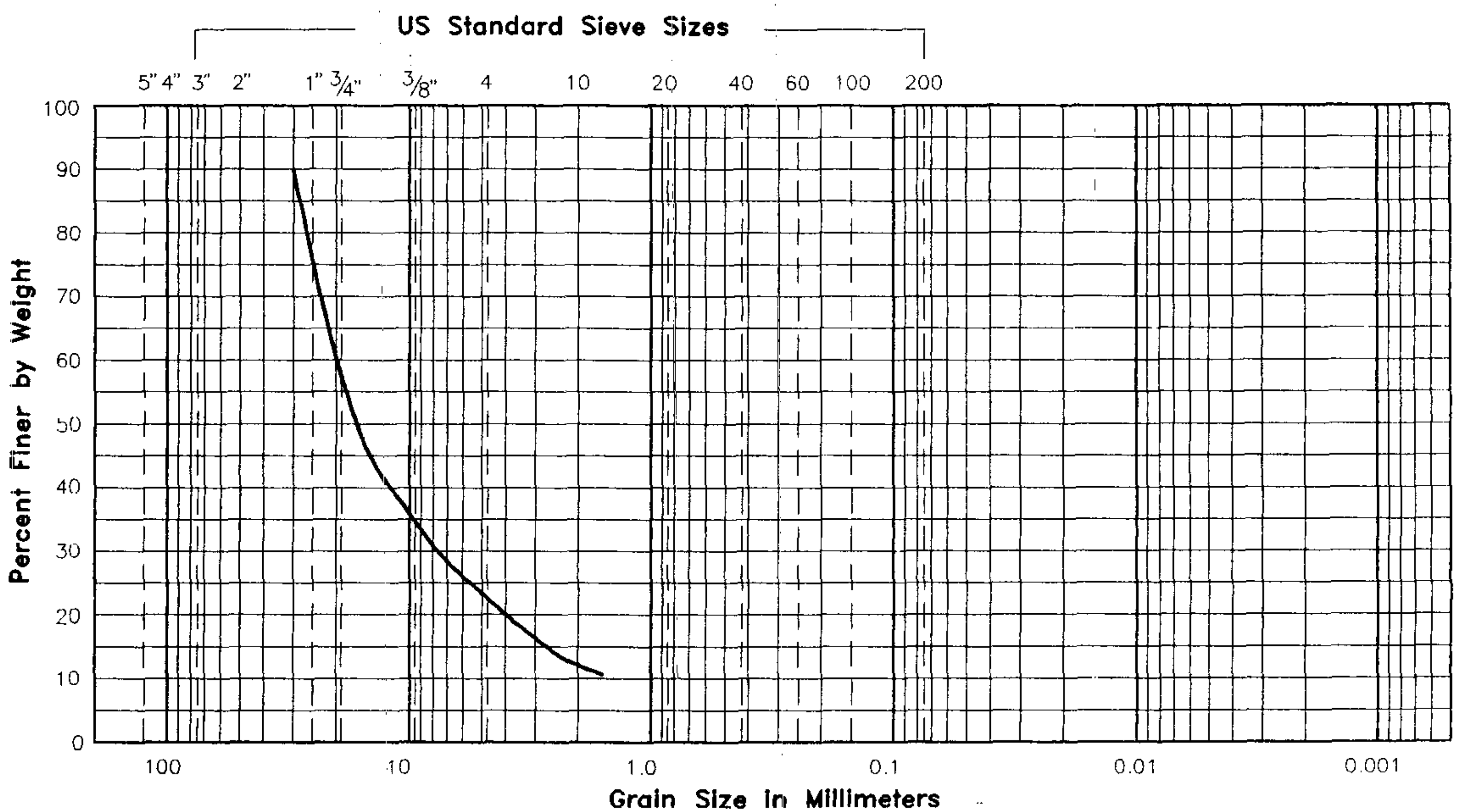


Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description

6-14-93 5:08 \ERSDF\40039

Figure 2-14. Required Size Distribution for Hanford Barrier Filter Sand

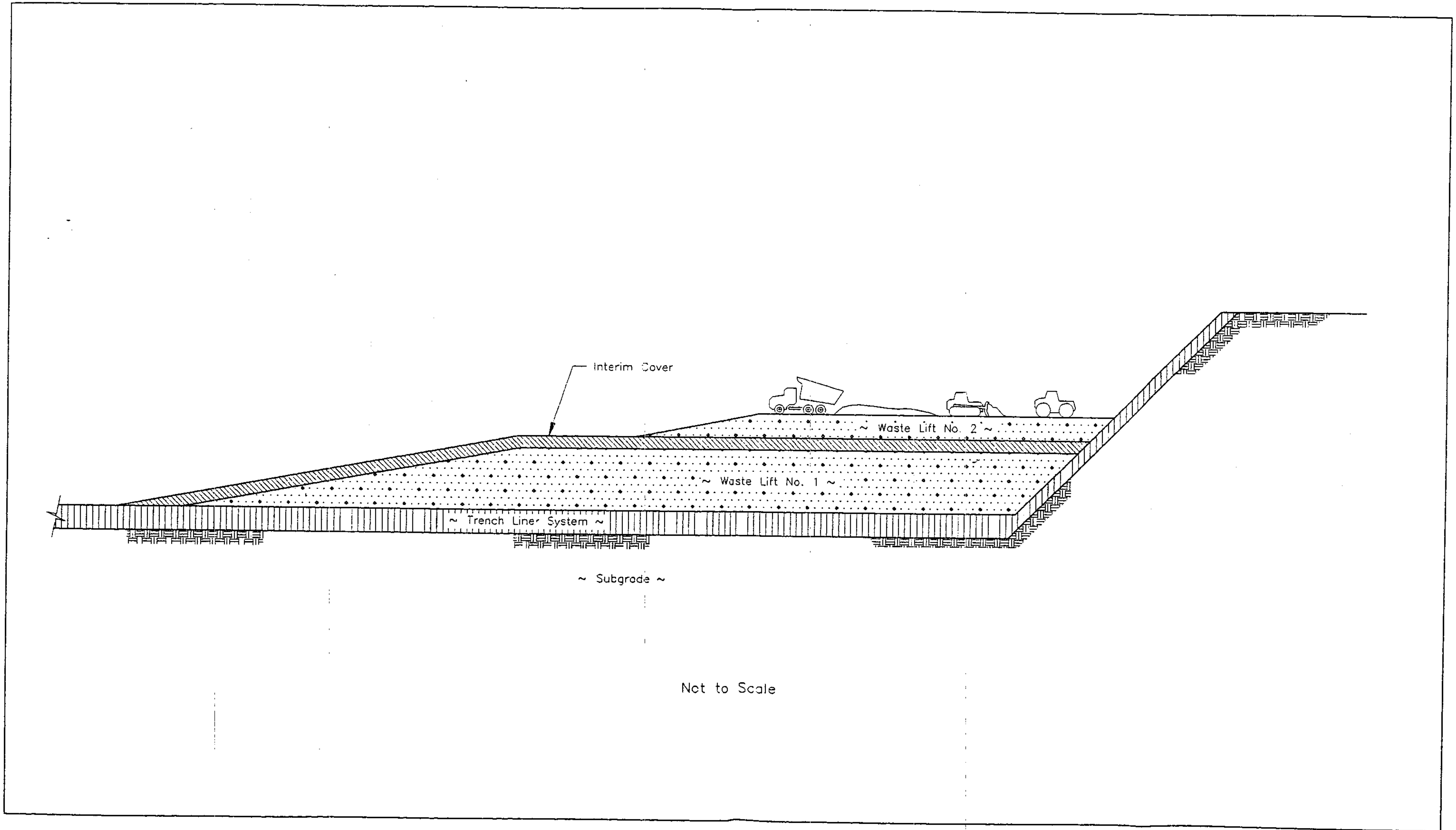


Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description

6-14-93 5:10 \ERSDF\40040

Figure 2-15. Required Size Distribution for Hanford Barrier



\WORK\923A017\42576 6-13-93 22:42

Figure 3-1. Interim Cover Use

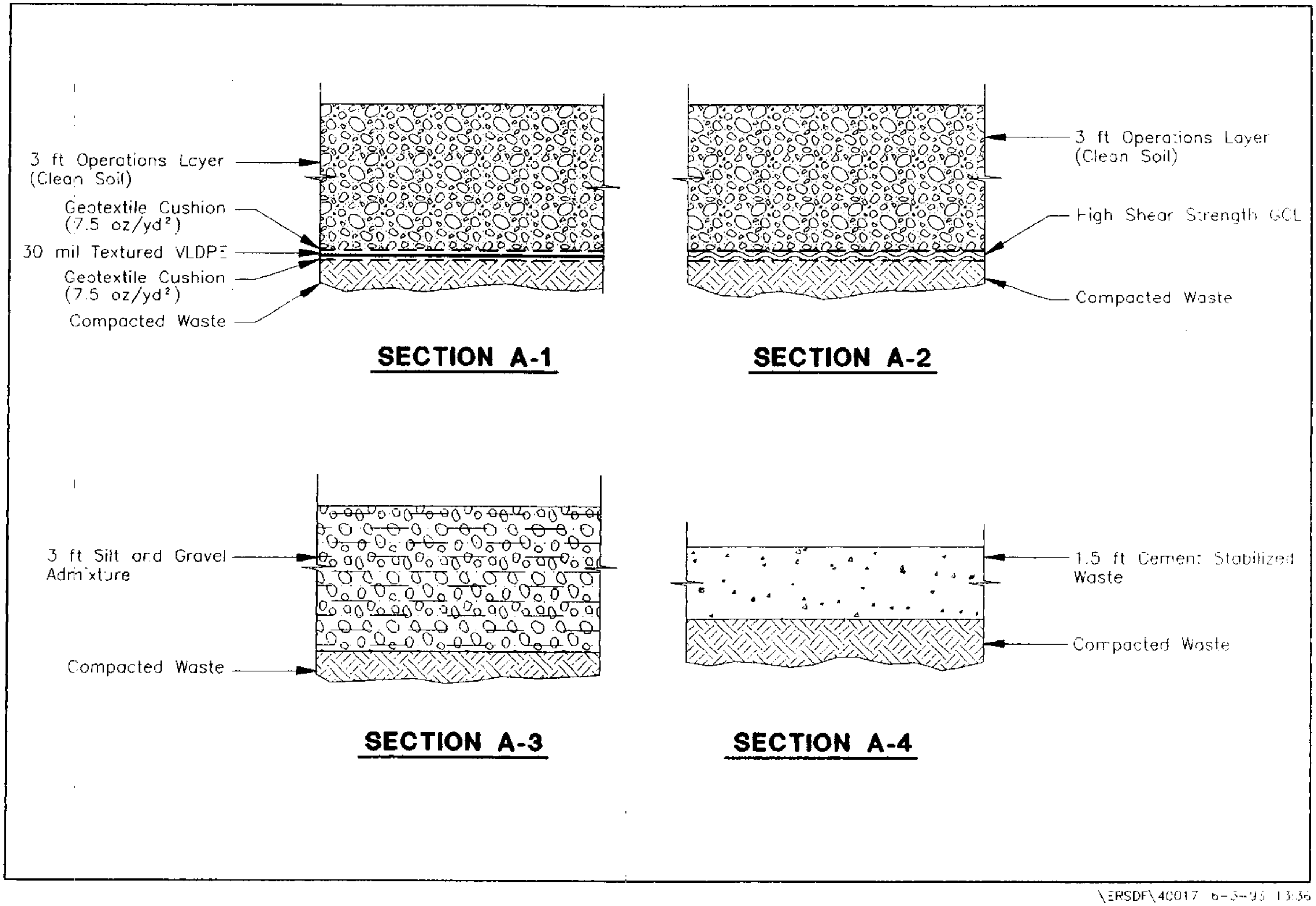


Figure 3-2. Low-Permeability Covers Intended for Traffic Conditions.

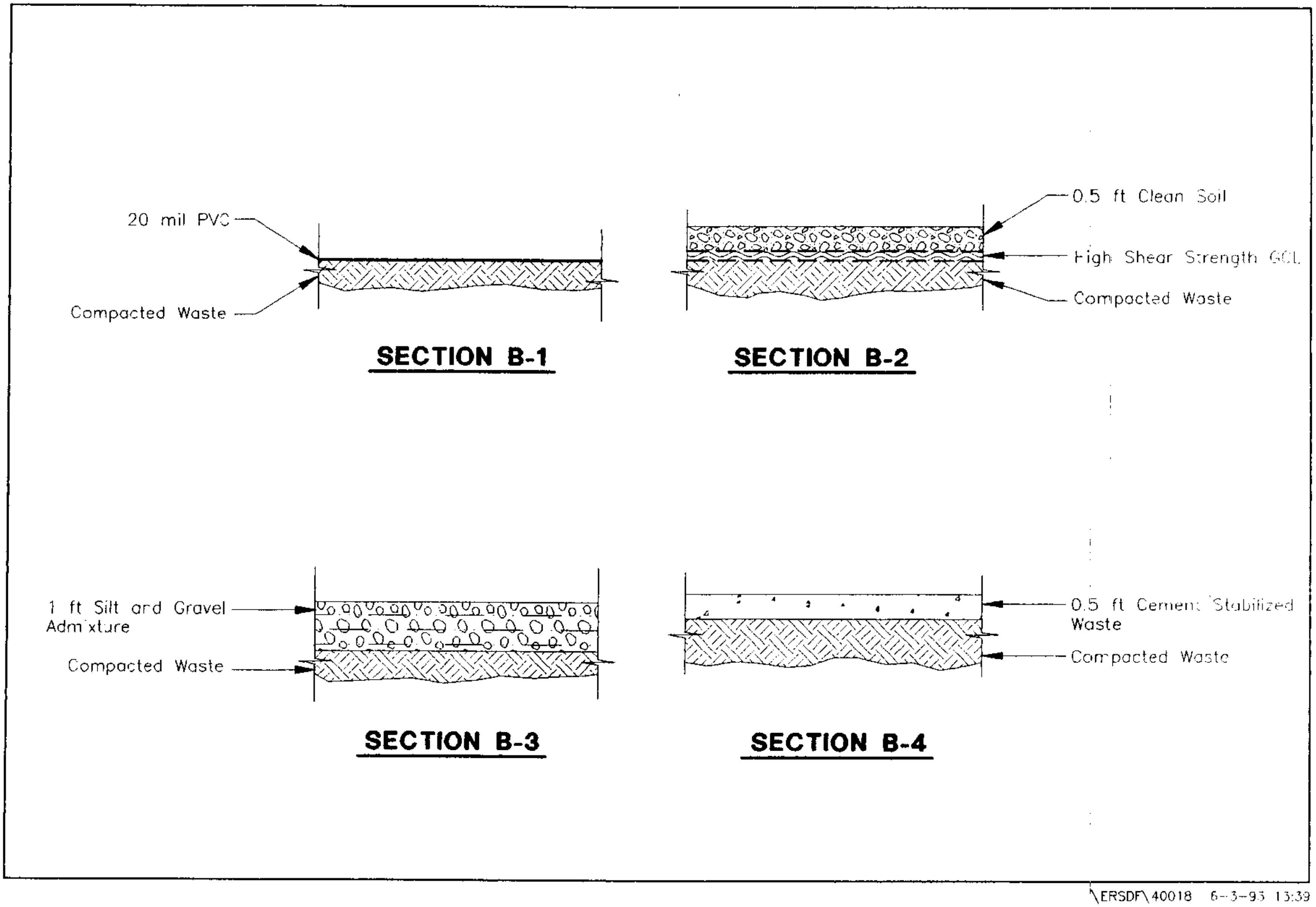
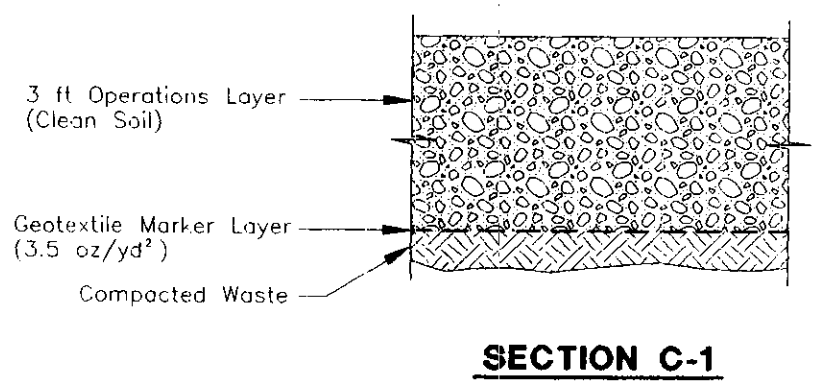


Figure 3-3. Low-Permeability Covers Not Intended for Traffic Conditions.



\WORK\923A017\40019 7-8-93 15:36

Figure 3-4. Permeable Cover Intended for Traffic Conditions.

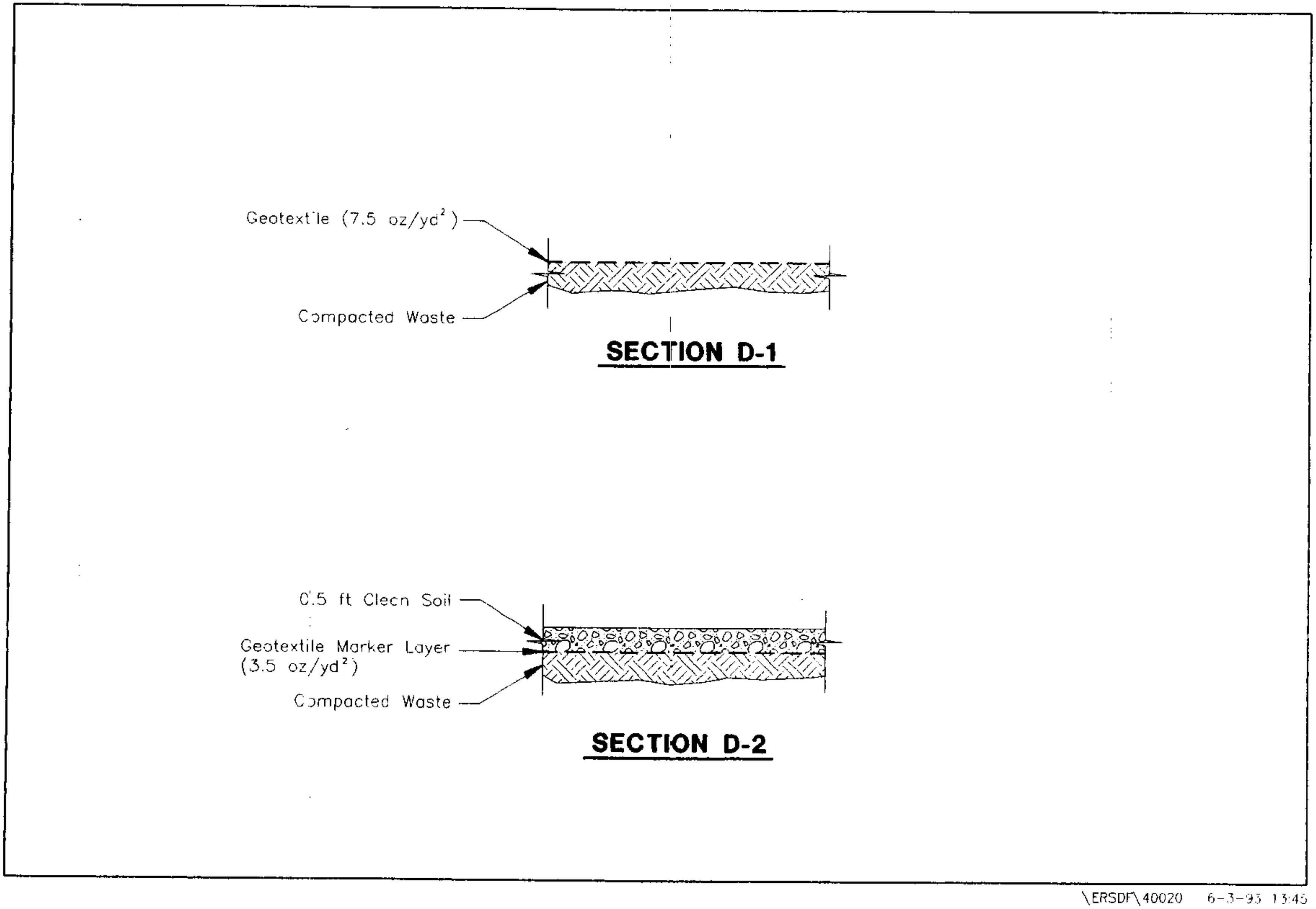


Figure 3-5. Permeable Covers Not Intended for Traffic Conditions.

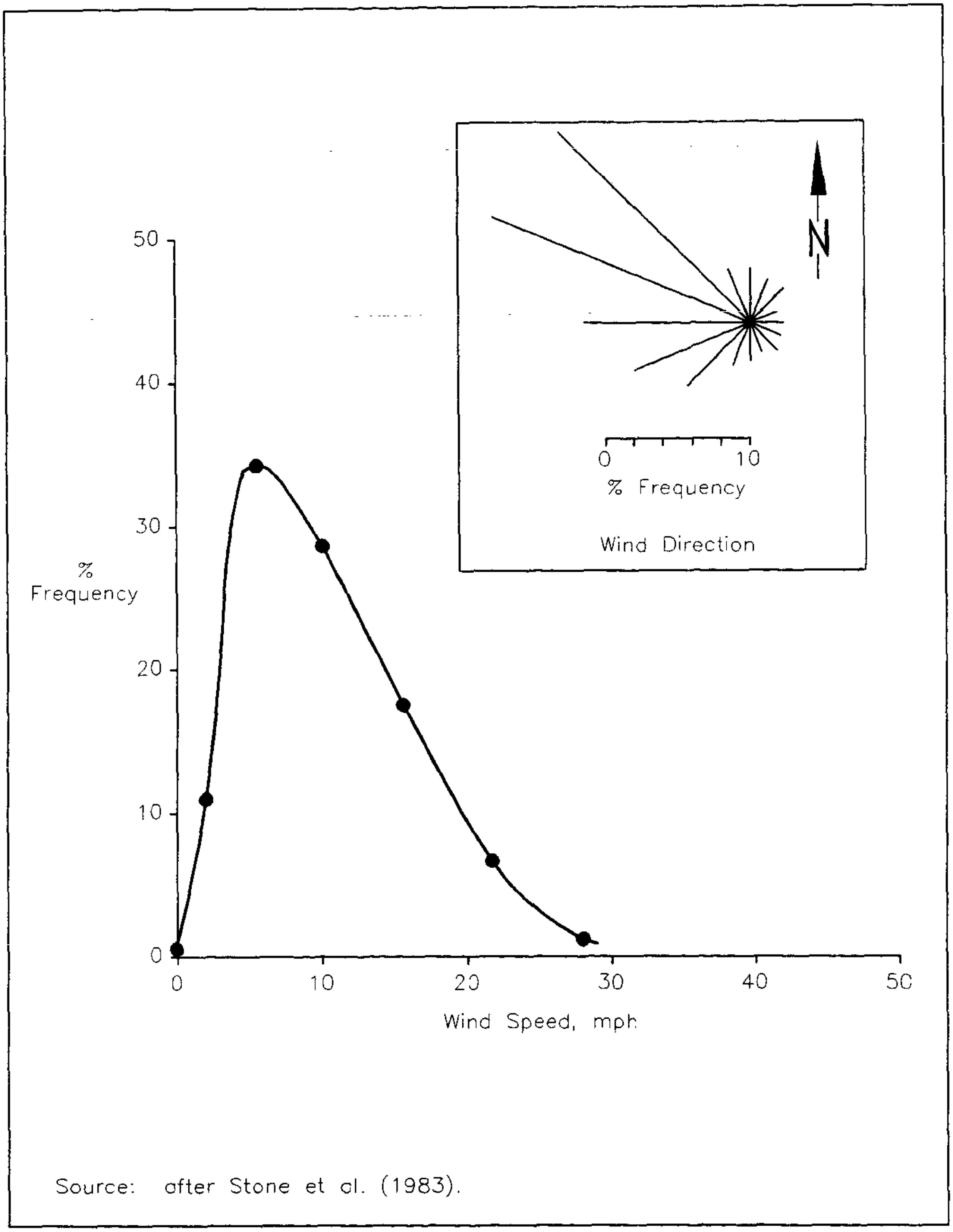


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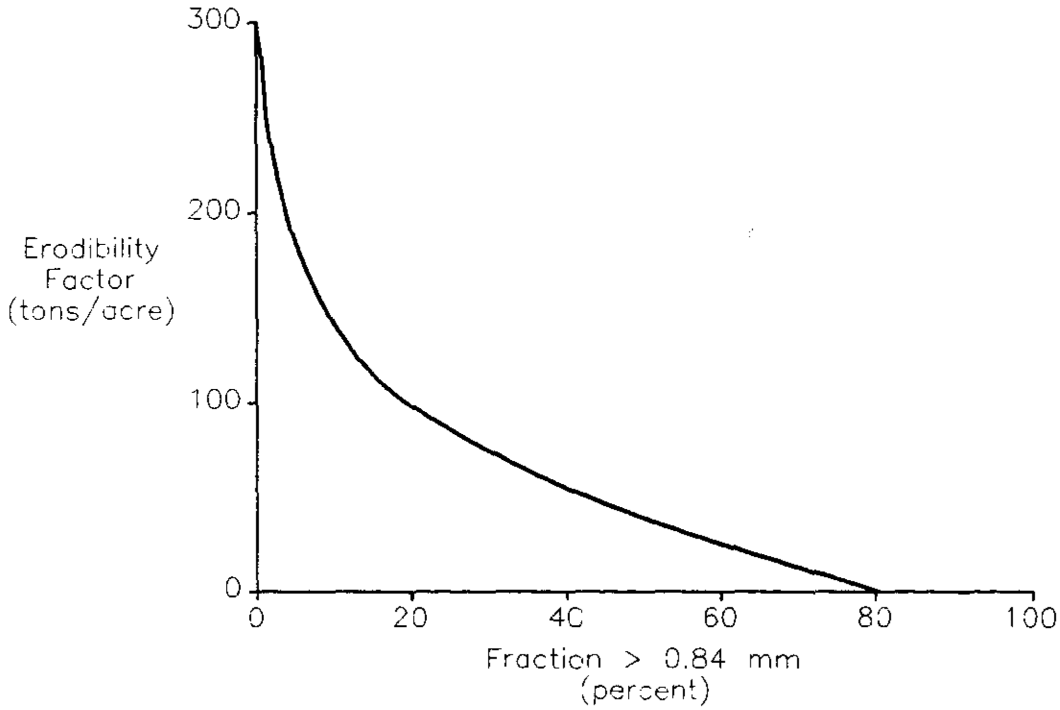
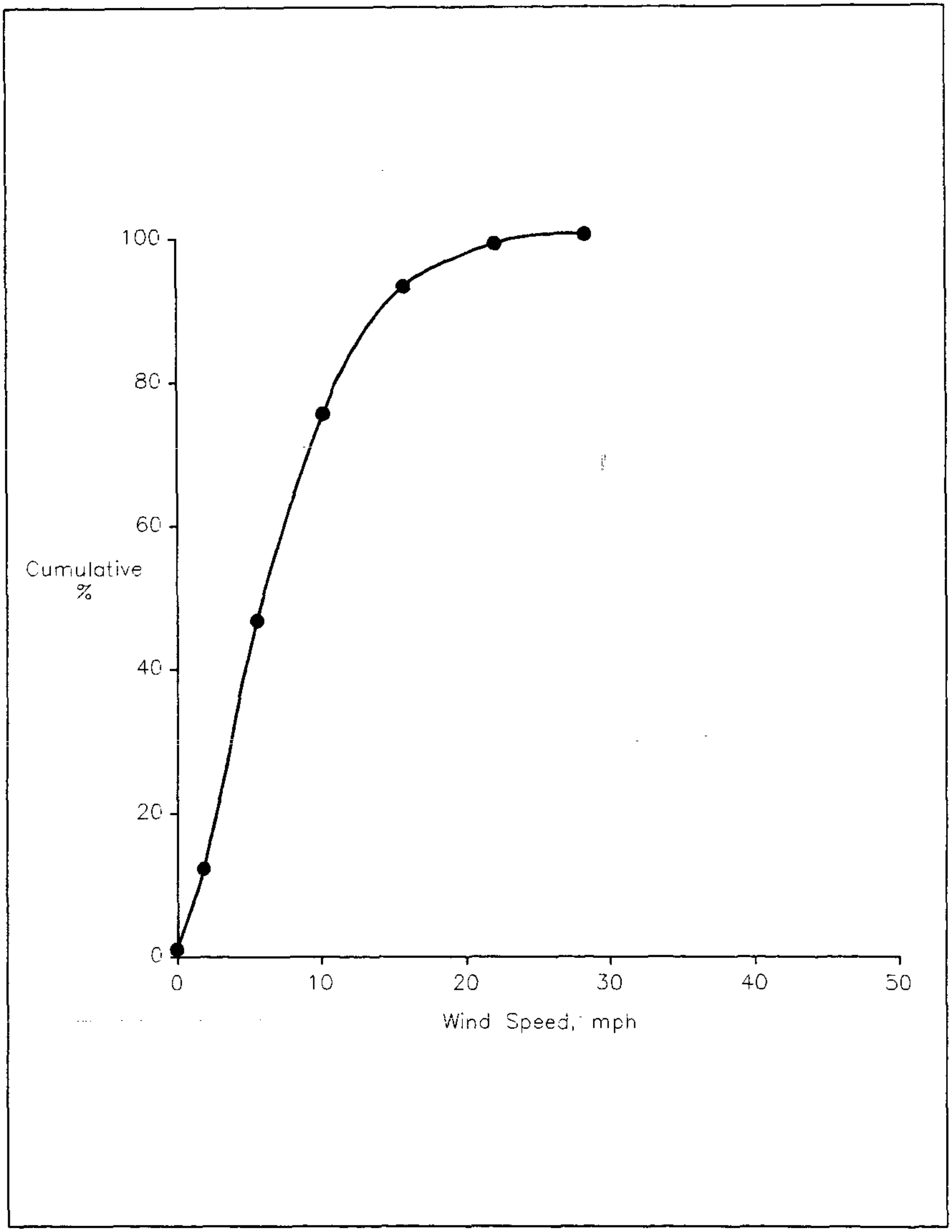
Figure 4-1. Wind Data.



Source: after EPA (1979).

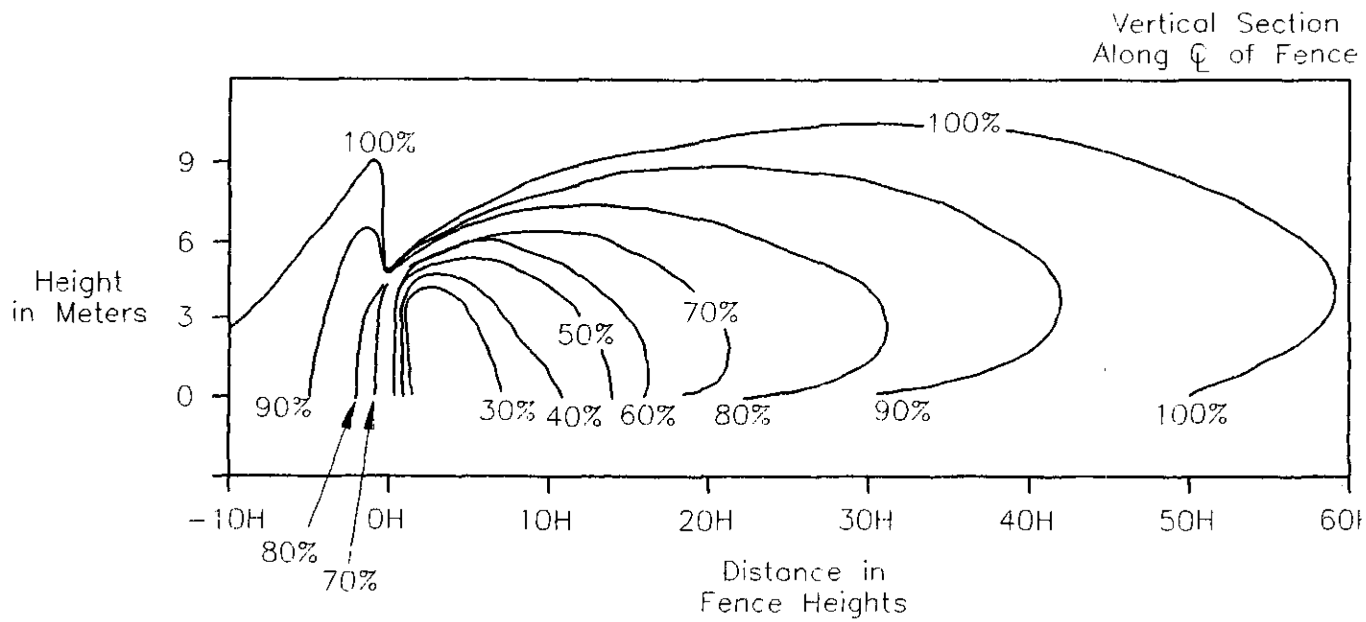
\WORK\923A0'7\42597 6-14-93 1:42

Figure 4-2. Erosion Susceptibility of Soils.



\WORK\923A017\42598 6-14-93 1:45

Figure 4-3. Cumulative Wind Speed Frequency.



Note: Fence height = 4.9 m.

Source: after Carnes and Drehmel (1982).

\WORK\923A017\42599 7-8-93 15:39

Figure 4-4. Effect of Windscreen on Wind Velocity.

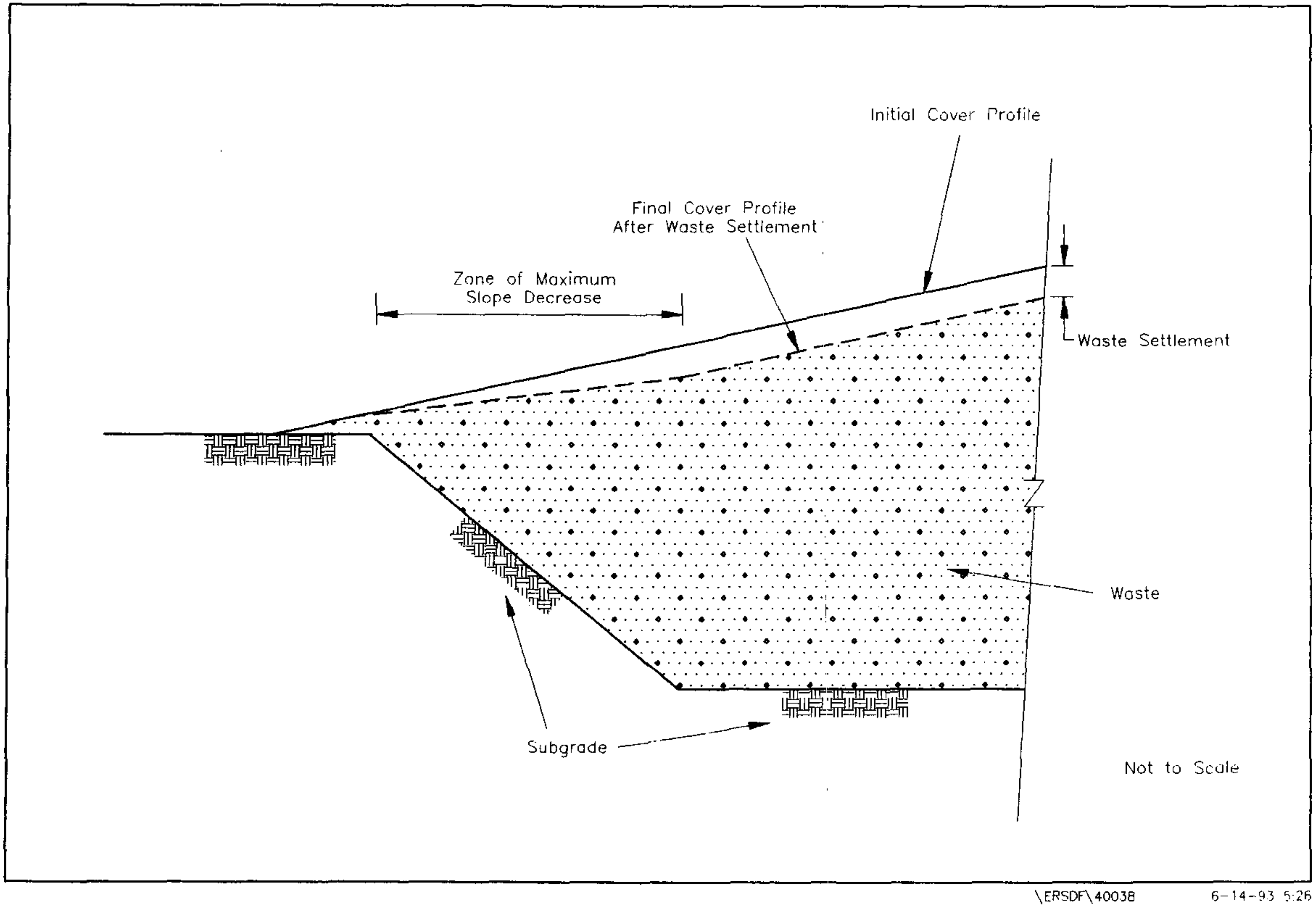


Figure 6-1. Cover Slope Changes Due to Waste Settlement

6F-

APPENDIX A

EXCAVATED SOIL
PROCESSING COSTS AND VOLUMES

Golder Associates

SUBJECT Cost and Volume of Soil Materials		
Job No. 923-A017	Made by FSS/AGM	Date 6-8-93
Ref. ERSDF	Checked RDL	Sheet 1 of 27
	Reviewed	

Cost Model

On a per yard basis, the number of yards that must be screened:

$$N = 1/P$$

where P = Percent of material

Cost per yard =

$$C = UN$$

where U = unit cost

Requirements for Hanford Barrier Matls

Pea gravel for silt: 15% by weight, 0.425 to 9.525 mm

Filter Sand D_{15}: 0.15 to 0.45 mm ✓ OK RDL

D_{50}: 0.375 to 1.2 mm ✓

D_{85}: 0.68 to 2.1 mm ✓

Filter Rock D_{15} = 2.3 mm ✓

D_{50} = 16 mm ✓

D_{85} = 27 mm ✓

Crushed Basalt: − 10" (layer description)

8-12" (cost estimate)

Available Soils

① Liner Admixing Soil: use sands/silts - grain size curves indicate that material is suitable as is, w/no screening

② Filter Sand: Assume between #10 and #100 sieves.
Use sand as source. Average %s (visually):

35-070	98 − 43 = 55	✓
35-066:	84 − 41 = 43	✓
32-072:	98 − 54 = 44	✓
32-070A:	99 − 53 = 46	✓
32-062:	98 − 27 = 71	✓
US Ecology:	100 − 47 = 53	✓

WHC est: $10.15/yd³

Ave: 52%

Golder Associates

SUBJECT Cost and Volume of Soil Materials		
Job No. 923-A017	Made by FSS	Date 6-8-93
Ref. ELSDF	Checked RDL	Sheet 2 of 27
	Reviewed	

③ Pea Gravel: Assume between 3/8" and slightly less than #4 sieve.

Obtain from Hanford gravels. (Visual inspection of GSD curves)

Sample 1: 21-10 = 11% ✓
Sample 3: 37-27 = 10% ✓
Sample 5: 36-20 = 16% ✓

Ave 12% ✓

WHC est: local sourced

④ Filter Rock: Assume between 1" and #10 sieve

Obtain from Hanford gravels. (Visual inspection of GSD curves)

Sample 1: 53-7 = 46% ✓
Sample 3: 64-18 = 46% ✓
Sample 5: 67-14 = 53% ✓

Ave 48% ✓

WHC Cost est: \$6.50/yd³ (also for drain gravel)

⑤ Capillary Break Layer: Assume 2" +

Obtain from Hanford Gravels: (visual inspection of GSD curves)

Sample 1: 20% ✓
Sample 3: 10% ✓
Sample 5: 23% ✓

Ave: 18% ✓

WHC cost est: \$26.09/yd³

GCS Golder Construction Services, Inc. Quality Assurance and Construction Management	SUBJECT Cost Comparison Basalt vs Cobbles - Hanford Barrier		
	Job No. 923-A017 Ref. ERSDF	Made by AGM Checked FSS Reviewed	Date 6-4-93 Sheet 3 of 27

Based upon discussion with Jim Beck of L + H Grading

Straight screening cost, including wash with water supplied = $ 2.00 / cubic yard

To haul water ten miles one way would add $ 1.00 / cubic yard for a total of $ 3.00 / cubic yard

PROJECT CONTACT REPORT

DATE: 6-4-93
PAGE 1 OF 1

J.S. CORPS OF ENGINEERS
WALLA WALLA DISTRICT

CONTRACT NO. DACW68-92-D-0001
DELIVERY ORDER NO. ________

Subject: Use Cobbles to replace crushed Basalt in the Hanford Barrier

Discussion:

\$2.00/cubic yard pick material up and through the screening plant - includes washing, but not setting up water

This cost includes mobilization and demobilization

Cost Haul one way ten miles
Extra \$1.00 yard

7-8,000 gallons per hour for washing

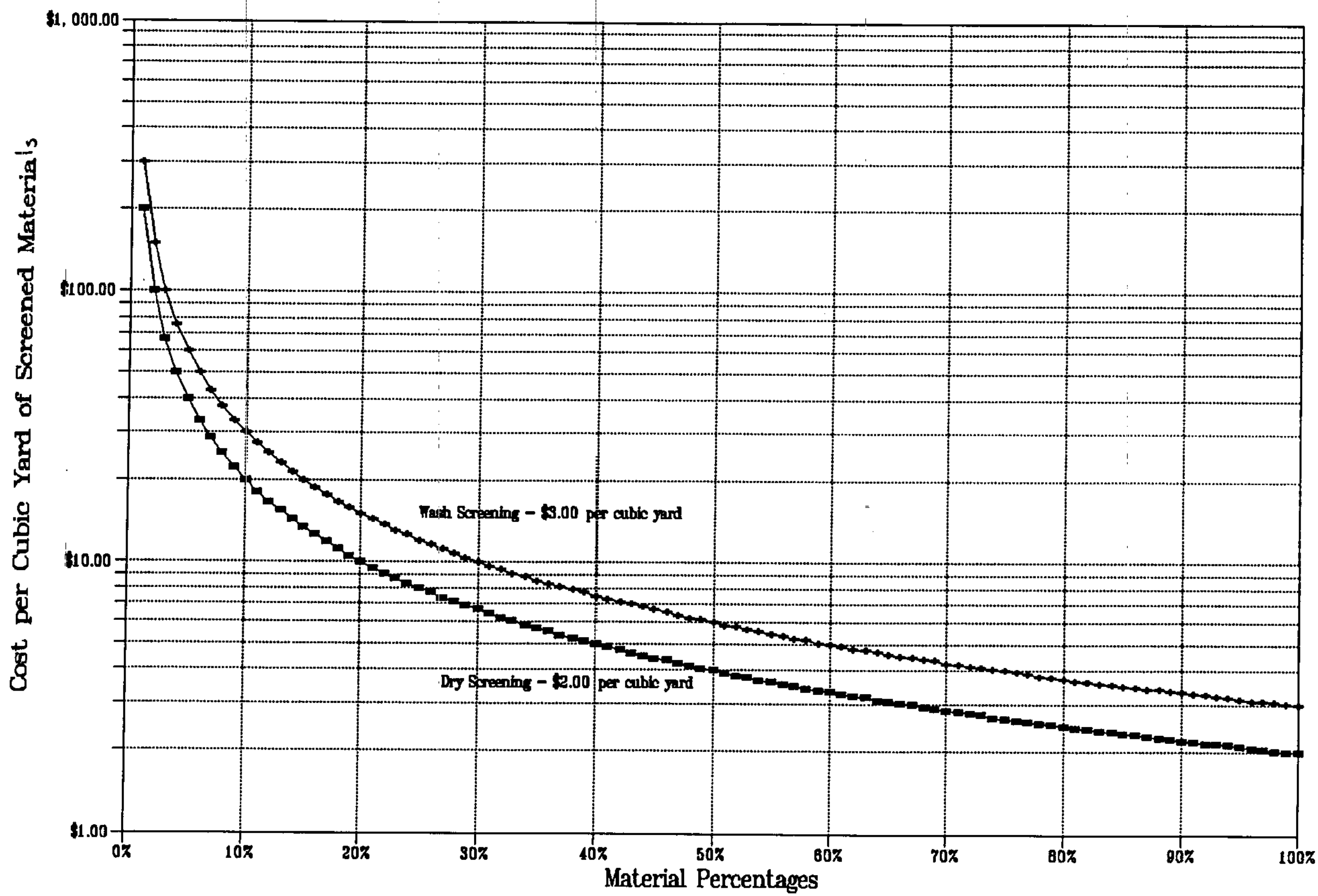
JMM PARTY	OTHER PARTY
Project Name: Design Studies	Organization's Name: L+H Grading
Employee's Name: Allan MacLeod	Address:
Employee's Company: Golder Associates	Phone No.: (503) 393-8897
Date: 6-4-93 Time: 10:35	Person's Name: Jim Beck

CALL PLACED BY: JMM ☐ OTHER PARTY ☐

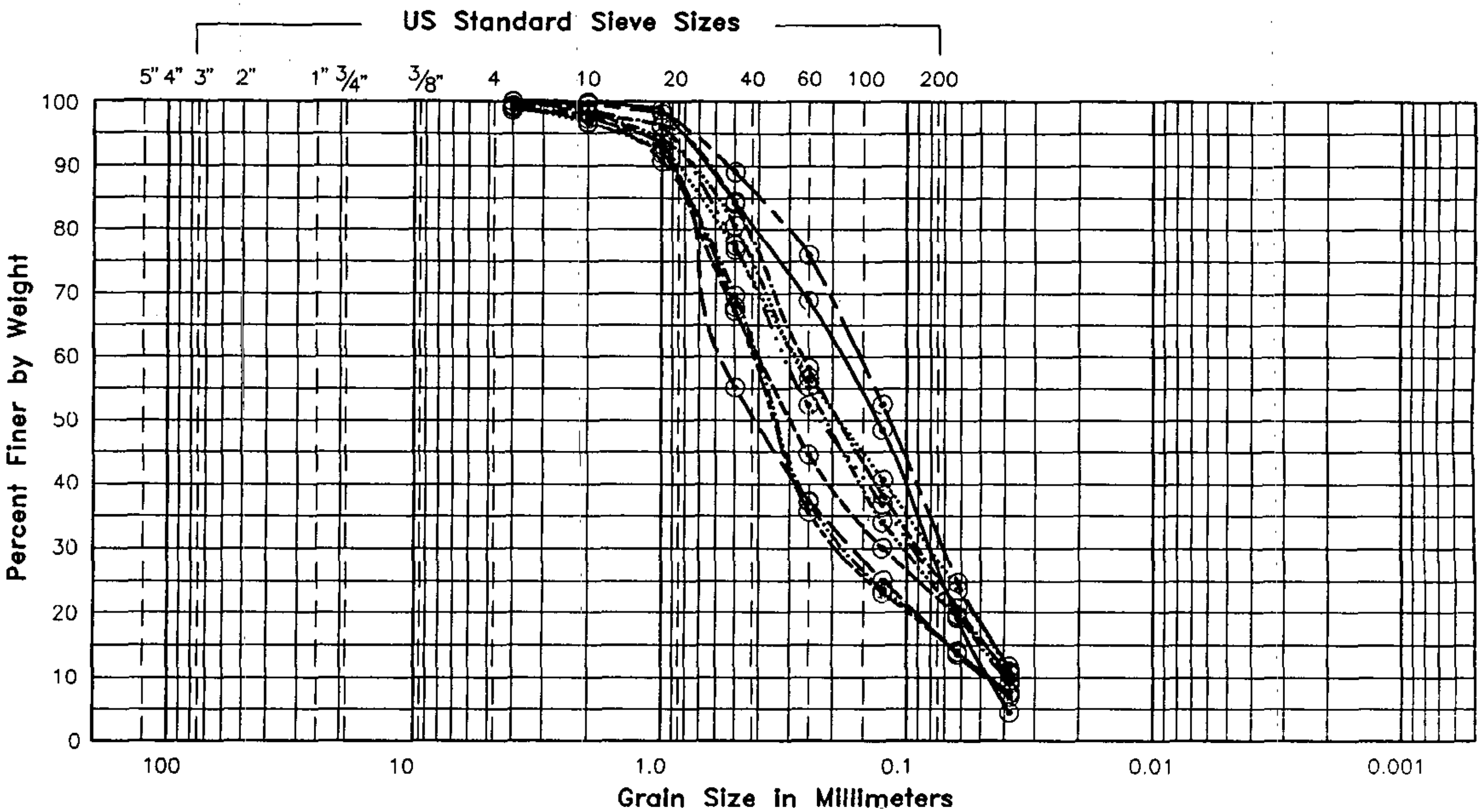
DISTRIBUTION:

☐ JMM
☐ File
☐

Hanford Barrier
Unit Screening Costs



Sheet 5 of 27



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-035-070	0, 5, 10, 20, 25, 30, 35, 40, 45, 50		–	–	–	

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA

Project No. 923-A017 Date 6-1-93 Tested By WESTINGHOUSE Reviewed By AA

Golder Associates

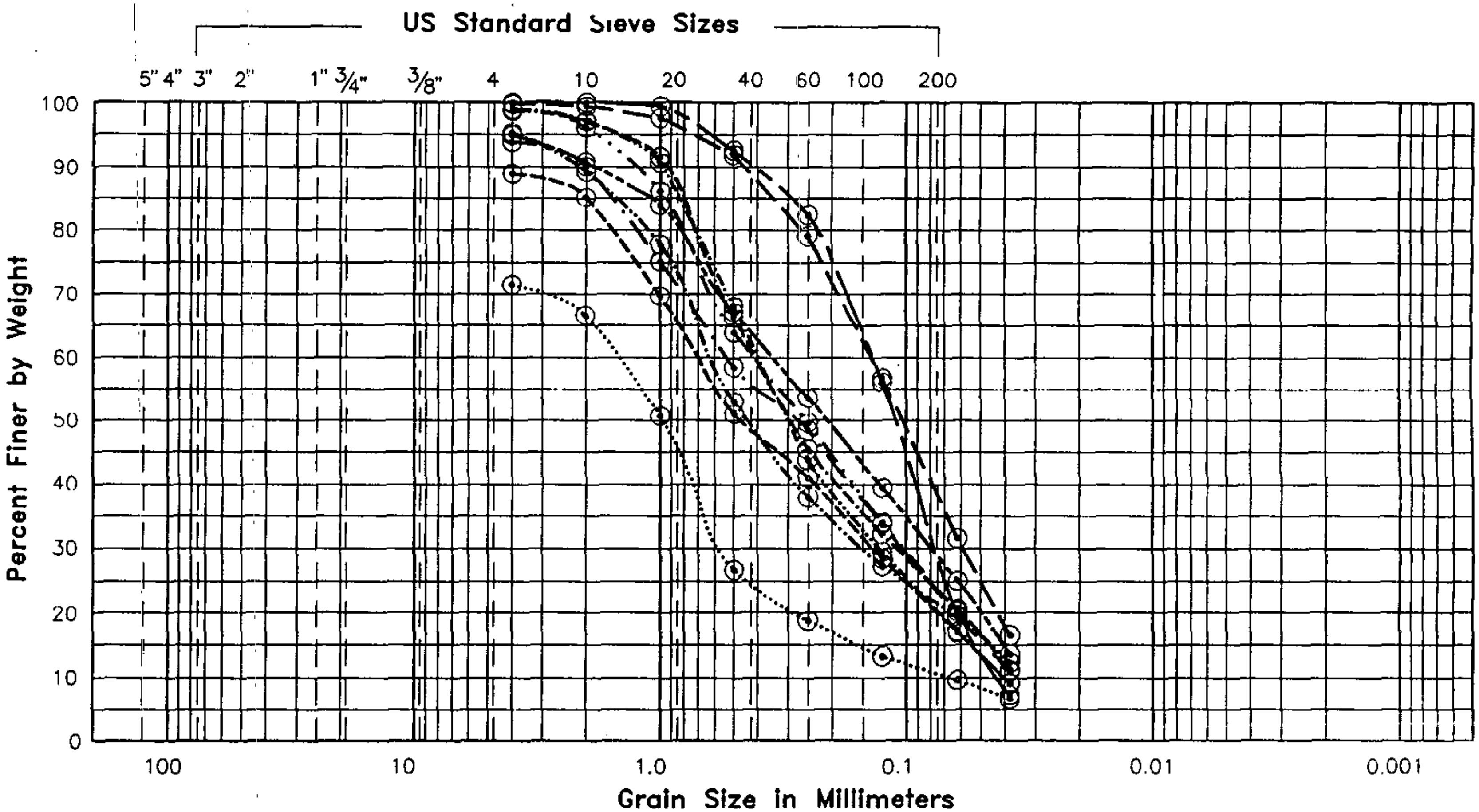
6-11-93 11:10 \ERSDF\40C35

Sheet 6 of 27

Figure 2-8. Grain Size Distribution - Well 6-35-70.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-1-93 Tested By WESTINGHOUSE Reviewed By NA



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-035-066	5 10 15 20 25 30 35 40 45 50	–	–	–	–	

Golder Associates

6-11-93 11:17 \ERSDF\40036

Sheet 7 of 27

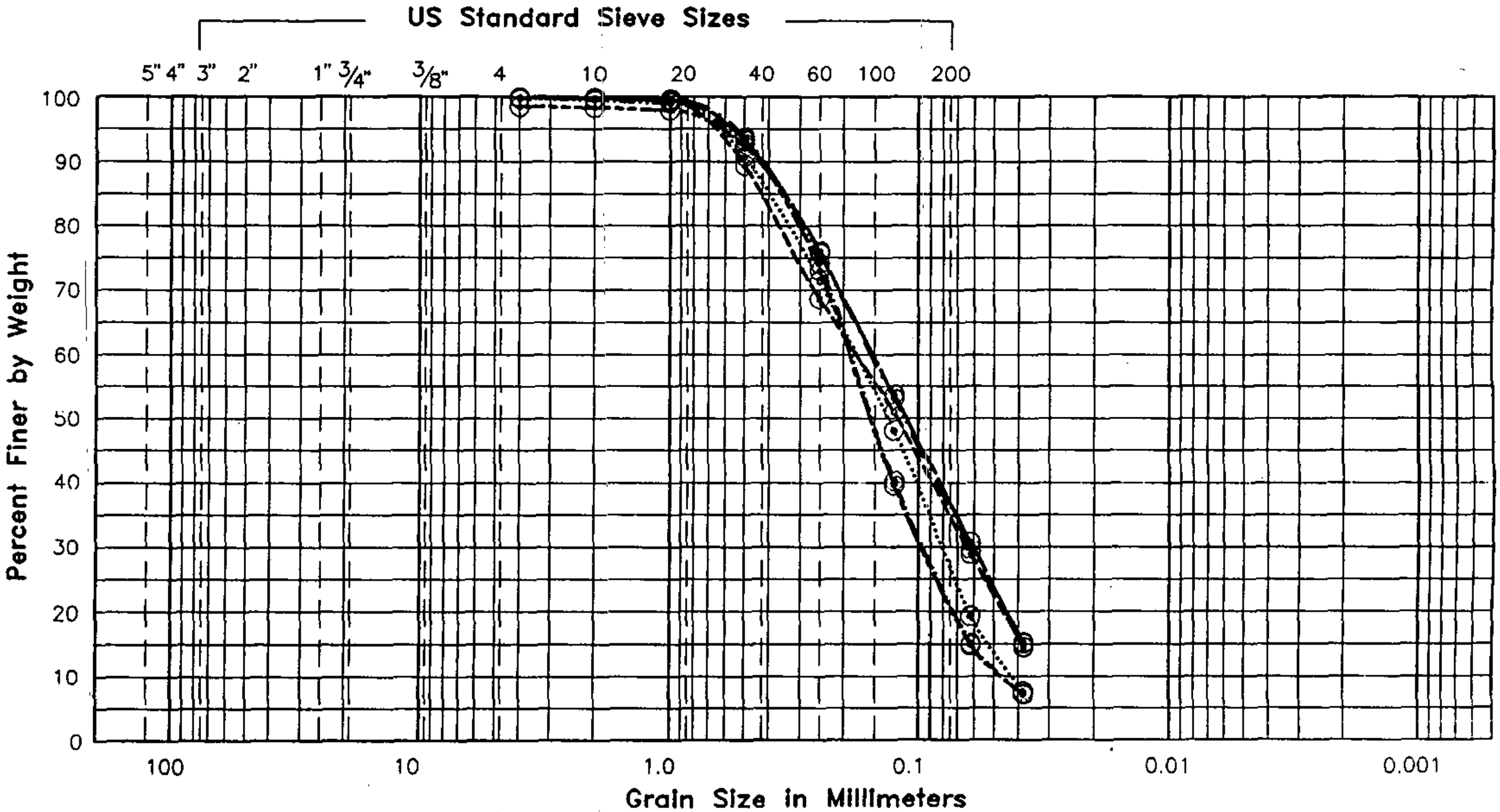
Figure 2-4. Grain Size Distribution - Well 6-35-66.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-1-93 Tested By WESTINGHOUSE Reviewed By NA

Golder Associates

6-11-93 11:19 \ERSDF\40037



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

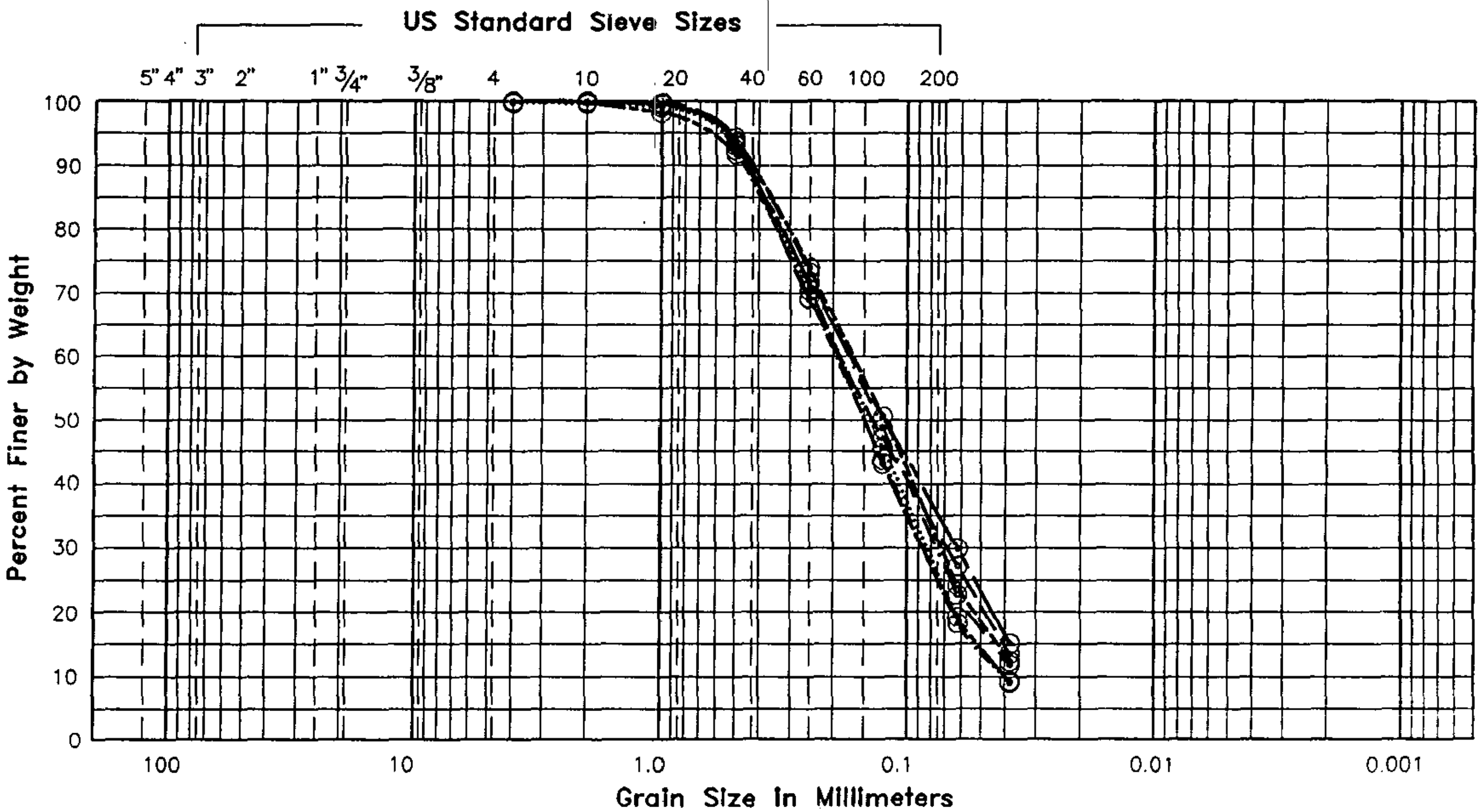
Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-032-072	5, 10, 15, 20, 25, 30, 35	–	–	–	–	

Sheet 8 of 27

Figure 2-5. Grain Size Distribution - Well 6-32-72.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-1-93 Tested By WESTINGHOUSE Reviewed By MA



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_P	I_P	Description
0699-032-070A	5 10 15 20 25 30 35	—	—	—	—	

Golder Associates

6-11-93 11:21 \ERSDF\40034

Sheet 9 of 27

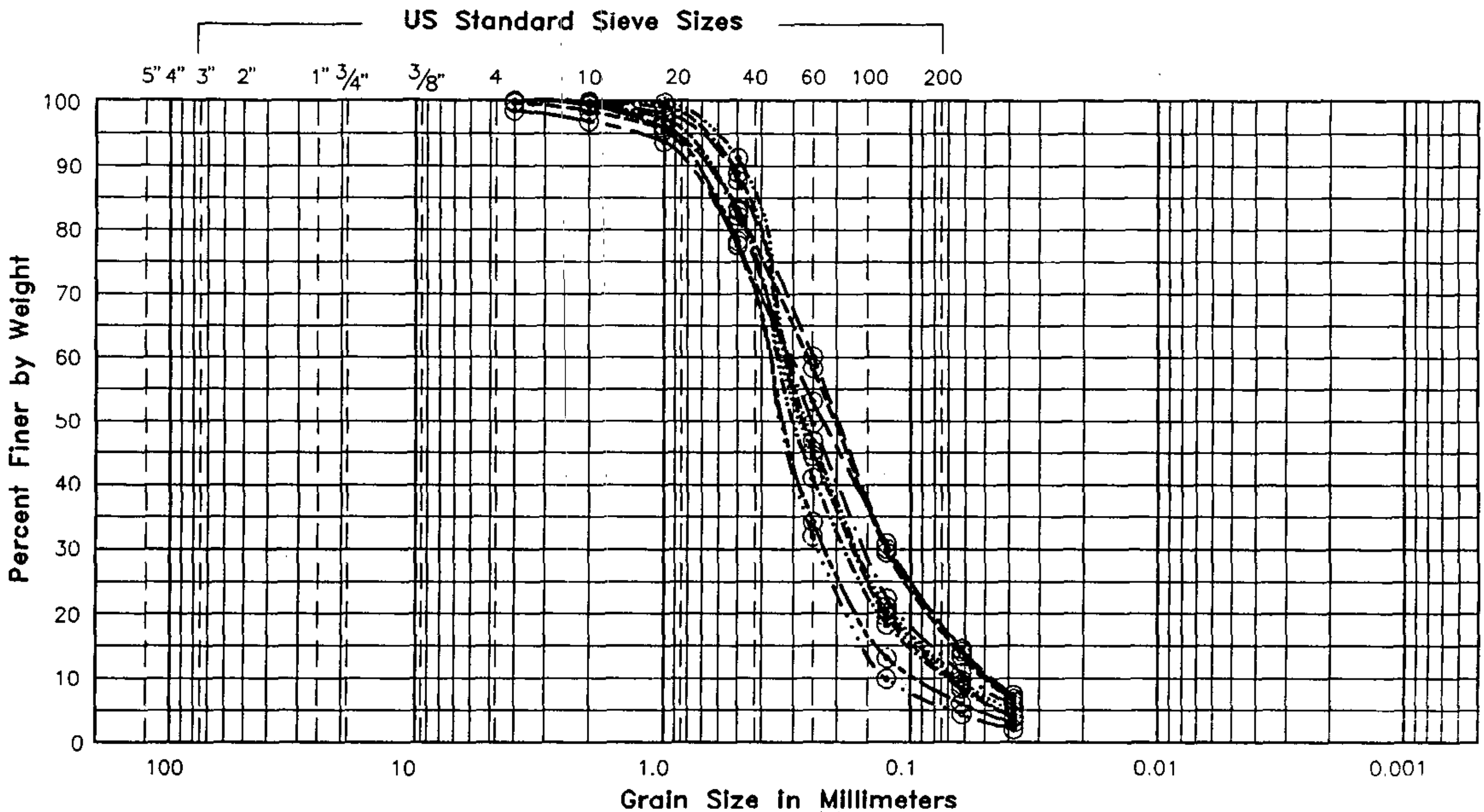
Figure 2-6. Grain Size Distribution - Well 6-32-70A.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-1-93 Tested By WESTINGHOUSE Reviewed By NA

Golder Associates

6-11-93 11:22 \ERSDF\40032



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
0699-032-062	5 10 15 20 25 30 35 40 45 50	–	–	–	–	

Sheet 10 of 27

Figure 2-7. Grain Size Distribution - Well 6-32-62.

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-14-93 Tested By MF Reviewed By DPO

GRAIN SIZE DISTRIBUTION

Golder Associates

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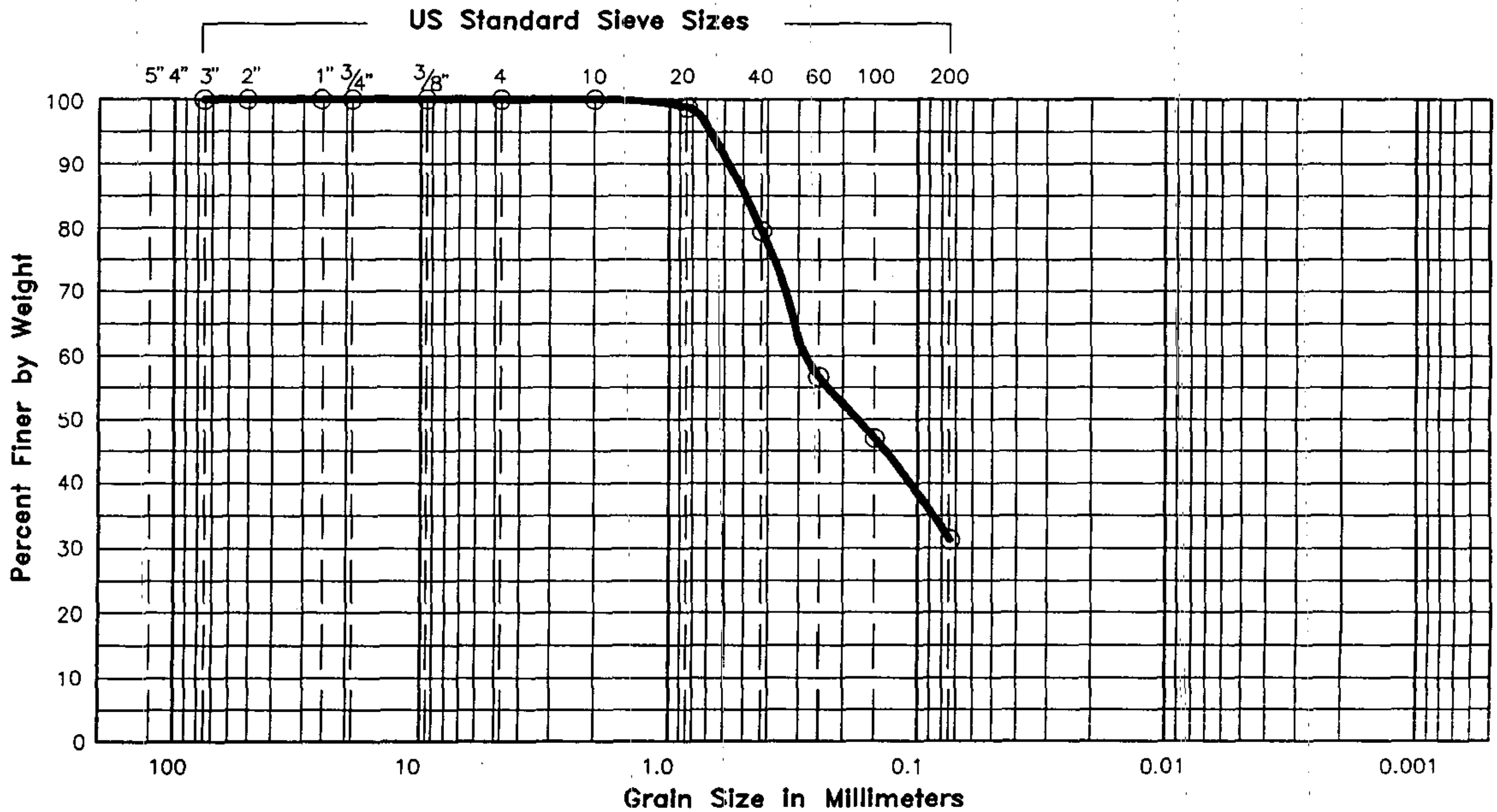

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
4	15 FT	1.8	–	–	–	Light olive gray (5Y6/1), m–f SAND and SILT, (SM).

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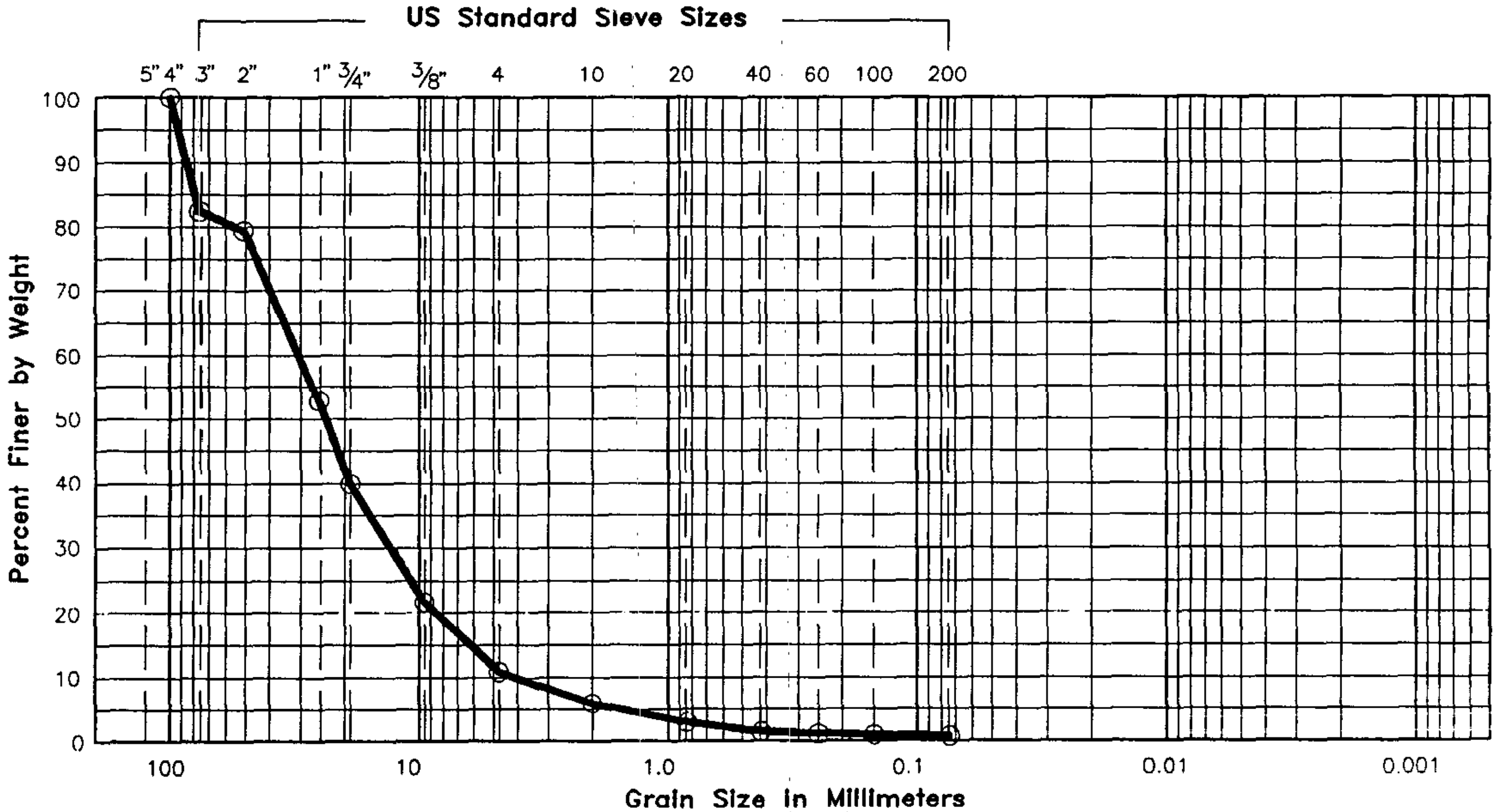
Figure 2-8. Grain Size Distribution - U.S. Ecology Sand Sample.

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 **Date** 6-14-93 **Tested By** MF **Reviewed By** DPO

GRAIN SIZE DISTRIBUTION

Golder Associates

6-14-93 8:60 \ERSDF\40042



Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_P	I_P	Description
1	5 ft	0.5	–	–	–	Yellowish gray (5Y7/2), c–f GRAVEL, some cobbles, little c–m sand, trace silt, (GW)

Figure 2-9. Grain Size Distribution - Gravel Pit B Sample 1.

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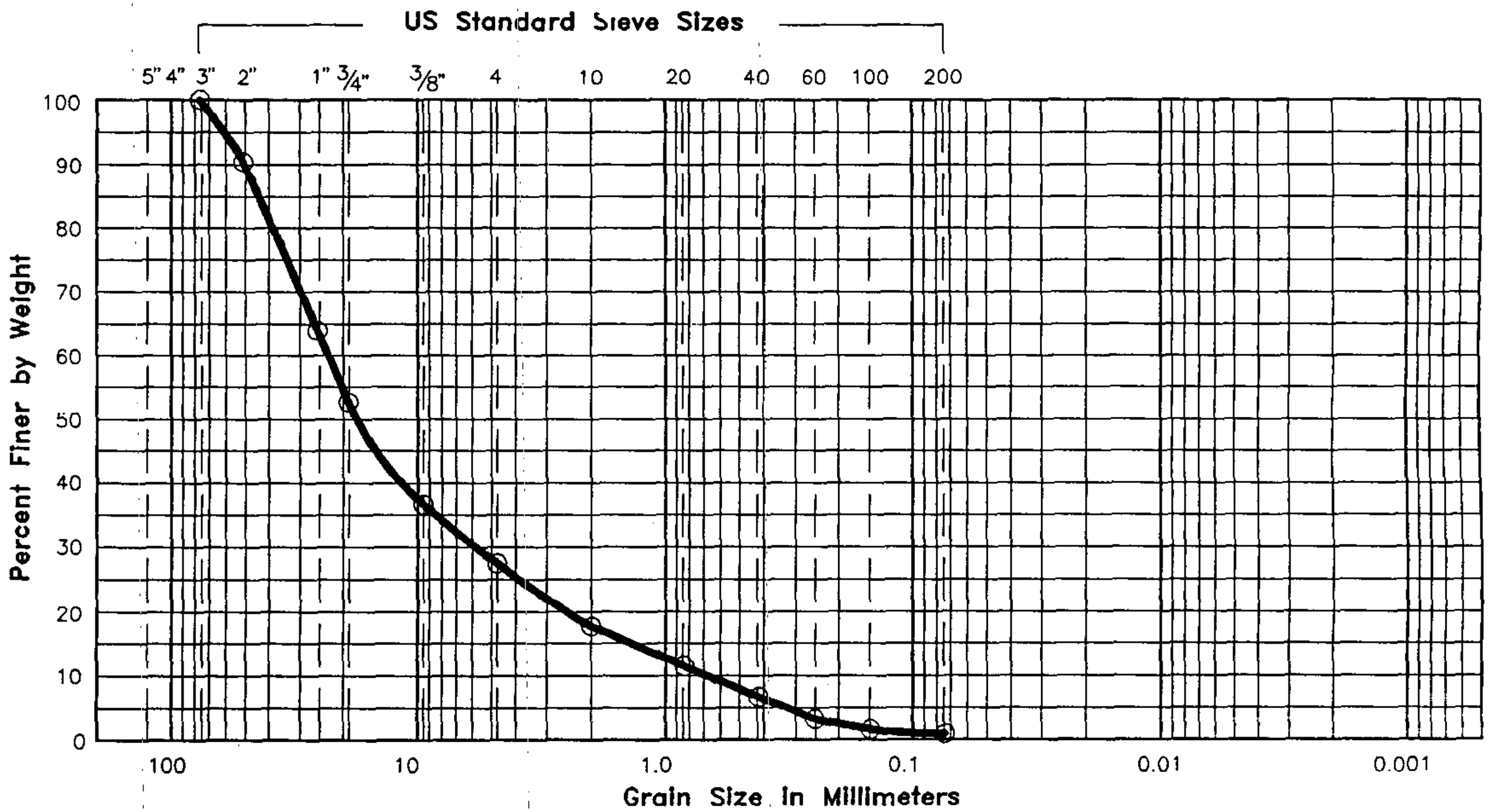

Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
3	7 ft	0.9	–	–	–	Medium light gray (N6), c–f GRAVEL, some c–f sand, trace silt, (GW).

Figure 2-10. Grain Size Distribution - Gravel Pit B Sample 3.

GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-14-93 Tested By MF Reviewed By DPO

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6-14-93 7:56 \ERSDF\40043

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GRAIN SIZE DISTRIBUTION

Project COE/ERSDF DESIGN STUDIES/WA
Project No. 923-A017 Date 6-14-93 Tested By MF Reviewed By DPO

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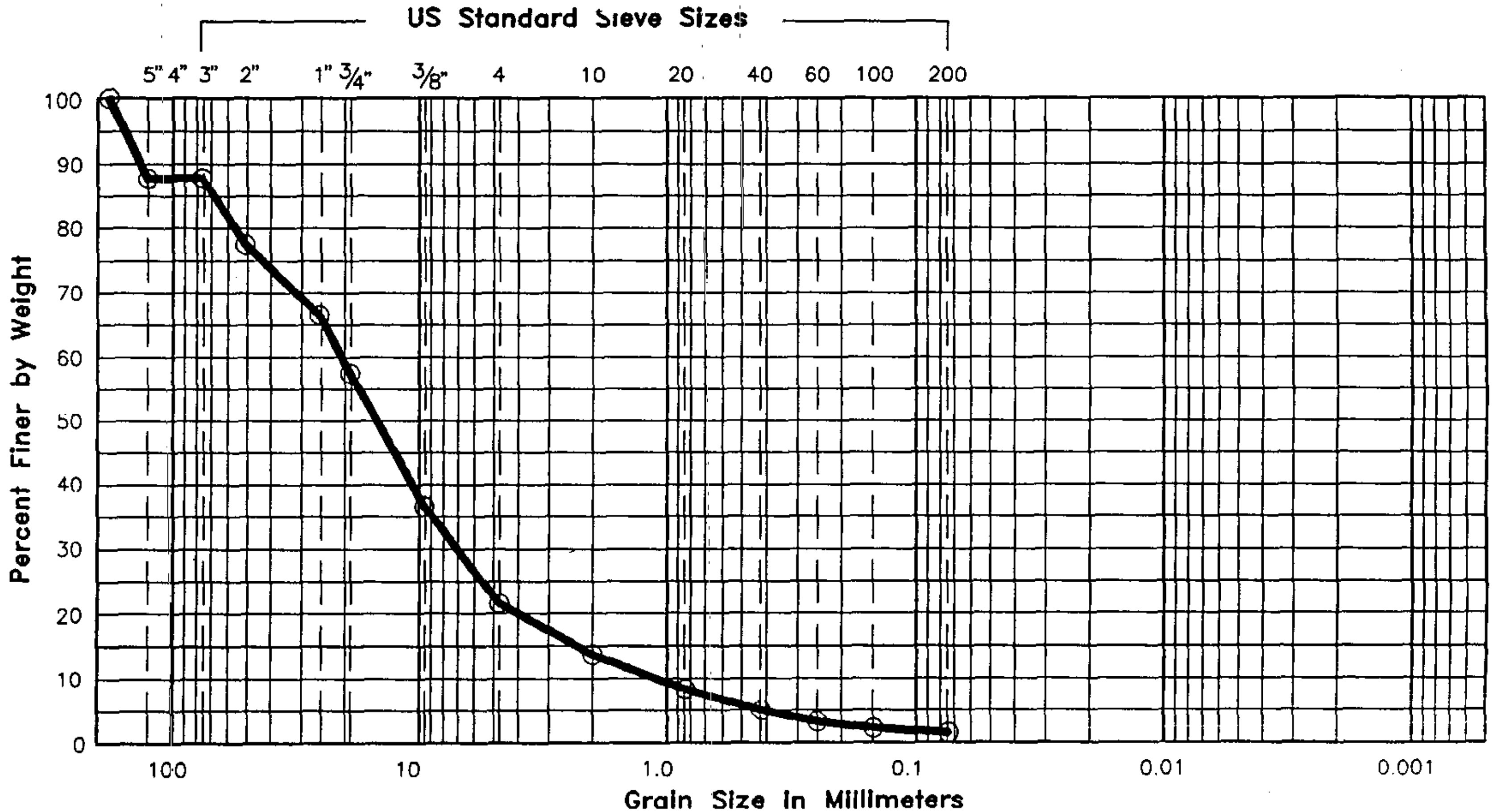


Cobbles	Gravel		Sand			Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

Boring No.	Elev. or Depth	W_n	W_L	W_p	I_p	Description
5	–	0.8	–	–	–	Yellowish gray (5Y7/2), c–f GRAVEL, some c–f sand, some cobbles, trace silt, (GW).

Sheet 14 of 27

Figure 2-11. Grain Size Distribution - Gravel Pit A Sample.

DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
320006	GRAVEL AND SAND FILTER LAYERS										
320006.02	SITEWORK										
320006.0200001	****************************** PLACEMENT OF GRAVEL AND SAND FILTER LAYERS ******************************	460	0	0	0	0	0	0	0	0	0
320006.0200002	LOAD TRUCKS WITH SCREENED RUN-OF-PIT GRAVEL.	460	3600 CY	0	0	0	23400	0	0	3510	26910
320006.0200004	HAUL AND DUMP GRAVEL AT SITE, ASSUME 8 MI ROUND TRIP	460	3600 CY	0	0	0	0	10080	0	1008	11088
320006.0200006	SPREAD AND LEVEL GRAVEL WITH DOZER/GRADER, 6 IN LAYER	460	3600 CY	58	1450	1692	0	0	0	471	3613
320006.0200008	COMPACT GRAVEL WITH VIBRA-TORY ROLLER, 2 PASSES.	460	3600 CY	18	450	360	0	0	0	122	932
320006.0200020	LOAD TRUCKS WITH SCREENED SAND.	460	3600 CY	0	0	0	36540	0	0	5481	42021
320006.0200022	HAUL AND DUMP SAND AT SITE, ASSUME 8 MI ROUND TRIP.	460	3600 CY	0	0	0	0	10080	0	1008	11088
320006.0200026	SPREAD AND LEVEL SAND WITH DOZER/GRADER, 6 IN LAYER	460	3600 CY	58	1450	1692	0	0	0	471	3613
320006.0200028	COMPACT SAND WITH VIBRATORY ROLLER, 2 PASSES.	460	3600 CY	18	450	360	0	0	0	122	932
SUBTOTAL	SITEWORK			152	3,800	4,104	59,940	20,160	0	12,193	100,197
	SALES TAX 7.80 %						4675		0		4675
	OH&P (ON MARKUPS ONLY)									701	701
TOTAL	COST CODE 46002 WBS 320006 (ESCALATION 0.00% - CONTINGENCY 15.00 %)			152	3,800	4,104	64,615	20,160	0	12,894	105,573
TOTAL WBS 320006 GRAVEL AND SAND FILTER LAYERS				152	3,800	4,104	64,615	20,160	0	12,894	105,573

Tax: 23400x7.8% = $1825
23400/3600 = $6.50
Total = $44,64[illegible] / 3600 = $12.[illegible]
OH+P: $274
Tax: 36540x7.8% = $2850
36540/3600 = $10.15
Total = $60931 / 3600 = $16.[illegible]
OH+P: $427

Sheet 15 of 27

DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
320004	PLACEMENT OF GRAVEL DRAINAGE LAYER										
320004.02	SITEWORK										
320004.0200000	**************************** PLACEMENT OF GRAVEL DRAINAGE LAYER ****************************	460	0	0	0	0	0	0	0	0	0
320004.0200002	LOAD TRUCKS WITH SCREENED RUN-OF-PIT GRAVEL.	460	5200 CY	0	0	0	33800	0	0	5070	38870
320004.0200004	HAUL AND DUMP GRAVEL AT SITE, ASSUME 8 MI ROUND TRIP	460	5200 CY	0	0	0	0	14560	0	1456	16016
320004.0200006	SPREAD AND LEVEL GRAVEL WITH DOZER/GRADER, 6 IN LAYER	460	5200 CY	83	2075	2444	0	0	0	678	5197
320004.0200008	COMPACT GRAVEL WITH VIBRATORY ROLLER, 2 PASSES.	460	5200 CY	26	650	520	0	0	0	176	1346
SUBTOTAL	SITEWORK			109	2,725	2,964	33,800	14,560	0	7,380	61,429
	SALES TAX 7.80 %						2636		0		2636
	OH&P (ON MARKUPS ONLY)									395	395
TOTAL	COST CODE 46002 WBS 320004 (ESCALATION 0.00% - CONTINGENCY 15.00 %)			109	2,725	2,964	36,436	14,560	0	7,775	64,460
TOTAL WBS 320004 PLACEMENT OF GRAVEL DRAINAGE LAYER				109	2,725	2,964	36,436	14,560	0	7,775	64,460

33800 / 5200 = 6.50

$64,460 / 5,200 yd³ = $12.40/yd

Sheet 16 of 27

DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
320005	CRUSHED BASALT LAYER/SIDE SLOPES										
320005.02	SITEWORK										
320005.0200001	**************************** PLACE CRUSHED BASALT BIOBARRIER LAYER AND SIDE SLOPES ****************************	460	0	0	0	0	0	0	0	0	0
320005.0200002	LOAD, HAUL AND SPREAD 8 TO 12 INCH CRUSHED BASALT. EXISTING QUARRY IS 17 MILES FROM SITE.	460	75000 CY	24188	604700	450000	600000	0	0	248205	1902905
SUBTOTAL	SITEWORK			24,188	604,700	450,000	600,000	0	0	248,205	1,902,905
	SALES TAX 7.80 %						46800		0		46800
	OH&P (ON MARKUPS ONLY)									7020	7020
TOTAL	COST CODE 46002 WBS 320005 (ESCALATION 0.00% - CONTINGENCY 15.00 %)			24,188	604,700	450,000	646,800	0	0	255,225	1,956,725
TOTAL WBS 320005 CRUSHED BASALT LAYER/SIDE SLOPES				24,188	604,700	450,000	646,800	0	0	255,225	1,956,725

$$\frac{\$1,956,725}{75,000\ yd^3} = \$26.09$$

Sheet 17 of 27

WESTINGHOUSE HANFORD COMPANY
W.A. SKELLY
JOB NO. E-062-93-RWO

** TEST - INTERACTIVE ESTIMATING **
HANFORD BARRIER

DATE 03/17/93 13:06:57
BY R.W. OHRT

DOE_R08 - ESTIMATE DETAIL BY WBS / COST CODE

ACCOUNT NUMBER	DESCRIPTION	COST CODE	QUANTITY	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB-CONTRACT	EQUIP-MENT	OH&P / B & I	TOTAL DOLLARS
320007	PLACEMENT OF COMPACTED SILT										
320007.02	SITEWORK										
320007.0200001	**************************** PLACEMENT OF COMPACTED SILT ****************************	460	0	0	0	0	0	0	0	0	0
320007.0200002	LOAD, HAUL AND DUMP MCGEE RANCH SILT, 36 MILE ROUND TRIP	460	19700 CY	3349	80376	51417	0	0	0	19769	151562 = $7.69/yd³
320007.0200004	SPREAD AND STATIC COMPACT TO 20" DEPTH IN 3 LIFTS, USING DOZER/GRADER, ROLLER AND WATER TRUCK.	460	19700 CY	2187	54675	38218	0	0	0	13934	106827
SUBTOTAL	SITEWORK			5,536	135,051	89,635	0	0	0	33,703	258,389
TOTAL	COST CODE 46002 WBS 320007 (ESCALATION 0.00% - CONTINGENCY 15.00 %)			5,536	135,051	89,635	0	0	0	33,703	258,389
TOTAL WBS 320007 PLACEMENT OF COMPACTED SILT				5,536	135,051	89,635	0	0	0	33,703	258,389

$$\frac{\$258{,}389}{19{,}700\ yd^3} = \$13.12/yd^3$$

Sheet 18 of 27

Hanford Barrier
Conceptual Description of Barrier Layers

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
1	100 (40)	McGee Ranch Silt with Pea Gravel Admix	McGee Ranch Silt mixed with pea gravel 15 % by wt. (0.425-9.525 mm diameter) .	The silt loam soil was selected for optimal water retention properties and should provide a good rooting medium for cover vegetation. The pea gravel is designed to minimize wind erosion of this silt without significantly affecting its moisture retention capabilities. The thickens of this layer was selected based on HELP modeling.
2	100 (40)	Compacted McGee Ranch Silt	McGee Ranch Silt from an approved source.	The compacted silt is designed to slow the percolation of soil moisture The extended residence time of moisture in this layer will increase the volume of moisture removed by evaporation and transpiration.
3	1 (0.40)	Geotextile Filter Fabric	Polypropylene, needled, non-woven fabric .	Prevent the migration of fine soil particles into the underlying filter sand during construction.
4	15 (6)	Filter Sand	Naturally occurring sand meeting the following filter requirements: D_{15} = 0.15 to 0.45 mm, D_{50} = 0.375 to 1.2 mm and D_{85} = 0.68 to 2.1 mm.	This layer will prevent the migration of soil fines into the underlying layer.

[1] Cover layers are listed sequentially from top to bottom.

Layer No.[1]	Thickness cm (in)	Layer Description	Specifications	Function
5	30 (25)	Filter Rock	Gravel mixture having a hydraulic conductivity of 1 cm/sec, meets the requirements of WSDOT M41-10, 9-03.9(3) and has the following gradations: D_{15} = 2.3 mm, D_{50} = 16 mm and D_{85} = 27 mm	This layer will prevent the migration of soil fines into the underlying layer.
6	150 (60)	Crushed Basalt (CB)	Minus 25 cm (10 in.) crushed basalt.	Prevents plant and animal intrusion into the underlying layer. This layer will provide protection from burrowing mammals indigenous to the Hanford site. The minimum thickness of this layer was determined to be six times the maximum diameter of the CB.
7	30 (12)	Filter Rock	Crushed rock 15.875 mm (5/8 in.) in diameter meeting the requirements of WSDOT M41-10, 9-03.9(3).	This lateral drainage layer will intercept percolating water and move it to the toe of the barrier for discharge. The material for this layer was selected to prevent clogging.
8	15 (6)	Asphalt Concrete	Asphalt concrete with a sprayed styrene-butadiene modified top coat.	This layer acts as a hydraulic barrier and will prevent plant and animal intrusion into the underlying soil. Asphalt barriers have been shown to provide protection from burrowing animals

[1] Cover layers are listed sequentially from top to bottom.

Layer No.[1]	Thickness cm (in)	Layer Description	Specifications	Function
9	10 (4)	Asphalt Base Course	15.875 mm (5/8 in.) diameter crushed basalt top course meeting the requirements of WSDOT M41-10, 9-03.9(3)	Provides a stable base for supporting the asphalt layer.
10	Variable	Grading Fill	WSDOT M41-10, 9-03.18 approved backfill.	This layer will provide a level smooth subgrade for construction of the overlying layers.

[1] Cover layers are listed sequentially from top to bottom.

Is there sufficient volume of Hanford gravel?

Required: Assume 400 ft-wide barrier over 300-foot-wide trench

Thickness = 5 feet

∴ Vol / linear foot = 400×5 = 2000 ft³ ✓

Allow 20% for increased thickness at margins ✓

2000 × 1.2 = 2400 ft³/ft

total length:
total vol = 35,000,000 yd³ (28,000,000 WHC est + ~25% for interim cover, etc)

✓
Stuck volume = 250 yd³/ linear foot (300 ft-wide trench, 3H:1V sideslopes, 100 ft-wide floor)

∴ $\frac{35,000,000 \text{ yd}^3}{250 \text{ yd}^3/\text{lin ft}}$ = 140,000 linear feet ✓

∴ req'd gravel volume = 2,400 × 140,000 = 336,000,000 ft³ ✓

= 12,400,000 yd³ ✓

Available:

Vol = Area × thickness × percent gravel

Area = (Area of Hanford gravel − site facilities area) × percent trench development × percent usable gravel × thickness

Area of gravel = 11330 × 2780 + ½ 11330 (4390 − 2780)
1610

31,497,400 + 9,120,650

= 40,618,050 ft² ✓

Golder Associates	SUBJECT Cost and Volume of Soil Materials		
	Job No. 923-A017 Ref. ERSDF	Made by FSS Checked RDL Reviewed	Date 6-8-93 Sheet 23 of 27

Area of site facilities = 4917 x 2429 = 11,943,393 ft² ✓

Percent development: assume trenches are 300' wide at top, 100' between trenches

∴ % development = $\frac{300}{100+300}$ = 75% ✓

Say 60% to allow for trench slopes, loss of ends, etc. ✓

Thickness of usable gravel layers

Borehole	Thickness, ft
W22-24	20
38-70	26
38-65	10
36-61A	25
35-66	25
35-70	13
Average:	20 ft ✓

Usable gravel = 18% (see sheet 2) ✓

∴ Avail volume = (40,618,050 − 11,943,393) * 0.6 * 20 x 0.18

= 61,937,260 ft³ ✓

= 2,300,000 yd³ ✓ not sufficient

$\frac{2.3}{12.4}$ = 19% of what is needed ✓

Golder Associates	SUBJECT Vol. of Soil Materials		
	Job No. 923-A017	Made by FSB	Date 6-8-93
	Ref. ERSDF	Checked RDL	Sheet 24 of 27
		Reviewed	

Is there sufficient drainage rock + gravel filter?

Required thickness = 2'

width = 400 ft/linear foot of trench

∴ Volume = 2 × 400 = 800 ft³/lin ft

Total Volume = 800 ft³/lin ft × 140,000 lin ft (see sheet 22)

= 112,000,000 ft³ ✓

= 4,150,000 yd³ ✓

Available As on sheet 22,

Vol = area * thickness * % usable

% usable (sheet 2) = 48%

∴ Vol = (40,618,050 - 11,943,393) * 0.6 * 20 * 0.48

= 165,166,024 ft³

= 6,100,000 yd³ ✓ OK

Is there sufficient pea gravel?

Required: thickness = 3.3 ft × 15% pea gravel = 0.5 ft

width = 400 ft/linear foot of trench

∴ Volume = 0.5 × 400 = 200 ft³/lin ft

Total Volume = 200 ft³/lin ft × 140,000 lin ft of trench (see sheet 22)

= 28,000,000 ft³

= 1,050,000 yd³

Available: As on sheet 22, Vol = area × thickness × % usable
Reduce by volume of drain rock + filter (this is cheaper)
∴ Vol = (12,700,000 - 4,150,000) × 0.12 (see sheet 2)

= 1,039,000 yd³ not quite

Golder Associates	SUBJECT Soil Material Volumes		
	Job No. 923-A017	Made by FSS	Date 6-8-93
	Ref. ERSDF	Checked RDL	Sheet 25 of 27
		Reviewed	

Admix Liner: **Required**: $\left(2 \times \frac{100}{\cos 18.43°} + 100\right) \times 3'$ thick

= 926 ft³/lin ft of trench ✓

Total Vol = 926 × 140,000 = 129,640,000 ft³

= 4,800,000 yd³ ✓

Avail: Assume all sand is suitable:

∴ Vol = Total excavation − gravel volume

= 35,000,000 yd³ − 12,700,000 yd³

= 22,300,000 yd³ OK ✓

Filter sand: **Required**: thickness = 6 inches

∴ Req'd volume = same as for pea gravel (see sheet 24)

= 1,050,000 yd³

Available: (total volume − admix soil) × % usable

= (22,300,000 − 4,800,000) × 0.52

= 9,100,000 yd³ ✓ OK

Silt: **Required**: thickness = (3.3 ft × 0.85 + 3.3 ft) = 6.1 ft

Assume 400-ft-wide barrier:

400 × 6.1 = 2440 ft³/lin ft ✓

Total Vol = 2440 × 140,000

= 341,600,000 ft³

= 12,700,000 yd³ ✓ unit est: $7.69/yd³

Golder Associates	SUBJECT Soil Volumes		
	Job No. 923-A017	Made by FSS	Date 6-8-93
	Ref. ERSDF	Checked RDL	Sheet 26 of 27
		Reviewed	

Available: (total volume - admix soil) * % usable

% usable, from grain size curves (visual inspection)

Source	% passing #200 sieve
35-070	25 ✓
35-066	25 ✓
32-072	29 ✓
32-070A	30 ✓
32-062	11 ✓
US Ecology	31 ✓

Average: 25% ✓

Available vol = (22,300,000 - 4,800,000) * 0.25

= 4,400,000 yd^3 ✓ not sufficient

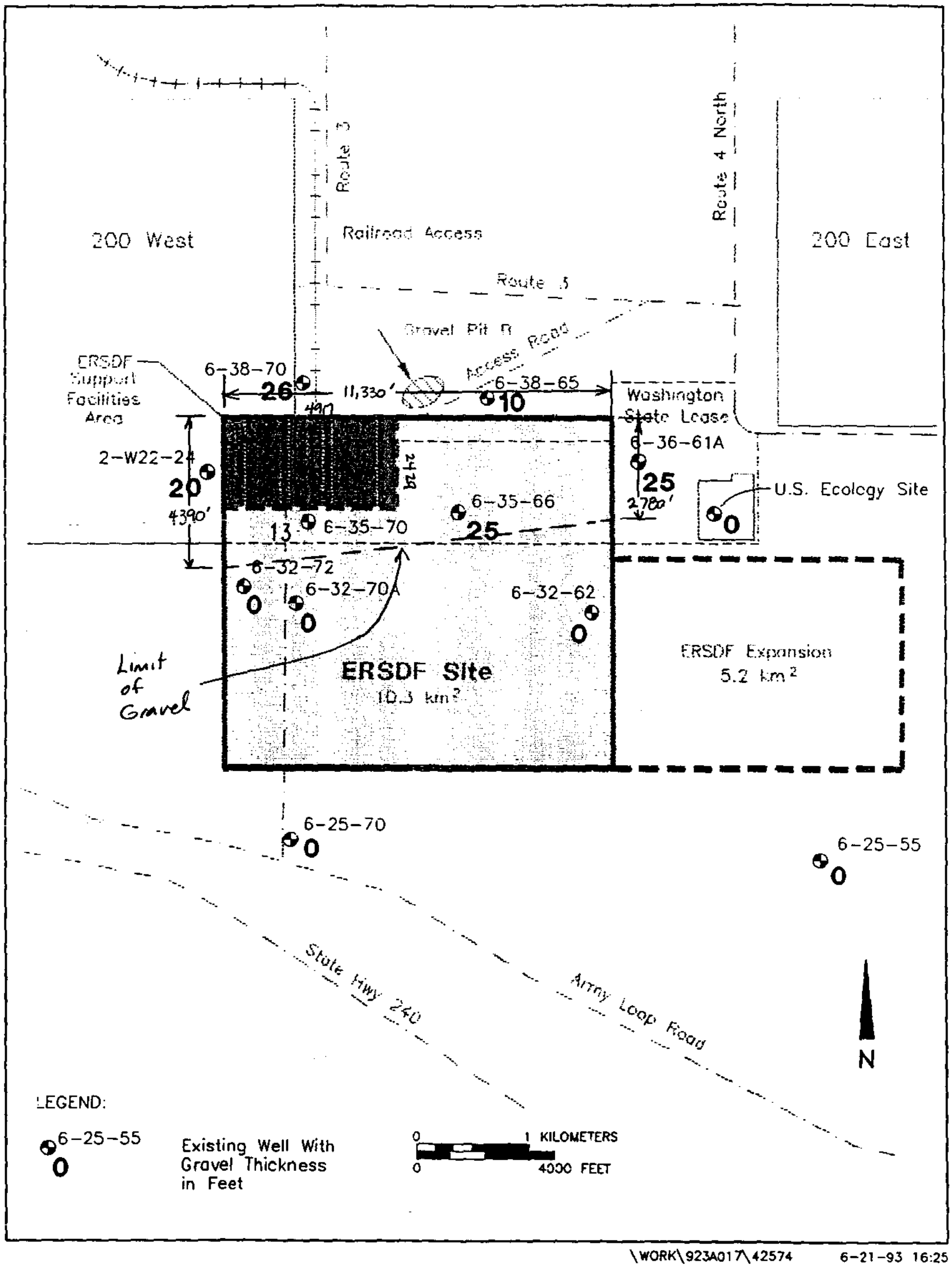


Figure 2-2. Thickness of Upper Gravel Sequence, Hanford Formation.

APPENDIX B

USACE
SOIL DRAINAGE MODELING

Environmental Restoration
Storage and Disposal Facility

SOIL DRAINAGE MODELING USING THE HELP ver. 2.0 COMPUTER CODE

June 1993

U.S. Army Corps of Engineers
Walla Walla District
Environmental Engineering Branch
Walla Walla, Washington

Summary

The Environmental Restoration - Storage and Disposal Facility is to be a landfill having the capacity to receive 22,936,800 m^3 (30,000,000 yds^3) of waste. The facility will be constructed adjacent to the Hanford Site 200 East Area. Landfill cells will receive contaminated soils and debris excavated from "past practice" disposal sites existing throughout the former nuclear production reservation. The Environmental Protection Agency computer code "Hydrologic Evaluation of Landfill Performance" (HELP) was used to model the proposed facility and to predict the flux of precipitation-derived moisture at the base of the landfill waste cells to evaluate the effectiveness of several different operating scenarios in minimizing base drainage. Future precipitation values were modeled using the U.S. Department of Agriculture computer code "Weather Generator" (WGEN) using historical weather statistics for the Hanford site obtained from Hanford Meteorological Station data. The WGEN code is incorporated into version 2.0 of the HELP model. Six alternative landfill geometries were modeled to reflect currently proposed options for disposal trench depth and cell construction sequences. Scenarios A through E assumed landfill cells filled with municipal-type waste deposits and scenario F assumed a contaminated soil waste. The completed landfill was assumed to be capped with the lower 4 layers of the permanent "Hanford Barrier" including the 0.3 meter (1 foot) drainage gravel/cushion layer, the 0.15 m (6 inch) geomembrane and asphalt barrier layer, the 0.10 m (4 in) base course, and an assumed 0.61 m (2 ft) thickness of foundation material. A total of 78 years were modeled reflecting a construction/operation period of 28 years combined with a 50 year landfill monitoring period.

Modeling scenario A consisted of a landfill containing a 60 foot thickness of waste separated into 3-6.1 m (3-20 ft) thick layers by 0.61 m (2 ft) thicknesses of compacted silt. Filling of a disposal trench in the vertical dimension was assumed to require 3 years. During each of the first two years, 6.1 m (20 ft) thick waste layers would be placed with each layer being covered with a 0.61 m (2 ft) compacted silt barrier. The final waste layer would be placed in year 3 with no silt course installed. Landfill capping would occur during year 4. Drainage at the base of the lowest waste layer peaked during year 1 at a flux of 3.7539 cm/yr (1.4779 in/yr). The flux decreased through the end of the modeling period at year 78 to a value of 0.1402 cm/yr (0.0552 in/yr). The drainage from waste deposits occurring after the impermeable cap was placed represents the release of moisture stored in the landfill soil/waste matrix as the barrier at the landfill surface effectively prevented the infiltration of

precipitation.

Modeling scenario B consisted of 10.7 m (35 ft) of waste separated into a lower 4.6 m (15 ft) thick layer and an upper 6.1 m (20 ft) thick layer by a 0.61 m (2 ft) compacted silt barrier course. Trench filling would require three years with the lower waste layer placed during year 1, the silt separating course and second waste layer placed during year 2, and the trench capped during year 3. Drainage at the base of the lower waste layer peaked during year 3 with a flux of 4.3810 cm/yr (1.7248 in/yr). The flux decreased thereafter, to a value of 0.1041 cm/yr (0.0410 in/yr) at year 78, the last year modeled.

Modeling scenario C consisted of a full 20.1 m (66 ft) thickness of waste being placed within a disposal trench during a single year. The landfill cap was installed during year 2. Scenario C did not include intermediate compacted silt infiltration barrier layers. Drainage at the base of the landfill peaked during year 2 at a rate of 4.8212 cm/yr (1.8981 in/yr). The flux continued to decrease for the remainder of the modeling period to a value of 0.4671 cm/yr (0.1839 in/yr) during year 78.

Modeling scenario D assumed a thickness of 9.8 m (32 ft) of waste materials all placed during year 1. Landfill capping was modeled for year 2. Moisture drainage from the base of the landfill peaked during year 2 at a value of 5.6393 cm/yr (2.2202 in/yr). The flux decreased for the remainder of the modeling period to a value of 0.2278 cm/yr (0.0897 in/yr) at year 78.

Scenario E included a 20.1 m (66 ft) waste layer placed during year 1. The waste would be exposed to precipitation-derived moisture infiltration during years 2 through 5, and the cap installed during year 6. No compacted silt infiltration barrier layers were included. Base drainage reached a maximum during year 1 at a value of 3.9781 cm/yr (1.5662 in/yr). The flux decreased to the final year of the modeling run, year 78, where a value of 0.4752 cm/yr (0.1871 in/yr) was calculated.

The final scenario modeled, scenario F, assumed a 20.1 m (66 ft) thickness of soil-type waste material being placed in a single year. Cap placement would occur during year 2. No silt infiltration barriers were included in scenario F. This model represents the disposal of material excavated from past practice units where liquid wastes were discharged over long periods directly to in-situ soil deposits. The contaminated soil was assumed to be a gravelly sand. Drainage peaked at the end of year 1 with a flux of 18.4671 cm/yr (7.2705 in/yr). A rapid decrease in flux occurred during years 2 through 10 followed by a more gradual decrease to a minimum value of 0.0838 cm/yr (0.0330 in/yr) calculated for year 78.

There appeared to be no clear advantage of one operating scenario over any other. In all cases, the moisture flux at the base of the landfill was continuing to decrease at the end of the modeling period.

Modeling of the Environmental Restoration - Storage and Disposal Facility performance using 6 construction alternatives indicate that some drainage can be expected from the base of the landfill for an extended period after the final cap is in place. The length of the drainage period and the flux will depend on the thickness of the waste/soil fill deposits and the length of time they are exposed to direct rainfall before capping. Drainage will continue after the cap is placed until the suction heads within the waste deposits stabilize with the surrounding natural soils. HELP modeling indicates the asphalt layer portion of the "Hanford Barrier" will reduce infiltration of precipitation-derived moisture amounts to an essentially zero flux rate.

The HELP model was written as a tool for the design of landfill leachate extraction systems. As such, it contains many conservative estimations of various input parameters and performs computations in a very conservative manner, i.e., models landfill drainage flux rates at levels higher than would be expected during normal construction and operation. Its ability to track a theoretical wetting front through a landfill deposit is very limited. Additional modeling is recommended using a detailed computer code capable of better resolution of the modeled soil and waste layers should more refined output be desired.

Table of Contents

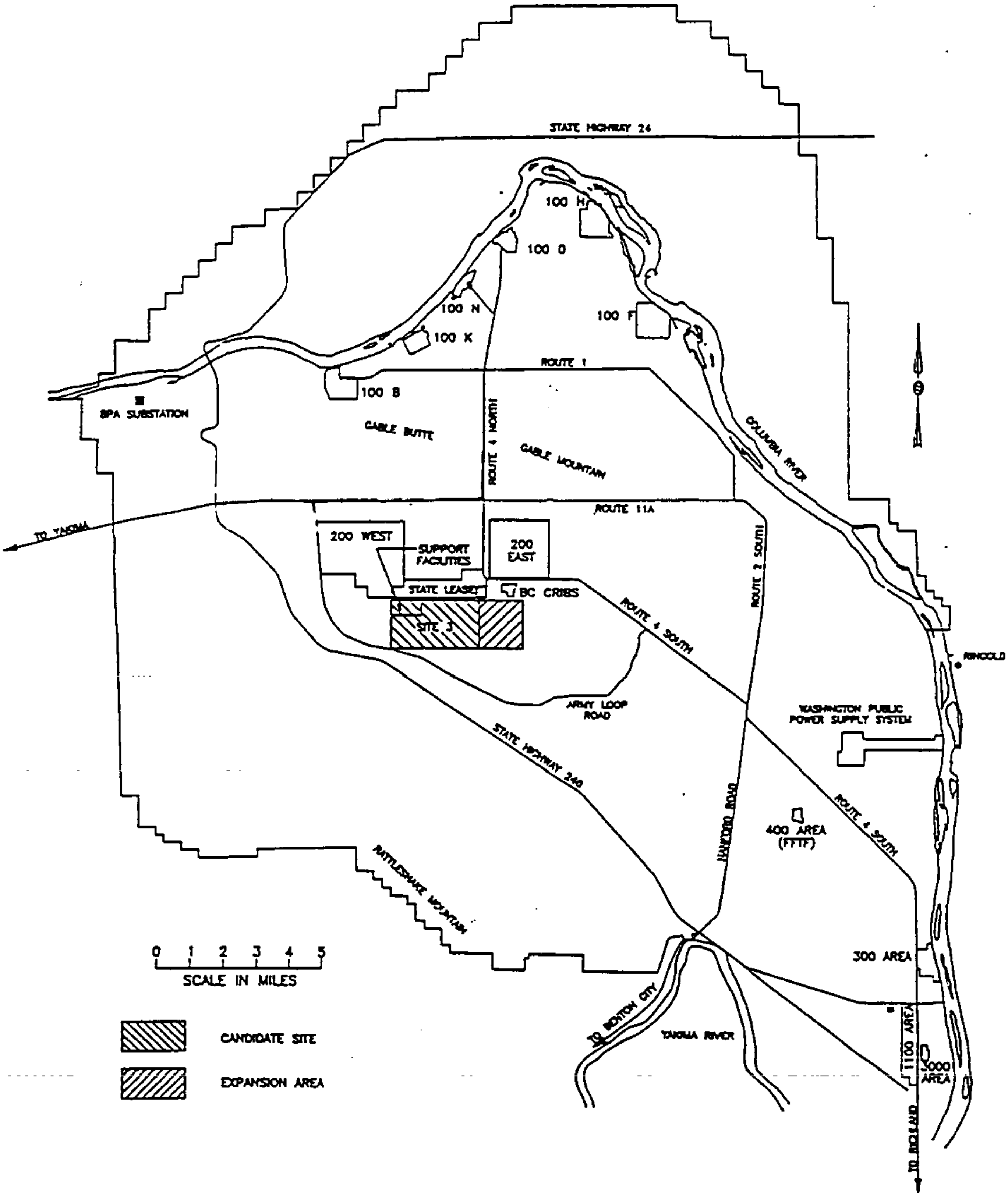
1.0 Scope

The Environmental Restoration - Storage and Disposal Facility (ER-SDF) is a proposed landfill having the capacity to receive 22,936,800 m^3 (30,000,000 yds^3) of waste. The facility will be constructed adjacent to the Hanford Site 200 East Area. Landfill cells will receive contaminated soils and debris excavated from "past practice" disposal sites existing throughout the former nuclear production reservation. Past practice landfills have yet to be fully characterized but are anticipated to contain contaminated natural soils and mixed debris consisting of demolition/decommissioning-derived materials, office wastes, etc. The Environmental Protection Agency computer code "Hydrologic Evaluation of Landfill Performance" (HELP) was used to model the proposed facility and to predict the flux of precipitation-derived moisture at the base of the lower waste layer to evaluate the effectiveness of several different operating scenarios in minimizing base drainage. Future precipitation values were modeled using the U.S. Department of Agriculture computer code "Weather Generator" (WGEN) using historical weather statistics for the Hanford site obtained from Hanford Meteorological Station data. The WGEN code is incorporated into version 2.0 of the HELP model. Six alternative landfill geometries were modeled to reflect currently proposed options for disposal trench depth and cell construction sequences. The completed landfill was assumed to be capped with the lower 4 layers of the permanent "Hanford Barrier". A total of 78 years were modeled reflecting a construction/operation period of 28 years combined with a 50 year landfill monitoring period.

2.0 Hydrologic Evaluation of Landfill Performance (HELP) Model

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts climatologic, soil and design data and utilizes a solution technique that accounts for the effects of surface storage, runoff, infiltration, percolation, evapotranspiration, soil moisture storage, and lateral drainage. The program was developed to facilitate rapid estimation of the amounts of runoff, drainage, and leachate that may be expected to result from a landfill. The HELP program was developed by the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, for the U.S. Environmental Protection Agency (EPA) Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, in response to needs identified by the EPA Office of Solid Waste, Washington, D.C. (Schroeder, 1992a).

Figure 1. Candidate Areas.



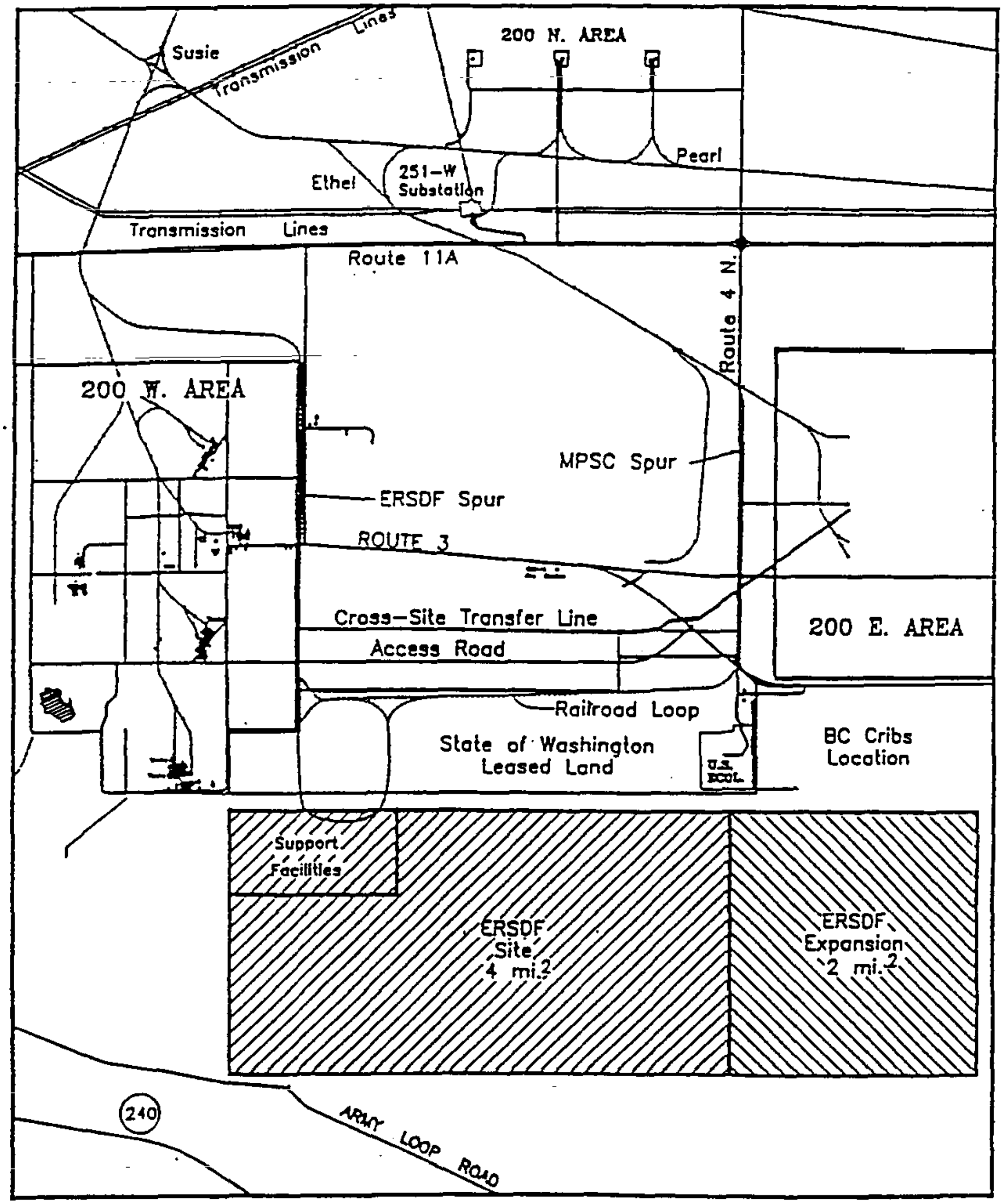
The hydrologic processes modeled by the program can be divided into two categories: surface processes and subsurface processes. The surface processes modeled are snowmelt, interception of rainfall by vegetation, surface runoff, and surface evaporation. The subsurface processes modeled are soil evaporation, plant transpiration, vertical unsaturated drainage, barrier-layer percolation, and lateral saturated drainage (Schroeder, 1992b).

Daily infiltration into the landfill is determined indirectly from a surface-water balance. Each day, infiltration is assumed to equal the sum of rainfall and snowmelt, minus the sum of runoff and surface evaporation. No surface water is held in storage from one day to the next. The daily surface-water accounting proceeds as follows. Snowfall is added to the surface snow storage, and then snowmelt is computed and added to rainfall. A rainfall-runoff relationship is used to determine the runoff resulting from the combined rainfall and snowmelt. Surface evaporation is then computed. Surface evaporation is not allowed to exceed the sum of surface snow storage and intercepted rainfall. The snowmelt and rainfall that does not run off or evaporate is assumed to infiltrate into the landfill (Schroeder, 1992b).

The first subsurface processes considered are soil evaporation and plant transpiration from the evaporative zone of the upper subprofile. These are computed on a daily basis. The evapotranspirative demand is distributed among the seven modeling segments in the evaporative zone (Schroeder, 1992b).

The other subsurface processes are modeled one subprofile at a time, from top to bottom, using a six-hour time step. If the subprofile contains a barrier-layer, the sum of the lateral drainage and barrier-layer percolation is first estimated. A storage-routing procedure is then used to redistribute the soil water among the modeling segments that comprise the subprofile. This procedure accounts for the external inflows and outflows computed or estimated previously (infiltration or percolation into the top segment, evapotranspiration from the segments in the evaporative zone, lateral drainage, and barrier-layer percolation), and vertical unsaturated drainage within the subprofile. The routing calculations, which proceed from top to bottom, yield estimates of lateral drainage and barrier-layer percolation. If the sum of these two outflows is not sufficiently close to the initial estimate, then the routing calculations are repeated using the improved estimate. Iteration continues until acceptable convergence is achieved. If the subprofile contains no barrier layer, lateral drainage and percolation are zero, so no iteration is needed (Schroeder, 1992b).

Figure 2. ERSDF Site



2.1 Precipitation Modeling

The HELP Program incorporates a routine for generating daily values of precipitation, solar radiation, minimum temperature and maximum temperature. This routine was developed by the USDA Agricultural Research Service (Richardson and Wright, 1984) based on a procedure described by Richardson (1981). The HELP user has the option of generating synthetic daily precipitation data rather than using default or manually entered historical data. Regardless of which precipitation input option is chosen, the program generates synthetic daily values of maximum temperature, minimum temperature and solar radiation. The generating routine is designed to preserve the dependence in time, the correlation between variables and the seasonal characteristics in actual weather data at the specified location.

Daily precipitation is generated using a Markov chain-gamma model. A first-order Markov chain is used to generate the occurrence of wet or dry days. In this model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.01 inch of rain or more. The model requires two transition probabilities: $P_i(W/W)$, the probability of a wet day on day i given a wet day on day i-1; and $P_i(W/D)$, the probability of a wet day on day i given a dry day on day i-1.

When a wet day occurs, the two-parameter gamma distribution is used to generate the precipitation amount. The two-parameter gamma distribution is used to describe the distribution of daily rainfall amounts. The density function, f(p), of the two-parameter gamma distribution is given by

$$f(p) = \frac{p^{\alpha-1} e^{-p/\beta}}{\beta^{\alpha} \gamma(\alpha)} \tag{1}$$

where p is the probability, α and β are distribution parameters, $\gamma(\alpha)$ is the gamma function of α and e is the base of natural logarithms.

The values of P(W/W), P(W/D), α and β vary continuously during the year for most locations. The precipitation generating routine uses monthly values of the four parameters. The HELP program contains these monthly values for 139 locations in the United States. These values were computed by the Agricultural Research Service from 20 years of daily precipitation data for each location.

Daily values of maximum temperature, minimum temperature and solar radiation are generated using the equation

$$t_i(j) = m_i(j)\,[X_i(j) \times c_i(j) + 1] \tag{2}$$

where

$t_i(j)$ = daily value of maximum temperature (j=1), minimum temperature (j=2), or solar radiation (j=3)

$m_i(j)$ = mean value on day i

$c_i(j)$ = coefficient of variation on day i

$X_i(j)$ = stochastically generated residual element for day i

The seasonal change in the means and coefficients of variation is described by the harmonic equation

$$u_i = \bar{u} + C\cos\left(\frac{2\pi}{365}(i-T)\right) \tag{3}$$

where

u_i = value of $m_i(j)$ or $c_i(j)$ on day i

u = mean value of u_i

C = amplitude of the harmonic

T = position of the harmonic in days

The Agricultural Research Service computed values of these parameters for the three variables on wet and dry days from 20 years of weather data at 31 locations. The HELP model contains values of these parameters for 184 cities. These values were taken from contour maps prepared by Richardson and Wright (1984).

The residual elements for Equation 2 are generated using a procedure that preserves important serial correlations and cross-correlations. The generating equation is

$$X_i(j) = A \times X_{i-1}(j) + B \times \varepsilon_i(j) \tag{4}$$

where $X_i(j)$ is a 3 x 1 matrix for day i whose elements are residuals of maximum temperature, minimum temperature, and solar radiation; ϵ_i is a 3 x 1 matrix of independent random components; and A and B are 3 x 3 matrices whose elements are defined such that the new sequences have the desired serial-correlation and cross-correlation coefficients. Richardson (1981) computed values or the relevant correlation coefficients from 20 years of weather data at 31 locations. The seasonal and spatial variation in these correlation coefficients were found to be negligible. The elements for the A and B matrices are therefore treated as constants (Schroeder, 1992b).

The weather generating portion of HELP collects climatic information stored in subsidiary data files for various U.S. cities to develop a rainfall model for the project site of interest. An input screen requests that the user provide a city and state which is close to the project area. The code then checks an internal listing to ensure that the desired city and state are included in the data files, then accesses the files to retrieve the data. Only Walla Walla and Yakima, Washington are included in the data files as choices representative of the climatic conditions of south-central Washington State. In order for the HELP program to perform weather generation using Hanford-specific climatic information, the Walla Walla, Washington entry in the TAPE2 data file was modified by replacing Walla Walla weather parameters with parameters derived from the Hanford Meteorologic Station weather records. The Hanford data listing for the TAPE2 file was obtained from Fayer *et al.*, 1992. The study which that report describes used the WGEN code to generate a weather model for the Hanford Site and reduced Hanford Meteorologic Station data to a form usable by the HELP modeling program. Table 1 lists the data included in the revised TAPE2 file entry for Walla Walla, Washington. The city name was not changed in the TAPE2 file so that the check lists included in the primary HELP code would not require modification.

2.2 Properties of Natural Soil Deposits

The HELP program makes use of many different soil characteristics. Three soil characteristics used throughout the program are porosity, field capacity and wilting point. The porosity used here is an effective value, defined as the volumetric water content at saturation (volume of water per unit bulk volume of material). Field capacity is defined conceptually as the water content that occurs after a prolonged period of gravity drainage. Wilting point is defined conceptually as the lowest water content that can be achieved by plant transpiration. Field capacity and wilting point are defined more precisely as the volumetric water contents at capillary pressures of 1/3 bar and 15 bars, respectively. All values for these variables used in the current study were taken from default soil type tables included in the HELP computer code.

Other soil characteristics are used for specific purposes. The soil evaporation calculation makes use of an evaporation coefficient. This coefficient indicates the ease with which water can be drawn upward through the soil by evaporation. Minimum infiltration rate is a soil characteristic that is used only for default soil types. If the user specifies a default soil type for the upper layer and does not input a runoff curve number, a value is computed based on minimum infiltration rate and vegetative cover. The saturated hydraulic conductivity is used in computing vertical drainage, lateral drainage, and barrier-layer percolation (Schroeder, 1992b).

Natural soil deposits excavated during the construction of the waste disposal trenches and from sites nearby the Storage and Disposal Facility will serve various specific purposes during the filling and capping of waste cells. Sandy gravels taken from the trench sites are assumed, for the purpose of modeling, to be used in the construction of the foundation and top course layers located directly below the asphalt/geomembrane barrier and the lateral drainage/cushioning layer directly overlying the barrier components. Silt deposits located at the McGee Ranch west of the construction site have been extensively investigated as the material source for the intermediate, compacted silt infiltration barrier layers (WHC, 1993a and 1993b).

Default soil types included within the HELP code were selected to reasonably match characteristics of site soils. Input values listed for the default soil types, specifically, soil porosity, wilting point, and field capacity, were then extracted from the HELP data tables. Soil type 1 was used to model soils existing at the trench locale. Properties of soil type 1 and the sources for the data used include:

Soil Classification:	Gravelly Sand
Porosity (HELP):	0.417
Field Capacity (HELP):	0.045 cm^3/cm^3
Wilting Point (HELP):	0.020 cm^3/cm^3
Saturated Hydraulic Conductivity (WHC, 1993a):	0.16 cm/sec

Soil type 8 was selected to model the McGee Ranch silt deposits. Properties of soil type 8 used as HELP input include:

Soil Classification:	Silt
Porosity (HELP):	0.463
Field Capacity (HELP):	0.232 cm^3/cm^3
Wilting Point (HELP):	0.116 cm^3/cm^3

Saturated Hydraulic Conductivity (WHC, 1993a):
0.0000012 cm/sec

All landfill layers constructed of the above defined soils were assumed to be compacted. Soil data used in the modeling reflect properties of compacted deposits.

The moisture content of soils placed during the disposal trench filling operation and during construction of the landfill cap must be controlled during placement in order to achieve desired compaction. Laboratory determination of optimum moisture content must be determined at various intervals during construction to account for variations in the soil texture. Preliminary testing to determine soil compaction criteria was performed by Westinghouse Hanford Company (WHC, 1993a). Optimum moisture content determined for the McGee Ranch silt was input to the HELP code. For the purposes of modeling, an optimum moisture content was chosen to reflect an average of published values for a gravelly sand soil type (Hunt, 1984). The following optimum moisture contents, measured on a weight percent basis, were used for HELP modeling:

Gravelly Sand	13%
Silt	16%

Gravimetric moisture content values were converted to volumetric measures for input to the HELP code. The formula used in making the necessary conversion was:

$$((wt\% \times \rho_b)/0.998\ g/cm^3)/100 \qquad (5)$$

(Campbell, 1992) where wt% is the gravimetric moisture content of the soil in percent, ρ_b is the bulk density of the soil in grams/cm^3, and 0.998 g/cm^3 is the density of water. Average densities of published values for gravelly sand and silt soil types were selected for modeling.

Gravelly Sand	120 pounds/ft^3 = 1.9222 g/cm^3
Silt	112 pounds/ft^3 = 1.8000 g/cm^3

(Hunt, 1984 and WHC, 1993a, respectively). Final volumetric moisture contents calculated as inputs for the HELP Model were:

Gravelly Sand	0.2504 cm^3/cm^3
Silt	0.2886 cm^3/cm^3

2.3 Moisture Content of Waste Deposits

Contaminated natural soils and mixed waste debris consisting

Table 1 - Weather-Generation Parameters Generated with WGENPAR Using Hanford Meteorological Station Data from the Period 1958-1987 (actual format for input to the WGEN code) (Fayer *et al.*, 1992).

```
WASH WALL
   46.57    65.22    59.62    42.63    26.07    18.16    0.154  -0.088    0.204  -0.129
  380.63   246.84   284.04
 0.439 0.516 0.388 0.317 0.301 0.252 0.294 0.258 0.337 0.319 0.444 0.484
 0.195 0.166 0.163 0.121 0.122 0.123 0.055 0.059 0.085 0.094 0.198 0.256
 30.1 37.8 44.4 52.3 61.3 69.3 76.6 74.6 66.2 53.1 39.5 33.1
  275  180  0.0  10  19  00
```

The data input file shown immediately above is defined, line by line, in the following:

Line Number	Variable Identifications
1	State City (The Walla Walla, WA TAPE2 data file was modified to include Hanford Met. Station data. The city name was not changed so that changes to the HELP code would not be necessary.)
2	ALAT TXMD TXMW TN ATX ATN CVTX ACVTX CVTN ACVTN
3	RMD RMW AR
4	PWW(January through December)
5	PWD(January through December)
6	TM(January through December)
7	IPL IHV BLAI IBG IFG IEG

of demolition-derived materials, office wastes, etc. presently buried within "past practice" landfills will be excavated and placed within the Storage and Disposal Facility. This material may have been in the ground for 45 to 50 years. No data is available as to the original moisture content of the material nor of its present moisture content. The HELP model will initiate a moisture content where an actual value is unknown. However, a more realistic approach was performed, i.e., modeling a hypothetical "past practice" landfill at the Hanford Site to develop a moisture content which an arbitrary thickness of landfilled waste will ultimately attain under local climatic conditions.

The hypothetical past practice landfill was 3.1 m (10 ft) in thickness; the lower 1.5 m (5 ft) containing municipal-type waste covered by a 1.5 m (5 ft) layer of soil. The waste was input to the HELP program using default soil type 18, municipal waste, data values. Typically, municipal waste will contain a high percentage of paper products which will increase its field capacity and likely overestimate the moisture content given the probable waste types present in Hanford past-practice landfills. The cover soil was assumed to consist of uncompacted gravelly sand, HELP default soil type 1 as defined in section 2.2, having an initial moisture content of 3.18%, on a weight percent basis (0.0612 cm^3/cm^3, on a volumetric basis). This value was determined by arithmetically averaging the moisture content of 168 soil samples collected during the Remedial Investigation Study of the Hanford Site 1100-EM-1 Operable Unit (DOE/RL, 1993). An infiltration barrier layer was not assumed to exist above the waste deposits. The waste layer moisture content selected to initiate the model run for a hypothetical past practice landfill was 0.2170 cm^3/cm^3, midway between the HELP default values for wilting point and field capacity. The model was run for a simulated time period of 9 years using average rainfall data of 15.77 cm/yr (6.21 in/yr) at which time the moisture content of the waste layer stabilized.

Soil Classification:	Municipal Waste
Default Soil Type	18
Porosity (HELP):	0.520
Field Capacity (HELP):	0.294 cm^3/cm^3
Wilting Point (HELP):	0.140 cm^3/cm^3
Saturated Hydraulic Conductivity (HELP):	0.0002 cm/sec

The modeled waste layer moisture content stabilized at a value of 0.2858 cm^3/cm^3. This value was used in subsequent modeling runs as the initial moisture content of waste introduced into the Storage and Disposal Facility. It is anticipated that this value represents a conservative moisture content, i.e., slightly higher than should be expected.

Summary data of HELP modeling runs for the determination of initial waste moisture content is provided on pages A1 through A4.

2.4 Vegetative Growth

The HELP program accounts for seasonal variation in leaf-area index through a general vegetative growth model. This model was extracted from the Simulator for Water Resources in Rural Basins program developed by the USDA Agricultural Research Service (Arnold *et al.*, 1986). The vegetative growth model computes daily values of leaf-area index based on the maximum value input by the user, daily temperature and solar radiation data, mean monthly temperatures, and the beginning and ending dates of the growing season. The maximum value of leaf-area index depends on the type of vegetation and the quality of the stand. The program supplies typical values for selected covers ranging from 0 for bare ground to 5 for an excellent stand of grass (Schroeder, 1992b).

2.5 Hanford Engineered Barrier

The Hanford Engineered Barrier, as currently envisioned, is illustrated in Figures 4 and 5. Its purpose is to prevent the infiltration of precipitation derived moisture through the buried waste, to prevent burrowing animals from reaching the deposits, and to prevent both inadvertent and intentional human intrusion into the waste cells. At the time of this study, plans for the timing/sequence of barrier construction and for the actual structure of the barrier at the ER-SDF site were being formulated. Therefore, only the lower four barrier layers, as depicted in Figure 4, were modeled: the 0.30 m (1 ft) drainage gravel/cushion layer; the 0.15 m (6 in) asphaltic concrete/geomembrane barrier layer; the 0.10 m (4 in) top course; and, an assumed 0.61 m (2 ft) thickness of foundation material. "In-situ soil", as depicted in Figure 4, represents the uppermost waste deposits of landfill cells.

Material assumed for the drainage gravel/cushion layer, the top course, and foundation material consisted of gravelly sand obtained during initial waste trench excavation. Properties of this soil type are presented in section 2.2. The material was assumed to be compacted.

Properties of the asphaltic concrete/geomembrane barrier layer were obtained from testing performed by Westinghouse Hanford Company (WHC, 1993a). The combination was modeled as

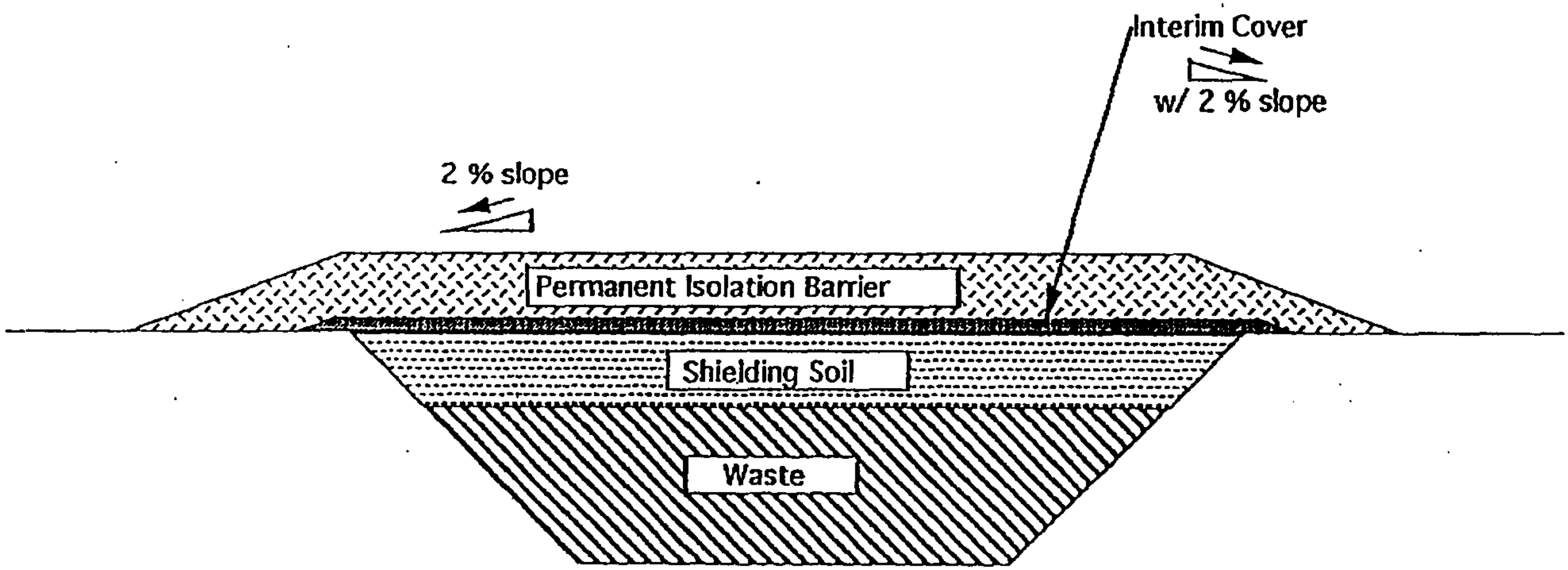
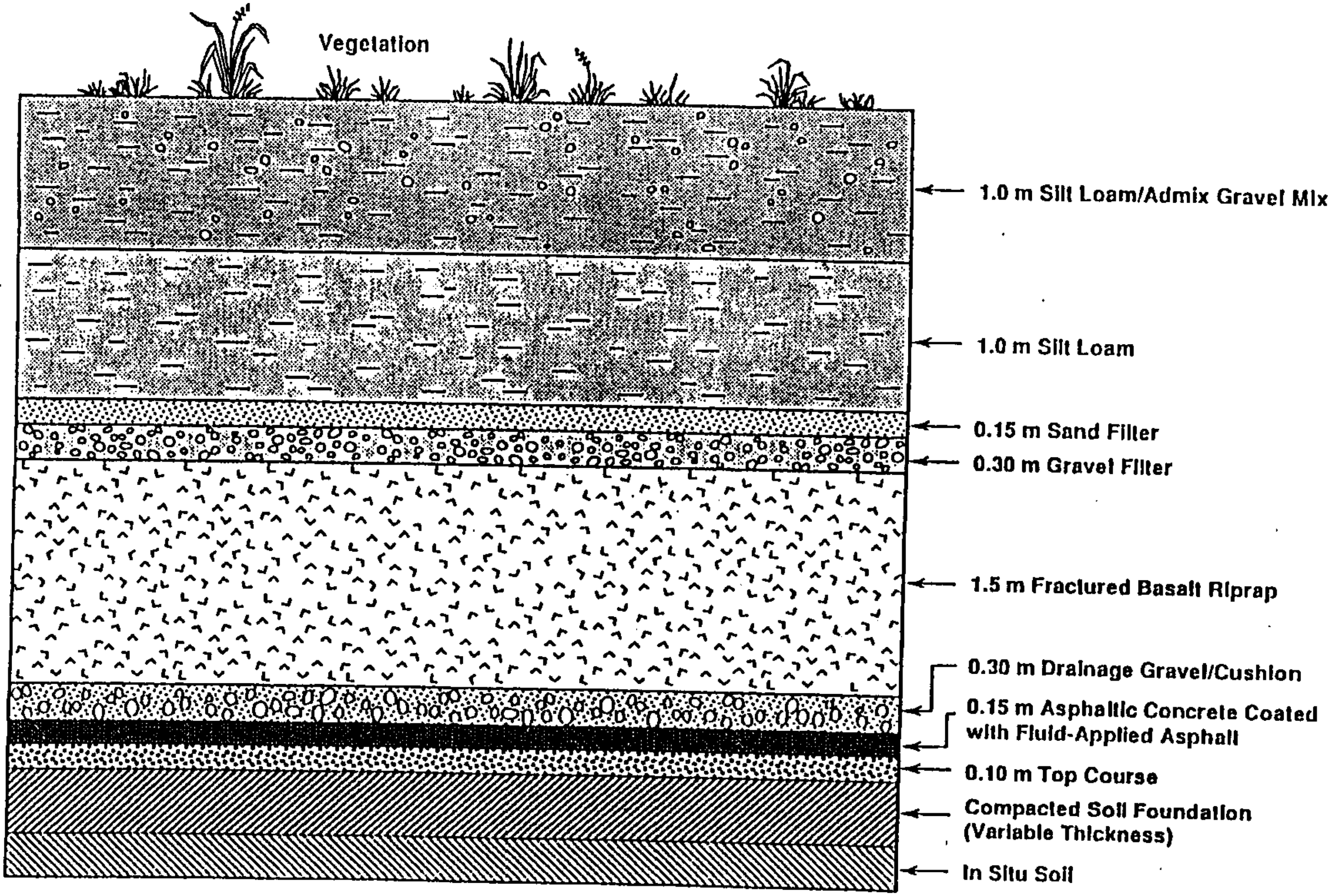


FIGURE 3: TRENCH CROSS SECTION
PERMANENT CLOSURE PHASE

FIGURE 4: Typical Barrier Cross Section



H9301009.1

HELP default soil type 4, barrier soil with flexible membrane. The geomembrane will consist of a 100 mil thick polymer material having a hydraulic conductivity of 10^{-11} cm/sec. HELP requires a "leakage fraction" value for the geomembrane; a ratio of the daily infiltration that occurs with the geomembrane in place to that which would occur without the geomembrane (Schroeder, 1992a). The leakage fraction can also be viewed as a measure of the small flaws which are created in the lining during placement, i.e., rips, punctures, imperfect seaming, etc. A value of 0.001 was used to model moderate heads above the liner and a moderate liner contact with the underlying asphalt layer (personal communication, Dr. P. Schroeder with J. McBane, May 1993). The barrier soil portion of soil type 4 was modeled as asphalt. Input data for the asphalt included:

Soil Classification:	Barrier Soil
Default Soil Type	4
Porosity:	0.050
Field Capacity:	0.030 cm^3/cm^3
Wilting Point:	0.020 cm^3/cm^3
Saturated Hydraulic Conductivity (WHC, 1993a)	0.00000001 cm/sec

(personal communication, Dr. P. Schroeder with J. McBane, May 1993). These values are not used in the HELP computations for a barrier soil layer (Schroeder, 1992a) but served to fulfill the program's input requirements.

3.0 HELP Evaluation of the Storage and Disposal Facility

Six alternative landfill geometries were modeled to reflect currently proposed options for disposal trench depth and cell construction sequences. The completed landfill was assumed to be capped with the lower 4 layers of the permanent "Hanford Barrier" including the 0.3 m (1 ft) drainage gravel/cushion layer, the 0.15 m (6 in) geomembrane and asphalt barrier layer, the 0.10 m (4 in) base course, and an assumed 0.61 m (2 ft) thickness of foundation material. A total of 78 years were modeled reflecting a construction/operation period of 28 years combined with a 50 year landfill monitoring period. The manual input option was used for all scenarios. A landfill surface area for modeling was set at 0.1 m^2 (1 ft^2). The unit basis for modeling was selected due to the infinite number of potential surface areas which could exist during waste placement within the landfill. Conversion of moisture fluxes presented herein to volumes will require specific knowledge of the surface area for the region/landfill geometry of interest.

3.1 Landfill Scenario A

Modeling scenario A consisted of a landfill containing a 60 foot thickness of waste separated into 3-6.1 m (3-20 ft) thick layers by 0.61 m (2 ft) thicknesses of compacted silt. Filling of a disposal trench in the vertical dimension was assumed to require 3 years. During each of the first two years, 6.1 m (20 ft) thick waste layers would be placed with each layer being covered with a 0.61 m (2 ft) compacted silt infiltration barrier. The final waste layer would be placed in year 3 with no silt course installed. Landfill capping would occur during year 4. Model results are summarized on pages B1 through B4.

The bottom graph on page B3 shows that drainage at the base of the lowest waste layer peaked during year 1 at a flux of 3.7539 cm/yr (1.4779 in/yr). The flux decreased thereafter, through the end of the modeling period at year 78 to a value of 0.1402 cm/yr (0.0552 in/yr). The drainage from waste deposits occurring after the impermeable cap was placed represents the release of moisture stored in the landfill soil/waste matrix as the barrier at the landfill surface effectively prevented the infiltration of precipitation. The graph peak which appears at year 4 occurs at the time of cap placement in the model. It represents the computational reaction of the model to the placement of additional layers to the modeled profile, in effect, burying the waste deposits at a greater depth. This is an illustration of the conservatism built into the HELP model. The effect is repeated in all subsequent HELP modeling runs.

The graph on the bottom of page B4 represents the amount of precipitation derived infiltration which penetrates the asphalt/geomembrane barrier layer. The peaks and valleys of the graph are direct reflections of the rainfall occurring within the previous year. HELP will not permit a barrier layer to totally exclude infiltration, another form of conservatism included in the model.

3.2 Landfill Scenario B

Modeling scenario B consisted of 10.7 m (35 ft) of waste separated into a lower 4.6 m (15 ft) thick layer and an upper 6.1 m (20 ft) thick layer by a 0.61 m (2 ft) compacted silt infiltration barrier. This model represents conditions in shallow burial trenches being considered for the ER-SDF. Trench filling would require three years with the lower waste layer placed during year 1, the silt separating course and second waste layer placed during year 2, and the trench capped during year 3. Summary output for Run B is included on pages C1 through C4.

The lower graph on page C3 shows drainage at the base of the lower waste layer peaking during year 5 with a flux of 4.3810 cm/yr (1.7248 in/yr). The flux decreases thereafter, to a value of 0.1041 cm/yr (0.0410 in/yr) at year 78, the last year modeled.

3.3 Landfill Scenario C

Modeling scenario C consisted of a full 20.1 m (66 ft) thickness of waste being placed within a disposal trench during a single year. The landfill cap was installed during year 2. Scenario C did not include intermediate compacted silt infiltration barrier layers. The purpose of this modeling run was to compare results with scenario A in which a similar thickness of material was placed in waste burial trenches but having intermediate soil infiltration barriers sandwiched within the waste cells. Summary data for Run C is presented on pages D1 through D4.

Drainage at the base of the landfill peaked during year 2 at a rate of 4.8212 cm/yr (1.8981 in/yr) as illustrated by the graph on the bottom of page D3. The flux continued to decrease for the remainder of the modeling period to a value of 0.4671 cm/yr (0.1839 in/yr) during year 78. This is approximately 1 cm (approx. 1/2 inch) greater peak flux and a slightly higher final flux than when soil infiltration barrier layers were included in the trench filling design.

3.4 Landfill Scenario D

Modeling scenario D assumed a thickness of 9.8 m (32 ft) of waste materials all placed during year 1. Landfill capping was modeled for year 2. Scenario D was modeled as a comparison to scenario B where a similar thickness of waste having an intermediate soil infiltration barrier layer was placed. Summary program output is provided on pages E1 through E4.

The bottom graph on page E3 shows moisture drainage from the base of the landfill peaking during year 2 at a value of 5.6393 cm/yr (2.2202 in/yr). The flux decreases for the remainder of the modeling period to a value of 0.2278 cm/yr (0.0897 in/yr) at year 78. This, again, represents an approximately 1 cm (approx. 1/2 inch) increase in the peak flux rate and slightly higher final flux rate when compared to a similar landfill having intermediate infiltration barriers.

3.5 Landfill Scenario E

Scenario E included a 20.1 m (66 ft) waste layer placed entirely during year 1. The waste would be exposed to precipitation-derived moisture infiltration during years 2 through 5, and the cap installed during year 6. No compacted silt infiltration barrier layers were included. Scenario E investigated the effect of delaying placement of the final cap over waste deposits. Results should be compared with scenario C which has a similar waste layer thickness but was capped in year 2 instead of year 6. Summary results are included on pages F1 through F4.

Base drainage was maximum during year 1 at a value of 3.9781 cm/yr (1.5662 in/yr) as illustrated by the bottom graph on page F3. The flux decreased to the final year of the modeling run, year 78, where a value of 0.4752 cm/yr (0.1871 in/yr) was calculated. The base drainage peak flux rate was slightly lower in this scenario than for the flux peak computed for a similar landfill capped very soon after filling operations were completed. The final fluxes for the two options were virtually identical. This may indicate the importance of evaporation in removing some of the moisture contained in the waste deposits prior to capping, but more likely is due to computational methods used by the HELP code.

3.6 Landfill Scenario F

The final scenario modeled, scenario F, assumed a 20.1 m (66 ft) thickness of soil-type waste material being placed in a single year. Cap placement would occur during year 2. No silt infiltration barriers were included in scenario F. This model represents the disposal of material excavated from past practice units where liquid wastes were discharged over long periods directly to in-situ soil deposits. The contaminated soil was assumed to be a gravelly sand. The initial soil waste moisture content used in the model was 0.0612 cm^3/cm^3 as described in section 2.3 for the gravelly sand cover soil of the theoretical past practice landfill. All other gravelly sand soil properties used are described in section 2.2. Results should be compared to scenario C which differed only in the material placed in the disposal trench. Summary results are presented on pages G1 through G4

The bottom graph on page G3 illustrates how drainage peaked at the end of year 1 with a flux of 18.4671 cm/yr (7.2705 in/yr). A rapid decrease in flux occurred during years 2 through 10 followed by a more gradual decrease to a minimum value of 0.0838 cm/yr (0.0330 in/yr) calculated for year 78. The peak flux was 13.5 cm (5.3 in) greater with this scenario than when municipal-type waste was modeled even though the initial moisture content of the soil-type waste was much lower than that of the former. The final flux, though, was 0.3810 cm/yr (0.15 in/yr) less in this scenario. These variations, again, are the results of the computational methods employed by the HELP computer code.

4.0 Modeling Conclusions

Modeling of the Environmental Restoration - Storage and Disposal Facility performance using 6 construction alternatives indicate that some drainage can be expected from the base of the landfill for an extended period after the final cap is in place. There appeared to be no clear advantage of one operating scenario over any other in significantly decreasing the drainage at the base of the landfill as computed by the HELP model. The length of the drainage period and the flux will depend on the thickness and type of the fill deposits and the length of time they are exposed to direct rainfall before capped. The inclusion of intermediate silt infiltration barrier layers did not appreciably decrease the predicted drainage fluxes. Drainage will continue after capping until the suction heads within the waste deposits stabilize with the surrounding natural soils. HELP modeling indicates the asphalt layer portion of the "Hanford Barrier" will reduce infiltration of precipitation-derived moisture amounts to an essentially zero flux rate.

The HELP model was written as a tool for the design of landfill leachate extraction systems. As such, it contains many conservative estimations of various input parameters and performs computations in a very conservative manner, i.e., models landfill drainage flux rates at levels higher than would be expected during normal construction and operation to ensure that collection systems are adequately sized to meet most contingencies. Its ability to track a theoretical wetting front through a landfill deposit is very limited. Additional modeling is recommended using a detailed computer code capable of better resolution of the modeled soil and waste layers should more refined output be desired.

5.0 References

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WASTE 1

Estimate Moisture Content of Existing Landfill Contents

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	WASTE LAYER DRAINAGE (in/yr)	WASTE LAYER DRAINAGE (cm/yr)	COVER SOIL MOISTURE (cm^3/cm^3)	WASTE SOIL MOISTURE (cm^3/cm^3)		
0					0.0612	0.2170		
1	6.21	15.7734	0.2257	0.5733	0.0456	0.2562		
2	6.21	15.7734	0.6384	1.6215	0.0456	0.2729		
3	6.21	15.7734	1.1371	2.8882	0.0456	0.2813		
4	6.21	15.7734	1.4537	3.6924	0.0456	0.2844		
5	6.21	15.7734	1.5806	4.0147	0.0456	0.2854		
6	6.21	15.7734	1.6226	4.1214	0.0456	0.2857		
7	6.21	15.7734	1.6353	4.1537	0.0456	0.2858		
8	6.21	15.7734	1.6396	4.1646	0.0456	0.2858		
9	6.21	15.7734	1.6396	4.1646	0.0456	0.2858		
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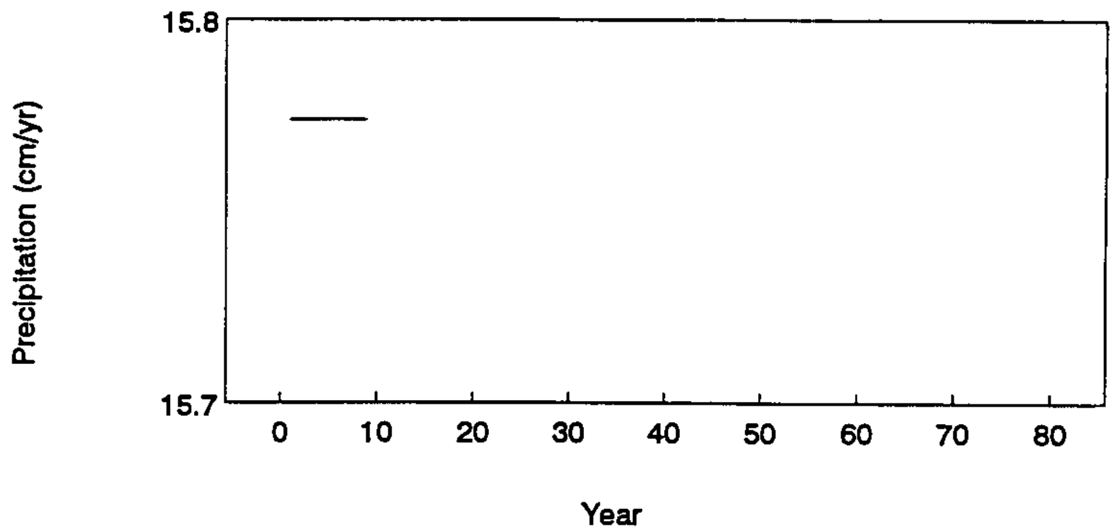
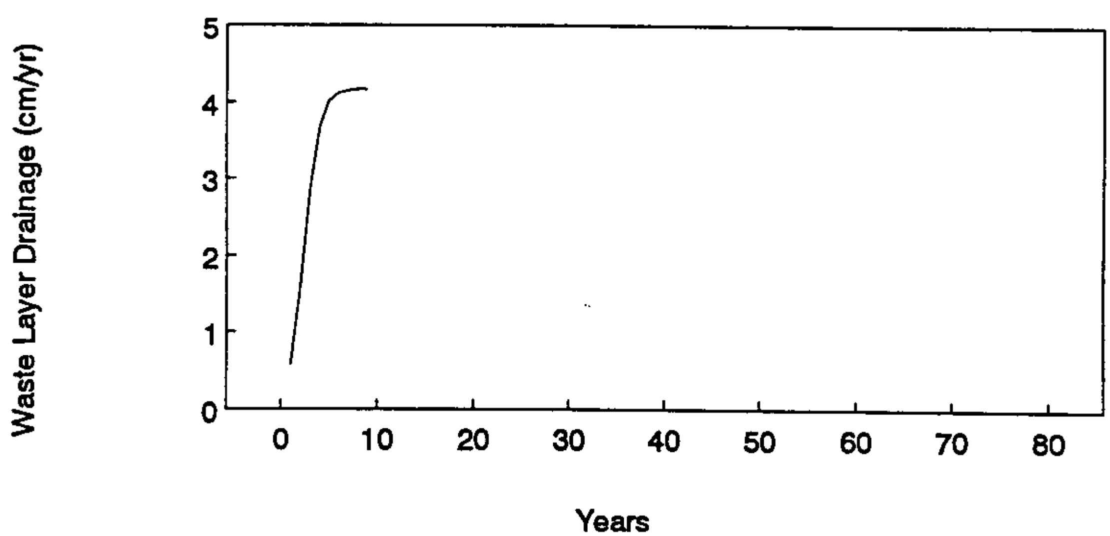
72								
73								
74								
75								
76								
77								
78								
Average:	6.21	15.7734	1.2858	3.2660	0.0472	0.2740		
Minimum:	6.21	15.7734	0.2257	0.5733	0.0456	0.2170		
Maximum:	6.21	15.7734	1.6396	4.1646	0.0612	0.2858		

ENVIRONMENTAL RESTORATION
STORAGE AND DISPOSAL FACILITY

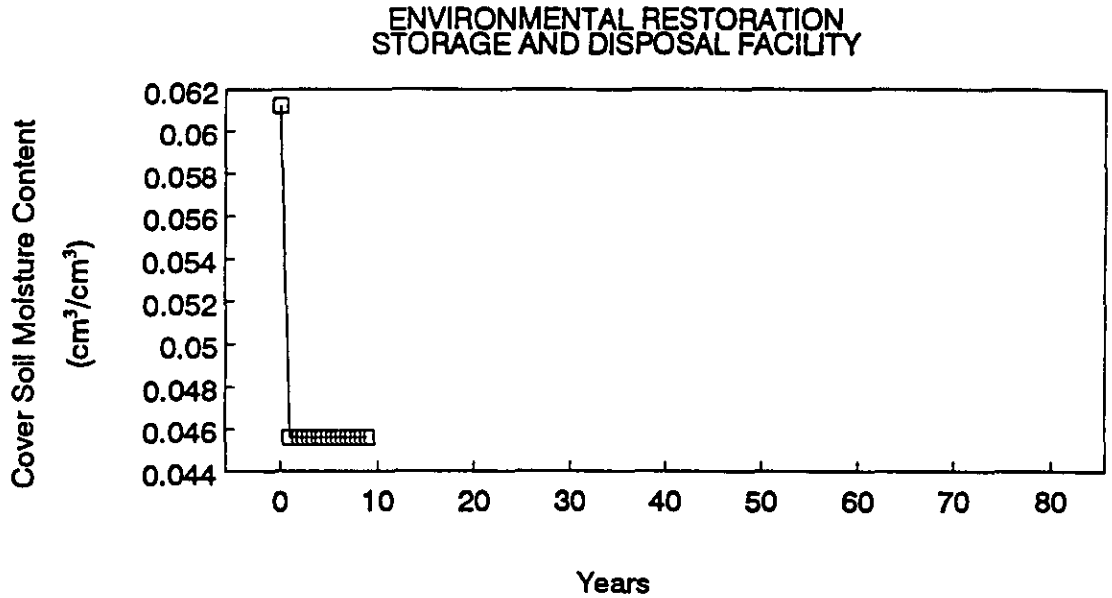


Minimum Precipitation (cm/yr):	**15.7734**
Maximum Precipitation (cm/yr):	**15.7734**
Average Precipitation (cm/yr):	**15.7734**

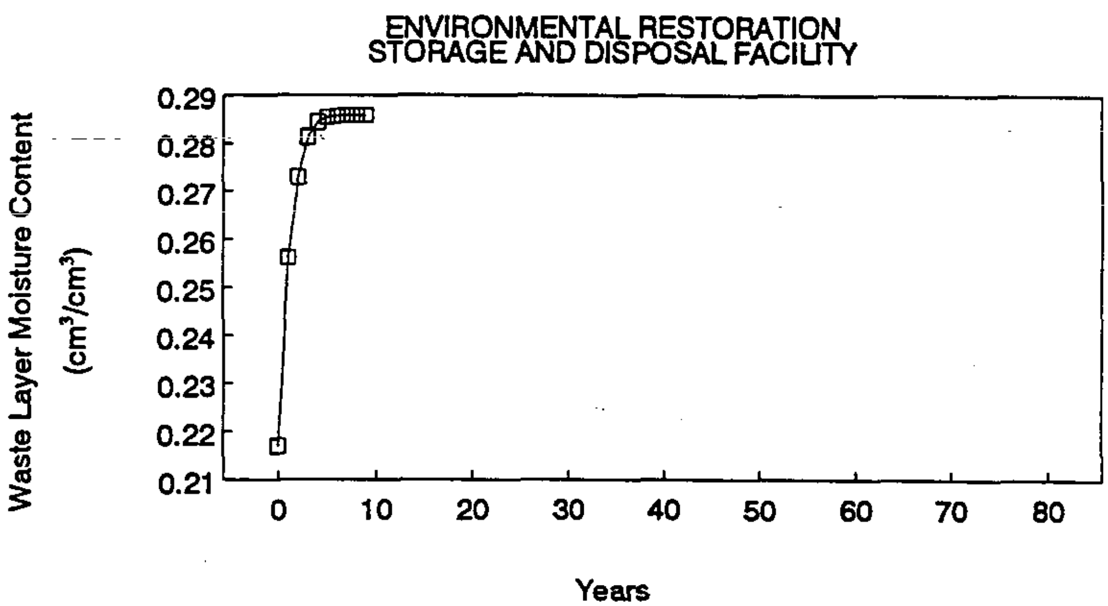
ENVIRONMENTAL RESTORATION
STORAGE AND DISPOSAL FACILITY



Minimum Drainage (cm/yr):	**0.5733**
Maximum Drainage (cm/yr):	**4.1646**
Average Drainage (cm/yr):	**3.2660**



Avg Soil Cover Layer Moisture (cm^3/cm^3): 0.0472

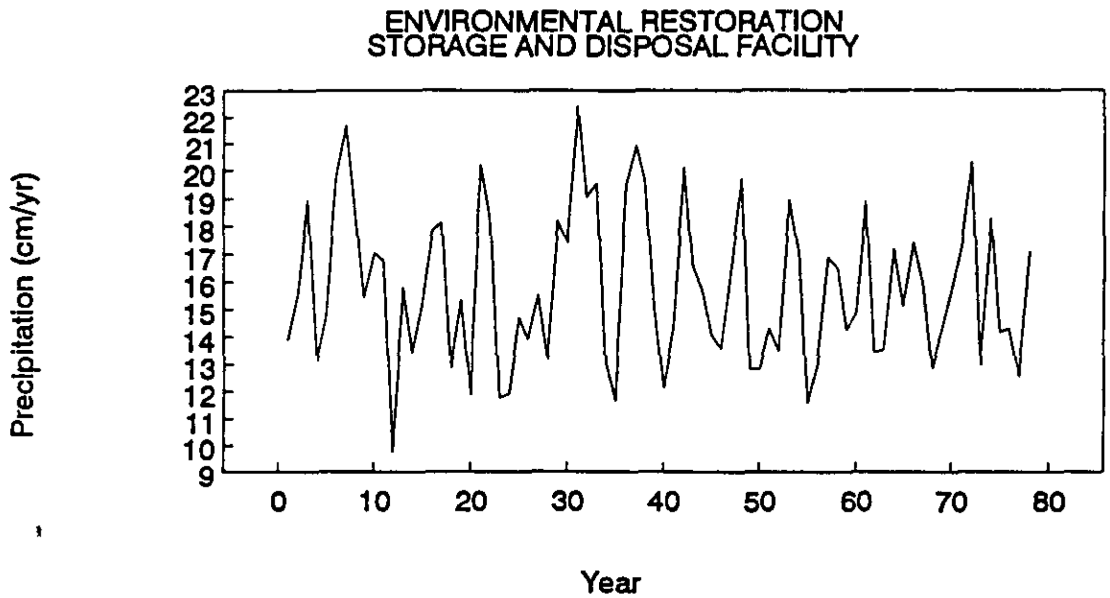


Avg Waste Layer Moisture (cm^3/cm^3): 3.2660

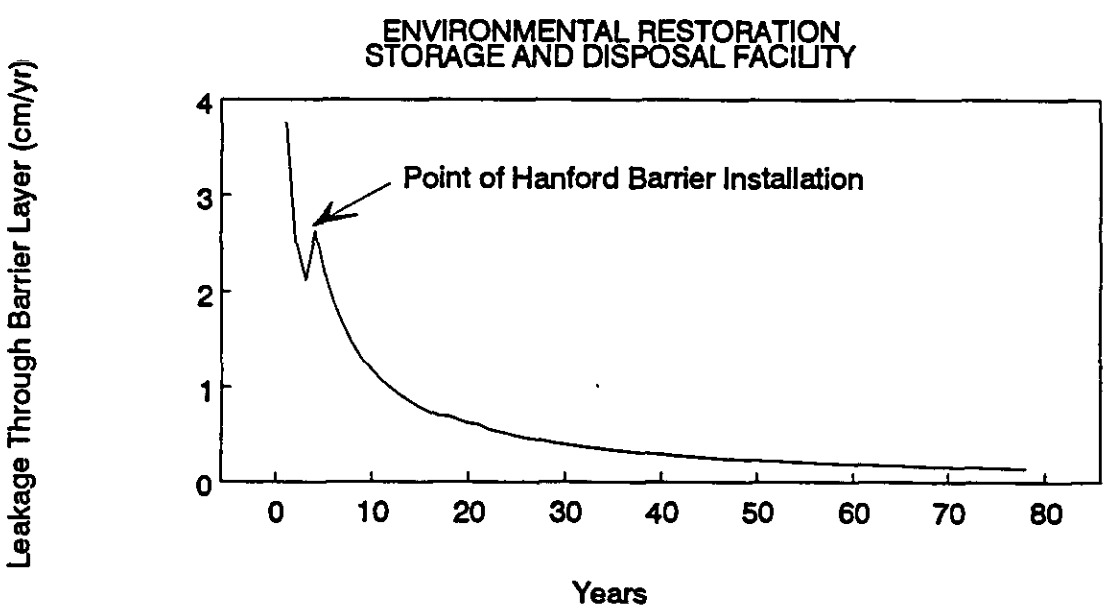
RUN A

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	LOWER WASTE LAYER DRAINAGE (in/yr)	LOWER WASTE LAYER DRAINAGE (cm/yr)	LOWER WASTE SOIL MOISTURE (cm³/cm³)	BARRIER LAYER DRAINAGE (in/yr)	BARRIER LAYER DRAINAGE (cm/yr)
0					0.2858		
1	5.47	13.8938	1.4779	3.7539	0.2775		
2	6.12	15.5448	0.9943	2.5255	0.2734		
3	7.46	18.9484	0.8317	2.1125	0.2699		
4	5.18	13.1572	1.0354	2.6299		0.0006	0.00152
5	5.80	14.7320	0.8656	2.1986		0.0005	0.00127
6	7.78	19.7612	0.7406	1.8811		0.0005	0.00127
7	8.54	21.6916	0.6472	1.6439		0.0006	0.00152
8	7.32	18.5928	0.5709	1.4501		0.0007	0.00178
9	6.07	15.4178	0.5112	1.2984		0.0007	0.00178
10	6.71	17.0434	0.4623	1.1742		0.0004	0.00102
11	6.60	16.7640	0.4227	1.0737		0.0004	0.00102
12	3.83	9.7282	0.3871	0.9832		0.0006	0.00152
13	6.21	15.7734	0.3577	0.9086		0.0003	0.00076
14	5.29	13.4366	0.3322	0.8438		0.0006	0.00152
15	5.95	15.1130	0.3108	0.7894		0.0005	0.00127
16	7.03	17.8562	0.2904	0.7376		0.0006	0.00152
17	7.13	18.1102	0.2730	0.6934		0.0004	0.00102
18	5.06	12.8524	0.2730	0.6934		0.0004	0.00102
19	6.05	15.3670	0.2576	0.6543		0.0003	0.00076
20	4.67	11.8618	0.2443	0.6205	0.2470	0.0004	0.00102
21	7.96	20.2184	0.2414	0.6132		0.0005	0.00127
22	7.21	18.3134	0.2200	0.5588		0.0005	0.00127
23	4.64	11.7856	0.2097	0.5326		0.0004	0.00102
24	4.69	11.9126	0.2007	0.5098		0.0006	0.00152
25	5.78	14.6812	0.1915	0.4864		0.0006	0.00152
26	5.48	13.9192	0.1835	0.4661		0.0007	0.00178
27	6.11	15.5194	0.1761	0.4473		0.0007	0.00178
28	5.18	13.1572	0.1697	0.4310		0.0006	0.00152
29	7.16	18.1864	0.1629	0.4138		0.0003	0.00076
30	6.85	17.3990	0.1570	0.3988		0.0006	0.00152
31	8.82	22.4028	0.1515	0.3848		0.0005	0.00127
32	7.49	19.0246	0.1467	0.3726		0.0005	0.00127
33	7.70	19.5580	0.1415	0.3594		0.0006	0.00152
34	5.13	13.0302	0.1370	0.3480		0.0002	0.00051
35	4.59	11.6586	0.1327	0.3371		0.0007	0.00178
36	7.66	19.4564	0.1290	0.3277		0.0005	0.00127
37	8.24	20.9296	0.1249	0.3172		0.0004	0.00102
38	7.72	19.6088	0.1213	0.3081		0.0004	0.00102
39	5.93	15.0622	0.1179	0.2995		0.0005	0.00127
40	4.77	12.1158	0.1150	0.2921	0.2337	0.0002	0.00051
41	5.63	14.3002	0.1114	0.2830		0.0004	0.00102
42	7.92	20.1168	0.1085	0.2756		0.0005	0.00127
43	6.52	16.5608	0.1058	0.2687		0.0005	0.00127
44	6.17	15.6718	0.1034	0.2626		0.0007	0.00178
45	5.53	14.0462	0.1007	0.2558		0.0005	0.00127
46	5.34	13.5636	0.0983	0.2497		0.0004	0.00102
47	6.52	16.5608	0.0960	0.2438		0.0006	0.00152
48	7.77	19.7358	0.0941	0.2390		0.0005	0.00127
49	5.04	12.8016	0.0917	0.2329		0.0003	0.00076

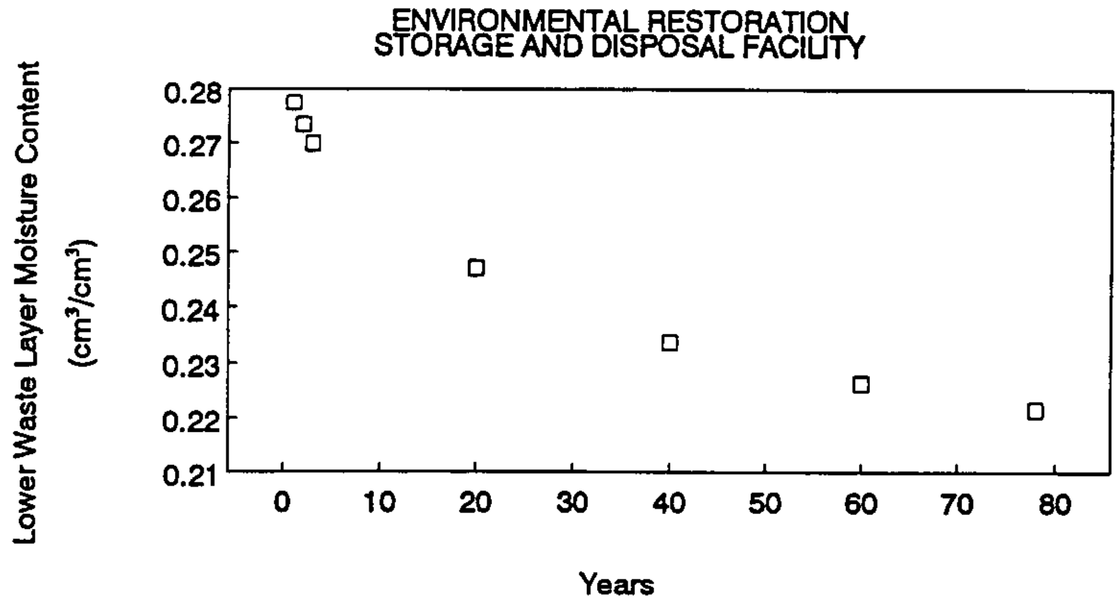
50	5.05	12.8270	0.0897	0.2278		0.0006	0.00152
51	5.64	14.3256	0.0878	0.2230		0.0007	0.00178
52	5.30	13.4620	0.0862	0.2189		0.0003	0.00076
53	7.46	18.9484	0.0842	0.2139		0.0004	0.00102
54	6.67	16.9418	0.0824	0.2093		0.0004	0.00102
55	4.56	11.5824	0.0808	0.2052		0.0002	0.00051
56	5.11	12.9794	0.0794	0.2017		0.0005	0.00127
57	6.64	16.8656	0.0777	0.1974		0.0003	0.00076
58	6.50	16.5100	0.0762	0.1935		0.0005	0.00127
59	5.61	14.2494	0.0748	0.1900		0.0005	0.00127
60	5.84	14.8336	0.0737	0.1872	0.2263	0.0003	0.00076
61	7.44	18.8976	0.0723	0.1836		0.0005	0.00127
62	5.29	13.4366	0.0710	0.1803		0.0006	0.00152
63	5.33	13.5382	0.0698	0.1773		0.0005	0.00127
64	6.77	17.1958	0.0688	0.1748		0.0006	0.00152
65	5.94	15.0876	0.0674	0.1712		0.0005	0.00127
66	6.86	17.4244	0.0663	0.1684		0.0004	0.00102
67	6.26	15.9004	0.0652	0.1656		0.0004	0.00102
68	5.05	12.8270	0.0643	0.1633		0.0005	0.00127
69	5.64	14.3256	0.0631	0.1603		0.0003	0.00076
70	6.19	15.7226	0.0622	0.1580		0.0006	0.00152
71	6.81	17.2974	0.0612	0.1554		0.0006	0.00152
72	8.01	20.3454	0.0604	0.1534		0.0007	0.00178
73	5.10	12.9540	0.0594	0.1509		0.0007	0.00178
74	7.19	18.2626	0.0585	0.1486		0.0004	0.00102
75	5.58	14.1732	0.0576	0.1463		0.0002	0.00051
76	5.64	14.3256	0.0569	0.1445		0.0006	0.00152
77	4.93	12.5222	0.0560	0.1422		0.0003	0.00076
78	6.73	17.0942	0.0552	0.1402	0.2216	0.0006	0.00152
Average:	6.22	15.7923	0.2238	0.5684	0.2544	0.0005	0.00124
Minimum:	3.83	9.7282	0.0552	0.1402	0.2216	0.0002	0.00051
Maximum:	8.82	22.4028	1.4779	3.7539	0.2775	0.0007	0.00178



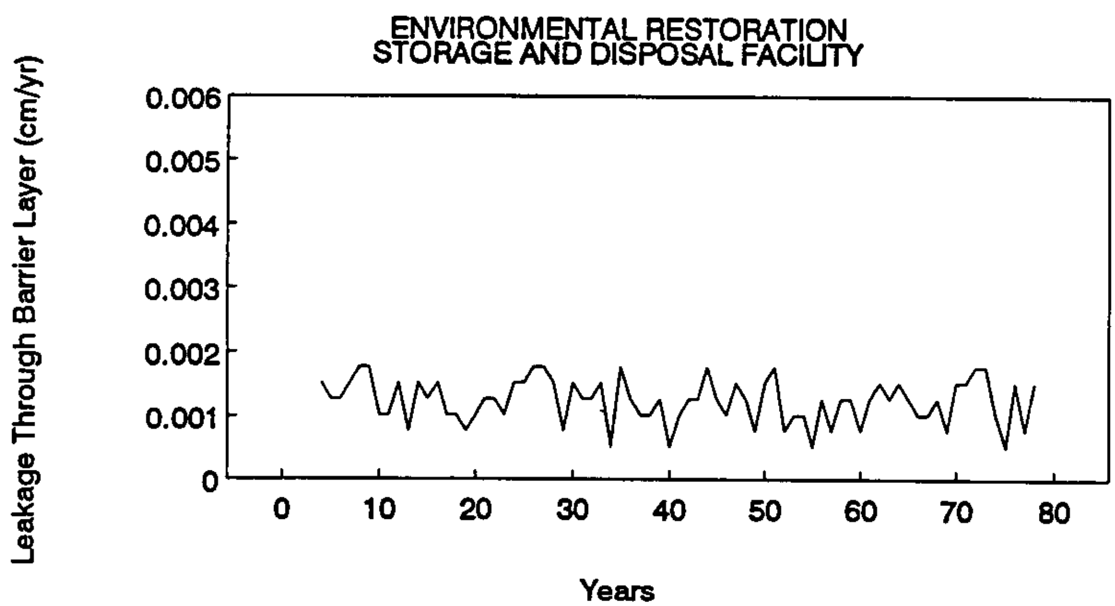
Minimum Precipitation (cm/yr): 9.7282
Maximum Precipitation (cm/yr): 22.4028
Average Precipitation (cm/yr): 15.7923



Minimum Drainage (cm/yr): 0.1402
Maximum Drainage (cm/yr): 3.7539
Average Drainage (cm/yr): 0.5684



Avg. Lower Waste Layer Moisture Content (cm^3/cm^3): **0.2544**

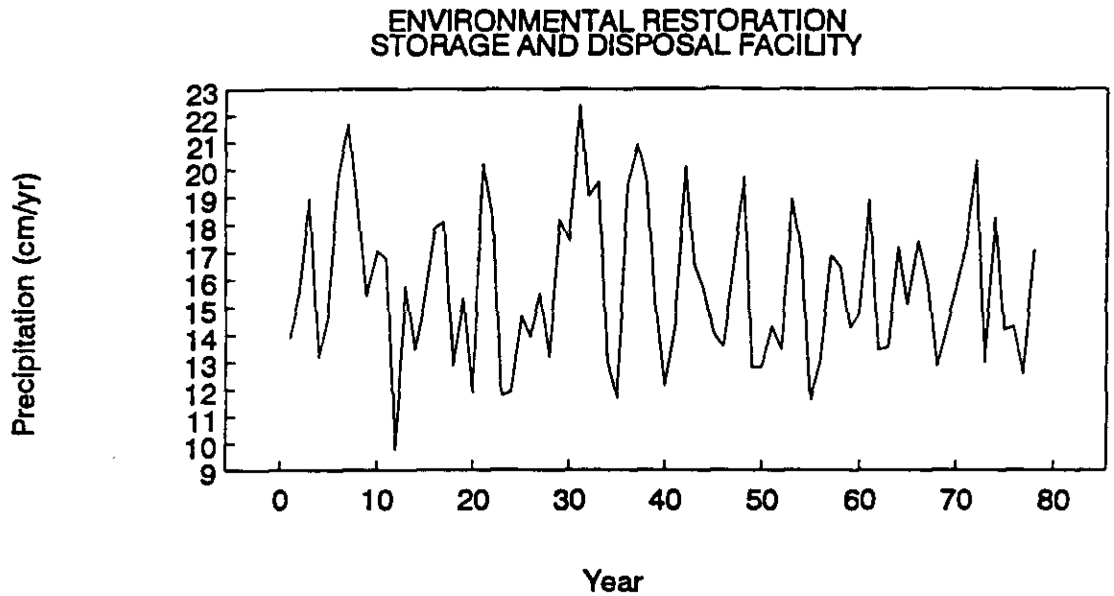


Avg. Barrier Layer Leakage (cm/yr): **0.0012395**

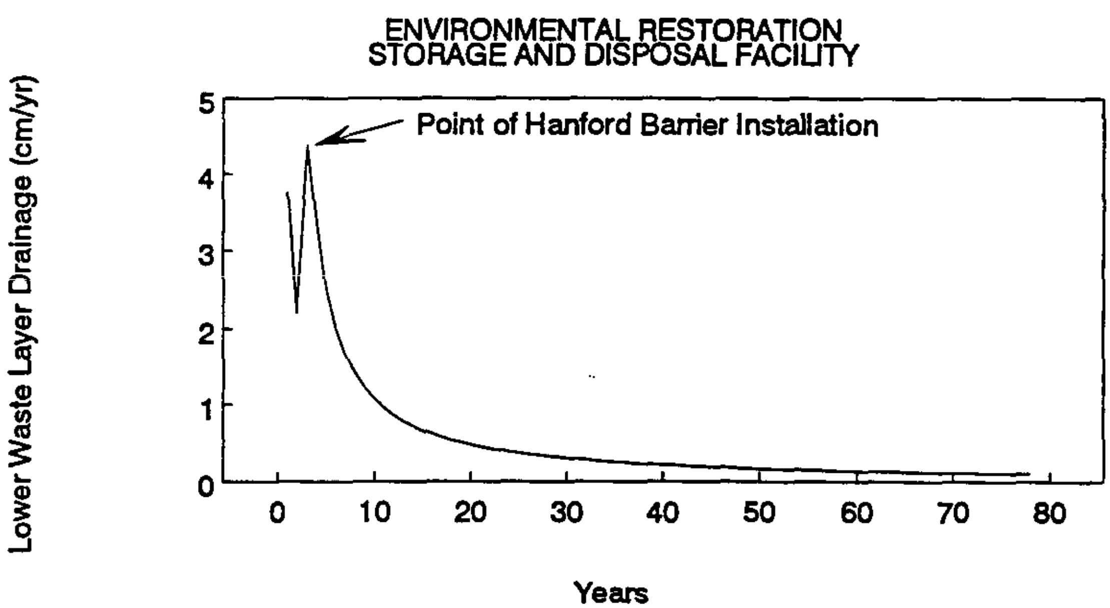
RUN B

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	BOTTOM LAYER DRAINAGE (in/yr)	BOTTOM LAYER DRAINAGE (cm/yr)	LOWER WASTE SOIL MOISTURE (cm^3/cm^3)	BARRIER LAYER DRAINAGE (in/yr)	BARRIER LAYER DRAINAGE (cm/yr)
0					0.2858		
1	5.47	13.8938	1.4830	3.7668	0.275		
2	6.12	15.5448	0.8682	2.2052	0.2702		
3	7.46	18.9484	1.7248	4.3810		0.0005	0.00127
4	5.18	13.1572	1.3162	3.3431		0.0003	0.00076
5	5.80	14.7320	0.9869	2.5067		0.0006	0.00152
6	7.78	19.7612	0.7860	1.9964		0.0005	0.00127
7	8.54	21.6916	0.6506	1.6525		0.0005	0.00127
8	7.32	18.5928	0.5549	1.4094		0.0005	0.00127
9	6.07	15.4178	0.4805	1.2205		0.0007	0.00178
10	6.71	17.0434	0.4239	1.0767		0.0007	0.00178
11	6.60	16.7640	0.3788	0.9622		0.0005	0.00127
12	3.83	9.7282	0.3430	0.8712		0.0003	0.00076
13	6.21	15.7734	0.3115	0.7912		0.0006	0.00152
14	5.29	13.4366	0.2857	0.7257		0.0004	0.00102
15	5.95	15.1130	0.2638	0.6701		0.0004	0.00102
16	7.03	17.8562	0.2455	0.6236		0.0004	0.00102
17	7.13	18.1102	0.2283	0.5799		0.0005	0.00127
18	5.06	12.8524	0.2137	0.5428		0.0004	0.00102
19	6.05	15.3670	0.2009	0.5103		0.0004	0.00102
20	4.67	11.8618	0.1899	0.4823	0.2423	0.0004	0.00102
21	7.96	20.2184	0.1788	0.4542		0.0006	0.00152
22	7.21	18.3134	0.1695	0.4305		0.0005	0.00127
23	4.64	11.7856	0.1612	0.4094		0.0004	0.00102
24	4.69	11.9126	0.1540	0.3912		0.0006	0.00152
25	5.78	14.6812	0.1466	0.3724		0.0006	0.00152
26	5.48	13.9192	0.1402	0.3561		0.0006	0.00152
27	6.11	15.5194	0.1343	0.3411		0.0007	0.00178
28	5.18	13.1572	0.1293	0.3284		0.0006	0.00152
29	7.16	18.1864	0.1239	0.3147		0.0003	0.00076
30	6.85	17.3990	0.1192	0.3028		0.0006	0.00152
31	8.82	22.4028	0.1149	0.2918		0.0005	0.00127
32	7.49	19.0246	0.1112	0.2824		0.0005	0.00127
33	7.70	19.5580	0.1071	0.2720		0.0006	0.00152
34	5.13	13.0302	0.1035	0.2629		0.0002	0.00051
35	4.59	11.6586	0.1002	0.2545		0.0007	0.00178
36	7.66	19.4564	0.0973	0.2471		0.0005	0.00127
37	8.24	20.9296	0.0941	0.2390		0.0004	0.00102
38	7.72	19.6088	0.0913	0.2319		0.0004	0.00102
39	5.93	15.0622	0.0887	0.2253		0.0005	0.00127
40	4.77	12.1158	0.0865	0.2197	0.2289	0.0002	0.00051
41	5.63	14.3002	0.0841	0.2136		0.0004	0.00102
42	7.92	20.1168	0.0818	0.2078		0.0005	0.00127
43	6.52	16.5608	0.0797	0.2024		0.0005	0.00127
44	6.17	15.6718	0.0779	0.1979		0.0007	0.00178
45	5.53	14.0462	0.0757	0.1923		0.0005	0.00127
46	5.34	13.5636	0.0739	0.1877		0.0004	0.00102
47	6.52	16.5608	0.0721	0.1831		0.0006	0.00152
48	7.77	19.7358	0.0706	0.1793		0.0006	0.00152
49	5.04	12.8016	0.0688	0.1748		0.0003	0.00076

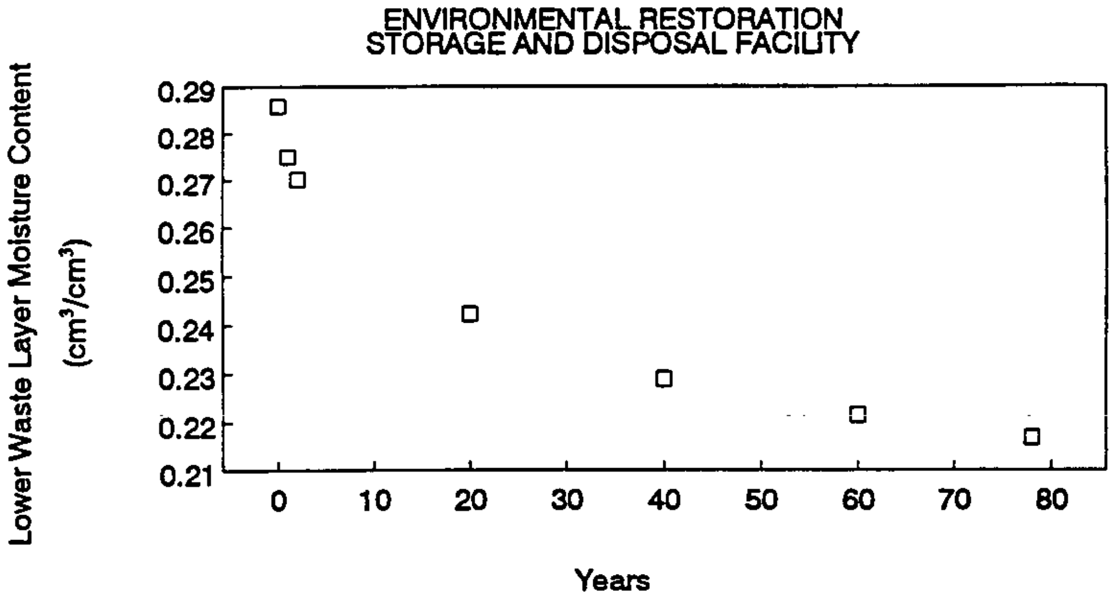
50	5.05	12.8270	0.0673	0.1709		0.0006	0.00152
51	5.64	14.3256	0.0658	0.1671		0.0007	0.00178
52	5.30	13.4620	0.0645	0.1638		0.0003	0.00076
53	7.46	18.9484	0.0630	0.1600		0.0004	0.00102
54	6.67	16.9418	0.0617	0.1567		0.0004	0.00102
55	4.56	11.5824	0.0605	0.1537		0.0002	0.00051
56	5.11	12.9794	0.0594	0.1509		0.0005	0.00127
57	6.64	16.8656	0.0581	0.1476		0.0003	0.00076
58	6.50	16.5100	0.0570	0.1448		0.0005	0.00127
59	5.61	14.2494	0.0559	0.1420		0.0005	0.00127
60	5.84	14.8336	0.0550	0.1397	0.2215	0.0003	0.00076
61	7.44	18.8976	0.0539	0.1369		0.0005	0.00127
62	5.29	13.4366	0.0529	0.1344		0.0006	0.00152
63	5.33	13.5382	0.0520	0.1321		0.0005	0.00127
64	6.77	17.1958	0.0512	0.1300		0.0006	0.00152
65	5.94	15.0876	0.0502	0.1275		0.0005	0.00127
66	6.86	17.4244	0.0494	0.1255		0.0004	0.00102
67	6.26	15.9004	0.0485	0.1232		0.0004	0.00102
68	5.05	12.8270	0.0479	0.1217		0.0005	0.00127
69	5.64	14.3256	0.0470	0.1194		0.0003	0.00076
70	6.19	15.7226	0.0462	0.1173		0.0006	0.00152
71	6.81	17.2974	0.0455	0.1156		0.0006	0.00152
72	8.01	20.3454	0.0449	0.1140		0.0007	0.00178
73	5.10	12.9540	0.0441	0.1120		0.0007	0.00178
74	7.19	18.2626	0.0435	0.1105		0.0004	0.00102
75	5.58	14.1732	0.0428	0.1087		0.0002	0.00051
76	5.64	14.3256	0.0423	0.1074		0.0006	0.00152
77	4.93	12.5222	0.0416	0.1057		0.0003	0.00076
78	6.73	17.0942	0.0410	0.1041	0.2169	0.0006	0.00152
Average:	6.22	15.7923	0.2126	0.5401	0.2487	0.0005	0.00123
Minimum:	3.83	9.7282	0.0410	0.1041	0.2169	0.0002	0.00051
Maximum:	8.82	22.4028	1.7248	4.3810	0.2858	0.0007	0.00178



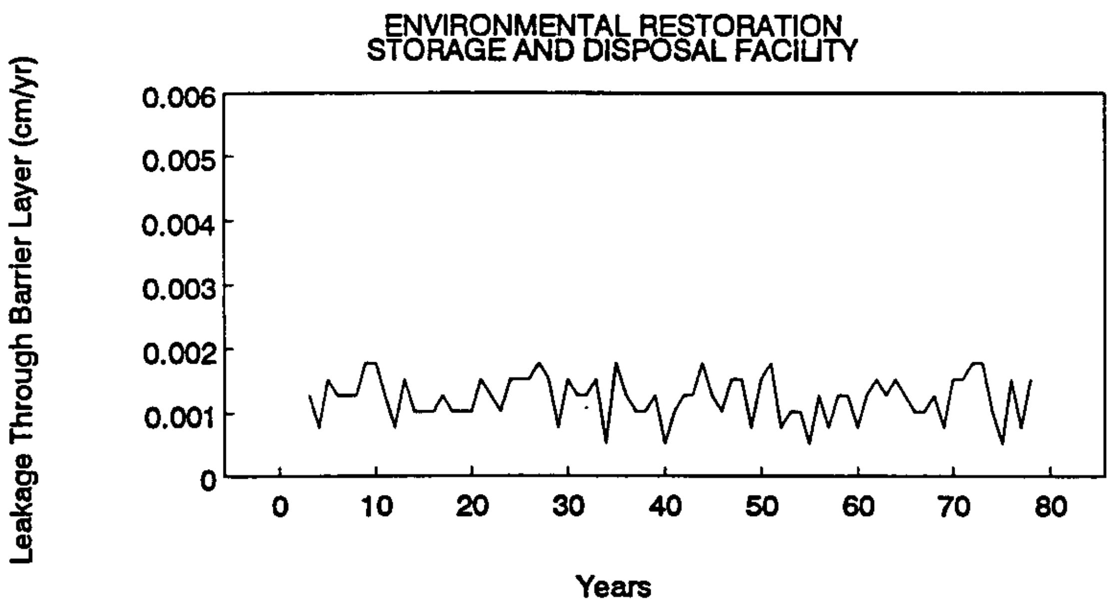
Minimum Precipitation (cm/yr): 9.7282
Maximum Precipitation (cm/yr): 22.4028
Average Precipitation (cm/yr): 15.7923



Minimum Drainage (cm/yr): 0.1041
Maximum Drainage (cm/yr): 4.3810
Average Drainage (cm/yr): 0.5401



Avg. Lower Waste Layer Moisture Content (cm^3/cm^3): 0.2486571

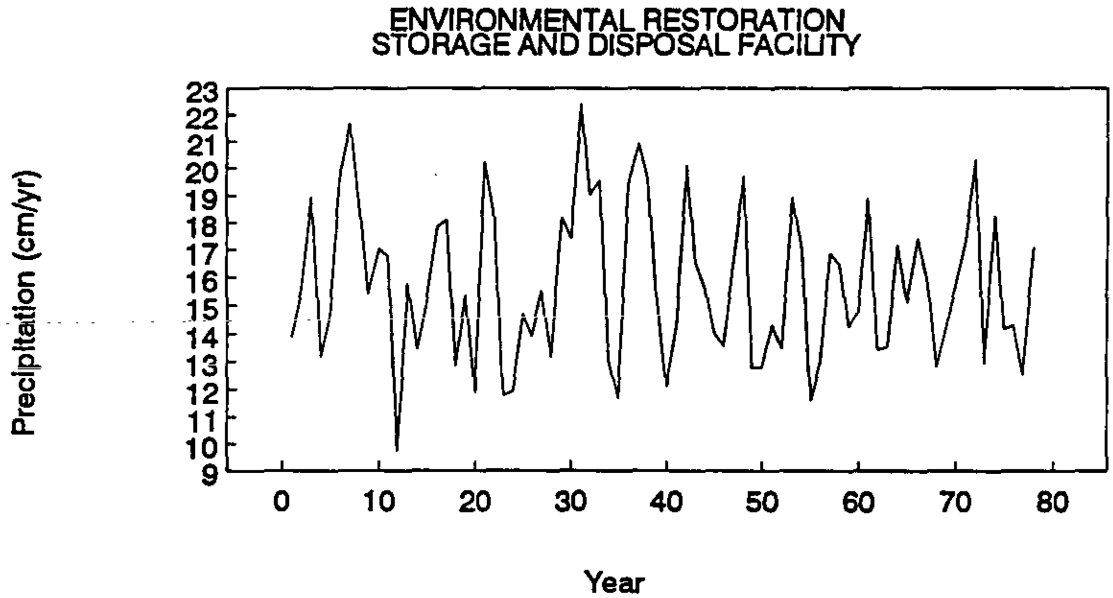


Avg. Barrier Layer Leakage (cm/yr): 0.0012298

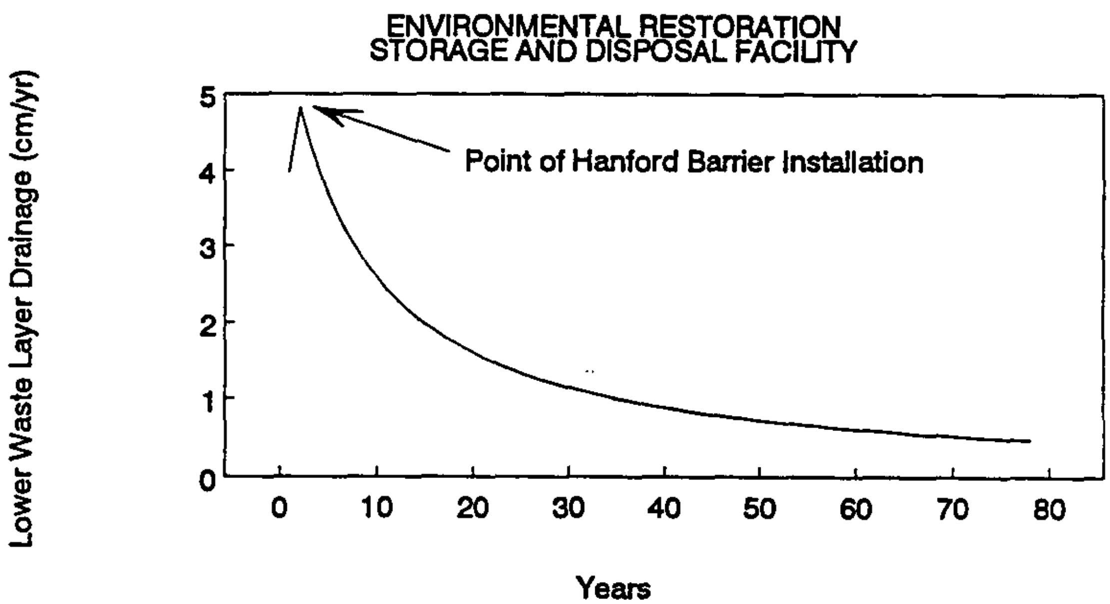
RUN C

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	BOTTOM LAYER DRAINAGE (in/yr)	BOTTOM LAYER DRAINAGE (cm/yr)	LOWER WASTE SOIL MOISTURE (cm^3/cm^3)	BARRIER LAYER DRAINAGE (in/yr)	BARRIER LAYER DRAINAGE (cm/yr)
0					0.2858		
1	5.47	13.8938	1.5662	3.9781	0.2832		
2	6.12	15.5448	1.8981	4.8212		0.0005	0.00127
3	7.46	18.9484	1.7288	4.3912		0.0005	0.00127
4	5.18	13.1572	1.5817	4.0175		0.0005	0.00127
5	5.80	14.7320	1.4483	3.6787		0.0005	0.00127
6	7.78	19.7612	1.3378	3.3980		0.0005	0.00127
7	8.54	21.6916	1.2420	3.1547		0.0006	0.00152
8	7.32	18.5928	1.1615	2.9502		0.0005	0.00127
9	6.07	15.4178	1.0847	2.7551		0.0005	0.00127
10	6.71	17.0434	1.0196	2.5898		0.0005	0.00127
11	6.60	16.7640	0.9615	2.4422		0.0004	0.00102
12	3.83	9.7282	0.9118	2.3160		0.0003	0.00076
13	6.21	15.7734	0.8623	2.1902		0.0006	0.00152
14	5.29	13.4366	0.8197	2.0820		0.0005	0.00127
15	5.95	15.1130	0.7809	1.9835		0.0003	0.00076
16	7.03	17.8562	0.7475	1.8987		0.0004	0.00102
17	7.13	18.1102	0.7130	1.8110		0.0005	0.00127
18	5.06	12.8524	0.6831	1.7351		0.0004	0.00102
19	6.05	15.3670	0.6555	1.6650		0.0004	0.00102
20	4.67	11.8618	0.6317	1.6045	0.2655	0.0004	0.00102
21	7.96	20.2184	0.6053	1.5375		0.0006	0.00152
22	7.21	18.3134	0.5833	1.4816		0.0005	0.00127
23	4.64	11.7856	0.5628	1.4295		0.0004	0.00102
24	4.69	11.9126	0.5450	1.3843		0.0006	0.00152
25	5.78	14.6812	0.5256	1.3350		0.0006	0.00152
26	5.48	13.9192	0.5087	1.2921		0.0006	0.00152
27	6.11	15.5194	0.4928	1.2517		0.0007	0.00178
28	5.18	13.1572	0.4791	1.2169		0.0006	0.00152
29	7.16	18.1864	0.4637	1.1778		0.0003	0.00076
30	6.85	17.3990	0.4503	1.1438		0.0006	0.00152
31	8.82	22.4028	0.4377	1.1118		0.0005	0.00127
32	7.49	19.0246	0.4269	1.0843		0.0005	0.00127
33	7.70	19.5580	0.4144	1.0526		0.0006	0.00152
34	5.13	13.0302	0.4036	1.0251		0.0002	0.00051
35	4.59	11.6586	0.3933	0.9990		0.0007	0.00178
36	7.66	19.4564	0.3845	0.9766		0.0005	0.00127
37	8.24	20.9296	0.3741	0.9502		0.0004	0.00102
38	7.72	19.6088	0.3652	0.9276		0.0004	0.00102
39	5.93	15.0622	0.3567	0.9060		0.0005	0.00127
40	4.77	12.1158	0.3495	0.8877	0.2540	0.0002	0.00051
41	5.63	14.3002	0.3404	0.8646		0.0004	0.00102
42	7.92	20.1168	0.3330	0.8458		0.0005	0.00127
43	6.52	16.5608	0.3258	0.8275		0.0005	0.00127
44	6.17	15.6718	0.3198	0.8123		0.0007	0.00178
45	5.53	14.0462	0.3123	0.7932		0.0005	0.00127
46	5.34	13.5636	0.3060	0.7772		0.0004	0.00102
47	6.52	16.5608	0.2999	0.7617		0.0006	0.00152
48	7.77	19.7358	0.2948	0.7488		0.0006	0.00152
49	5.04	12.8016	0.2884	0.7325		0.0003	0.00076

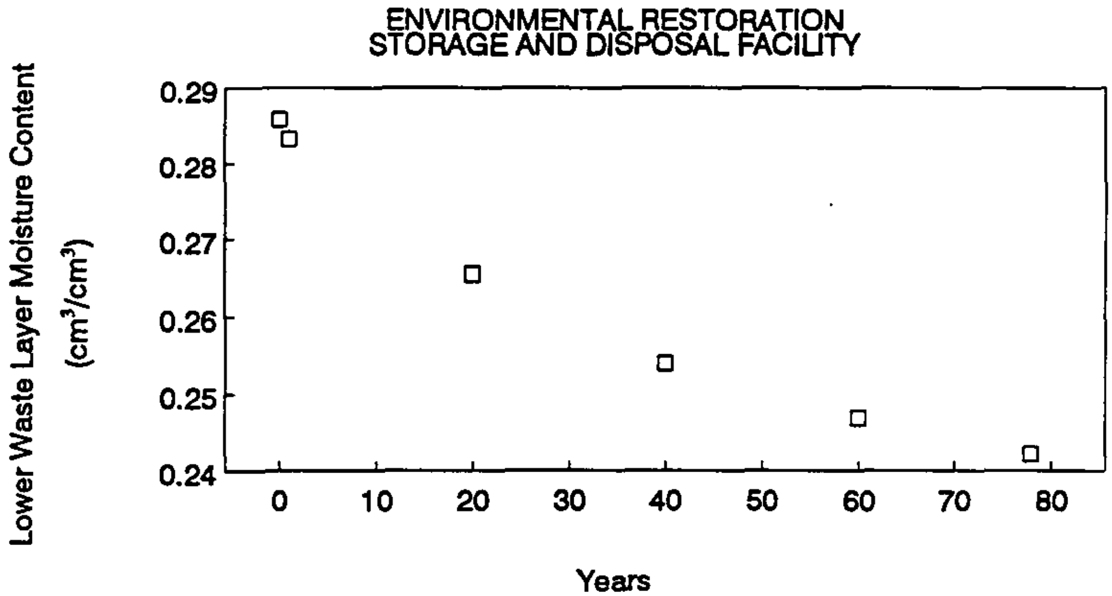
50	5.05	12.8270	0.2829	0.7186		0.0006	0.00152
51	5.64	14.3256	0.2777	0.7054		0.0007	0.00178
52	5.30	13.4620	0.2733	0.6942		0.0003	0.00076
53	7.46	18.9484	0.2677	0.6800		0.0004	0.00102
54	6.67	16.9418	0.2629	0.6678		0.0004	0.00102
55	4.56	11.5824	0.2584	0.6563		0.0002	0.00051
56	5.11	12.9794	0.2546	0.6467		0.0005	0.00127
57	6.64	16.8656	0.2496	0.6340		0.0003	0.00076
58	6.50	16.5100	0.2455	0.6236		0.0005	0.00127
59	5.61	14.2494	0.2415	0.6134		0.0005	0.00127
60	5.84	14.8336	0.2382	0.6050	0.2469	0.0003	0.00076
61	7.44	18.8976	0.2343	0.5951		0.0005	0.00127
62	5.29	13.4366	0.2306	0.5857		0.0006	0.00152
63	5.33	13.5382	0.2271	0.5768		0.0005	0.00127
64	6.77	17.1958	0.2242	0.5695		0.0006	0.00152
65	5.94	15.0876	0.2202	0.5593		0.0005	0.00127
66	6.86	17.4244	0.2169	0.5509		0.0004	0.00102
67	6.26	15.9004	0.2138	0.5431		0.0004	0.00102
68	5.05	12.8270	0.2133	0.5418		0.0005	0.00127
69	5.64	14.3256	0.2077	0.5276		0.0003	0.00076
70	6.19	15.7226	0.2047	0.5199		0.0006	0.00152
71	6.81	17.2974	0.2019	0.5128		0.0006	0.00152
72	8.01	20.3454	0.1997	0.5072		0.0007	0.00178
73	5.10	12.9540	0.1964	0.4989		0.0007	0.00178
74	7.19	18.2626	0.1938	0.4923		0.0004	0.00102
75	5.58	14.1732	0.1912	0.4856		0.0002	0.00051
76	5.64	14.3256	0.1892	0.4806		0.0006	0.00152
77	4.93	12.5222	0.1863	0.4732		0.0003	0.00076
78	6.73	17.0942	0.1839	0.4671	0.2422	0.0006	0.00152
Average:	6.22	15.7923	0.5175	1.3145	0.2584	0.0005	0.00122
Minimum:	3.83	9.7282	0.1839	0.4671	0.2422	0.0002	0.00051
Maximum:	8.82	22.4028	1.8981	4.8212	0.2832	0.0007	0.00178



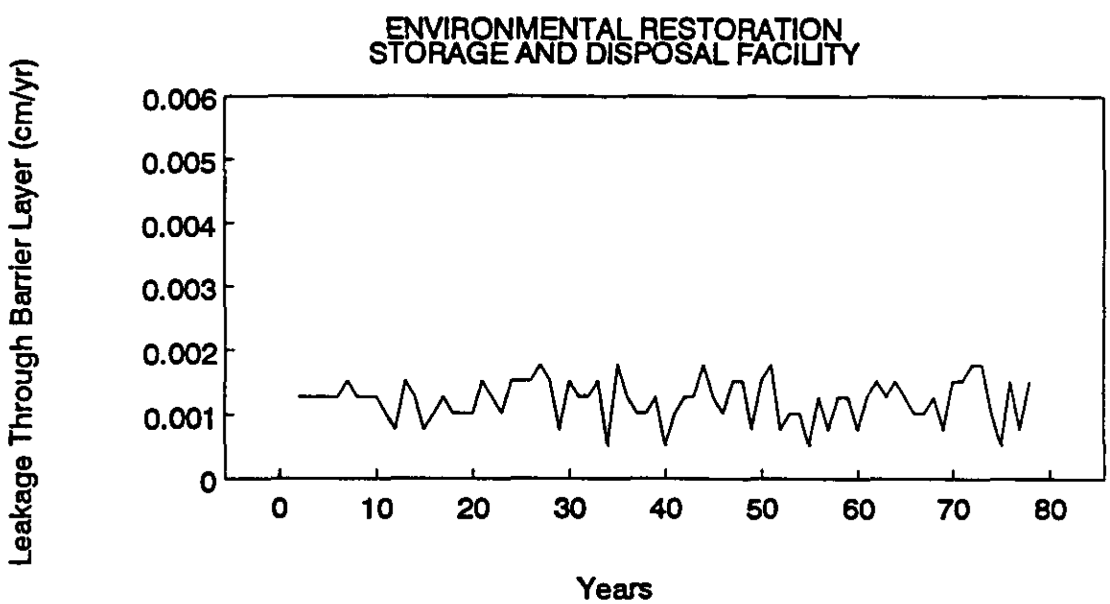
Minimum Precipitation (cm/yr): 9.73
Maximum Precipitation (cm/yr): 22.40
Average Precipitation (cm/yr): 15.79



Minimum Drainage (cm/yr): 0.4671
Maximum Drainage (cm/yr): 4.8212
Average Drainage (cm/yr): 1.3145



Avg. Lower Waste Layer Moisture Content (cm^3/cm^3): 0.2629

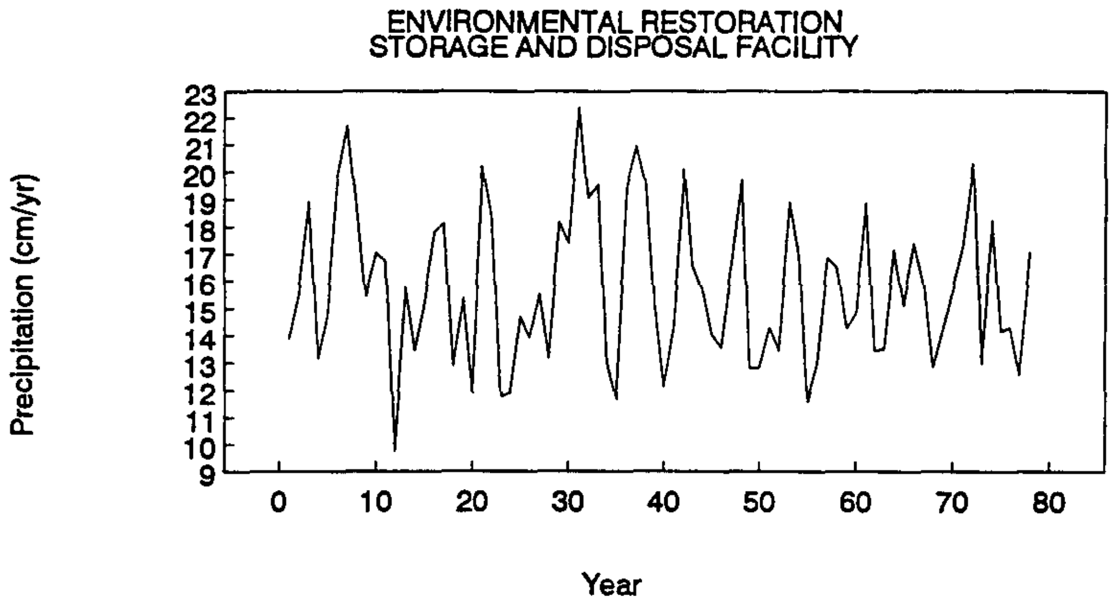


Avg. Barrier Layer Leakage (cm/yr): 0.00122

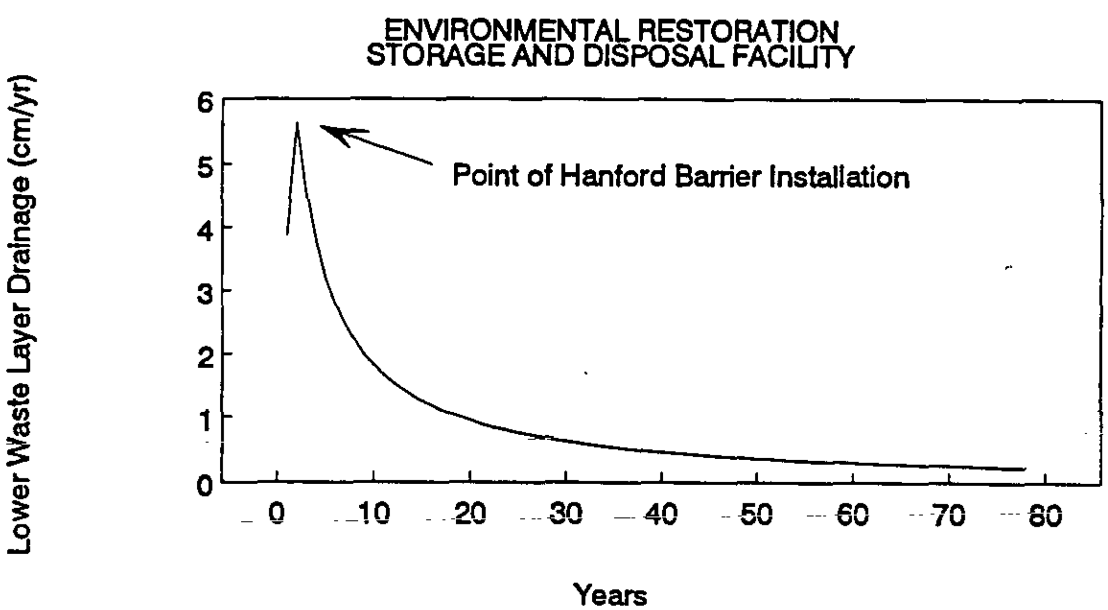
RUN D

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	BOTTOM LAYER DRAINAGE (in/yr)	BOTTOM LAYER DRAINAGE (cm/yr)	LOWER WASTE SOIL MOISTURE (cm^3/cm^3)	BARRIER LAYER DRAINAGE (in/yr)	BARRIER LAYER DRAINAGE (cm/yr)
0					0.2858		
1	5.47	13.8938	1.5245	3.8722	0.2805		
2	6.12	15.5448	2.2202	5.6393		0.0005	0.00127
3	7.46	18.9484	1.7948	4.5588		0.0004	0.00102
4	5.18	13.1572	1.4922	3.7902		0.0005	0.00127
5	5.80	14.7320	1.2666	3.2172		0.0005	0.00127
6	7.78	19.7612	1.1002	2.7945		0.0005	0.00127
7	8.54	21.6916	0.9708	2.4658		0.0006	0.00152
8	7.32	18.5928	0.8698	2.2093		0.0005	0.00127
9	6.07	15.4178	0.7831	1.9891		0.0005	0.00127
10	6.71	17.0434	0.7132	1.8115		0.0005	0.00127
11	6.60	16.7640	0.6543	1.6619		0.0004	0.00102
12	3.83	9.7282	0.6056	1.5382		0.0003	0.00076
13	6.21	15.7734	0.5605	1.4237		0.0006	0.00152
14	5.29	13.4366	0.5227	1.3277		0.0005	0.00127
15	5.95	15.1130	0.4894	1.2431		0.0003	0.00076
16	7.03	17.8562	0.4612	1.1714		0.0004	0.00102
17	7.13	18.1102	0.4337	1.1016		0.0005	0.00127
18	5.06	12.8524	0.4101	1.0417		0.0004	0.00102
19	6.05	15.3670	0.3889	0.9878		0.0004	0.00102
20	4.67	11.8618	0.3707	0.9416	0.2549	0.0004	0.00102
21	7.96	20.2184	0.3523	0.8948		0.0006	0.00152
22	7.21	18.3134	0.3363	0.8542		0.0005	0.00127
23	4.64	11.7856	0.3216	0.8169		0.0004	0.00102
24	4.69	11.9126	0.3090	0.7849		0.0006	0.00152
25	5.78	14.6812	0.2957	0.7511		0.0006	0.00152
26	5.48	13.9192	0.2842	0.7219		0.0006	0.00152
27	6.11	15.5194	0.2735	0.6947		0.0007	0.00178
28	5.18	13.1572	0.2642	0.6711		0.0006	0.00152
29	7.16	18.1864	0.2542	0.6457		0.0003	0.00076
30	6.85	17.3990	0.2455	0.6236		0.0006	0.00152
31	8.82	22.4028	0.2374	0.6030		0.0005	0.00127
32	7.49	19.0246	0.2304	0.5852		0.0005	0.00127
33	7.70	19.5580	0.2226	0.5654		0.0006	0.00152
34	5.13	13.0302	0.2158	0.5481		0.0002	0.00051
35	4.59	11.6586	0.2094	0.5319		0.0007	0.00178
36	7.66	19.4564	0.2039	0.5179		0.0005	0.00127
37	8.24	20.9296	0.1977	0.5022		0.0004	0.00102
38	7.72	19.6088	0.1922	0.4882		0.0004	0.00102
39	5.93	15.0622	0.1871	0.4752		0.0005	0.00127
40	4.77	12.1158	0.1827	0.4641	0.2419	0.0002	0.00051
41	5.63	14.3002	0.1774	0.4506		0.0004	0.00102
42	7.92	20.1168	0.1730	0.4394		0.0005	0.00127
43	6.52	16.5608	0.1688	0.4288		0.0005	0.00127
44	6.17	15.6718	0.1652	0.4196		0.0007	0.00178
45	5.53	14.0462	0.1609	0.4087		0.0005	0.00127
46	5.34	13.5636	0.1572	0.3993		0.0004	0.00102
47	6.52	16.5608	0.1537	0.3904		0.0006	0.00152
48	7.77	19.7358	0.1508	0.3830		0.0006	0.00152
49	5.04	12.8016	0.1471	0.3736		0.0003	0.00076

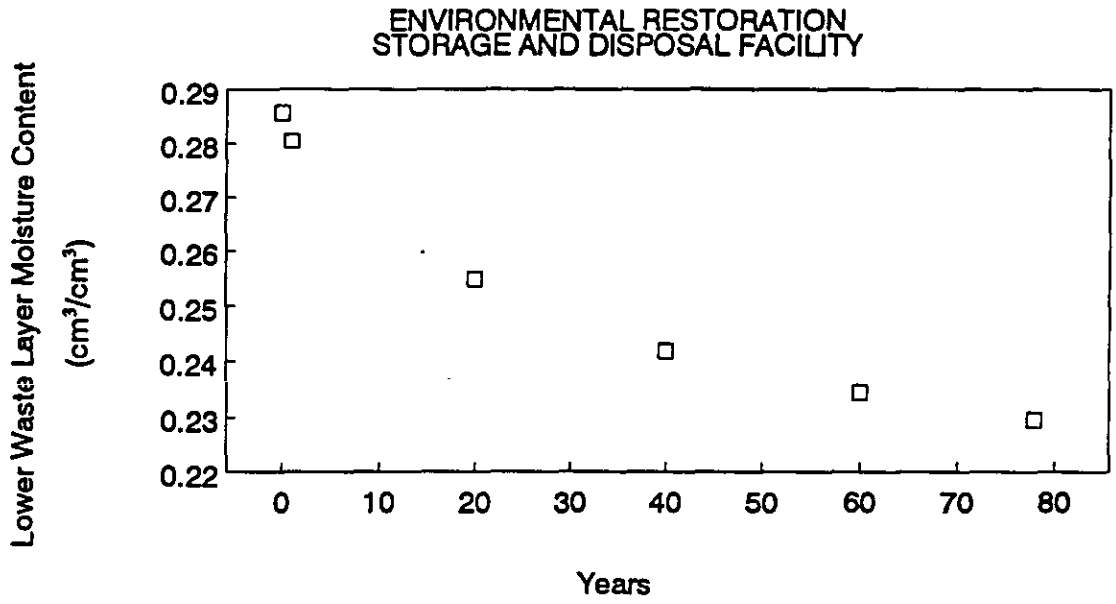
50	5.05	12.8270	0.1440	0.3658		0.0006	0.00152
51	5.64	14.3256	0.1410	0.3581		0.0007	0.00178
52	5.30	13.4620	0.1386	0.3520		0.0003	0.00076
53	7.46	18.9484	0.1354	0.3439		0.0004	0.00102
54	6.67	16.9418	0.1328	0.3373		0.0004	0.00102
55	4.56	11.5824	0.1302	0.3307		0.0002	0.00051
56	5.11	12.9794	0.1281	0.3254		0.0005	0.00127
57	6.64	16.8656	0.1254	0.3185		0.0003	0.00076
58	6.50	16.5100	0.1231	0.3127		0.0005	0.00127
59	5.61	14.2494	0.1209	0.3071		0.0005	0.00127
60	5.84	14.8336	0.1191	0.3025	0.2344	0.0003	0.00076
61	7.44	18.8976	0.1166	0.2962		0.0005	0.00127
62	5.29	13.4366	0.1146	0.2911		0.0006	0.00152
63	5.33	13.5382	0.1127	0.2863		0.0005	0.00127
64	6.77	17.1958	0.1111	0.2822		0.0006	0.00152
65	5.94	15.0876	0.1090	0.2769		0.0005	0.00127
66	6.86	17.4244	0.1072	0.2723		0.0004	0.00102
67	6.26	15.9004	0.1055	0.2680		0.0005	0.00127
68	5.05	12.8270	0.1041	0.2644		0.0005	0.00127
69	5.64	14.3256	0.1022	0.2596		0.0003	0.00076
70	6.19	15.7226	0.1007	0.2558		0.0006	0.00152
71	6.81	17.2974	0.0992	0.2520		0.0006	0.00152
72	8.01	20.3454	0.0980	0.2489		0.0007	0.00178
73	5.10	12.9540	0.0963	0.2446		0.0007	0.00178
74	7.19	18.2626	0.0949	0.2410		0.0004	0.00102
75	5.58	14.1732	0.0935	0.2375		0.0002	0.00051
76	5.64	14.3256	0.0925	0.2350		0.0006	0.00152
77	4.93	12.5222	0.0909	0.2309		0.0003	0.00076
78	6.73	17.0942	0.0897	0.2278	0.2296	0.0006	0.00152
Average:	6.22	15.7923	0.3510	0.8916	0.2483	0.0005	0.00122
Minimum:	3.83	9.7282	0.0897	0.2278	0.2296	0.0002	0.00051
Maximum:	8.82	22.4028	2.2202	5.6393	0.2805	0.0007	0.00178



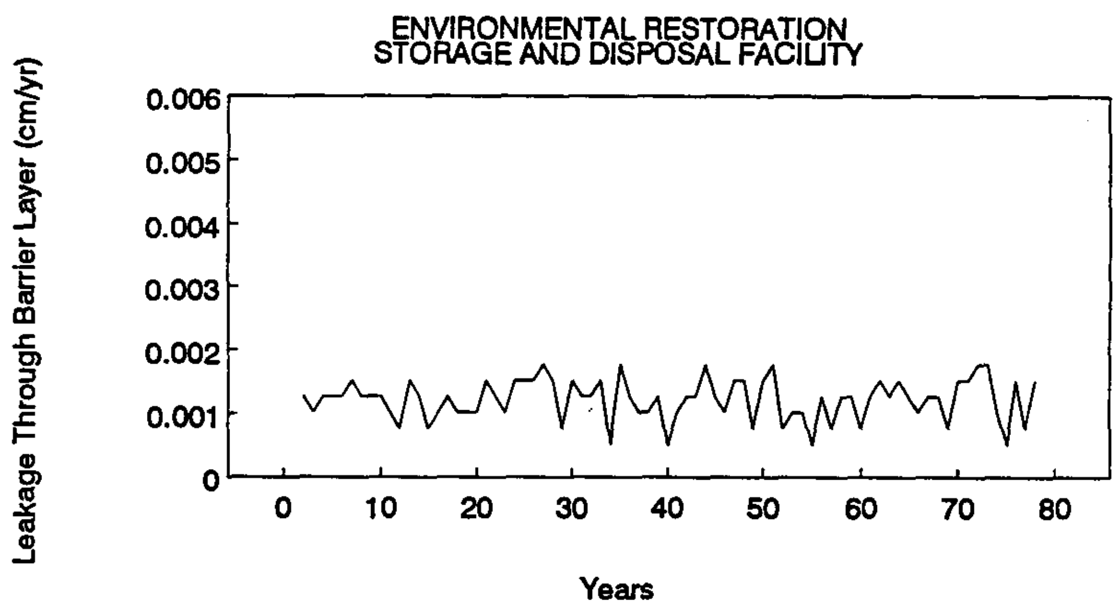
Average Precipitation (cm/yr): 15.7923
Minimum Precipitation (cm/yr): 9.7282
Maximum Precipitation (cm/yr): 22.4028



Average Drainage (cm/yr): 0.8916
Minimum Drainage (cm/yr): 0.2278
Maximum Drainage (cm/yr): 5.6393



Avg. Lower Waste Layer Moisture Content (cm^3/cm^3): 0.2545

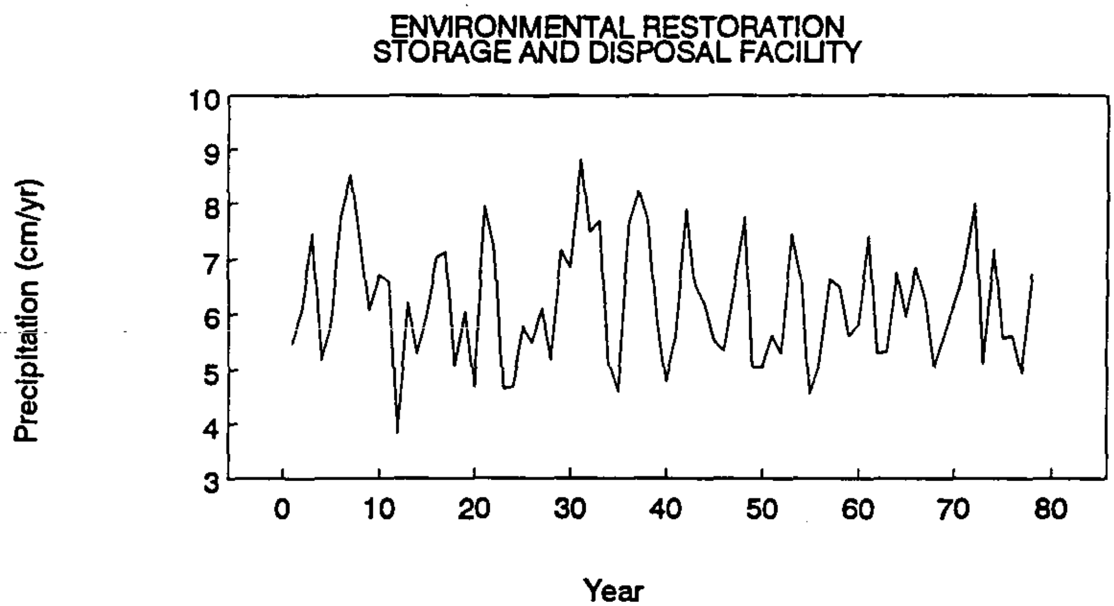


Avg. Barrier Layer Leakage (cm/yr 0.00122

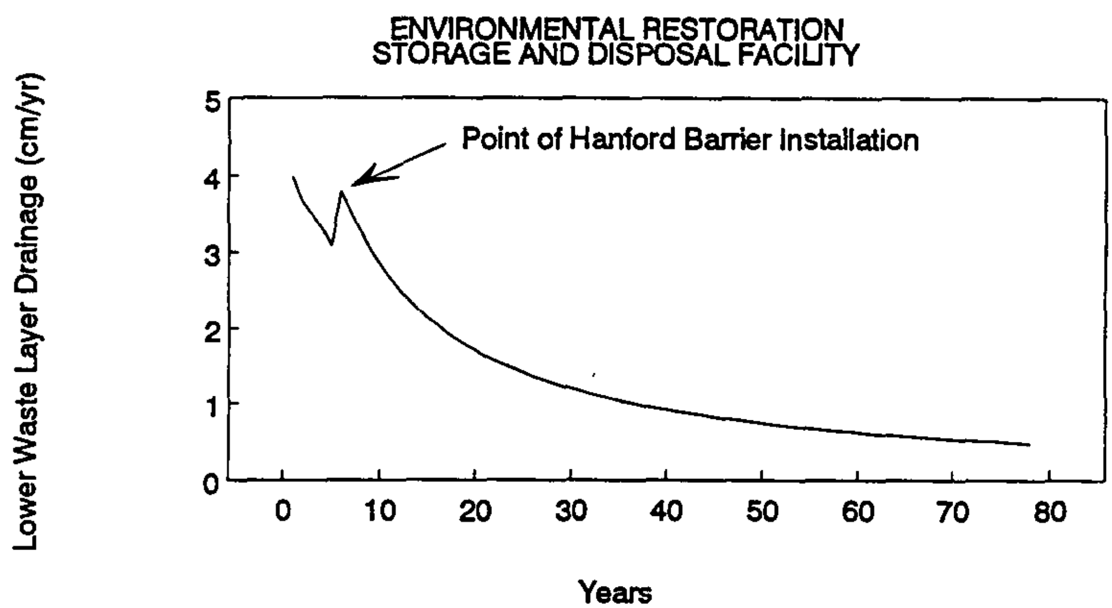
RUN E

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	BOTTOM LAYER DRAINAGE (in/yr)	BOTTOM LAYER DRAINAGE (cm/yr)	LOWER WASTE SOIL MOISTURE (cm^3/cm^3)	BARRIER LAYER DRAINAGE (in/yr)	BARRIER LAYER DRAINAGE (cm/yr)
0					0.2858		
1	5.47	13.8938	1.5662	3.9781			
2	6.12	15.5448	1.4389	3.6548			
3	7.46	18.9484	1.3760	3.4950			
4	5.18	13.1572	1.2990	3.2995			
5	5.80	14.7320	1.2136	3.0825	0.2776		
6	7.78	19.7612	1.4932	3.7927		0.0005	0.00127
7	8.54	21.6916	1.3867	3.5222		0.0005	0.00127
8	7.32	18.5928	1.2899	3.2763		0.0005	0.00127
9	6.07	15.4178	1.1980	3.0429		0.0007	0.00178
10	6.71	17.0434	1.1203	2.8456		0.0004	0.00102
11	6.60	16.7640	1.0514	2.6706		0.0004	0.00102
12	3.83	9.7282	0.9928	2.5217		0.0003	0.00076
13	6.21	15.7734	0.9351	2.3752		0.0005	0.00127
14	5.29	13.4366	0.8857	2.2497		0.0005	0.00127
15	5.95	15.1130	0.8411	2.1364		0.0004	0.00102
16	7.03	17.8562	0.8026	2.0386		0.0005	0.00127
17	7.13	18.1102	0.7633	1.9388		0.0006	0.00152
18	5.06	12.8524	0.7294	1.8527		0.0004	0.00102
19	6.05	15.3670	0.6983	1.7737		0.0004	0.00102
20	4.67	11.8618	0.6714	1.7054	0.2667	0.0004	0.00102
21	7.96	20.2184	0.6415	1.6294		0.0005	0.00127
22	7.21	18.3134	0.6170	1.5672		0.0005	0.00127
23	4.64	11.7856	0.5942	1.5093		0.0004	0.00102
24	4.69	11.9126	0.5745	1.4592		0.0006	0.00152
25	5.78	14.6812	0.5531	1.4049		0.0006	0.00152
26	5.48	13.9192	0.5345	1.3576		0.0006	0.00152
27	6.11	15.5194	0.5171	1.3134		0.0007	0.00178
28	5.18	13.1572	0.5021	1.2753		0.0006	0.00152
29	7.16	18.1864	0.4853	1.2327		0.0003	0.00076
30	6.85	17.3990	0.4708	1.1958		0.0006	0.00152
31	8.82	22.4028	0.4570	1.1608		0.0005	0.00127
32	7.49	19.0246	0.4453	1.1311		0.0005	0.00127
33	7.70	19.5580	0.4317	1.0965		0.0006	0.00152
34	5.13	13.0302	0.4201	1.0671		0.0002	0.00051
35	4.59	11.6586	0.4090	1.0389		0.0007	0.00178
36	7.66	19.4564	0.3995	1.0147		0.0005	0.00127
37	8.24	20.9296	0.3884	0.9865		0.0004	0.00102
38	7.72	19.6088	0.3789	0.9624		0.0004	0.00102
39	5.93	15.0622	0.3697	0.9390		0.0005	0.00127
40	4.77	12.1158	0.3620	0.9195	0.2547	0.0002	0.00051
41	5.63	14.3002	0.3529	0.8964		0.0004	0.00102
42	7.92	20.1168	0.3449	0.8760		0.0005	0.00127
43	6.52	16.5608	0.3373	0.8567		0.0005	0.00127
44	6.17	15.6718	0.3309	0.8405		0.0007	0.00178
45	5.53	14.0462	0.3229	0.8202		0.0005	0.00127
46	5.34	13.5636	0.3162	0.8031		0.0004	0.00102
47	6.52	16.5608	0.3097	0.7866		0.0006	0.00152
48	7.77	19.7358	0.3043	0.7729		0.0006	0.00152
49	5.04	12.8016	0.2974	0.7554		0.0003	0.00076

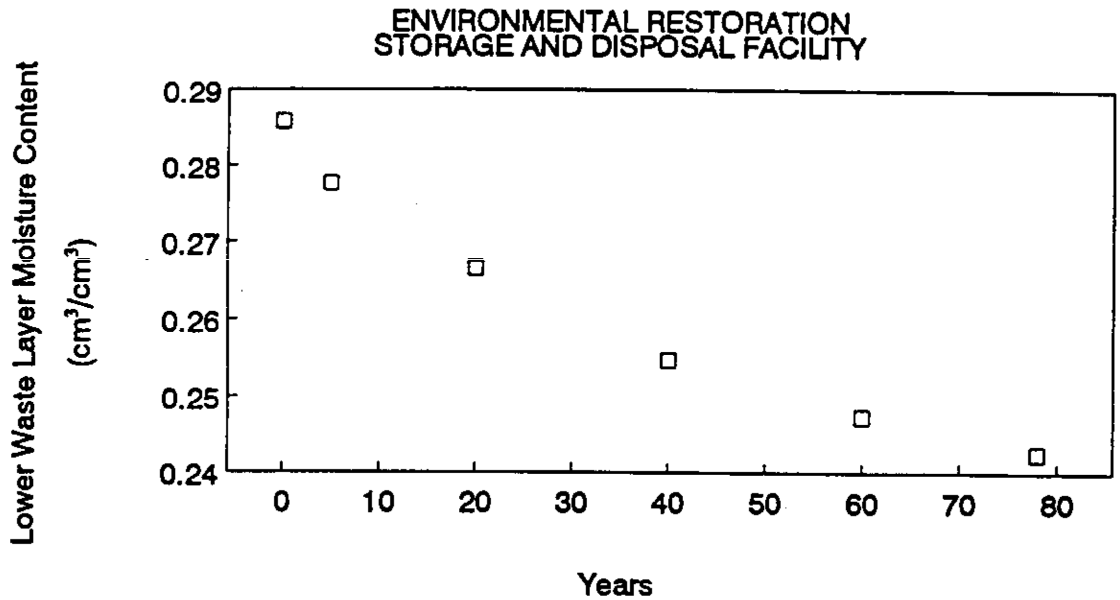
50	5.05	12.8270	0.2917	0.7409		0.0006	0.00152	
51	5.64	14.3256	0.2861	0.7267		0.0007	0.00178	
52	5.30	13.4620	0.2815	0.7150		0.0003	0.00076	
53	7.46	18.9484	0.2755	0.6998		0.0004	0.00102	
54	6.67	16.9418	0.2705	0.6871		0.0004	0.00102	
55	4.56	11.5824	0.2657	0.6749		0.0002	0.00051	
56	5.11	12.9794	0.2618	0.6650		0.0005	0.00127	
57	6.64	16.8656	0.2565	0.6515		0.0003	0.00076	
58	6.50	16.5100	0.2522	0.6406		0.0005	0.00127	
59	5.61	14.2494	0.2479	0.6297		0.0005	0.00127	
60	5.84	14.8336	0.2445	0.6210	0.2473	0.0003	0.00076	
61	7.44	18.8976	0.2394	0.6081		0.0005	0.00127	
62	5.29	13.4366	0.2356	0.5984		0.0006	0.00152	
63	5.33	13.5382	0.2318	0.5888		0.0005	0.00127	
64	6.77	17.1958	0.2289	0.5814		0.0006	0.00152	
65	5.94	15.0876	0.2247	0.5707		0.0005	0.00127	
66	6.86	17.4244	0.2213	0.5621		0.0004	0.00102	
67	6.26	15.9004	0.2180	0.5537		0.0004	0.00102	
68	5.05	12.8270	0.2154	0.5471		0.0005	0.00127	
69	5.64	14.3256	0.2117	0.5377		0.0003	0.00076	
70	6.19	15.7226	0.2087	0.5301		0.0006	0.00152	
71	6.81	17.2974	0.2057	0.5225		0.0006	0.00152	
72	8.01	20.3454	0.2034	0.5166		0.0007	0.00178	
73	5.10	12.9540	0.2000	0.5080		0.0007	0.00178	
74	7.19	18.2626	0.1973	0.5011		0.0004	0.00102	
75	5.58	14.1732	0.1946	0.4943		0.0002	0.00051	
76	5.64	14.3256	0.1926	0.4892		0.0006	0.00152	
77	4.93	12.5222	0.1895	0.4813		0.0003	0.00076	
78	6.73	17.0942	0.1871	0.4752	0.2425	0.0006	0.00152	
Average:	6.22	15.7923	0.5251	1.3338	0.2578	0.0005	0.00122	
Minimum:	3.83	9.7282	0.1871	0.4752	0.2425	0.0002	0.00051	
Maximum:	8.82	22.4028	1.5662	3.9781	0.2776	0.0007	0.00178	



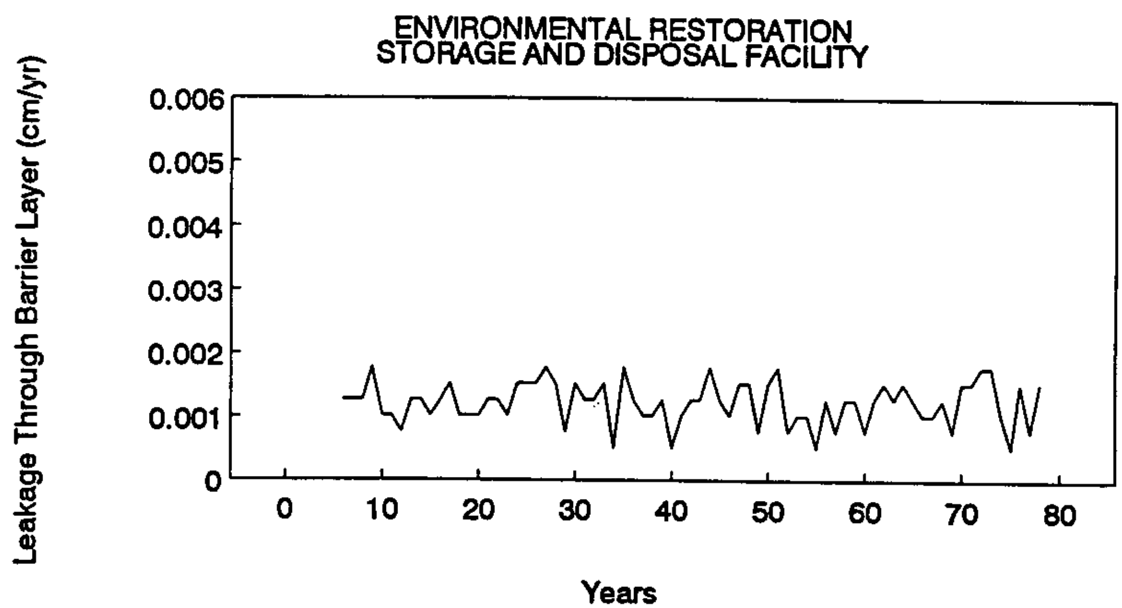
Average Precipitation (cm/yr): 15.7923
Minimum Precipitation (cm/yr): 9.7282
Maximum Precipitation (cm/yr): 22.4028



Average Drainage (cm/yr): 1.3338
Minimum Drainage (cm/yr): 0.4752
Maximum Drainage (cm/yr): 3.9781



Avg. Lower Waste Layer Moisture Content (cm^3/cm^3): 0.2624

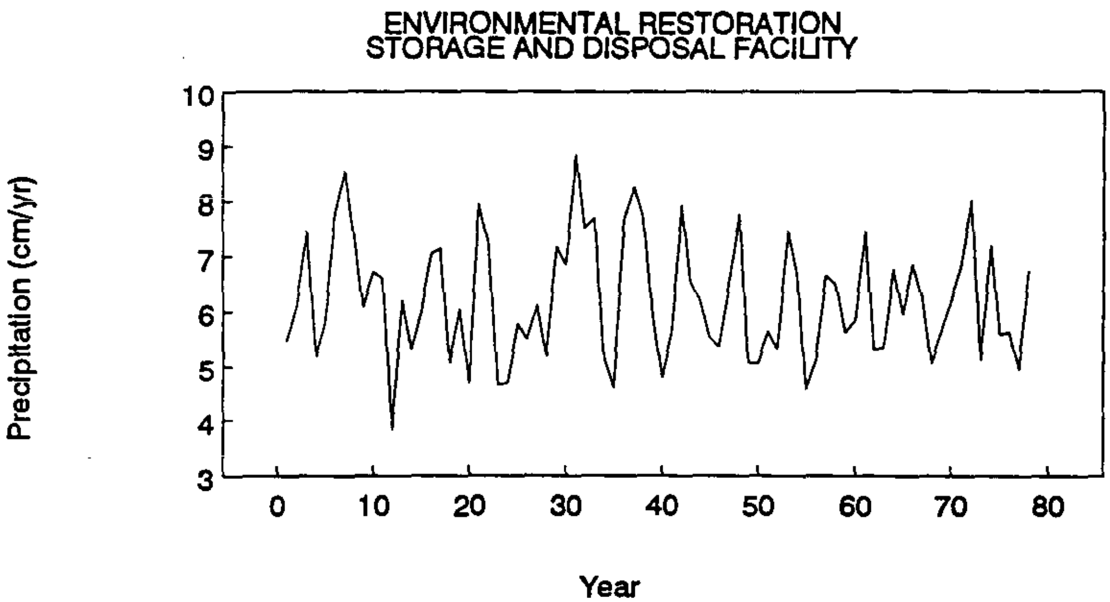


Avg. Barrier Layer Leakage (cm/yr): 0.00122

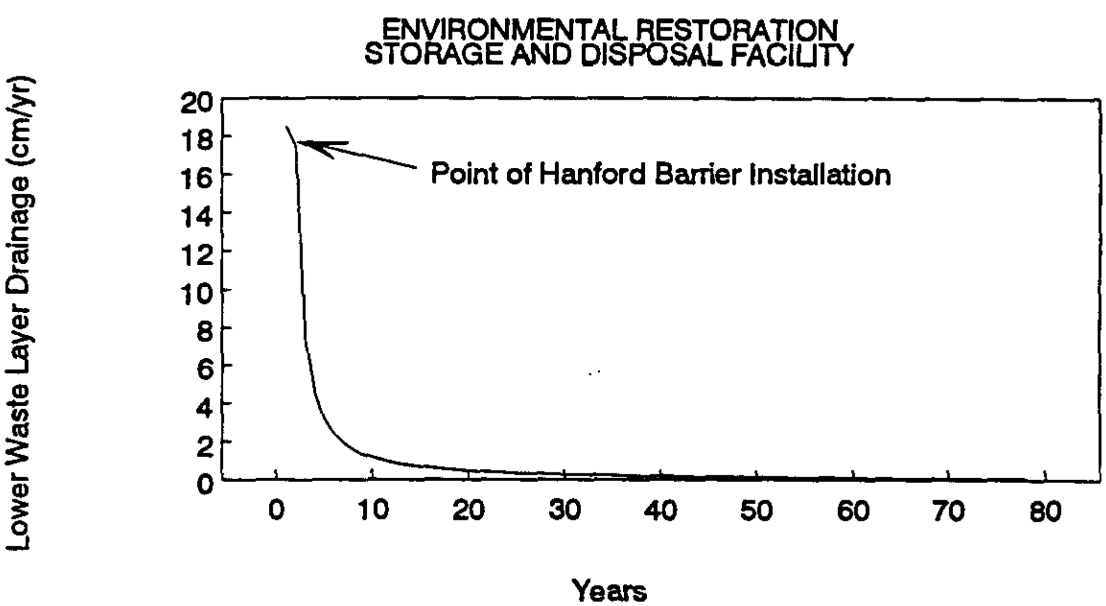
RUN F

YEAR	PRECIP (in/yr)	PRECIP (cm/yr)	BOTTOM LAYER DRAINAGE (in/yr)	BOTTOM LAYER DRAINAGE (cm/yr)	LOWER WASTE SOIL MOISTURE (cm³/cm³)	BARRIER LAYER DRAINAGE (in/yr)	BARRIER LAYER DRAINAGE (cm/yr)
0					0.0612		
1	5.47	13.8938	7.2705	18.4671	0.0534		
2	6.12	15.5448	6.8756	17.4640		0.0005	
3	7.46	18.9484	2.8950	7.3533		0.0004	
4	5.18	13.1572	1.7637	4.4798		0.0005	
5	5.80	14.7320	1.2365	3.1407		0.0005	
6	7.78	19.7612	0.9413	2.3909		0.0005	0.00127
7	8.54	21.6916	0.7531	1.9129		0.0006	0.00152
8	7.32	18.5928	0.6252	1.5880		0.0005	0.00127
9	6.07	15.4178	0.5293	1.3444		0.0005	0.00127
10	6.71	17.0434	0.4582	1.1638		0.0005	0.00127
11	6.60	16.7640	0.4027	1.0229		0.0004	0.00102
12	3.83	9.7282	0.3592	0.9124		0.0003	0.00076
13	6.21	15.7734	0.3219	0.8176		0.0006	0.00152
14	5.29	13.4366	0.2918	0.7412		0.0005	0.00127
15	5.95	15.1130	0.2664	0.6767		0.0003	0.00076
16	7.03	17.8562	0.2454	0.6233		0.0004	0.00102
17	7.13	18.1102	0.2261	0.5743		0.0005	0.00127
18	5.06	12.8524	0.2098	0.5329		0.0004	0.00102
19	6.05	15.3670	0.1956	0.4968		0.0003	0.00076
20	4.67	11.8618	0.1835	0.4661	0.0376	0.0004	0.00102
21	7.96	20.2184	0.1713	0.4351		0.0006	0.00152
22	7.21	18.3134	0.1613	0.4097		0.0005	0.00127
23	4.64	11.7856	0.1524	0.3871		0.0004	0.00102
24	4.69	11.9126	0.1447	0.3675		0.0006	0.00152
25	5.78	14.6812	0.1369	0.3477		0.0006	0.00152
26	5.48	13.9192	0.1302	0.3307		0.0007	0.00178
27	6.11	15.5194	0.1241	0.3152		0.0007	0.00178
28	5.18	13.1572	0.1188	0.3018		0.0006	0.00152
29	7.16	18.1864	0.1133	0.2878		0.0003	0.00076
30	6.85	17.3990	0.1085	0.2756		0.0006	0.00152
31	8.82	22.4028	0.1041	0.2644		0.0005	0.00127
32	7.49	19.0246	0.1003	0.2548		0.0005	0.00127
33	7.70	19.5580	0.0962	0.2443		0.0006	0.00152
34	5.13	13.0302	0.0926	0.2352		0.0002	0.00051
35	4.59	11.6586	0.0893	0.2268		0.0007	0.00178
36	7.66	19.4564	0.0864	0.2195		0.0005	0.00127
37	8.24	20.9296	0.0832	0.2113		0.0004	0.00102
38	7.72	19.6088	0.0805	0.2045		0.0004	0.00102
39	5.93	15.0622	0.0779	0.1979		0.0005	0.00127
40	4.77	12.1158	0.0756	0.1920	0.0348	0.0002	0.00051
41	5.63	14.3002	0.0731	0.1857		0.0004	0.00102
42	7.92	20.1168	0.0709	0.1801		0.0005	0.00127
43	6.52	16.5608	0.0688	0.1748		0.0005	0.00127
44	6.17	15.6718	0.0671	0.1704		0.0007	0.00178
45	5.53	14.0462	0.0650	0.1651		0.0005	0.00127
46	5.34	13.5636	0.0632	0.1605		0.0004	0.00102
47	6.52	16.5608	0.0616	0.1565		0.0006	0.00152
48	7.77	19.7358	0.0601	0.1527		0.0005	0.00127
49	5.04	12.8016	0.0584	0.1483		0.0003	0.00076

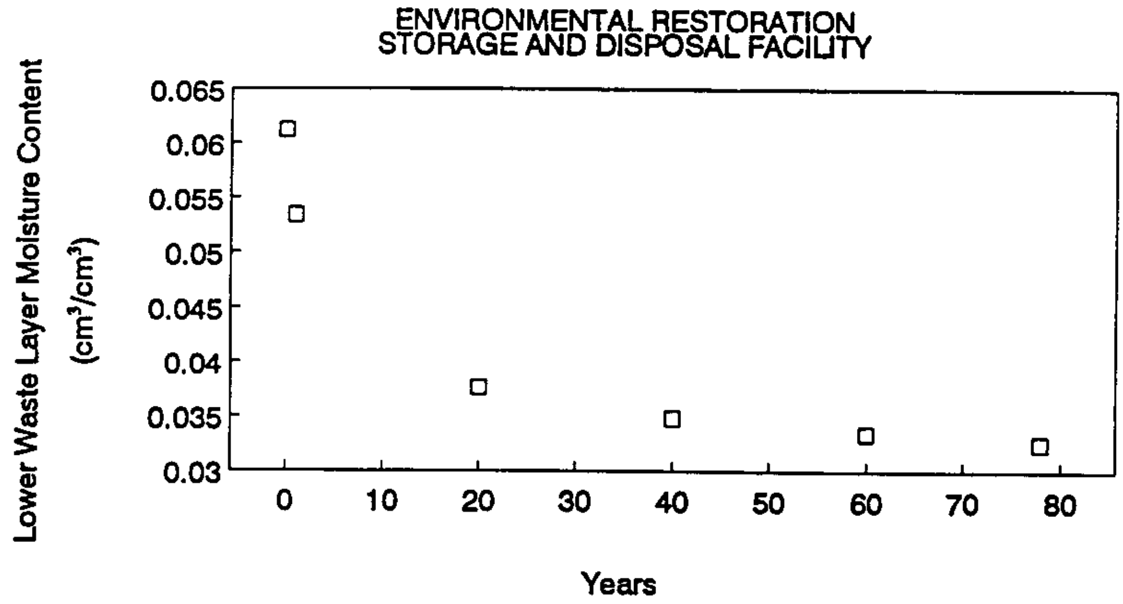
50	5.05	12.8270	0.0570	0.1448		0.0006	0.00152
51	5.64	14.3256	0.0556	0.1412		0.0007	0.00178
52	5.30	13.4620	0.0544	0.1382		0.0003	0.00076
53	7.46	18.9484	0.0529	0.1344		0.0004	0.00102
54	6.67	16.9418	0.0517	0.1313		0.0004	0.00102
55	4.56	11.5824	0.0506	0.1285		0.0002	0.00051
56	5.11	12.9794	0.0496	0.1260		0.0005	0.00127
57	6.64	16.8656	0.0483	0.1227		0.0003	0.00076
58	6.50	16.5100	0.0473	0.1201		0.0005	0.00127
59	5.61	14.2494	0.0463	0.1176		0.0005	0.00127
60	5.84	14.8336	0.0455	0.1156	0.0334	0.0003	0.00076
61	7.44	18.8976	0.0449	0.1140		0.0005	0.00127
62	5.29	13.4366	0.0439	0.1115		0.0006	0.00152
63	5.33	13.5382	0.0431	0.1095		0.0005	0.00127
64	6.77	17.1958	0.0423	0.1074		0.0006	0.00152
65	5.94	15.0876	0.0414	0.1052		0.0005	0.00127
66	6.86	17.4244	0.0406	0.1031		0.0004	0.00102
67	6.26	15.9004	0.0399	0.1013		0.0004	0.00102
68	5.05	12.8270	0.0392	0.0996		0.0005	0.00127
69	5.64	14.3256	0.0384	0.0975		0.0003	0.00076
70	6.19	15.7226	0.0377	0.0958		0.0006	0.00152
71	6.81	17.2974	0.0371	0.0942		0.0006	0.00152
72	8.01	20.3454	0.0365	0.0927		0.0007	0.00178
73	5.10	12.9540	0.0358	0.0909		0.0007	0.00178
74	7.19	18.2626	0.0352	0.0894		0.0004	0.00102
75	5.58	14.1732	0.0346	0.0879		0.0002	0.00051
76	5.64	14.3256	0.0341	0.0866		0.0006	0.00152
77	4.93	12.5222	0.0335	0.0851		0.0003	0.00076
78	6.73	17.0942	0.0330	0.0838	0.0325	0.0006	0.00152
Average:	6.22	15.7923	0.3864	0.9814	0.0383	0.0005	0.00121
Minimum:	3.83	9.7282	0.0330	0.0838	0.0325	0.0002	0.00051
Maximum:	8.82	22.4028	7.2705	18.4671	0.0534	0.0007	0.00178



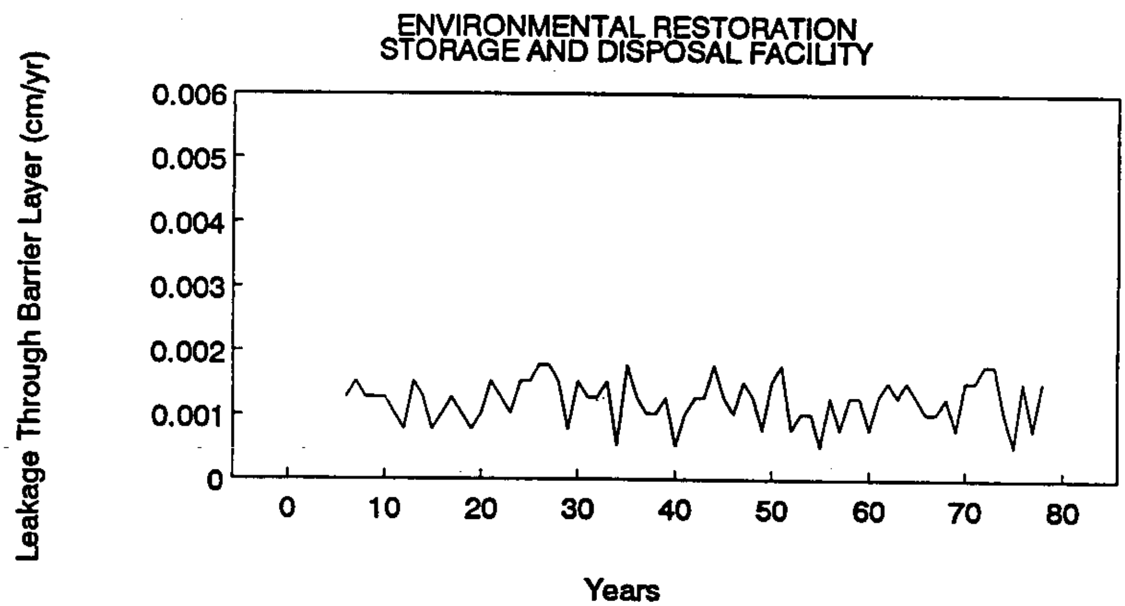
Average Precipitation (cm/yr): 15.7923
Minimum Precipitation (cm/yr): 9.7282
Maximum Precipitation (cm/yr): 22.4028



Average Drainage (cm/yr): 0.9814
Minimum Drainage (cm/yr): 0.0838
Maximum Drainage (cm/yr): 18.4671



Avg. Lower Waste Layer Moisture Content (cm^3/cm^3): **0.0422**



Avg. Barrier Layer Leakage (cm/yr): **0.00121**

APPENDIX C

INTERIM COVER COSTS

Golder Associates	SUBJECT ERSDF COVER COST ESTIMATE		
	Job No. 923-A017	Made by JPP	Date 5/25/93
	Ref. ERSDF	Checked RDL	Sheet 1 of 15
		Reviewed	

ITEM: GEOTEXTILE (7.5oz/yd², nonwoven)

ASSUMPTIONS: COST OF MATERIAL AND INSTALLATION, LEVEL C PERSONAL PROTECTION

UNIT COST: \$0.20/sf (see telecon) ✓

ITEM: 30 mil TEXTURED VLDPE

ASSUMPTIONS: COST OF MATERIAL AND INSTALLATION, LEVEL C PERSONAL PROTECTION

UNIT COST: \$1.00/sf (see telecon) ✓

ITEM: HIGH SHEAR STRENGTH GCL

ASSUMPTIONS: COST OF MATERIAL, GENERAL CONTRACTOR INSTALLATION, LEVEL C PERSONAL PROTECTION

UNIT COST: \$0.70/sf (see telecon) ✓

ITEM: OPERATIONS LAYER / CLEAN SOIL

REFERENCE: MEANS SITE WORK + LANDSCAPE COST DATA, 1993

ASSUMPTIONS: 1500 ft haul to obtain clean soil

EXCAVATE + MOVE: Elevating scraper, 11cy, sand + gravel, 1500 ft haul = \$2.06/cy ✓ (MEANS, 022-246-0

ASSUME A 50% INCREASE COST DUE TO DECONNING OF EQUIPMENT = \$3.09/cy ✓

SPREADING: 200 hp dozer, 50' haul, sand + gravel = \$0.53/cy (MEANS, 022-208-4000)

GRADING: Large area, : \$0.57/sy = \$0.06/sf (MEANS, 025-122-0100)

(3 FT THICK) = \$3.09 + \$0.53 = \$3.62/cy • $\frac{cy}{27ft^3}$ • $\frac{3ft^3}{ft^2}$ = \$0.40 + \$0.06/sf = \$0.46 ✓

(0.5 ft THICK) = \$3.09 + \$0.53 = \$3.62 $\frac{cy}{27ft^3}$ • $\frac{0.5ft^3}{ft^2}$ = \$0.07 + \$0.06/sf = \$0.13 ✓

Golder Associates	SUBJECT ERSDF COVER COST ESTIMATE		
	Job No. 923-A017 Ref. ERSDF	Made by JPP Checked RDL Reviewed	Date 5/25/93 Sheet 2 of 15

ITEM: SILT AND GRAVEL ADMIXTURE

ASSUMPTIONS: 25% McGee Ranch Silt admixed to gravel. McGee Ranch 20 mile one way haul.

EXCAVATE + MOVE TO MIXING TABLE: Elevating Scraper, 11 cy, sand + gravel, 1500 ft haul, ✓ \$2.06/cy (Means, 022-246-0100)

EXCAVATE + LOAD TRUCK w/ McGee SILT: Front End Loader, wheel mounted, 3 cy, ✓ \$0.87/cy (MEANS, 022-238-1601)

HAUL = Borrow material, highway haulers, bank measure, no loading needed, 20 cy dump trailer, 20 mile round trip, 8.6 load/hr (MEANS, 022-266-1255) USE COST EXTRAPOLATION SHOWN ON PAGE 15 TO ESTIMATE COST FOR 40 MILE ROUND TRIP: \$12/CY ✓

MIXING SILT AND GRAVEL: Assume cost of mixing is similar to compacting ✓ Sheepsfoot or wobbly wheel roller, 6" lifts, 2 passes (Means, 022-226-5000) \$0.38/cy

EXCAVATE + MOVE TO COVER: Elevating Scraper, 11 cy, sand + gravel, 1500 ft haul = \$2.06/cy ✓ (Means, 022-246-01
Assume a 50% increase cost due to deconning of equipment: \$3.09/cy ✓

SPREADING: 200 hp dozer, 50' haul, sand + gravel = \$0.53/cy ✓ (Means, 022-208-4000)

GRADING: Large Area \$0.57/sy ~ \$0.06/sf ✓

COMPACTION: Sheepsfoot or wobbly wheel roller, 6" lifts, 4 passes: \$0.75/cy ✓ (Means, 022-226-5640)

Weighted average cost of admixture = (0.75)(\$2.06/cy) + (0.25)(\$.87/cy) + (.25)(\$12/cy) = \$4.76/cy ✓

Cost/cy = \$4.76/cy + \$0.38/cy + \$3.09/cy + \$0.53/cy + \$0.75/cy = \$9.51 / 9 = \$1.06/sf ✓ for 3' thick section

(3 ft THICK) = \$1.06/sf + \$0.06/sf = \$1.12/sf ✓

(1 ft THICK) = (\$1.06/sf)(1/3) + \$0.06/sf = \$0.41/sf ✓

(0.5 ft THICK) = (\$1.06/sf)(1/6) + \$0.06/sf = \$0.23/sf ✓

ITEM: 20 mil PVC GEOMEMBRANE

ASSUME: COST OF MATERIAL AND INSTALLATION, LEVEL C PERSONAL PROTECTION

UNIT COST: \$0.34/sf (See telecon) ✓

ITEM: PROOFROLLING WASTE SURFACE

PROOFROLLING: Riding vibrating roller, 6" lifts, 2 passes = \$0.29/cy (MEANS, 022-224-5)
Assume proofrolling equivalent to referenced lift compaction cost.

UNIT COST: $\frac{\$0.29}{cy} \cdot \frac{cy}{9sf} = \$0.03/sf$ ✓

ITEM: CEMENT STABILIZED WASTE

ASSUME: CEMENT STABILIZED WASTE IS PLACED AND COMPACTED AT NO COST, MATERIAL WILL NEED ADDITIONAL SPREADING TO ENSURE PROPER LIFT THICKNESS.

SPREADING: 200hp dozer, 50' haul, sand + gravel = \$0.53/cy

UNIT COST: $\frac{\$0.53}{CY} \cdot \frac{CY}{27ft^3} \cdot \frac{1.5ft^3}{ft^2} = \$0.03/sf$ (1.5 ft THICK)

$\frac{\$0.53}{CY} \cdot \frac{CY}{27ft^3} \cdot \frac{0.5ft^3}{ft^2} = \$0.01/sf$ (0.5 ft THICK)

ITEM: GEOTEXTILE MARKER LAYER

ASSUME: COST OF MATERIAL, INSTALLATION, LEVEL C PERSONAL PROTECTION

UNIT COST: \$0.14/sf (see telecon) ✓

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC. FILE: Project

PROJECT CONTACT REPORT

DATE: 4/28/93
PAGE 1 OF 1

U.S. CORPS OF ENGINEERS
WALLA WALLA DISTRICT

CONTRACT NO. DACW68-92-D-0001
DELIVERY ORDER NO. ______

Subject: Geomembrane & Geotextile Costs

Discussion:

Level C Protection

Quantity ~ 50,000 ft²

40 mil HDPE = $0.50 - 0.70/sf

Trevira 1120 (6 oz) = $0.14 - $0.18/sf

Trevira 1125 (7.5 oz) : $0.16 - $0.20/sf

Trevira 1112 (3.5 oz) : $0.14/sf

Trevira 1114 (4.5 oz) : $0.15/sf

JMM PARTY	OTHER PARTY
Project Name: ERSDF Design Studies	Organization's Name: National Seal Co.
Employee's Name: John Pellicer	Address:
Employee's Company: Golder Assoc	Phone No.: (714) 753-9200
Date: 4/28/93 Time:	Person's Name: Doug Peterson

CALL PLACED BY: JMM ☒ OTHER PARTY ☐

DISTRIBUTION:

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FILE: Project

PROJECT CONTACT REPORT

DATE: 5/26/93
PAGE 1 OF 1

U.S. CORPS OF ENGINEERS
WALLA WALLA DISTRICT

CONTRACT NO. DACW68-92-D-0001
DELIVERY ORDER NO. ________

Subject: Geomembrane Cost Estimate

Discussion:

Quantity = 50,000 ft^2

PVC (nonreinforced 30 mil) = \$0.20/sf (materials) + \$0.15/sf (install level C) = \$0.35/sf

PVC (nonreinforced 20 mil) = \$0.15/sf (materials) + \$0.15/sf (install level C) = \$0.30/sf

MOB/DEMOB = \$2000 $\frac{\$2000}{50,000 sf}$ = \$0.04/sf

JMM PARTY	OTHER PARTY
Project Name: ERSDF Design Studies	Organization's Name: Watersaver Co.
Employee's Name: John Pellicer	Address:
Employee's Company: Golder Assoc.	Phone No.: 1 (800) 525-2424
Date: 5/26/93 Time:	Person's Name: Dave Fullerton

CALL PLACED BY: JMM ☒ OTHER PARTY ☐

DISTRIBUTION:

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PROJECT CONTACT REPORT

DATE: 5/3/93
PAGE 1 OF 1

U.S. CORPS OF ENGINEERS
WALLA WALLA DISTRICT

CONTRACT NO. DACW68-92-D-0001
DELIVERY ORDER NO. ______

Subject: ERSDF Cover Costs

Discussion:

Quantity = 50,000 ft^2

- $0.60/sf material delivered
- $0.05/sf installation - General contractor installs
- Assume Level C protection doubles installation cost = $0.10/sf

Total: $0.70/sf

JMM PARTY	OTHER PARTY
Project Name: ERSDF Design Studies	Organization's Name: CLAYMAX
Employee's Name: John Pellicer	Address:
Employee's Company: Golder Assoc.	Phone No.: (312) CLAYMAX
Date: 5/3/93 Time:	Person's Name: Jens Sorenson

CALL PLACED BY: JMM ☒ OTHER PARTY ☐

DISTRIBUTION:

☐ JMM
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☐

7/15

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PROJECT CONTACT REPORT

DATE: 5/25/93
PAGE 1 OF 1

U.S. CORPS OF ENGINEERS
WALLA WALLA DISTRICT

CONTRACT NO. DACW68-92-D-0001
DELIVERY ORDER NO. ______

Subject: ERSDF Cover Costs

Discussion:

Quantity ~ 40,000 ft²

- 30 mil VLDPE Textured is the thinnest they make
- Assume Level C Protection
- $1.00/sf delivered + installed.

JMM PARTY	OTHER PARTY
Project Name: ERSDF Design Studies	Organization's Name: Gundle Lining
Employee's Name: John Pellicer	Address:
Employee's Company: Golder Assoc.	Phone No.: (713) 443-8564
Date: 5/25/93 Time: 11:30 Am	Person's Name: Steve Danton

CALL PLACED BY: JMM ☒ OTHER PARTY ☐

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☐

2 SITE WORK

		022 100 | Grading	CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
104	0010	GRADING Site excav. & fill, see div 022-200										104
	0020	Fine grading, see div 025-122										
		022 200 | Excav, Backfill, Compact										
204	0010	BACKFILL By hand, no compaction, light soil (R022-220)	1 Clab	14	.571	C.Y.		10.60		10.60	16.65	204
	0100	Heavy soil		11	.727			13.50		13.50	21	
	0300	Compaction in 6" layers, hand tamp, add to above	↓	20.60	.388			7.20		7.20	11.30	
	0400	Roller compaction operator walking, add	B-10A	100	.120			2.67	.79	3.46	4.97	
	0500	Air tamp, add	B-9	190	.211			3.99	.76	4.75	7.10	
	0600	Vibrating plate, add	A-1	60	.133			2.47	.98	3.45	4.95	
	0800	Compaction in 12" layers, hand tamp, add to above	1 Clab	34	.235			4.36		4.36	6.85	
	0900	Roller compaction operator walking, add	B-10A	150	.080			1.78	.53	2.31	3.32	
	1000	Air tamp, add	B-9	285	.140			2.66	.51	3.17	4.73	
	1100	Vibrating plate, add	A-1	90	.089	↓		1.65	.65	2.30	3.31	
208	0010	**BACKFILL, STRUCTURAL** Dozer or F.E. loader										208
	0020	From existing stockpile, no compaction										
	2000	75 H.P., 50' haul, sand & gravel	B-10L	1,100	.011	C.Y.		.24	.27	.51	.66	
	2020	Common earth		975	.012			.27	.30	.57	.75	
	2040	Clay		850	.014			.31	.34	.65	.86	
	2200	150' haul, sand & gravel		550	.022			.49	.53	1.02	1.33	
	2220	Common earth		490	.024			.54	.60	1.14	1.50	
	2240	Clay		425	.028			.63	.69	1.32	1.73	
	2400	300' haul, sand & gravel		370	.032			.72	.79	1.51	1.98	
	2420	Common earth		330	.036			.81	.88	1.69	2.21	
	2440	Clay	↓	290	.041			.92	1.01	1.93	2.53	
	3000	105 H.P., 50' haul, sand & gravel	B-10W	1,350	.009			.20	.31	.51	.64	
	3020	Common earth		1,225	.010			.22	.34	.56	.71	
	3040	Clay		1,100	.011			.24	.38	.62	.78	
	3200	150' haul, sand & gravel		670	.018			.40	.62	1.02	1.29	
	3220	Common earth		610	.020			.44	.68	1.12	1.42	
	3240	Clay		550	.022			.49	.75	1.24	1.58	
	3300	300' haul, sand & gravel		465	.026			.57	.89	1.46	1.86	
	3320	Common earth		415	.029			.64	1	1.64	2.09	
	3340	Clay	↓	370	.032			.72	1.12	1.84	2.34	
	4000	200 H.P., 50' haul, sand & gravel	B-10B	2,500	.005			.11	.33	.44	.53	
	4020	Common earth		2,200	.005			.12	.38	.50	.61	
	4040	Clay		1,950	.006			.14	.43	.57	.68	
	4200	150' haul, sand & gravel		1,225	.010			.22	.68	.90	1.09	
	4220	Common earth		1,100	.011			.24	.76	1	1.20	
	4240	Clay		975	.012			.27	.85	1.12	1.36	
	4400	300' haul, sand & gravel		805	.015			.33	1.03	1.36	1.65	
	4420	Common earth		735	.016			.36	1.13	1.49	1.81	
	4440	Clay	↓	660	.018			.40	1.26	1.66	2.01	
	5000	300 H.P., 50' haul, sand & gravel	B-10M	3,170	.004			.08	.29	.37	.45	
	5020	Common earth		2,900	.004			.09	.32	.41	.49	
	5040	Clay		2,700	.004			.10	.34	.44	.53	
	5200	150' haul, sand & gravel		2,200	.005			.12	.42	.54	.65	
	5220	Common earth		1,950	.006			.14	.48	.62	.73	
	5240	Clay		1,700	.007			.16	.55	.71	.84	
	5400	300' haul, sand & gravel		1,500	.008			.18	.62	.80	.95	
	5420	Common earth		1,350	.009			.20	.69	.89	1.06	
	5440	Clay	↓	1,225	.010	↓		.22	.76	.98	1.17	
	6000	For compaction, see div. 022-226										
	6010	For trench backfill, see div. 022-254 & 258										
216	0011	**BORROW** Bank measure, loaded onto 12 C.Y. hauler, no haul incl.										216
	4000	Common earth, shovel, 1 C.Y. bucket	B-12N	840	.019	C.Y.	3.50	.43	.70	4.63	5.30	

	022 200 Excav, Backfill, Compact		CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
216	4010	1-1/2 C.Y. bucket	B-12O	1,135	.014	C.Y.	3.50	.32	.74	4.56	5.15	216
	4020	3 C.Y. bucket	B-12T	1,800	.009		3.50	.20	.60	4.30	4.82	
	4030	Front end loader, wheel mounted										
	4050	3/4 C.Y. bucket	B-10R	550	.022	C.Y.	3.50	.49	.43	4.42	5.05	
	4060	1-1/2 C.Y. bucket	B-10S	970	.012		3.50	.28	.34	4.12	4.64	
	4070	3 C.Y. bucket	B-10T	1,575	.008		3.50	.17	.32	3.99	4.46	
	4080	5 C.Y. bucket	B-10U	2,600	.005		3.50	.10	.36	3.96	4.41	
	5000	Select granular fill, shovel, 1 C.Y. bucket	B-12N	925	.017		5	.39	.63	6.02	6.80	
	5010	1-1/2 C.Y. bucket	B-12O	1,250	.013		5	.29	.67	5.96	6.70	
	5020	3 C.Y. bucket	B-12T	1,980	.008		5	.18	.55	5.73	6.40	
	5030	Front end loader, wheel mounted							.34			
	5050	3/4 C.Y. bucket	B-10R	800	.015	C.Y.	5	.33	.29	5.62	6.35	
	5060	1-1/2 C.Y. bucket	B-10S	1,065	.011		5	.25	.31	5.56	6.25	
	5070	3 C.Y. bucket	B-10T	1,735	.007		5	.15	.29	5.44	6.05	
	5080	5 C.Y. bucket	B-10U	2,850	.004		5	.09	.33	5.42	6	
	6000	Clay, till, or blasted rock, shovel, 1 C.Y. bucket	B-12N	715	.022		3.70	.51	.82	5.03	5.75	
	6010	1-1/2 C.Y. bucket	B-12O	965	.017		3.70	.37	.87	4.94	5.60	
	6020	3 C.Y. bucket	B-12T	1,530	.010		3.70	.24	.71	4.65	5.20	
	6030	Front end loader, wheel mounted										
	6035	3/4 C.Y. bucket	B-10R	465	.026	C.Y.	3.70	.57	.51	4.78	5.50	
	6040	1-1/2 C.Y. bucket	B-10S	825	.015		3.70	.32	.40	4.42	5	
	6045	3 C.Y. bucket	B-10T	1,340	.009		3.70	.20	.37	4.27	4.79	
	6050	5 C.Y. bucket	B-10U	2,200	.005		3.70	.12	.43	4.25	4.73	
	6060	Front end loader, track mounted										
	6065	1-1/2 C.Y. bucket	B-10N	715	.017	C.Y.	3.70	.37	.50	4.57	5.20	
	6070	3 C.Y. bucket	B-10P	1,190	.010		3.70	.22	.64	4.56	5.10	
	6075	5 C.Y. bucket	B-10Q	1,835	.007		3.70	.15	.58	4.43	4.93	
	7000	Topsoil or loam from stockpile, shovel, 1 C.Y. bucket	B-12N	840	.019		12.10	.43	.70	13.23	14.75	
	7010	1-1/2 C.Y. bucket	B-12O	1,135	.014		12.10	.32	.74	13.16	14.60	
	7020	3 C.Y. bucket	B-12T	1,800	.009		12.10	.20	.60	12.90	14.25	
	7030	Front end loader, wheel mounted										
	7050	3/4 C.Y. bucket	B-10R	550	.022	C.Y.	12.10	.49	.43	13.02	14.50	
	7060	1-1/2 C.Y. bucket	B-10S	970	.012		12.10	.28	.34	12.72	14.10	
	7070	3 C.Y. bucket	B-10T	1,575	.008		12.10	.17	.32	12.59	13.90	
	7080	5 C.Y. bucket	B-10U	2,600	.005		12.10	.10	.36	12.56	13.85	
	8900	For larger hauling units, deduct from above								30%		
226	0010	COMPACTION R022-220										226
	5000	Riding, vibrating roller, 6" lifts, 2 passes	B-10Y	2,600	.005	C.Y.		.10	.12	.22	.29	
	5020	3 passes		1,950	.006			.14	.16	.30	.39	
	5040	4 passes		1,300	.009			.21	.24	.45	.59	
	5060	12" lifts, 2 passes		5,200	.002			.05	.06	.11	.15	
	5080	3 passes		3,900	.003			.07	.08	.15	.20	
	5100	4 passes		2,600	.005			.10	.12	.22	.29	
	5600	Sheepsfoot or wobbly wheel roller, 6" lifts, 2 passes	B-10G	2,600	.005			.10	.20	.30	.38	
	5620	3 passes		1,950	.006			.14	.26	.40	.50	
	5640	4 passes		1,300	.009			.21	.39	.60	.75	
	5680	12" lifts, 2 passes		5,200	.002			.05	.10	.15	.19	
	5700	3 passes		3,900	.003			.07	.13	.20	.25	
	5720	4 passes		2,600	.005			.10	.20	.30	.38	
	6000	Towed sheepsfoot or wobbly wheel roller, 6" lifts, 2 passes	B-10D	3,000	.004			.09	.31	.40	.48	
	6020	3 passes		2,250	.005			.12	.42	.54	.64	
	6030	4 passes		1,500	.008			.18	.63	.81	.96	
	6050	12" lifts, 2 passes		6,000	.002			.04	.16	.20	.24	
	6060	3 passes		4,500	.003			.06	.21	.27	.32	
	6070	4 passes		3,000	.004			.09	.31	.40	.48	
	6200	Vibrating roller, 6" lifts, 2 passes	B-10C	2,600	.005			.10	.36	.46	.55	

	022 200 | Excav, Backfill, Compact		CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
234	4500	City block within zone of influence, minimum	A-8	25,200	.001	S.F.		.03		.03	.04	234
	4600	Maximum	•	15,100	.002	•		.04		.04	.07	
	5000	Excavate and load boulders, less than 0.5 C.Y.	B-10T	80	.150	C.Y.		3.34	6.25	9.59	12.05	
	5020	0.5 C.Y. to 1 C.Y.	B-10U	100	.120			2.67	9.45	12.12	14.50	
	5200	Excavate and load blasted rock, 3 C.Y. power shovel	B-12T	1,530	.010			.24	.71	.95	1.14	
	5400	Haul boulders, 25 Ton off-highway dump, 1 mile round trip	B-34E	330	.024			.47	1.76	2.23	2.66	
	5420	2 mile round trip		275	.029			.57	2.11	2.68	3.19	
	5440	3 mile round trip		225	.036			.69	2.58	3.27	3.90	
	5460	4 mile round trip		200	.040			.78	2.90	3.68	4.38	
	5600	Bury boulders on site, less than 0.5 C.Y., 300 H.P. dozer										
	5620	150' haul	B-10M	310	.039	C.Y.		.86	2.99	3.85	4.61	
	5640	300' haul		210	.057			1.27	4.41	5.68	6.80	
	5800	0.5 to 1 C.Y., 300 H.P. dozer, 150' haul		300	.040			.89	3.09	3.98	4.77	
	5820	300' haul		200	.060			1.34	4.63	5.97	7.15	
238	0010	**EXCAVATING, BULK BANK MEASURE** Common earth piled	R022 -240									238
	0020	For loading onto trucks, add								15%	15%	
	0050	For mobilization and demobilization, see division 022-274	R022 -250									
	0100	For hauling, see division 022-266										
	0200	Backhoe, hydraulic, crawler mtd., 1 C.Y. cap. = 75 C.Y./hr.	B-12A	600	.027	C.Y.		.60	.96	1.56	1.97	
	0250	1-1/2 C.Y. cap. = 100 C.Y./hr.	B-12B	800	.020			.45	.91	1.36	1.69	
	0260	2 C.Y. cap. = 130 C.Y./hr.	B-12C	1,040	.015			.35	.93	1.28	1.55	
	0300	3 C.Y. cap. = 160 C.Y./hr.	B-12D	1,620	.010			.22	1.33	1.55	1.80	
	0310	Wheel mounted, 1/2 C.Y. cap. = 30 C.Y./hr.	B-12E	240	.067			1.51	1.34	2.85	3.77	
	0360	3/4 C.Y. cap. = 45 C.Y./hr.	B-12F	360	.044			1	1.26	2.26	2.92	
	0500	Clamshell, 1/2 C.Y. cap. = 20 C.Y./hr.	B-12G	160	.100			2.26	2.78	5.04	6.50	
	0550	1 C.Y. cap. = 35 C.Y./hr.	B-12H	280	.057			1.29	1.86	3.15	4.02	
	0950	Dragline, 1/2 C.Y. cap. = 30 C.Y./hr.	B-12I	240	.067			1.51	1.90	3.41	4.39	
	1000	Dragline, 3/4 C.Y. cap. = 35 C.Y./hr.		280	.057			1.29	1.63	2.92	3.76	
	1001	3/4 C.Y. cap. = 35 C.Y./hr.		280	.057			1.29	1.63	2.92	3.76	
	1050	1-1/2 C.Y. cap. = 65 C.Y./hr.	B-12P	520	.031			.70	1.42	2.12	2.62	
	1100	3 C.Y. cap. = 112 C.Y./hr.	B-12V	900	.018			.40	.99	1.39	1.70	
	1200	Front end loader, track mtd., 1-1/2 C.Y. cap. = 70 C.Y./hr.	B-10N	560	.021			.48	.64	1.12	1.43	
	1250	2-1/2 C.Y. cap. = 95 C.Y./hr.	B-10O	760	.016			.35	.60	.95	1.21	
	1300	3 C.Y. cap. = 130 C.Y./hr.	B-10P	1,040	.012			.26	.73	.99	1.20	
	1350	5 C.Y. cap. = 160 C.Y./hr.	B-10Q	1,620	.007			.16	.66	.82	.97	
	1500	Wheel mounted, 3/4 C.Y. cap. = 45 C.Y./hr.	B-10R	360	.033			.74	.65	1.39	1.86	
	1550	1-1/2 C.Y. cap. = 80 C.Y./hr.	B-10S	640	.019			.42	.51	.93	1.21	
	1600	2-1/4 C.Y. cap. = 100 C.Y./hr.	B-10T	800	.015			.33	.63	.96	1.20	
	1601	3 C.Y. cap. = 100 C.Y./hr.	•	1,100	.011			.24	.46	.70	.87	
	1650	5 C.Y. cap. = 185 C.Y./hr.	B-10U	1,480	.008			.18	.64	.82	.98	
	1800	Hydraulic excavator, truck mtd, 1/2 C.Y. = 30 C.Y./hr.	B-12J	240	.067			1.51	2.45	3.96	4.99	
	1850	48 inch bucket, 1 C.Y. = 45 C.Y./hr.	B-12K	360	.044			1	2.25	3.25	4.01	
	3700	Shovel, 1/2 C.Y. capacity = 55 C.Y./hr.	B-12L	440	.036			.82	1.01	1.83	2.37	
	3750	3/4 C.Y. capacity = 85 C.Y./hr.	B-12M	680	.024			.53	.76	1.29	1.64	
	3800	1 C.Y. capacity = 120 C.Y./hr.	B-12N	960	.017			.38	.61	.99	1.24	
	3850	1-1/2 C.Y. capacity = 160 C.Y./hr.	B-12O	1,280	.013			.28	.65	.93	1.15	
	3900	3 C.Y. cap. = 250 C.Y./hr.	B-12T	2,000	.008			.18	.54	.72	.88	
	4000	For soft soil or sand, deduct								15%	15%	
	4100	For heavy soil or stiff clay, add								60%	60%	
	4200	For wet excavation with clamshell or dragline, add								100%	100%	
	4250	All other equipment, add								50%	50%	
	4400	Clamshell in sheeting or cofferdam, minimum	B-12H	160	.100			2.26	3.26	5.52	7.05	
	4450	Maximum	•	60	.267			6.05	8.70	14.75	18.75	
	8000	For hauling excavated material, see div. 022-266										
242	0010	**EXCAVATING, BULK, DOZER** Open site										242
	2000	75 H.P., 50' haul, sand & gravel	B-10L	460	.026	C.Y.		.58	.63	1.21	1.59	

SITE WORK 2

022 200 | Excav, Backfill, Compact

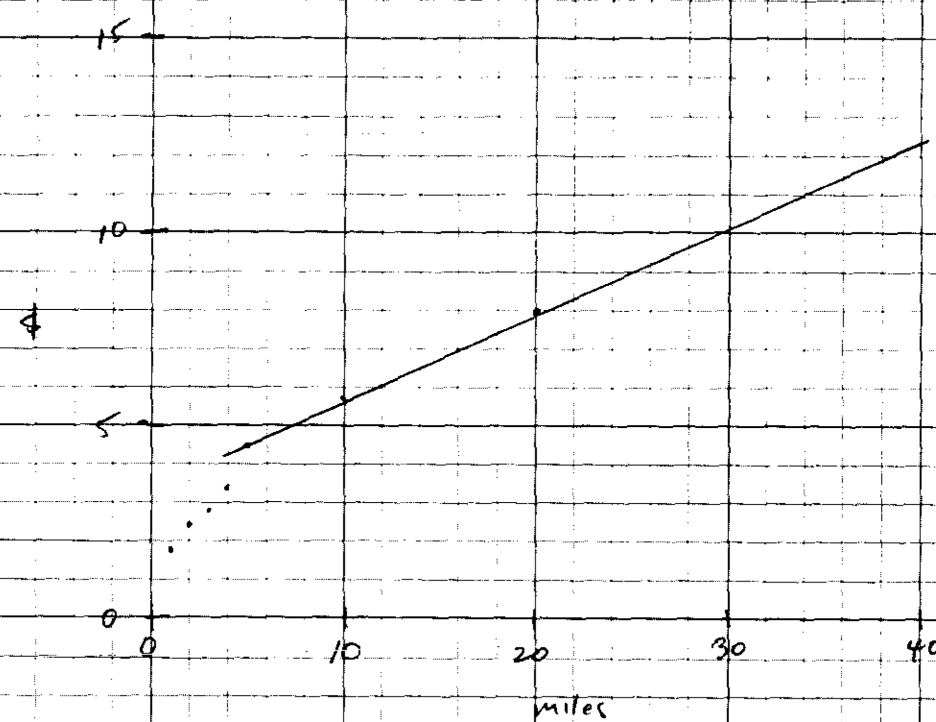
022 200	Excav, Backfill, Compact	CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
[illegible]	Common earth	B-10L	400	.030	C.Y.		.67	.73	1.40	1.83	242
[illegible]	Clay		250	.048			1.07	1.17	2.24	2.92	
[illegible]	1[illegible]' haul, sand & gravel		230	.052			1.16	1.27	2.43	3.18	
[illegible]	Common earth		200	.060			1.34	1.46	2.80	3.66	
2240	Clay		125	.096			2.14	2.33	4.47	5.85	
2400	300' haul, sand & gravel		120	.100			2.23	2.43	4.66	6.10	
2420	Common earth		100	.120			2.67	2.92	5.59	7.30	
2440	Clay		65	.185			4.11	4.49	8.60	11.25	
3000	105 H.P., 50' haul, sand & gravel	B-10W	700	.017			.38	.59	.97	1.24	
3020	Common earth		610	.020			.44	.68	1.12	1.42	
3040	Clay		385	.031			.69	1.08	1.77	2.26	
3200	150' haul, sand & gravel		310	.039			.86	1.34	2.20	2.79	
3220	Common earth		270	.044			.99	1.54	2.53	3.21	
3240	Clay		170	.071			1.57	2.44	4.01	5.10	
3300	300' haul, sand & gravel		140	.086			1.91	2.96	4.87	6.20	
3320	Common earth		120	.100			2.23	3.46	5.69	7.20	
3340	Clay		100	.120			2.67	4.15	6.82	8.65	
4000	200 H.P., 50' haul, sand & gravel	B-10B	1,400	.009			.19	.59	.78	.94	
4020	Common earth		1,230	.010			.22	.68	.90	1.07	
4040	Clay		770	.016			.35	1.08	1.43	1.72	
4200	150' haul, sand & gravel		595	.020			.45	1.40	1.85	2.23	
4220	Common earth		516	.023			.52	1.61	2.13	2.57	
4240	Clay		325	.037			.82	2.56	3.38	4.08	
4400	300' haul, sand & gravel		310	.039			.86	2.68	3.54	4.27	
4420	Common earth		270	.044			.99	3.08	4.07	4.91	
4440	Clay		170	.071			1.57	4.89	6.46	7.80	
5000	300 H.P., 50' haul, sand & gravel	B-10M	1,900	.006			.14	.49	.63	.76	
5020	Common earth		1,650	.007			.16	.56	.72	.87	
5040	Clay		1,025	.012			.26	.90	1.16	1.39	
5200	150' haul, sand & gravel		920	.013			.29	1.01	1.30	1.56	
5220	Common earth		800	.015			.33	1.16	1.49	1.78	
5240	Clay		500	.024			.53	1.85	2.38	2.86	
5400	300' haul, sand & gravel		470	.026			.57	1.97	2.54	3.04	
5420	Common earth		410	.029			.65	2.26	2.91	3.49	
5440	Clay		250	.048			1.07	3.71	4.78	5.70	
5500	460 H.P., 50' haul, sand & gravel	B-10X	1,930	.006			.14	.62	.76	.90	
5510	Common earth		1,680	.007			.16	.72	.88	1.03	
5520	Clay		1,050	.011			.25	1.15	1.40	1.65	
5530	150' haul, sand & gravel		1,290	.009			.21	.93	1.14	1.35	
5540	Common earth		1,120	.011			.24	1.07	1.31	1.55	
5550	Clay		700	.017			.38	1.72	2.10	2.48	
5560	300' haul, sand & gravel		660	.018			.40	1.82	2.22	2.63	
5570	Common earth		575	.021			.46	2.09	2.55	3.01	
5580	Clay		350	.034			.76	3.44	4.20	4.95	
6000	700 H.P., 50' haul, sand & gravel	B-10V	3,500	.003			.08	.77	.85	.97	
6010	Common earth		3,035	.004			.09	.89	.98	1.11	
6020	Clay		1,925	.006			.14	1.40	1.54	1.75	
6030	150' haul, sand & gravel		2,025	.006			.13	1.33	1.46	1.66	
6040	Common earth		1,750	.007			.15	1.54	1.69	1.92	
6050	Clay		1,100	.011			.24	2.44	2.68	3.06	
6060	300' haul, sand & gravel		1,030	.012			.26	2.61	2.87	3.27	
6070	Common earth		900	.013			.30	2.99	3.29	3.75	
6080	Clay		550	.022			.49	4.89	5.38	6.15	
6090	For dozer with ripper, see div. 022-278										
0010	EXCAVATION, BULK, SCRAPERS R022-240										246
0100	Elevating scraper 11 C.Y., sand & gravel 1500' haul	B-33F	690	.020	C.Y.		.46	1.24	1.70	2.06	

See the **Reference Section** for reference number information, Crew Listings and City Cost Indexes.

		022 200 | Excav, Backfill, Compact	CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
262	0150	Spread fill, from stockpile with 2-1/2 C.Y. F.E. loader										262
	0170	130 H.P. 300' haul	B-10P	600	.020	C.Y.		.44	1.27	1.71	2.08	
	0190	With dozer 300 H.P. 300' haul	B-10M	600	.020	"		.44	1.54	1.98	2.38	
	0400	For compaction of embankment, see div. 022-226										
	0500	Gravel fill, compacted, under floor slabs, 4" deep	B-37	10,000	.005	S.F.	.09	.09	.01	.19	.26	
	0600	6" deep		8,600	.006		.15	.11	.01	.27	.36	
	0700	9" deep		7,200	.007		.23	.13	.02	.38	.47	
	0800	12" deep		6,000	.008		.31	.16	.02	.49	.61	
	1000	Alternate pricing method, 4" deep		120	.400	C.Y.	8.10	7.85	1.02	16.97	22.50	
	1100	6" deep		160	.300		8.10	5.90	.77	14.77	18.95	
	1200	9" deep		200	.240		8.10	4.71	.61	13.42	16.90	
	1300	12" deep		220	.218		8.10	4.29	.56	12.95	16.20	
	1500	For fill under exterior paving, see division 022-308										
266	0011	HAULING Excavated or borrow material, highway haulers R022-240										266
	0012	bank measure, no loading included										
	0020	6 C.Y. dump truck, 1/4 mile round trip, 5.0 loads/hr.	B-34A	240	.033	C.Y.		.65	1.32	1.97	2.44	
	0030	1/2 mile round trip, 4.1 loads/hr.		197	.041			.79	1.60	2.39	2.97	
	0040	1 mile round trip, 3.3 loads/hr.		160	.050			.97	1.97	2.94	3.66	
	0100	2 mile round trip, 2.6 loads/hr.		125	.064			1.24	2.52	3.76	4.68	
	0150	3 mile round trip, 2.1 loads/hr.		100	.080			1.56	3.16	4.72	5.85	
	0200	4 mile round trip, 1.8 loads/hr.		85	.094			1.83	3.71	5.54	6.90	
	0310	12 C.Y. dump truck, 1/4 mile round trip 3.7 loads/hr.	B-34B	356	.022			.44	1.09	1.53	1.87	
	0320	1/2 mile round trip, 3.2 loads/hr.		308	.026			.51	1.26	1.77	2.15	
	0330	1 mile round trip 2.7 loads/hr.		260	.031			.60	1.49	2.09	2.56	
	0400	2 mile round trip, 2.2 loads/hr.		210	.038			.74	1.85	2.59	3.16	
	0450	3 mile round trip, 1.9 loads/hr.		180	.044			.86	2.15	3.01	3.69	
	0500	4 mile round trip, 1.6 loads/hr.		150	.053			1.04	2.59	3.63	4.43	
	0540	5 mile round trip, 1 load/hr.		98	.082			1.59	3.96	5.55	6.80	
	0550	10 mile round trip, .75 load/hr.		49	.163			3.18	7.90	11.08	13.55	
	0560	20 mile round trip, .5 load/hr.		32	.250			4.86	12.10	16.96	21	
	0600	16.5 C.Y. dump trailer, 1 mile round trip, 2.6 loads/hr.	B-34C	340	.024			.46	1.41	1.87	2.25	
	0700	2 mile round trip, 2.1 loads/hr.		275	.029			.57	1.75	2.32	2.79	
	1000	3 mile round trip, 1.8 loads/hr.		235	.034			.66	2.04	2.70	3.26	
	1100	4 mile round trip, 1.6 loads/hr.		210	.038			.74	2.29	3.03	3.65	
	1110	5 mile round trip, 1 load/hr.		132	.061			1.18	3.64	4.82	5.80	
	1120	10 mile round trip, .75 load/hr.		100	.080			1.56	4.80	6.36	7.70	
	1130	20 mile round trip, .5 load/hr.		66	.121			2.36	7.30	9.66	11.60	
	1150	20 C.Y. dump trailer, 1 mile round trip, 2.5 loads/hr.	B-34D	400	.020			.39	1.20	1.59	1.92	
	1200	2 mile round trip, 2 loads/hr.		320	.025			.49	1.50	1.99	2.39	
	1220	3 mile round trip, 1.7 loads/hr.		270	.030			.58	1.78	2.36	2.84	
	1240	4 mile round trip, 1.5 loads/hr.		240	.033			.65	2.01	2.66	3.20	
	1245	5 mile round trip, 1.1 load/hr.		172	.047			.90	2.80	3.70	4.46	
	1250	10 mile round trip, .85 load/hr.		136	.059			1.14	3.54	4.68	5.65	
	1255	20 mile round trip, .6 load/hr.		96	.083			1.62	5	6.62	8	
	1300	Hauling in medium traffic, add								20%	20%	
	1400	Heavy traffic, add								30%	30%	
	1600	Grading at dump, or embankment if required, by dozer	B-10B	1,000	.012			.27	.83	1.10	1.33	
	1800	Spotter at fill or cut, if required	1 Clab	8	1	Hr.		18.55		18.55	29	
	2000	Off highway haulers										
	2010	22 C.Y. rear or bottom dump, 1000' round trip, 4.5 loads/hr.	B-34F	800	.010	C.Y.		.19	1.14	1.33	1.55	
	2020	1/2 mile round trip, 4.2 loads/hr.		740	.011			.21	1.23	1.44	1.67	
	2030	1 mile round trip, 3.9 loads/hr.		685	.012			.23	1.33	1.56	1.81	
	2040	2 mile round trip, 3.3 loads/hr.		580	.014			.27	1.57	1.84	2.13	
	2050	34 C.Y. rear or bottom dump, 1000' round trip, 4 loads/hr.	B-34G	1,090	.007			.14	1.06	1.20	1.39	
	2060	1/2 mile round trip, 3.8 loads/hr.		1,035	.008			.15	1.12	1.27	1.46	

Golder Associates

SUBJECT ERSDF COVER COST ESTIMATE		
Job No. 923-A017	Made by JPP	Date 5/25/93
Ref. ERSDF	Checked RDL	Sheet 15 of 15
	Reviewed	



(REF: Means, 022-266-1150 to 1255)

MEMORANDUM

TO: FILE 923-A017 June 4, 1993

FR: JOHN PELLICER

RE: ASSUMPTIONS USED FOR COVER SECTION COST ESTIMATES

GEOSYNTHETICS

- Level C personal protection for laborers installing geosynthetics

SILT AND GRAVEL ADMIXTURE

- 25% McGee Ranch silt is admixed to gravel
- Distance to McGee Ranch is a 20 mile one way trip
- Cost of hauling Silt and Gravel Admixture to burial trench was increased 50% due to decontamination of equipment hauling material into the trench
- Means quotes prices for hauling borrow material in a 20 cubic yard truck for 1 mile up to a 20 mile round trip. The estimated round trip to the McGee Ranch is a 40 mile round trip. The Means costs versus round trip distance was plotted and a cost of $12/cy was extrapolated from this data.

OPERATIONS LAYER

- Soil used for operations layer or clean soil may be obtained within 1500 feet of the site
- Cost of hauling Operations Layer to the burial trench was increased 50% due to decontamination of equipment hauling material into the trench

CLEAN SOIL

- Soil used for operations layer or clean soil may be obtained within 1500 feet of the site
- Cost of hauling Clean Soil to the burial trench was increased 50% due to decontamination of equipment hauling material into the trench

CEMENT STABILIZED WASTE

- Cement Stabilized Waste is hauled, placed and compacted at no cost since the material needs to be disposed of anyway. A cost was included for additional spreading to ensure proper lift thickness.

PROOF ROLLING

- Proof rolling was assumed to have an equivalent cost compared to a riding vibratory roller compacting fill (see calculations).

025 100 | Walk/Rd/Parkng Paving

			CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
116	0010	COLD LAID ASPHALT PAVEMENT 0.5 gal. asphalt/S.Y. per in. depth										116
	0020	Well graded granular aggregate										
	0100	Blade mixed in windrows, spread & compacted 4" course	B-90A	1,600	.035	S.Y.	3.60	.77	.98	5.35	6.25	
	0200	Traveling plant mixed in windrows, compacted 4" course	B-90B	3,000	.016		3.60	.35	.46	4.41	5	
	0300	Rotary plant mixed in place, compacted 4" course	"	3,500	.014		3.60	.30	.39	4.29	4.85	
	0400	Central stationary plant, mixed, compacted 4" course	B-36	7,200	.006	↓	7.20	.12	.16	7.48	8.25	
120	0010	CONCRETE PAVEMENT Including joints, finishing, and curing										120
	0020	Fixed form, 12' pass, unreinforced, 6" thick	B-26	3,000	.029	S.Y.	13.50	.61	.60	14.71	16.45	
	0030	7" thick		2,850	.031		15.75	.64	.63	17.02	19.05	
	0100	8" thick		2,700	.033		18	.68	.66	19.34	21.50	
	0200	9" thick		2,900	.030		20.50	.63	.62	21.75	24	
	0300	10" thick		2,100	.042		22.50	.87	.85	24.22	27.50	
	0400	12" thick		1,800	.049		27	1.02	1	29.02	32	
	0500	15" thick	↓	1,500	.059	↓	34	1.22	1.20	36.42	40	
	0510	For small irregular areas, add						100%		100%		
	0600	For continuous welded steel reinforcement over 10' wide, add				S.Y.				4.30		
	0610	Under 10' wide, add								6.45		
	0700	Finishing, broom finish small areas	2 Cefi	135	.119	↓		2.73		2.73	4.08	
	0730	Transverse expansion joints, incl. premolded bit. jt. filler	C-1	150	.213	L.F.	1	4.73	.16	5.89	8.70	
	0740	Transverse construction joint using bulkhead	"	73	.438	"	1.45	9.70	.34	11.49	17.20	
	0750	Longitudinal joint tie bars, grouted	B-23	70	.571	Ea.	2.25	10.85	8.20	21.30	28.50	
	1000	Curing, with sprayed membrane by hand	2 Clab	1,500	.011	S.Y.	.15	.20		.35	.48	
	1650	For integral coloring, see div. 033-126										
	3000	Cold planing incl. cleaning, 1-1/2" thick	B-32	170	.188	S.Y.		4.27	9.50	13.77	17	
122	0010	FINE GRADE Area to be paved with grader, small area	B-11L	800	.020			.43	.70	1.13	1.43	122
	0100	Large area	"	2,000	.008			.17	.28	.45	.57	
	0200	Grade subgrade for base course, roadways	B-32B	17,000	.001	↓		.03	.07	.10	.13	
	0300	Fine grade, base course for paving, see div. 022-308										
	1020	For large parking lots	B-32C	5,000	.010	S.Y.		.21	.32	.53	.67	
	1050	For small irregular areas		2,000	.024			.52	.81	1.33	1.69	
	1100	Fine grade for slab on grade, confined area, machine	↓	1,500	.032			.69	1.08	1.77	2.25	
	1150	Hand grading	B-18	700	.034			.66	.06	.72	1.10	
	1200	Fine grade granular base for sidewalks and bikeways	B-63	2,000	.020			.39	.05	.44	.66	
	3000	Hand grade select gravel, including compaction, 4" deep	B-18	555	.043			.83	.08	.91	1.39	
	3100	6" deep		400	.060			1.15	.11	1.26	1.93	
	3120	8" deep	↓	300	.080			1.54	.15	1.69	2.58	
	3300	Finishing grading slopes, gentle	B-11L	8,900	.002			.04	.06	.10	.13	
	3310	Steep slopes	"	7,100	.002	↓		.05	.08	.13	.16	
128	0010	SIDEWALKS, DRIVEWAYS, & PATIOS No base										128
	0020	Asphaltic concrete, 2" thick	B-37	720	.067	S.Y.	2.95	1.31	.17	4.43	5.50	
	0100	2-1/2" thick	"	660	.073	"	3.63	1.43	.19	5.25	6.40	
	0110	Bedding for brick or stone, mortar, 1" thick	D-1	300	.053	S.F.	.21	1.14		1.35	2	
	0120	2" thick	"	200	.080		.45	1.72		2.17	3.15	
	0130	Sand, 2" thick	B-18	8,000	.003		.07	.06	.01	.14	.18	
	0140	4" thick	"	4,000	.006	↓	.15	.12	.01	.28	.36	
	0300	Concrete, 3000 psi, cast in place with 6 x 6 - W1.4 x W1.4 mesh,										
	0310	broomed finish, no base, 4" thick	B-24	600	.040	S.F.	.92	.87		1.79	2.35	
	0350	5" thick		545	.044		1.10	.95		2.05	2.68	
	0400	6" thick	↓	510	.047	↓	1.28	1.02		2.30	2.98	
	0440	For other finishes, see Div. 033-450										
	0450	For bank run gravel base, 4" thick, add	B-18	2,500	.010	S.F.	.12	.18	.02	.32	.44	
	0520	8" thick, add	"	1,600	.015		.24	.29	.03	.56	.74	
	0550	Exposed aggregate finish, add to above, minimum	B-24	1,875	.013		.06	.28		.34	.50	
	0600	Maximum		455	.053		.21	1.14		1.35	1.99	
	0700	Patterned surface, add to above min.		1,200	.020			.43		.43	.67	
	0710	Maximum	↓	500	.048	↓		1.04		1.04	1.60	

APPENDIX D

DAILY SOIL COVER COST

Golder Associates

SUBJECT ERSDF – Cost of Clean Soil Daily Cover		
Job No. 923-A017	Made by FSS	Date 6-25-93
Ref. ERSDF	Checked RDL	Sheet 1 of 3
	Reviewed	

Cost of 6" clean soil cover: from interim cover estimate

Table 3-1, Section D-2 : 0.37 / ft²

extra excavation: elevating scraper, 11 yd³, sand & gravel, 1500 ft haul

Means 022-246-0100 : $2.06/yd³

$\$2.06 \times \frac{1}{27} \times \frac{1}{2} = \$0.04$ ✓

Total: $0.41 / ft² ✓

= $18,000 / acre ✓

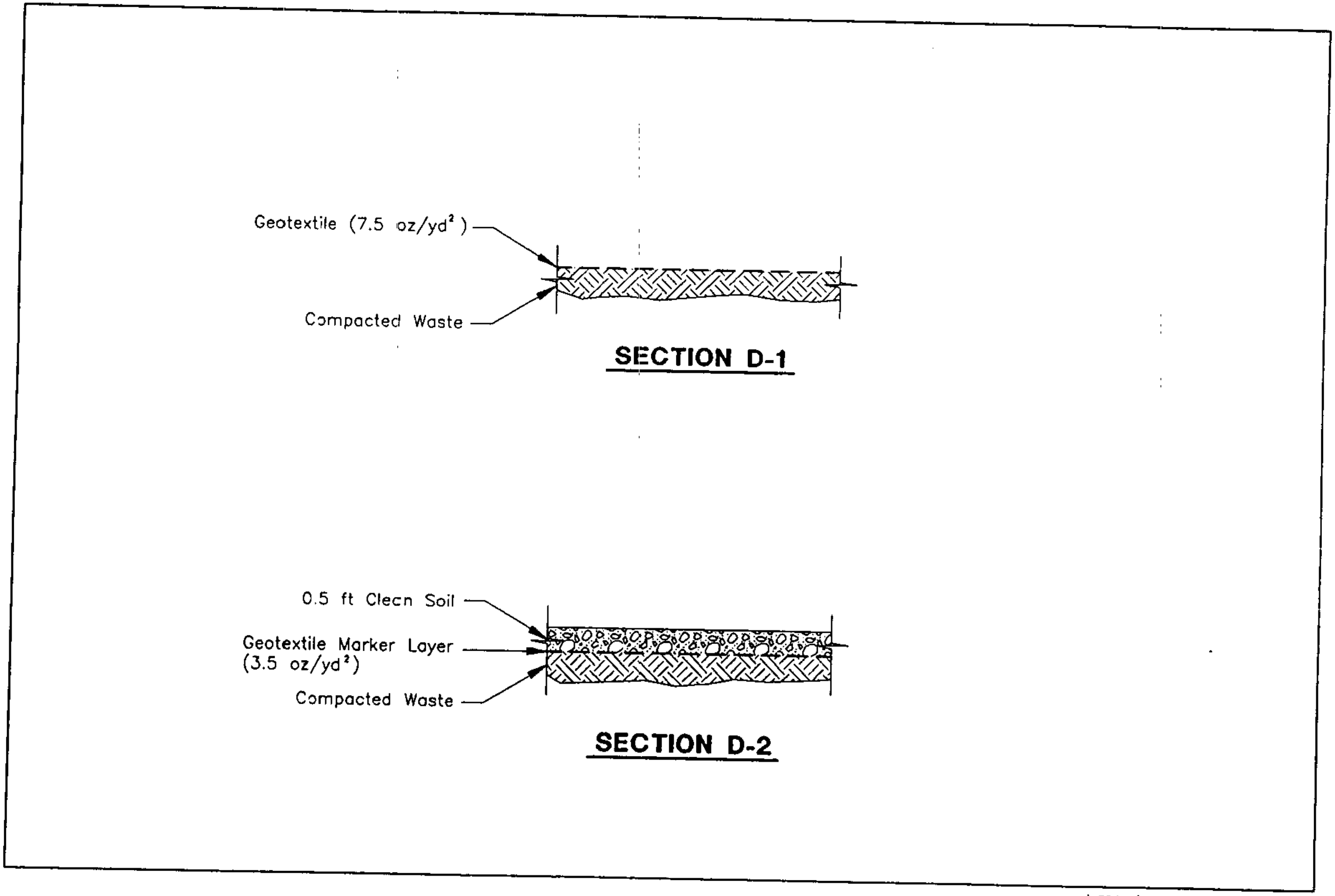


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Figure 3-5. Permeable Covers Not Intended for Traffic Conditions.

Sheet 2 of 3

2 SITE WORK

		022 200 | Excav, Backfill, Compact	CREW	DAILY OUTPUT	MAN-HOURS	UNIT	1993 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P
242	2020	Common earth	B-10L	400	.030	C.Y.		.67	.73	1.40	1.8[illegible]
	2040	Clay		250	.048			1.07	1.17	2.24	2.9[illegible]
	2200	150' haul, sand & gravel		230	.052			1.16	1.27	2.43	3.1[illegible]
	2220	Common earth		200	.060			1.34	1.46	2.80	3.6[illegible]
	2240	Clay		125	.096			2.14	2.33	4.47	5.8[illegible]
	2400	300' haul, sand & gravel		120	.100			2.23	2.43	4.66	6.1[illegible]
	2420	Common earth		100	.120			2.67	2.92	5.59	7.3[illegible]
	2440	Clay	↓	65	.185			4.11	4.49	8.60	11.2[illegible]
	3000	105 H.P., 50' haul, sand & gravel	B-10W	700	.017			.38	.59	.97	1.24
	3020	Common earth		610	.020			.44	.68	1.12	1.42
	3040	Clay		385	.031			.69	1.08	1.77	2.26
	3200	150' haul, sand & gravel		310	.039			.86	1.34	2.20	2.79
	3220	Common earth		270	.044			.99	1.54	2.53	3.21
	3240	Clay		170	.071			1.57	2.44	4.01	5.10
	3300	300' haul, sand & gravel		140	.086			1.91	2.96	4.87	6.20
	3320	Common earth		120	.100			2.23	3.46	5.69	7.20
	3340	Clay	↓	100	.120			2.67	4.15	6.82	8.65
	4000	200 H.P., 50' haul, sand & gravel	B-10B	1,400	.009			.19	.59	.78	.94
	4020	Common earth		1,230	.010			.22	.68	.90	1.07
	4040	Clay		770	.016			.35	1.08	1.43	1.72
	4200	150' haul, sand & gravel		595	.020			.45	1.40	1.85	2.23
	4220	Common earth		516	.023			.52	1.61	2.13	2.57
	4240	Clay		325	.037			.82	2.56	3.38	4.08
	4400	300' haul, sand & gravel		310	.039			.86	2.68	3.54	4.27
	4420	Common earth		270	.044			.99	3.08	4.07	4.91
	4440	Clay	↓	170	.071			1.57	4.89	6.46	7.80
	5000	300 H.P., 50' haul, sand & gravel	B-10M	1,900	.006			.14	.49	.63	.76
	5020	Common earth		1,650	.007			.16	.56	.72	.87
	5040	Clay		1,025	.012			.26	.90	1.16	1.39
	5200	150' haul, sand & gravel		920	.013			.29	1.01	1.30	1.56
	5220	Common earth		800	.015			.33	1.16	1.49	1.78
	5240	Clay		500	.024			.53	1.85	2.38	2.86
	5400	300' haul, sand & gravel		470	.026			.57	1.97	2.54	3.04
	5420	Common earth		410	.029			.65	2.26	2.91	3.49
	5440	Clay	↓	250	.048			1.07	3.71	4.78	5.70
	5500	460 H.P., 50' haul, sand & gravel	B-10X	1,930	.006			.14	.62	.76	.90
	5510	Common earth		1,680	.007			.16	.72	.88	1.03
	5520	Clay		1,050	.011			.25	1.15	1.40	1.65
	5530	150' haul, sand & gravel		1,290	.009			.21	.93	1.14	1.35
	5540	Common earth		1,120	.011			.24	1.07	1.31	1.55
	5550	Clay		700	.017			.38	1.72	2.10	2.48
	5560	300' haul, sand & gravel		660	.018			.40	1.82	2.22	2.63
	5570	Common earth		575	.021			.46	2.09	2.55	3.01
	5580	Clay	↓	350	.034			.76	3.44	4.20	4.95
	6000	700 H.P., 50' haul, sand & gravel	B-10V	3,500	.003			.08	.77	.85	.97
	6010	Common earth		3,035	.004			.09	.89	.98	1.11
	6020	Clay		1,925	.006			.14	1.40	1.54	1.75
	6030	150' haul, sand & gravel		2,025	.006			.13	1.33	1.46	1.66
	6040	Common earth		1,750	.007			.15	1.54	1.69	1.92
	6050	Clay		1,100	.011			.24	2.44	2.68	3.06
	6060	300' haul, sand & gravel		1,030	.012			.26	2.61	2.87	3.27
	6070	Common earth		900	.013			.30	2.99	3.29	3.75
	6080	Clay	↓	550	.022	↓		.49	4.89	5.38	6.15
	6090	For dozer with ripper, see div. 022-278									
246	0010	EXCAVATION, BULK, SCRAPERS R022-240									
	0100	Elevating scraper 11 C.Y., sand & gravel 1500' haul	B-33F	690	.020	C.Y.		.46	1.24	1.70	2.06

APPENDIX E

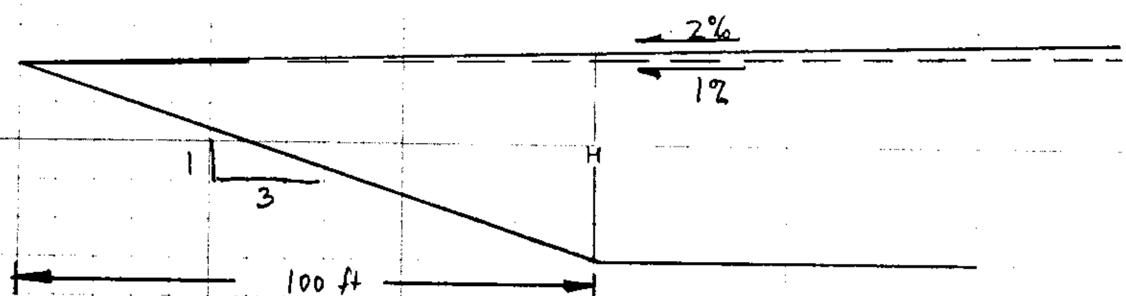
WASTE SETTLEMENT CALCULATIONS

Golder Associates

SUBJECT WASTE SETTLEMENT CALCULATION		
Job No. 923-A017	Made by JPP	Date 6/3/93
Ref. ERSDF	Checked FSB	Sheet 1 of 1
	Reviewed	

OBJECTIVE: Determine how much waste settlement is required to reduce the cover grade from 2% to 1%.

ASSUMPTIONS:
- Waste consists of contaminated noncohesive sands and gravels
- Subgrade and soil liner settlement is negligible
- Waste will be placed in lifts and compacted.
- Geometry of burial cell is similar to section shown below
- Initial cover grade is 2%, + minimum cover grade is 1%.



Not To Scale

- Height of waste fill at break in floor liner slope

  Waste Height = (100 ft)(0.33) + (100 ft)(0.02) = 35.3 ft

- Maximum change in cover slope is 1% or 1 ft/100 ft
- Maximum change in height of cover slope at floor slope break is 1 ft.
- Calculate maximum allowable settlement percentage for waste

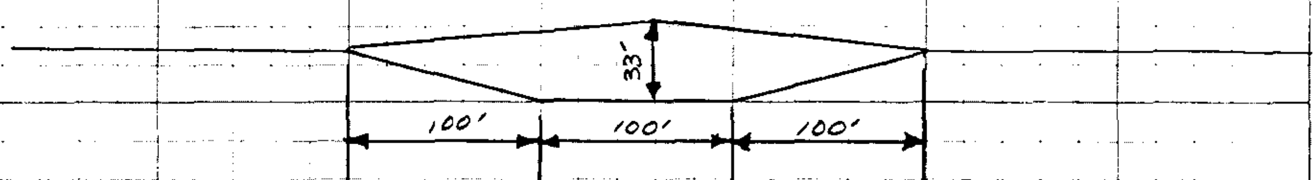
$$\text{MAX. \% STRAIN} = \frac{\Delta H}{H_o} = \frac{1\ ft}{35.3\ ft} = 2.8\%$$

$H_o = 35.3$ FT

$\Delta H = H_o - H_{final} = 35.3 - (35.3 - 1) = 1$

Problem: Estimate elastic or immediate settlement of waste in ERSDF due to placement of the final cover (hanford barrier). From the vertical settlement, calculate the differential settlement of the cap.

Given: 1) Geometry of Landfill - 100' wide, 33', deep, 3H:1V side slopes



2) Final cover, Hanford Barrier, appoximately 15' thick.

3) Waste - primarily composed of contaminated granular soils, ranging from gravels to silty sands

Assumptions: 1-Dimensional Elastic settlement Analysis can be used to estimate settlement of the waste due to placement of the final cap. Other assumptions will be noted during the analysis.

Golder Associates	SUBJECT Settlement Calculations		
	Job No. 923-A017 Ref. ERSDF	Made by QDY Checked FSB Reviewed	Date 6-24-93 Sheet 2 of 6

Calculations: 1-D Elastic Settlement

$$\rho_s = \frac{\sigma_v H}{E}$$

where: ρ_s = settlement

H = thickness of compressible material

E = Elastic constant for material

σ_v = Change in vertical stress

Assign a Elastic constant to the waste material; 2 conditions analyzed:

1) Waste placed in 2'-3' lifts w/ no compaction other than construction equipment.

2) Waste placed in 1' lifts w/ compaction from vibratory drum rollers

Using Schmertmann (1970) conversion for a clean fine to medium sand and slightly silty sands:

$$E_s = 7N \text{ TSF}$$

where:

N = Blow Count (SPT)

E_s = Elastic Constant for the material

For condition 1, based on engineering judgement, the material would be atleast loose, or 4 blow count material (4 N)

For condition 2, based on engineering judgement, the material would be atleast medium dense, or 15 blow count material.

Golder Associates	SUBJECT Settlement Calculations		
	Job No. 923-AC17	Made by RDJ	Date 6-24-93
	Ref. ERSDF	Checked FSB	Sheet 3 of 6
		Reviewed	

Calculations: (continued)

Elastic Constant

Condition 1 – $E_s = (7)(4) = 28$ TSF

Condition 2 – $E_s = (7)(15) = 105$ TSF

Change in vertical stress due to placement of the Hanford barrier,

- barrier is about 15' thick
- assume unit weight = 125 pcf for barrier

$\therefore \sigma_v = (15)(125)$

$\sigma_v = \frac{1,875 \text{ psf}}{2000 \text{ lb}} = 0.93$ TSF ✓

Calculate vertical settlement for 33' of waste

(1) Condition 1;

$\rho_s = \frac{\sigma_v H}{E_s}$

$\rho_s = \frac{(0.93 \text{ TSF})(33')}{28 \text{ TSF}}$

$\rho_s = 1.1$ ft (3.3%) ✓

(2) Condition 2;

$\rho_s = \frac{(0.93 \text{ TSF})(33')}{(105 \text{ TSF})}$

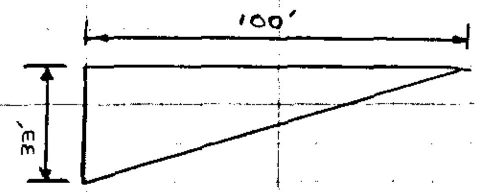
$\rho_s = 0.29$ ft (1%) ✓

Golder Associates	SUBJECT Settlement Calculations		
	Job No. 923-A017 Ref. ERSDF	Made by BDY Checked FSS Reviewed	Date 6-24-93 Sheet 4 of 6

Calculations: (continued)

Calculate Differential Settlement of Cap due to Elastic Settlement - change in slope

① Condition 1



Assume 0' settlement at edge & maximum settlement where waste is 33' thick.

$\rho_d = \frac{1.1'}{100'} = 1\%$

② Condition 2

$\rho d = \frac{0.29'}{100'} = 0.3\%$

Summary of Calculations

① For case 1, waste placed in loose condition;
- maximum vertical settlement = 1.1 ft
- Differential settlement in 100' = 1%

② For case 2, waste compacted to a medium dense condition;
- maximum vertical settlement = 0.3 ft
- Differential settlement in 100' = 0.3%

150 miles from Gainesville. The sands tested were above the water table, and include silty fine sand to uniform medium sand. However, most tests involved only fine sand with a uniformity coefficient of 2 to 2.5.

Fig. 4 includes 29 screw-plate tests from two research sites on the campus of the University of Florida. To condense the results from these 29, Fig. 4 shows only the average values for each group of tests at the same depth at the same site. Dashed lines indicate the spread of the data from one site. These special research tests involved only two plate depths, 2.8 ft and 6.1 ft. Nine tests were also made on 1.0 sq ft rigid, circular plates at these same plate depths at one of these sites. Again, average values and spread are indicated. The adjacent number indicates the number of individual tests in the average. The eight remaining sites account for 24 screw-plate tests at depths ranging from 3 ft to 26 ft, averaging 9.3 ft. At one of these sites data were also available from three 1-ft square rigid plate tests by Law Engineering Testing Co. Thus, the total number of individual plate tests included in Fig. 4 consists of 53 screw-plate and 12 rigid plate tests.

It appears from Fig. 4 that about 90% of these data fall within the factor-of-2 band shown. It is not surprising that a good correlation exists between compressibility and cone bearing in sands because in some ways the penetration of the cone is similar to the expansion of a spherical or cylindrical cavity, or both (2). Alternatively, if the cone is thought of as measuring bearing capacity and hence shear strength, then one can also argue, as the writer has already done, that the compressibility of sand is greatly dependent on its shear strength.

To convert screw-plate compressibility into E_s values required for Eq. 6 only required backfiguring that E_s value needed to satisfy Eq. 6 and each measured settlement. This resulted in the correlation in Fig. 5. Because the grouping of the individual points proved similar to that in Fig. 4, only the factor-of-two- band is shown (dashed lines). With this band as a guide the writer then chose a single correlation line for design in ordinary sands. Thus

$$E_s = 2\,q_c \quad \text{(7)}$$

This line was chosen because it falls within the screw-plate band, because it results in generally acceptable predictions for settlement in the subsequent test cases and also because of its simplicity. Eq. 7 permits the use of inexpensive cone bearing data to estimate static sand compressibility, as represented by E_s. Then compute settlement from Eq. 6.

Webb (40) recently reported the results of an independent correlation study in South Africa between the insitu screw-plate compressibility of fine to medium sands below the water table and cone bearing. His data include seven tests using a 6-in. diam plate (0.20 sq ft), eight tests with a 9-in. plate (0.44 sq ft) and one test with a 15-in. plate (1.23 sq ft). Cone bearing ranged between about 10 tsf and 100 tsf. He offers the following correlation equation for converting q_c to his E':

$$E' \text{ (tsf)} = 2.5\,(q_c + 30 \text{ tsf}) \quad \text{(8)}$$

Comparison of the elastic settlement formula in his paper and Eq. 6 herein shows that $E_s = C_1 C_2\ 0.6\ E'$. This assumes a constant E_s for a $2B$ depth below the screw-plate, permitting $\Sigma\, I_z\, \Delta z$ = area under $2B$-0.6 I_z distribution = $0.60B$. The average product $C_1 C_2$ used by the writer when converting his screw-plate data was about 0.88. Thus, $E_s \approx 0.53\ E'$. Webb's equation then converts to $E_s \approx 1.32\,(q_c + 30)$. Further comparison with Eq. 7 now shows the same prediction for E_s when $q_c \approx 60$ tsf, and a difference of [illegible] or less when q_c lies between 35 tsf and 170 tsf. Reference to Tables 1 and 2 shows that this range includes most natural sands. Such agreement supports the validity of using cone bearing data to estimate the insitu compressibility of sand under a screw-plate.

Method of Accounting for Soil Layering, Including a Rigid Boundary Layer.— The simple I_z distribution developed herein from elastic theory and model experiments assumed or used a homogeneous foundation material. But sand deposits vary in strength and compressibility with depth. It is further assumed that the I_z distribution remains the same irrespective of the nature of [illegible] such layering and that the effects of such layering are approximately, but adequately, accounted for by varying the E_s value in Eq. 6 in accord with Eq. 7.

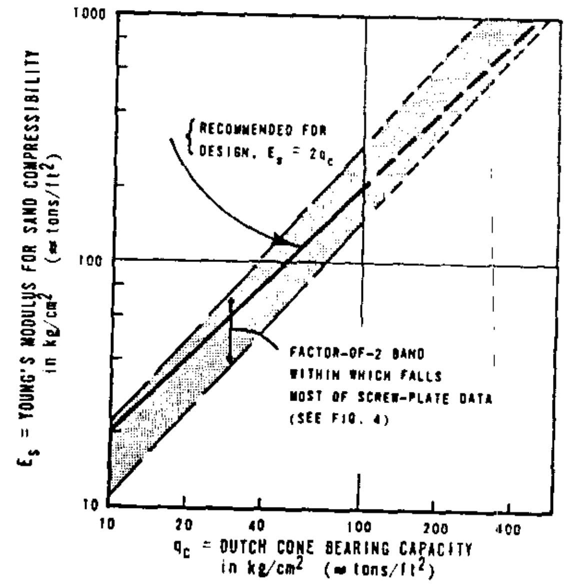


FIG. 5.—CORRELATION BETWEEN q_c AND E_s RECOMMENDED FOR USE IN ORDINARY DESIGN

It is possible that the above method of accounting for layering represents an oversimplification and will result in serious error under special circumstances not now appreciated. More research would be useful to define the limitations of this method and to improve it. Model studies, especially computer simulation using the nonlinear, stress dependent finite element technique, appear to have great promise for investigating such problems. This approach to layering also includes the treatment of a rigid boundary layer encountered within the interval 0 to $2B$. The $2B$-0.6 I_z distribution remains the same but the soils below this boundary, to the depth $2B$, are assumed to have a very high modulus. Vertical strains below such a boundary then become negligible and can be taken equal to zero.

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using a 10% limiting depth of 1200 cm. In this case a 50% increase in Δp results in only a 38% increase in the predicted settlement.

It is unusual for static load tests in sands to exhibit underlinear load settlement behavior, usually it is approximately linear a low pressure and becomes progressively more overlinear as bearing capacity failure is approached. This may be a further indication of some significant theoretical inaccuracy in the Buisman-DeBeer method.

At this point it is well to note again that both methods ignore at least one effect of layering in E_s values. The Buisman-DeBeer method does not include a correction for changes in the profile of vertical stress increase resulting from layering. The new strain-distribution method does not include a correction for changes in I_z resulting from layering.

TEMPORARY USE OF STANDARD PENETRATION TEST DATA

Although used world wide, presently the static cone penetration test is not used extensively in the United States. An engineer may not be able to specify this type of test on his project because the necessary equipment is not available. On the other hand, use of the SPT is common and the equipment is readily available. It is therefore of interest to note any empirical correlation that may exist between q_c and N.

Many investigators have explored this correlation. Meyerhof (24) suggested that $q_c/N = 4$. Others are noted by Sanglerat (30) and Schultze (33). The writer's experience with this correlation in granular soils, limited mostly to uniform fine sands but including some silty and medium sands, is summarized by the data in Fig. 9. The mean values of q_c/N fall in the range of 4.0 to 4.5, which for fine sands checks Meyerhof's suggestion. But there is a great spread around the means. This should be expected. Both types of tests, but particularly the SPT (11,26), are subject to error. The many sites, testing laboratories, drillers and types of equipment involved in the writer's data accentuate the variability in SPT results. However, in all cases N was to be determined in substantial accord with ASTM D1586. It should be noted that at some individual sites, with only one laboratory, driller and piece of equipment involved, the q_c/N correlation spread was similar to that presented for all sites. At other sites the spread was much less.

It is also quite clear from the writer's experience, and that of others, that the q_c/N ratio varies with grain size and perhaps with gradation. The finer grained the soil, the smaller the q_c/N ratio, reaching as low as about 1.0 for some clays and as high as 18 (22,23), for some gravels.

If an engineer wishes to use the settlement estimate procedure of Buisman-DeBeer, or the new one suggested herein, but he has only SPT N-values, then he must convert these as best as he can to q_c values. This conversion should ordinarily be conservative, with the q_c values on the low side of reality. Obviously, in view of the potential scatter demonstrated by the data in Fig. 9, it is much more desirable, and should lead to less expensive design, to have direct determination of q_c. As a temporary expedient the writer recommends the following q_c/N ratios which are usually conservative:

Soil Type	q_c/N
Silts, sandy silts, slightly cohesive silt-sand mixtures	2.0
Clean, fine to med. sands & slightly silty sands	3.5
Coarse sands & sands with little gravel	5
Sandy gravels and gravel	6

Assume these ratios are independent of depth, relative density, and conditions. The writer also suggests that as many N-values as possible be obtained to minimize, by averaging, the large correlation error possible with only few data.

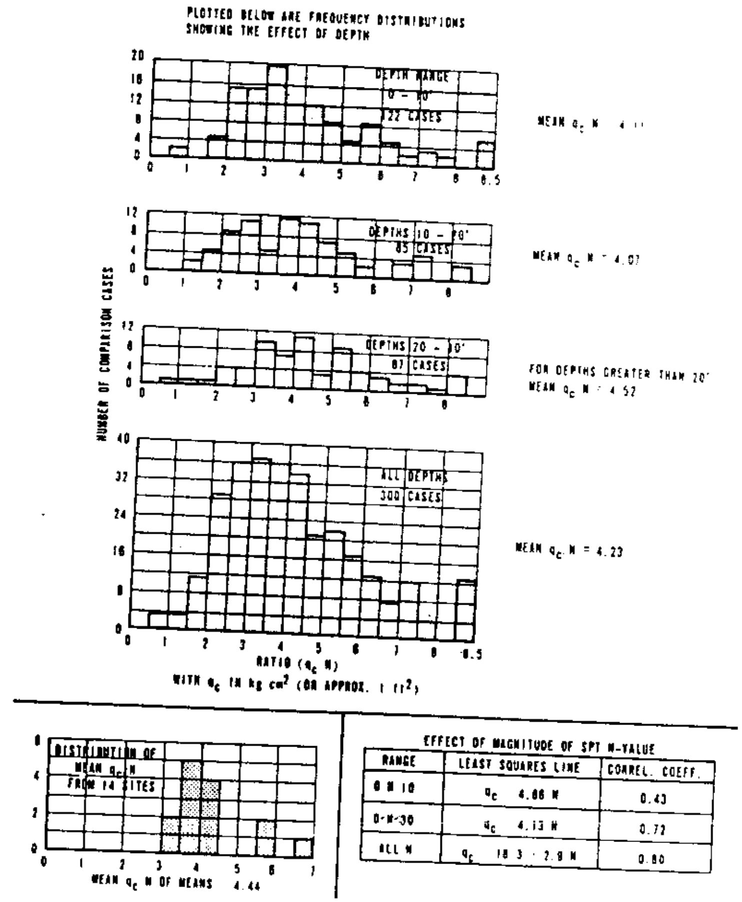

FIG. 9.—DATA FOR CORRELATING N AND q_c IN SILTY TO MEDIUM SANDS (Comparison holes 3-10 ft apart; All q_c by University of Florida; N by 7 firms at 14 sites, 13 of which in Florida; All N are uncorrected.)

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