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DOE/RL-93-33
Rev. 1

Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas

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Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Bechtel Hanford, Inc.
Richland, Washington

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EXECUTIVE SUMMARY

The 200 Areas of the U.S. Department of Energy (DOE) at the Hanford Site are included on the National Priorities List (NPL) under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*. Inclusion on the NPL initiates the remedial investigation (RI) and feasibility study (FS) process of characterizing the nature and extent of contamination and selecting remedial actions.

Under the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement), 10 aggregate area management studies were prepared for the 200 Areas in support of RI/FS activities. These aggregate area management studies summarize characterization information for 200 Area waste-management units. Aggregate area management studies also arrange waste-management units into analogous groups and recommend a range of potential remedial technologies.

The aggregate area management studies also recommended that focused feasibility studies (FFS) be performed for those alternatives that have broad application and are considered viable from an effectiveness, implementability, and cost standpoint. One particular alternative recommended in the Aggregate Area Management Study (AAMS) Reports for a FFS is remediation with surface barriers. This FFS was undertaken based on that recommendation.

This FFS evaluates a total of four conceptual barrier designs for different types of waste sites. The Hanford Barrier, the Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier are being considered as the baseline design for the purpose of the FFS evaluation. A fourth barrier design, the Standard RCRA Subtitle C Barrier, is also evaluated in this FFS; it is commonly applied at other waste sites across the country. These four designs provide a range of cover options to minimize health and environmental risks associated with a site and specific waste categories for active design life periods of 30, 100, 500, and 1,000 years. Design criteria for the 500 and 1,000-year design life barriers include design performance to extend beyond active institutional control and monitoring periods.

- **Hanford Barrier**. This barrier is the baseline design for sites with Greater-Than-Class C (GTCC) low-level waste (LLW) and/or GTCC mixed waste, and/or significant inventories of transuranic (TRU) constituents. This barrier is designed to remain functional for a performance period of 1,000 years and to provide the maximum practicable degree of containment and hydrologic protection of the evaluated designs. The Hanford Barrier is composed of nine layers of durable material with a combined thickness of 4.5 m (14.7 ft). The barrier layers are designed to maximize moisture retention and evapotranspiration capabilities, and to minimize moisture infiltration and biointrusion, considering long-term variations in Hanford Site climate.

  The primary structural differences between the Hanford Barrier and other barriers discussed in this report are increased thicknesses of individual layers and the inclusion of a coarse-fractured basalt layer to control biointrusion and to limit inadvertent human intrusion.

- **Modified RCRA Subtitle C Barrier**. This barrier is the baseline design for sites containing dangerous waste, Category 3 LLW and/or Category 3 mixed LLW, and Category 1 mixed LLW. This barrier is designed to provide long-term containment and hydrologic protection for a performance period of 500 years. The performance period is based on radionuclide concentration and activity limits for Category 3 LLW. The Modified RCRA Subtitle C Barrier is composed of eight layers of durable material with a combined minimum thickness of 1.7 m (5.5 ft). This design incorporates *Resource Conservation and Recovery Act of 1976* "minimum technology guidance" (MTG) (EPA 1989), with modifications for extended performance. One major change is the elimination of the clay layer, which may desiccate and crack over time in an arid environment. The geomembrane component has also been eliminated because of its uncertain long-term durability.

The Modified RCRA Subtitle C Barrier is similar in structure to the Hanford Barrier, but layer thicknesses are reduced and there is no fractured basalt layer. The design incorporates provisions for biointrusion and human intrusion control. However, the provisions are modest relative to the corresponding features in the Hanford Barrier design, reflecting the reduced toxicity of the subject waste and the reduced design-life criterion.

The Modified RCRA Subtitle C Barrier design could be enhanced by increasing the thickness of the topsoil layers and by including some type of intrusion deterrence layer (similar in function to the fractured basalt layer of the Hanford Barrier) so that it would provide additional protection for sites with significant inventories of TRU constituents. This is a potential evolutionary direction for the Subtitle C Barrier.

- **Standard RCRA Subtitle C Barrier**. This barrier design can be used at treatment, storage, and disposal (TSD) sites and sites containing dangerous constituents. This barrier is designed to provide containment and hydrologic protection for a period of 30 years, to include institutional control consisting of monitoring and necessary maintenance. The Standard RCRA Subtitle C Barrier is composed of four primary layers with a combined minimum thickness of 165 cm (65 in.). The barrier layers are designed to shed surface waters, and only minimally account for moisture retention and evapotranspiration capabilities. Biointrusion is mitigated primarily by institutional control, monitoring, and maintenance. However, MTG suggest using optional surface layer treatments for biointrusion considerations.

The Standard RCRA Subtitle C Barrier technology meets U.S. Environmental Protection Agency (EPA) Minimum Technology Guidelines (MTG) as established in EPA/530-SW-89-047, *Technical Guidance Document, Final Covers on Hazardous Waste Landfills and Surface Impoundments*. The Standard RCRA Subtitle C Barrier has limited applications and use at the Hanford Site. Limitations include the following:

- Limited design life that may be inadequate for the radioactive waste categories
- Anticipated high surveillance and maintenance and operations cost caused by implementation of the low permeability layer design features in an arid climate condition
- Maintenance and operations cost caused by surface water run-on and runoff control, collection, and discharge facilities.

- **Modified RCRA Subtitle D Barrier**. This barrier is the baseline design for nonradiological and nonhazardous solid waste sites, as well as Category 1 LLW sites where hazardous constituents are not present. The Modified RCRA Subtitle D Barrier is composed of four layers of durable material with a combined minimum thickness of 0.90 m (2.9 ft). It is designed to provide limited biointrusion and limited hydrologic protection (relative to the other two barrier designs) for a performance period of 100 years. The performance period is consistent with the radionuclide concentrations and activity limits specified for Category 1 LLW. The 100-year design life is also consistent with the minimum expected duration of active institutional control.

Design criteria for the four designs were determined by screening potentially applicable or relevant and appropriate regulations, regulatory guidance documents, and recognized design standards. Those regulations or standards that are relevant to conceptual designs of surface barriers were retained as design criteria (Section 2.0).

Following design criteria development, existing cover designs for Hanford Site applications were reviewed. These designs were modified, as necessary, to conform to the requirements and criteria identified in Section 2.0. The four evaluated barrier designs are described in Section 3.0. The designs were reviewed against the design criteria to verify conformance, and were evaluated against the nine EPA *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) evaluation criteria (Section 4.0).

It is recognized that sources of some of the materials identified for barrier construction may be culturally and/or ecologically sensitive. Alternative materials and sources have been considered and further evaluation of materials may be warranted.

A flow diagram (Section 5.0) summarizes the proposed implementation logic for barrier evaluation for designated waste-management units. Application of the diagram will require site-specific contaminant inventory information. Section 5.0 also addresses design issues to be considered during definitive design and recommendations for additional activities in support of barrier development and construction.

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FIGURES

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APPENDICES

ACRONYMS

AAMS	aggregate area management study
ARAR	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ERA	expedited response action
FFS	focused feasibility study
FRS	final remedy selection
FS	feasibility study
GTCC	Greater-Than-Class C
HDPE	high-density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
HPPS	Hanford Site Past-Practice Strategy
HLW	high-level waste
IRM	interim remedial measure
LFI	limited field investigation
LL	low level
LLW	low-level waste
MFS	minimum functional standards
MTG	minimum technology guidance
NPL	*National Priorities List*
NRC	Nuclear Regulatory Commission
NRDWL	Nonradiological Dangerous Waste Landfill
PNNL	Pacific Northwest National Laboratory
QRA	qualitative risk assessment
RAO	remedial action objectives
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	Revised Code of Washington
RFI/CMS	RCRA field investigation/corrective measures study
RI	remedial investigation
SDRI	sealed double-ring infiltrometer
SWL	solid waste landfill
TAP	toxic air pollutant
T-BACT	toxic-best available control technology
TBC	to be considered
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRU	transuranic
TSD	treatment, storage, and disposal
USDA	U.S. Department of Agriculture
USLE	universal soil loss equation
VOC	volatile organic compounds
WAC	*Washington Administrative Code*
WDOT	Washington Department of Transportation
WEQ	wind erosion equation

WIDS	Waste Information Data System
WIPP	Waste Isolation Pilot Plant
WMU	waste-management unit

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) at the Hanford Site in Washington State is organized into numerically designated operational areas consisting of the 100, 200, 300, 400, 600, and 1100 Areas (Figure 1-1). In November 1989, the U.S. Environmental Protection Agency (EPA) included the 200 Areas (as well as the 100, 300, and 1100 Areas) of the Hanford Site on the National Priorities List (NPL) under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). Inclusion on the NPL initiates the remedial investigation (RI) and feasibility study (FS) process to characterize the nature and extent of contamination, assess risks to human health and the environment, and select remedial actions.

The *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology 1991) was developed and signed by representatives from the EPA, Washington State Department of Ecology (Ecology), and DOE in May 1989 to provide a framework to implement and integrate cleanup activities. The scope of the agreement covers CERCLA past-practice, *Resource Conservation and Recovery Act of 1976* (RCRA) past-practice, and RCRA treatment, storage, and disposal (TSD) activities on the Hanford Site. The 1991 revision to the Tri-Party Agreement required that an aggregate area approach be implemented in the 200 Areas based on the *Hanford Site Past-Practice Strategy* (HPPS) (DOE-RL 1992b) and established a milestone (M-27-00) to complete 10 Aggregate Area Management Study (AAMS) Reports (DOE-RL 1992a through 1992j) in 1992.

The AAMS reports outlined a process, similar to the initial scoping phase of the CERCLA RI/FS process, to evaluate existing site data to develop a preliminary conceptual model, perform a preliminary risk assessment, and provide recommendations on the appropriate HPPS path for each waste-management unit (WMU) and unplanned release site. The AAMS reports also recommended that focused feasibility studies (FFS) be prepared for the 200 Areas. An FFS evaluates selected remedial alternatives based on their implementability, cost, and effectiveness.

This FFS evaluates generic conceptual designs for covers that could be used in the 200 Areas. The information developed in this screening effort can be used during the site-specific evaluation of 200 Area waste sites that will evaluate the various remedial alternatives and, ultimately, propose specific remedial action for each site. The use of these cover designs for waste sites at other locations throughout the Hanford Site is not precluded by the work in this FFS. The site-specific evaluation at the other waste sites could factor in considerations that were not part of this evaluation (i.e., different land use, threatened and endangered species, etc.), but the site-specific evaluation could use the results of this FFS as their baseline cover design.

1.1 BACKGROUND

The following sections provide background information regarding (1) the location of the 200 Areas, (2) the HPPS, and (3) the AAMS program.

1.1.1 Hanford Site 200 Areas

The Hanford Site occupies about 1,450 km^2 (560 mi^2) of the southeastern part of Washington State north of the confluence of the Yakima and Columbia Rivers. The 200 Areas, located near the center of the Hanford Site, encompass the 200 West, 200 East, and 200 North Areas. Operations in the 200

Areas were mainly related to separation of special nuclear materials from spent nuclear fuel. The 200 Areas contain related chemical processing, fuel processing, and waste-management facilities.

The 200 NPL site encompasses the 200 Areas and selected portions of the 600 Area. The 200 NPL site includes a total of 44 operable units comprised of 20 in the 200 East Area, 17 in the 200 West Area, 1 in the 200 North Area, and 6 isolated operable units. The 200 NPL site contains more than 1,000 waste sites, as identified in the Waste Information Data System (WIDS) (BHI 1994), including CERCLA and RCRA past-practice WMUs, unplanned release sites, RCRA TSD units, and surplus facilities. Principal types of waste sites include storage tanks; landfills; liquid waste infiltration structures such as ponds, cribs, and ditches; and unplanned release sites. Unplanned releases are generally releases from WMUs or spills. The Tri-Party Agreement (Ecology et al. 1991) describes the assignment of WMUs and unplanned release sites to specific operable units and defines the various types of waste sites.

1.1.2 Hanford Site Past-Practice Strategy

The HPPS was developed by Ecology, EPA, and DOE to streamline the existing RI/FS and RCRA facility investigation/corrective measures study (RFI/CMS) processes at the Hanford Site. Primary objectives were to (1) develop a process to meet the statutory requirements and (2) consolidate CERCLA RI/FS and RCRA past-practice RFI/CMS guidance to ensure protection of human health and welfare and the environment at the Hanford Site. The HPPS streamlines investigations and documentation and promotes the use of interim actions to accelerate cleanup. The process relies on the observational approach--refining activities based on knowledge gained as work progresses--to streamline both the documentation and cleanup activities.

For the 200 Areas, the first step was to evaluate existing information through the AAMS process. Based on this information, recommendations were made in the AAMS reports (DOE-RL 1992a through 1992j) regarding which HPPS path to pursue for individual past-practice WMUs, unplanned release sites, and groundwater contaminant plumes. The strategy established four types of remediation paths, including expedited response action (ERA), interim remedial measure (IRM), limited field investigation (LFI), and final remedy selection (FRS). The four paths are defined as follows:

- **ERA path**. Existing or near-term unacceptable health or environmental risk from a site is determined or suspected, and a rapid response is necessary to mitigate the problem.

- **IRM path**. Existing data are sufficient to indicate that the waste site poses a risk through one or more exposure pathways, and additional investigations are not needed to screen the likely range of remedial alternatives for interim actions.

- **LFI path**. Minimum site data are needed to support IRM or other interim decisions and can be obtained in a less formal manner than that needed to support a final remedial decision.

- **FRS path**. The FRS is accomplished within the framework and process defined for RI/FS and RFI/CMS programs with the objective of reaching a defensible final decision. All sites (including low-priority sites) are addressed in a comprehensive manner to reach closure. The FRS path integrates information obtained from ERAs, IRMs, and LFIs; satisfies any additional data needs; and conducts a cumulative baseline risk assessment to support the final Record of Decision (ROD) for an entire operable unit or aggregate area.

The HPPS recognizes that the NPL does not require an RI/FS before cleanup begins. The HPPS indicates that, for IRMs, a remedy might be obvious or, at most, an FFS might be needed to select a remedy. The FFSs focus on technologies that are most viable, thereby limiting the number of remedial alternatives evaluated.

1.1.3 Aggregate Area Management Study Program

Ten reports resulted from the 200 Areas AAMS program (DOE-RL 1992a through 1992j), including reports for eight source and two groundwater aggregate areas. Source aggregate areas were defined based on major 200 Area processing plants, including the U Plant, Z Plant, S Plant, and T Plant in the 200 West Area; B Plant, Plutonium Uranium Extraction Facility (PUREX), and Semi-Works in the 200 East Area; and a fuel element storage area designated as the 200 North Area. The eight source AAMS reports were designed to evaluate source terms, primarily for past-practice sites, on a plantwide scale. Environmental media of interest included air, biota, surface water, surface soil, and unsaturated subsurface soil. In addition, the AAMS reports provide extensive documentation on contaminant inventories, release mechanisms, transport pathways, contaminant characteristics, and conceptual models of the individual areas (see Section 4.0 of specific AAMS reports). These reports also present screening criteria for remedial action objectives (RAO) and technologies and identify technologies that pertain to individual WMUs (see Section 7.0 of specific AAMS reports).

The major objective of the AAMS program was to determine and recommend the appropriate HPPS path for performing cleanup actions for each WMU or unplanned release site.

Another objective of the AAMS program was to provide recommendations for FFSs that could be expedited to support near-term actions at high-priority sites within the framework of the HPPS. Section 7.0 of the AAMS reports (DOE-RL 1992a through DOE-RL 1992j) identifies preliminary remedial alternatives. This was accomplished by first establishing preliminary RAOs for various environmental media. An overall RAO was identified for the 200 Areas:

> *"Reduce the risk of harmful effects to the environment and human users of the area by isolating or permanently reducing the toxicity, mobility, or volume of contaminants from the source areas to meet applicable or relevant and appropriate requirements (ARAR) or risk-based levels that will allow industrial use of the area"* (DOE-RL 1992a through 1992j).

Next, potential remedial technologies were screened based on their effectiveness, implementability, and cost. Technologies considered most viable were grouped into "remedial alternatives" for each general response action (i.e., no action, institutional controls, removal, aboveground treatment, and disposal, containment, and in situ treatment). The remedial alternatives were then developed to treat a major component of the 200 Areas contaminated WMUs or unplanned release sites. Finally, the AAMS reports recommended preparation of FFSs for the viable remedial alternatives for the various media of concern.

For the containment general response action, an engineered multimedia cover, with or without vertical barriers, was identified and considered to pertain to sites with radionuclides, heavy metals, inorganic compounds, and/or organic compounds. A cover satisfied the RAOs of protecting human health and the environment from direct exposures to contaminated soil, biomobilization, and airborne contaminants. Specifically, a cover is considered effective in minimizing (1) infiltration of precipitation into contaminated soil, thereby minimizing the driving force for downward migration of contaminants, (2) migration of windblown dust that originates from contaminated surface soils, (3) penetration of biota into the waste zone, (4) potential for direct exposure to contamination, and (5) the volatilization of volatile organic compounds (VOC) and tritium to the atmosphere (refer to Section 7.4.2 of the source AAMS reports). Table 7-4 of DOE-RL (1992a through 1992j) indicates that covers make up one of several alternatives that potentially have broad applicability to remediating various types of WMUs throughout the 200 Areas. Because of the potential broad application of covers to 200 Area sites, the 200 Area source AAMS reports recommended that an FFS be prepared that focuses on generic cover designs for various waste categories rather than designs for specific waste sites.

1.2 SCOPE AND OBJECTIVES

The scope of this FFS is to develop and evaluate a limited number of conceptual cover designs that could be applied to waste sites in the 200 Areas. The cover designs have been developed generically to provide traceability to applicable or relevant and appropriate requirements (ARAR) and technical guidance. These generic conceptual cover designs can then provide the basis for the cover remedial alternative evaluated in a site-specific FFS. However, a site-specific evaluation of the ARARs and technical guidance will be done to ensure that the cover evaluated in the FFS is appropriate for the waste site-specific characteristics. A site-specific evaluation could result in modifying the generic conceptual cover designs or in evaluating a more appropriate cover for the waste site.

The cover alternatives described in this document were derived from conceptual cover designs originally developed in support of Hanford Site past-practices, waste management, permitting, and RCRA closure activities. Existing designs were used as a basis because considerable engineering evaluations and treatability studies have been completed or are ongoing to support these designs. Therefore, implementing the cover alternative to the 200 Area waste sites is simplified because lengthy studies will not generally be necessary before application. Long-term performance and maintenance objectives and design criteria were established based on an evaluation of ARARs and engineering criteria. Existing cover designs were evaluated against the established criteria and modified accordingly.

This FFS provides generic conceptual designs of covers for waste-site applications rather than site-specific definitive designs. The generic conceptual designs describe the layer sequence in section view through the cover, but do not include construction details, such as terminating the edges of the layers or sideslope configuration. Definitive design must consider the actual contaminant inventory, site geology, topography, and perimeter configuration; and other physical features, such as proximity and surface grading of adjoining facilities or waste sites.

When a site is recommended for remediation under the IRM path, the IRM process described in HPPS will be followed to formulate a conceptual model and perform a qualitative risk assessment (QRA) for the site. The QRA includes a human health evaluation and a separate environmental evaluation. The specific methodology for QRAs is provided in the *Hanford Site Risk Assessment Methodology* (DOE-RL 1993b). The pathways typically evaluated in the QRA include the following:

- Soil ingestion
- Fugitive dust inhalation
- Inhalation of volatile organic chemicals from soil (if present)
- Ingestion of water
- External radiation exposure.

Additional pathways may be evaluated if site information or the physical properties of chemical constituents present suggest that other significant exposure pathways might exist.

Based on the conceptual model and the QRA, an evaluation will be made to determine if the IRM is justified. If so, a separate evaluation will determine if a specific remedial action can be selected. This FFS can be used to help focus the evaluation of remedial alternatives by providing the basis for the cover alternative for the application, considering the type and concentration of waste present and the results of the QRA.

Waste-management units in the 200 Areas that have been identified as candidates for remediation with surface barriers (including high- and low-priority sites) are listed in Appendix B. It is expected that a surface barrier will be one of the remedial alternatives evaluated for each of these sites. Covers may be selected as IRMs for high-priority (i.e., IRM and LFI candidate) sites, or as final remedies for low-priority sites (FRS candidates). The decision logic for determining the appropriate cover option to evaluate for a given site (Section 5.0) is not dependent on the remediation path. Where covers are selected initially as IRMs, it is generally expected that they would also be designated as final remedies.

This FFS report also provides recommendations for any additional studies that may be necessary to facilitate the near-term implementation of the conceptual designs described in this report. These recommendations are provided in Section 5.0. This FFS report provides a limited number of preengineered cover options to support the IRM path. Decision logic for determining the appropriate cover alternative to be evaluated for specific types of sites is provided in Section 5.0.

1.3 GENERAL APPROACH

A seven-step approach was followed in conducting this FFS.

1. **Definition of Waste Categories Present in the 200 Areas**. Section 1.4 summarizes the types of waste present at WMUs in the 200 Areas. The definitions provided in Section 1.4 conform to existing DOE terminology. Section 1.4 also includes a table of 200 Area WMUs (summarized by waste category) that have been identified in source AAMS reports (DOE-RL 1992a through 1992j) as candidates for remediation with engineered surface barriers, following either the IRM or the LFI path.

2. **Preliminary Identification of ARARs and Technical Guidance**. A matrix of pertinent ARARs was developed for each waste type identified in Step 1 (radioactive, dangerous, or nonradioactive/nondangerous). The ARARs (including chemical-, location-, and action-specific requirements) were screened for the generic waste types previously discussed. The ARARs that provide criteria pertinent to covers and cover conceptual design, landfill or land-disposal facility conceptual design, or performance criteria for covering and/or containment of waste were retained for further consideration as FFS generic conceptual design criteria. Regulations considered applicable to a particular waste type were included in the matrix. Requirements that may be relevant and appropriate, depending on site type, were included in the matrix to develop a cover design that would encompass all ARARs. Where regulations were not either applicable or relevant and appropriate, but contained technical criteria that was pertinent to conceptual design development, these regulations were captured in the technical guidance section. Further evaluation of ARARs and technical guidance will also be conducted during the waste site-specific evaluation of remedial alternatives.

3. **Establishment of Conceptual Performance and Design Criteria**. Criteria were established based on the ARARs and technical guidance determined in Step 2 to relate to generic conceptual cover designs. The conceptual performance and design criteria considered the

possibilities of combining the various requirements and guidance to allow for a limited number of cover conceptual designs to be implemented for multiple waste types (radioactive, mixed, dangerous, and nonrad/nondangerous).

4. **Preliminary Evaluation of Cover Types.** Alternative cover concepts were evaluated for the various waste categories to identify specific concepts that best met the design criteria developed for each category. The alternatives were based on existing designs for applications on the Hanford Site (modified, as necessary, to meet the current design criteria).

5. **Preparation of Generic Conceptual Designs.** Generic conceptual designs were prepared consistent with the performance and design criteria established in Step 3.

6. **Detailed Evaluation.** Conformance of the conceptual cover designs to their respective performance and design criteria and the nine criteria prescribed in EPA (1988) was evaluated.

7. **Development of Conclusions and Recommendations.** Section 5.0 summarizes the results of the conceptual design process, identifies issues to be resolved during definitive design, and provides recommendations for additional engineering studies needed to support timely implementation of barrier technology. A logic chart for barrier determinations is included that relates the cover options developed in this FFS to waste categories.

1.4 WASTE SITES AND WASTE CATEGORY DESIGNATIONS

Terminology used at the Hanford Site and other DOE facilities for radiological, dangerous, and other solid waste types is defined as follows:

- **Radioactive Waste.** Solid, liquid, or gaseous material that contains radionuclides regulated under the *Atomic Energy Act of 1954*, as amended, that is of negligible economic value considering costs of recovery. Radioactive waste includes high-level waste (HLW), transuranic (TRU) waste, and low-level waste (LLW).

- **Spent Nuclear Fuel.** Fuel that has been withdrawn from a nuclear reactor following irradiation, but that has not been reprocessed to remove its constituent elements.

- **HLW.** The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid that contains a combination of TRU waste and fission products in concentrations requiring permanent isolation.

- **LLW.** Waste that contains radioactivity and is not classified as HLW or TRU waste. Certain test specimens of fissionable material may be classified as LLW, provided the concentration of TRU is less than 100 nCi/g. The LLW classification limits are provided in Appendix A.

When liquid HLW is separated into high-activity and low-activity fractions in connection with reprocessing operations, the low-activity action is considered to be non-HLW. Non-HLW is managed by DOE as LLW or TRU waste.

- **Byproduct Material.** As defined in 10 CFR 962.3, byproduct material means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or using special nuclear material.

- **TRU Waste.** Currently, DOE defines TRU waste as waste that is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g at the time of assay, without regard to source or form. A transuranium radionuclide is any radionuclide with an atomic number greater than 92. To be classified as TRU waste, the waste must have been disposed after 1970.

Before 1970, there was no requirement to segregate TRU waste from LLW, and a considerable volume of LLW with TRU radionuclides was disposed in burial grounds at various DOE sites. Examples include liquids from processing plants and excess equipment contaminated with TRU constituents. In 1970, the Atomic Energy Commission directed that all government waste with TRU radionuclides greater than 10 nCi/g be stored in retrievable form. In 1984, DOE revised the threshold limit for TRU waste from 10 nCi/g to 100 nCi/g. Thus, there may be TRU constituents present at some sites, but they may not meet the definition as TRU waste and would not be required to follow the TRU waste requirements.

Newly generated, stored, and/or retrieved solid TRU waste, including TRU mixed waste, must be certified for shipment to the Waste Isolation Pilot Plant (WIPP). Solid TRU waste that does not need the degree of isolation provided by a geologic repository or that fails to be certified or approved for disposal at WIPP is to be disposed by alternative methods, which could include disposal at the Hanford Site.

A classification scheme for commercial LLW was promulgated by the Nuclear Regulatory Commission (NRC) in Title 10 *Code of Federal Regulations* (CFR), Part 61. This scheme identified four LLW categories: Class A, Class B, Class C, and Greater-Than-Class C (GTCC). Waste is classified according to concentrations of listed long- and short-lived radionuclides and other unlisted radionuclides. The DOE did not adopt this scheme for use at DOE facilities. Instead, field offices were given latitude to develop site-specific waste classification limits for LLW. The LLW system used at the Hanford Site is described in WHC-EP-0063-4 (WHC 1993).

The Hanford Site system has three LLW waste categories: Category 1 (analogous to NRC Classes A and B), Category 3 (analogous to Class C), and GTCC as originally defined by NRC. Category 1 and 3 waste are defined based on the activity limits listed in Appendix A. As with the NRC system, a "sum-of-fractions" rule is used to evaluate waste with multiple constituents.

- **Dangerous (RCRA Subtitle C) Waste.** Dangerous waste is a solid waste that exhibits certain characteristics (i.e., it is ignitable, corrosive, reactive, or toxic) according to criteria in WAC 173-090, or is listed as a dangerous waste in WAC 173-303-080 through 173-303-083.

Hazardous waste is regulated at the federal level in accordance with RCRA Subtitle C; Washington State regulates "dangerous wastes" that encompass the federal hazardous waste as well as other state requirements and are in accordance with Chapter 70.105 of the Revised Code of Washington (RCW), *Hazardous Waste Management Act*. Hazardous waste is specifically listed or characterized under 40 CFR 261. The term "dangerous waste" will, thus, be used henceforth.

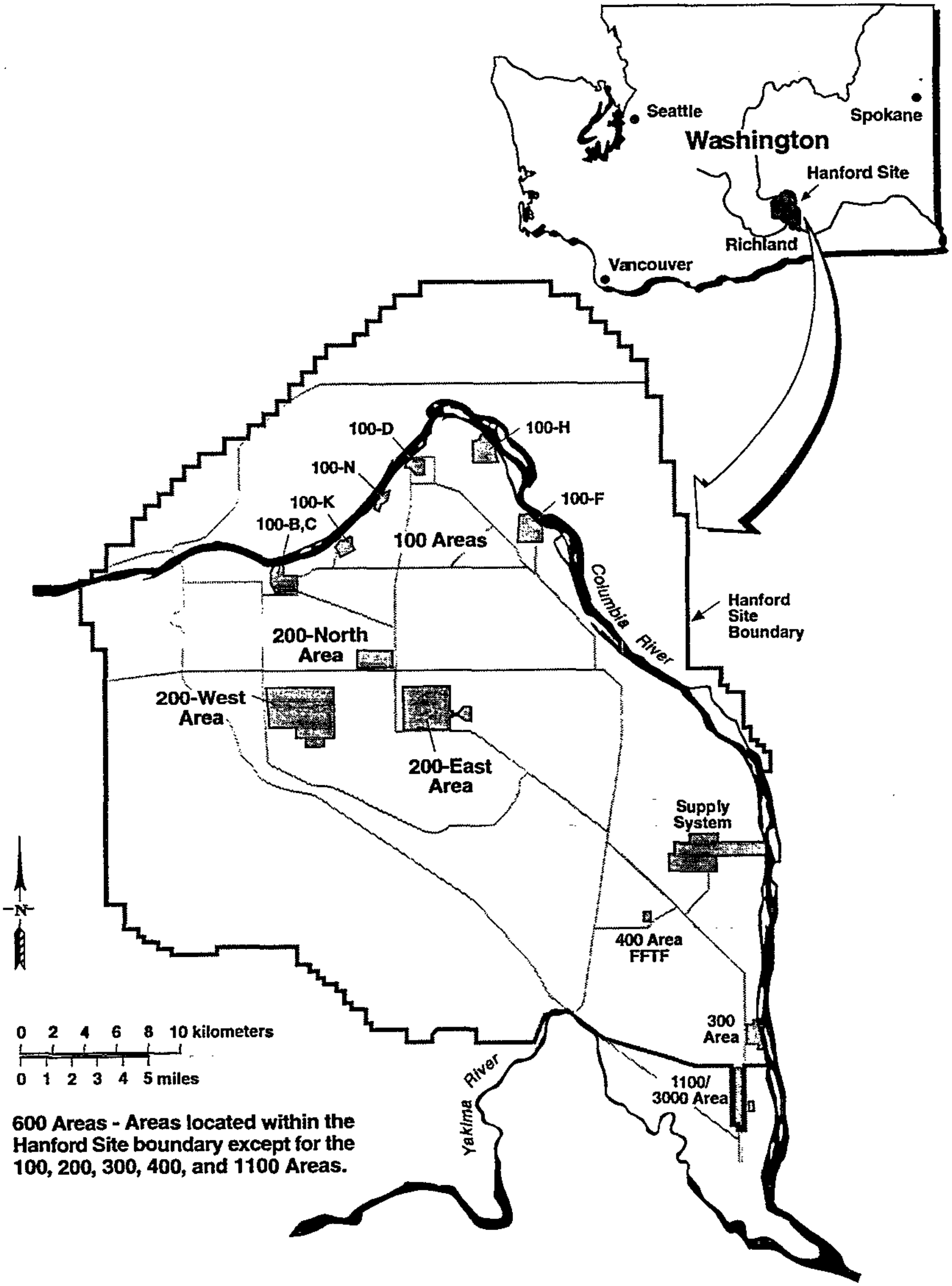
- **Mixed Waste.** Waste containing both radioactive and dangerous waste.

- **Solid (RCRA Subtitle D) Waste.** Solid waste is defined as any discarded material resulting from industrial, commercial, mining, and agricultural operations, and from community activities.

Waste-management units identified in the source AAMS reports (DOE-RL 1992a through 1992j), as candidates for remediation with surface barriers, are listed in Appendix B. The information in Appendix B includes waste category designations for the units, as identified in BHI (1994). The designations are based on current inventory information and may not account for all contaminants present at each individual unit. However, the information may provide a reasonable representation of the waste types in the subject units.

As summarized in Table 1-1, the categories include waste containing TRU constituents, LLW, dangerous waste, mixed dangerous and radiological waste, and nondangerous/nonradioactive solid waste. Based on the data presented in Table 1-1, four waste types are identified that encompass all 200 Area waste sites: (1) TRU constituents, (2) LLW, (3) RCRA Subtitle C waste, and (4) RCRA Subtitle D waste. These four categories establish the preliminary ARARs and performance and design criteria discussed in Section 2.0.

Figure 1-1. Hanford Site Map.



600 Areas - Areas located within the Hanford Site boundary except for the 100, 200, 300, 400, and 1100 Areas.

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Table 1-1. Waste Category Site Summary.

Waste Category	No. of Sites[a]
Waste with TRU constituents	30
LLW and LL/mixed waste	239
Dangerous (RCRA C) waste	8
Nondangerous/nonradiological (RCRA D) solid waste	14
Total	291

RCRA C = *Resource Conservation and Recovery Act*, Subtitle C.
RCRA D = *Resource Conservation and Recovery Act*, Subtitle D.
[a]From Appendix B

2.0 DESIGN CRITERIA DEVELOPMENT

2.1 APPROACH TO DEVELOPING GENERIC CONCEPTUAL DESIGN CRITERIA

Generic conceptual design criteria for engineered surface barriers for 200 Area waste sites were developed by considering ARARs and other technical guidance documents that are or potentially are pertinent to barrier design and performance. The overall objective was to achieve adequate protection of human health and the environment.

Section 2.1.1 outlines the approach and process to evaluate and retain ARARs. Section 2.1.2 outlines the approach and process to evaluate technical guidance that contain other engineering factors that affect cover design. The ARARs considered in this FFS for cover design are summarized in Table 2-1. Section 2.2 describes ARARs, and Section 2.3 describes the technical guidance that pertain to cover designs in this FFS. Section 2.4 summarizes the performance and design criteria that pertain to the generic conceptual cover designs.

2.1.1 Regulatory Criteria (ARARs)

The ARARs were evaluated, including contaminant-, location-, and action-specific requirements. The ARARs were retained for further consideration in this FFS if they provided standards that pertain to the engineering design and/or performance of barriers, covers, landfills, or land disposal facilities, or containment of waste in engineered units. Sections 2.1.1.1 and 2.1.1.2 describe the rationale for retaining ARARs.

The following ARARs evaluation was conducted for the generic baseline cover designs. The final determination of site-specific ARARs will be made in the ROD.

2.1.1.1 ARARs. An ARAR is a promulgated federal or state statute or regulation that establishes requirements that would apply to or otherwise be relevant and appropriate for the implementation of a remedial action under CERCLA. The ARARs are typically grouped into contaminant-specific, location-specific, and action-specific categories. The ARARs in each category were evaluated for their relevance to the development of generic cover designs in this FFS.

Contaminant-specific ARARs generally are used to establish acceptable limits for hazardous chemical and radiological constituents in various environmental media, based on human health and ecological risks and exposure pathways. The ARARs may influence the site-specific selection of remediation alternatives by setting objectives that the alternatives must meet to reduce risks to health and the environment. Thus, these ARARs relate more to the acceptability of a cover as a remedial alternative and not as much to the establishment of design or performance criteria for the cover designs in this FFS. Therefore, contaminant-specific ARARs were not retained as cover-design criteria, and any site-specific criteria can be incorporated in the site-specific FFS development.

Contaminant-specific ARARs were evaluated on a preliminary basis in Section 6.2 of the source AAMS reports (see Table 6-1 of individual reports). Based on that evaluation, it is considered unlikely that significant modifications would be required to any of the generic conceptual cover designs developed in this FFS to properly account for contaminant-specific ARARs. However, this group of ARARs will be reconsidered during definitive cover designs for individual sites to verify that contaminants will be appropriately isolated and immobilized.

Although several location-specific ARARs apply or may be relevant to the siting of land-disposal facilities and waste-containment units, it was determined that they only address where certain activities (e.g., waste disposal) may or may not be conducted. Although such standards prescribe the types of environmental locations in which certain types of waste may be disposed, they do not dictate cover-design criteria or performance requirements. Consequently, the generic conceptual cover designs described in this FFS do not include standards based on location-specific ARARs.

Action-specific ARARs generally include design and performance considerations when implementing remedial alternatives. A significant number of ARARs of this type were found to relate to cover designs. Action-specific ARARs constitute the majority of the regulatory criteria that were determined to be ARARs for the cover designs in this FFS.

The retained ARARs are summarized in Table 2-1 and evaluated in Section 2.2. The CERCLA mandates that remedies must comply with any promulgated standard, requirement, criteria, or limitation under a state environmental- or facility-siting law that is more stringent than any federal standard, requirement, or limitation, if applicable or relevant and appropriate to the hazardous substance or release in question. Therefore, Table 2-1 and Section 2.2 present only the state version of an equivalent federal requirement where the state version is more stringent.

The ARARs have been organized by the types of waste to which they are pertinent: LLW, dangerous waste, and solid waste. No sites that received TRU waste are addressed in this FFS. TRU waste is defined as waste generated and disposed after 1970 that contains in excess of 100 nCi/g of TRU constituents. Sites may contain TRU constituents, generally at low concentrations. Citations to the federal and state regulations are provided. In general, 10 CFR includes regulations promulgated by the NRC and/or DOE. The 40 CFR regulations are promulgated by EPA. Washington State regulations promulgated by Ecology and the Washington State Department of Health are adopted under WAC.

2.1.2 Technical Guidance Criteria

A separate evaluation was undertaken to identify other sources of technical guidance that may be pertinent to the design criteria and/or performance standards of surface barriers, but are not considered ARARs. The value and variety of available design materials is extensive and would be difficult to present in any comprehensive fashion; however, of the potential reference sources, only a limited number were found that provide specific guidance pertinent to covers. These sources are identified as design criteria for covers. The materials reviewed include promulgated federal and state statutes or regulations that are not considered an ARAR, federal and state guidance documents, engineering and construction specifications, computer codes to evaluate hydrologic performance of surface barriers (the Hydrologic Evaluation of Landfill Performance [HELP] Model and the Pacific Northwest National Laboratory's [PNNL] UNSAT-H Model [Fayer and Jones 1990]), reference sources concerning frost depth and design-storm criteria, and previous research and engineering reports on barrier topics for various Hanford Site applications.

A preliminary listing of other technical guidance documents that provide sources of design criteria is provided in Section 2.3 and Table 2-2.

2.2 REGULATORY REQUIREMENTS

The ARARs that were retained for consideration in developing the generic conceptual cover-design criteria are described in the following sections.

2.2.1 Low-Level Waste

Regulations that pertain to land disposal of LLW have been promulgated by the NRC. These regulations include requirements affecting design and performance of covers for LLW disposal sites. The EPA, Ecology, and Washington State Department of Health have also promulgated regulations controlling air emissions of radionuclides and limiting public exposure to airborne radionuclides. These regulations may affect design and performance of covers for LLW disposal sites. The sections that follow describe relevant requirements identified as ARARs for LLW sites.

2.2.1.1 10 CFR Part 61--Licensing Requirements for Land Disposal of Radioactive Waste; Subpart C--Performance Objectives.

61.41 Protection of the general population from releases of radioactivity.

Concentrations of radioactive material that may be released to the general environment in groundwater, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 mrem to the whole body or 75 mrem to any other organ of any member of the public. A reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as reasonably achievable (ALARA).

61.42 Protection of individuals from inadvertent intrusion.

Design, operation, and closure of the land-disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

61.44 Stability of the disposal site after closure.

The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.

2.2.1.2 Chapter 173-480 WAC--Ambient Air Quality Standards and Emission Limits for Radionuclides.

WAC 173-480-040 Ambient Standard.

Emissions of radionuclides in the air shall not cause a maximum accumulated dose equivalent of more than 25 mrem/yr to the whole body or 75 mrem/yr to a critical organ of any member of the public. Doses due to ^{220}Rn, ^{222}Rn, and their respective decay products are excluded from these limits.

WAC 173-480-050 General standards for maximum permissible emissions.

(1) All radionuclide emission units are required to meet the emission standards in this chapter. At a minimum all emission units shall meet WAC 402-10-010 requiring every reasonable effort to maintain radioactive materials in effluents to unrestricted areas, ALARA.

(2) Prevention of significant deterioration: The emission requirements for an emission unit of radionuclides shall be the same for all areas of the state independent of prevention of significant deterioration classification.

(3) Whenever another federal or state regulation or limitation in effect controls the emission of radionuclides to the ambient air, the more stringent control of emissions shall govern.

2.2.1.3 Chapter 246-221 WAC--Radiation Protection Standards.

246-221-060 Dose limits for individual members of the public.

(1) Each licensee or registrant shall conduct operations so that:

(a) The total effective dose equivalent to individual members of the public from the licensed or registered operation does not exceed 1 mSv (0.1 rem) in a year.

(b) The dose in any unrestricted area from external sources does not exceed 0.02 mSv (0.002 rem) in any one hour.

2.2.1.4 Chapter 246-247 WAC--Radiation Protection--Air Emissions.

WAC 246-247-040 Standards.

The ambient air quality standards and emission limits for radionuclides shall be those promulgated by Ecology in Chapter 173-480 WAC. The Ecology ambient standard requires that emissions of radionuclides in the air shall not cause a maximum accumulated dose equivalent of more than 25 mrem/yr to the whole body or 75 mrem/yr to a critical organ of any member of the public. Doses due to ^{220}Rn, ^{222}Rn, and their respective decay products are excluded from this chapter.

2.2.2 RCRA Federal/State Dangerous Waste (Subtitle C)

Both EPA and Ecology have promulgated regulations pertaining to the disposal and management of dangerous waste. These regulations include requirements affecting design and performance of covers for dangerous waste disposal sites. The relevant requirements have been identified as ARARs and are described in the following sections.

2.2.2.1 40 CFR Part 264--EPA Regulations for Owners and Operators of Permitted Hazardous Waste Facilities and 40 CFR Part 265--EPA Interim Status Standards for Owners and Operators of Hazardous Waste Facilities.

40 CFR 264 and 265 Subpart G--Closure and Postclosure; 40 CFR 264.111/265.111 Closure performance standard.

The owner or operator must close the facility in a manner that:

(a) Minimizes the need for further maintenance

(b) Controls, minimizes, or eliminates to the extent necessary to protect human health and the environment, postclosure escape of dangerous waste, dangerous constituents, leachate, contaminated runoff, or dangerous waste decomposition products to the ground, surface water, groundwater, or the atmosphere.

40 CFR 264 and 265 Subpart K--Surface Impoundments; 40 CFR 264.228/265.228 Closure and postclosure care.

(a)(2)(iii) Cover the surface impoundment with a (final) cover designed and constructed to:

(A) Provide long-term minimization of the migration of liquids through the closed impoundment

(B) Function with minimum maintenance

(C) Promote drainage and minimize erosion or abrasion of the (final) cover

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

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

(b)(4) Prevent run-on and runoff from eroding or otherwise damaging the (final) cover.

40 CFR 264 and 265 Subpart N--Landfills; 40 CFR 264.310/265.310 Closure and postclosure care.

(a) At closure of the landfill or upon closure of any cell, the owner or operator must cover the landfill or cell with a (final) cover designed and constructed to:

(1) Provide long-term minimization of the migration of liquids through the closed landfill

(2) Function with minimum maintenance

(3) Promote drainage and minimize erosion or abrasion of the (final) cover

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

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

(b)(5) Prevent run-on and runoff from eroding or otherwise damaging the (final) cover.

2.2.2.2 Chapter 173-303 WAC--Dangerous Waste Regulations.

WAC 173-303-610 Closure and postclosure.

(2) **Closure performance standard.** The owner or operator must close the facility in a manner that:

(a)(i and ii) (Refer to 40 CFR 264.11(a),(b)).

(iii) Returns the land to the appearance and use of surrounding land areas to the degree possible, given the nature of the previous dangerous waste activity.

WAC 173-303-650 Surface impoundments.

(6) Closure and postclosure care.

(a)(ii)(C)(I) Provide long-term minimization of the migration of liquids through the closed impoundment with a material that has a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

(a)(ii)(C)(II)-(IV) (Refer to 40 CFR 264.228(a)(2)(iii)(B)-(D)).

WAC 173-303-665 Landfills.

(6) Closure and postclosure care.

(a)(i)-(v) (Refer to 40 CFR 264.310(a)(1)-(5)).

(b)(v) (Refer to 40 CFR 264.310(b)(4)).

2.2.3 RCRA Federal/State Solid Waste (Subtitle D)

Both EPA and Ecology have promulgated regulations pertaining to the disposal and management of solid waste. These regulations include requirements affecting design and performance of covers for solid waste disposal sites. The relevant requirements have been identified as ARARs and are described in the following sections.

2.2.3.1 40 CFR Part 241--Guidelines for the Land Disposal of Solid Waste.

40 CFR 241.209 Cover Material.

40 CFR 241.209-1 Requirement.

Cover material shall be applied, as necessary, to minimize fire hazards, infiltration of precipitation, odors, and blowing litter; control gas venting and vectors; discourage scavenging; and provide a pleasing appearance.

40 CFR 241.209-2 Recommended procedures: Design.

Plans should specify:

(a) Cover material sources and soil classifications (Unified Soil Classification System or U.S. Department of Agriculture [USDA] Classification System).

(b) Surface grades and side slopes needed to promote maximum runoff, without excessive erosion, to minimize infiltration.

(c) Procedures to promote vegetative growth as promptly as possible to combat erosion and improve appearance of idle and completed areas.

(d) Procedures to maintain cover material integrity (e.g., regrading and recovering).

2.2.3.2 Chapter 173-304 WAC--Minimum Functional Standards (MFS) for Solid Waste Handling.

WAC 173-304-407 General closure and postclosure requirements.

(3) Closure performance standard. Each owner or operator shall close their facility in a manner that:

(a) Minimizes the need for further maintenance

(b) Controls, minimizes, or eliminates threats to human health and the environment from postclosure escape of solid waste constituents, leachate, landfill gases, contaminated rainfall or waste decomposition products to the ground, groundwater, and the atmosphere.

WAC 173-304-460(2) Landfilling Standards.

(2) Minimum functional standards for performance.

(a) Groundwater. An owner or operator of a landfill shall not contaminate the groundwater underlying the landfill, beyond the point of compliance. Contamination and point of compliance are defined in WAC 173-304-100.

(b) Air quality and toxic air emissions.

(i) An owner or operator of a landfill shall not allow explosive gases generated by the facility whose concentration exceeds:

(A) Twenty-five percent of the lower explosive limit for the gases in facility structures (excluding gas control or recovery system components)

(B) The lower explosive limit for the gases at the property boundary or beyond

(C) One hundred parts per million by volume of hydrocarbons (expressed as methane) in offsite structures.

(ii) An owner or operator of a landfill shall not cause a violation of any ambient air quality standard at the property boundary or emission standard from any emission of landfill gases, combustion, or any other emission associated with a landfill.

(c) Surface waters. An owner or operator of a landfill shall not cause a violation of any receiving water quality standard or violate Chapter 90.48 RCW from discharges of surface runoff, leachate, or any other liquid associated with a landfill.

2.2.4 Other Materials TBC

Other TBCs as design criteria include standards or codes that are not promulgated as law and address areas not covered under ARARs listed above. No TBCs are currently identified that relate specifically to cover-designs that are not covered in ARARs. Technical guidance that provides more detail regarding the implementation of ARAR requirements discussed above are provided in Section 2.3. The combination of ARARs and technical guidance then establish the conceptual-design criteria for the various barriers.

2.3 TECHNICAL GUIDANCE

Documents exist that provide design criteria that are not considered an ARAR, but contain technical guidance that are considered pertinent. These technical-guidance criteria are contained in sections of promulgated statutes that are not considered applicable or relevant and appropriate, state or federal statutes that are not promulgated, state or federal guidance documents, or industry documents generated to document good engineering practices. Technical guidance will be integrated with the ARARs discussed in Section 2.2 to develop design criteria for the cover designs. Technical guidance and their associated source, that are contained in federal, state, or DOE documents that relate to cover designs, are provided below.

2.3.1 Federal and State Statutes and Guidance Documents

2.3.1.1 10 CFR Part 61--Licensing Requirements for Land Disposal of Radioactive Waste; Subpart D--Technical Requirements for Land Disposal Facilities.

61.51 Disposal site design for land disposal.

(a)(4) Covers must be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.

(a)(5) Surface features must direct surface water drainage away from disposal units at velocities and gradients that will not result in erosion that will require ongoing active maintenance in the future.

(a)(6) The disposal site must be designed to minimize, to the extent practicable, the contact of water with waste during storage, the contact of standing water with waste during disposal, or standing water with waste after disposal.

61.52 Land-disposal facility operation and disposal site closure.

(a)(2) Waste designated as Class C must be disposed of so that the top of the waste is a minimum of 5 m (16.4 ft) below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years.

2.3.1.2 Solid Waste Landfill Design Manual (Ecology Pub. No. 87-13).

This manual was published by Ecology as a guidance document to assist in implementing of the MFS for solid waste handling in WAC 173-304.

2.3.1.3 Technology Guidance Document--Final Covers on Hazardous Waste Landfills and Surface Impoundments (EPA/530-SW-89-047).

This document summarizes EPA's minimum technology guidance (MTG) on final cover systems for dangerous waste landfills and surface impoundments. The MTG cover is a multilayer design consisting of a vegetated top layer, drainage layer, and low-permeability layer.

2.3.1.4 RCRA Federal/State Solid Waste (Subtitle D)--WAC 173-304-460.

WAC 173-304-460 Landfilling standards.

(3) MFS for design.

(a)(iv) Designing the landfill to collect the runoff of surface waters and other liquids resulting from a 24-hr, 25-year storm from the active area and closed portions of a landfill.

(e)(i) At least 60 cm (24 in.) of 1 x 10^{-6} cm/s or lower permeability soil or equivalent shall be placed upon the final lifts unless the landfill is located in an area having mean annual precipitation of less than 30 cm (12 in.), in which case at least 60 cm (24 in.) of 1 x 10^{-5} cm/s or lower permeability soil or equivalent shall be placed upon the final lifts. Artificial liners may replace soil covers if a minimum thickness of 1.3 mm (50 mil) is used.

(e)(ii) The grade of surface slopes shall not be less than 2%, nor the grade of side slopes more than 33%.

(e)(iii) Final cover of at least 15 cm (6 in.) of topsoil be placed over the soil cover and seeded with grass, other shallow rooted vegetation, or other native vegetation.

2.3.2 Other Design Guidance

Resources that relate to civil construction and engineering practice and pertain to covers for all waste categories are provided below in an alphabetical listing of these materials. These documents are used to evaluate the conceptual designs and are not specifically referenced as technical guidance in Section 2.5, except for the Hanford Plant Standards, which is discussed in Section 2.5.

Hanford Plant Standards: Design Criteria. Provides criteria for and descriptions of design basis environmental events such as maximum frost depth, probable maximum flood, wind loads and tornados, earthquake loadings, and allowable bearing pressures for foundations. The standards state that the bottom of foundations for permanent buildings at the Hanford Site to be placed at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade. For frost protection purposes, this criterion will be applied to the lateral drainage layer and the low-permeability asphalt component of the Hanford Barrier and Modified RCRA Subtitle C Barrier designs.

HELP Model (Schroeder et al. 1988). This numerical model is widely used in civil engineering practice and is accepted by the regulatory agencies as a predictive tool to evaluate the hydrologic performance of liner and cover systems. The HELP Model is particularly useful to evaluate design alternatives at the conceptual level of detail. Three of the evaluated cover designs discussed in later sections of this FFS were evaluated with this model. However, the model itself is not a source of design criteria or performance objectives.

Seepage, Drainage, and Flow Nets (Cedergren 1989). This reference provides engineering criteria and procedures for design of graded filters. Criteria for design of graded filter media apply to covers that require filter-layer elements. The graded filter criteria are also published in various guidance documents, such as EPA (1989) and Ecology (1987).

UNSAT-H Model (Fayer and Jones 1990). Another numerical model developed to evaluate the hydrologic performance of multilayer soil barrier systems. The UNSAT-H Model was developed specifically for arid climate applications. This model was developed locally by PNNL and has been calibrated for soil textures, vegetation patterns, and arid climate conditions present at the Hanford Site. The UNSAT-H Model was used to evaluate three of the cover designs in this FFS. However, the code itself is not a source of design criteria or performance requirements.

Washington Department of Transportation Standard Specifications for Road, Bridge, and Municipal Construction. This resource provides useful specifications for various aspects of earth work construction. Regarding the cover designs discussed in this FFS, this reference provides a source for specifications relating to asphalt subbase preparation, asphalt preparation, and asphalt installation. The Hanford Barrier and the Modified RCRA C Barrier include a low-permeability asphalt-layer component. The specification cited for grading fill that forms the base layer for the evaluated covers is also a Washington Department of Transportation (WDOT) standard. These standards were cited because they are in common use in civil construction in Washington State.

USDA Wind Erosion Equation and Universal Soil Loss Equation. Soil loss estimates have a direct bearing on design of the topsoil layer component of a cover system. These USDA procedures are standard agricultural engineering methods for estimating soil erosion and are particularly useful design methods for surface barriers at the conceptual design stage. The procedures are not sources of design criteria or performance objectives.

2.4 ARARs AND TECHNICAL GUIDANCE FOR CONSIDERATION IN DEFINITIVE DESIGN

The ARARs and technical guidance that did not contribute to the development of conceptual cover-design criteria are identified in this section. These criteria will need to be considered during the definitive design and, thus, are not discussed in Section 2.5.

40 CFR 264.111/265.111(b), 40 CFR 264.228/265.228(b)(4), 40 CFR 264.310/265.310(b)(5), and **WAC 173-303-665(6)(b)(v) (ARARs).**

> The scope of definitive design will include the preparation of grading plans to control the effects of runoff and run-on of storm water from the covered area and adjacent areas. Cover slope lengths and angles, the length and width dimensions of the covered area, and the grades and surface conditions of adjoining areas are all site-specific considerations in developing grading plans. These issues cannot be addressed in generic conceptual designs.

40 CFR 241.209-2 (c) and (d) (ARARs).

Procedures to promote vegetative growth and to maintain the integrity of cover material after construction will be addressed as aspects of definitive design.

WAC 173-304-407 (3)(b) (ARARs).

According to the waste inventory information provided in the AAMS reports, the waste-management units listed in Appendix B rarely, if ever, received putrescible solid waste (i.e., septage or food waste). Therefore, control of landfill gas is not expected to be a consequential issue for definitive design of covers for most units. However, there are several active and inactive solid waste landfills on the Hanford Site. Landfill gas production and control is a potential design issue for units that are former solid waste landfill operations.

WAC 173-304-460 (3)(a)(iv) (Technical Guidance).

It is impractical to provide designs of systems for run-on and runoff collection as part of a generic conceptual design study. A variety of factors at individual sites, such as areal extent, adjoining topography, and vegetation, will have a significant effect on the volume of surface water to be managed from the design storm. However, runoff from the design storm can be estimated on a per-acre basis at the conceptual design stage. Design storm analyses for the Hanford Barrier, Modified RCRA Subtitle C Barrier, and Modified RCRA Subtitle D Barrier options are provided in Appendix C-4 of this FFS. Complete designs of systems for collection and routing of surface water will be deferred to definitive design.

2.5 CONCEPTUAL DESIGN CRITERIA

A limited number of cover designs are desired to streamline future FFS, detailed design, and construction implementation activities. To provide this limited number of designs, a grouping of the performance and design criteria established in Sections 2.2 and 2.3 has been performed, and four generic conceptual cover designs have been developed. These are the Hanford Barrier, the Modified RCRA Subtitle C Barrier, the Standard RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier. The grouping is based on the types of waste that are expected to be present at waste sites throughout the 200 Areas. The performance and design criteria must also be evaluated based on waste site-specific characteristics during the development of site-specific FFS, to ensure the cover is appropriate for the waste site.

Performance and design criteria for each barrier are discussed (Sections 2.5.1 through 2.5.4) with traceability to the pertinent ARARs and technical guidance documents. Where common design criteria are addressed in both ARARs and technical guidance documents, the ARARs and technical guidance have been listed and discussed together. This grouping is intended to expedite design-criteria development and the relationship of ARARs as requirements and technical guidance, as guidance should not be forgotten. The sections discuss the type of sites the cover designs can be applied to, what waste site types are grouped together, along with the justification for the grouping. Table 2-3 summarizes the cover designs and associated waste site types that have been grouped under that design. Tables 2-4, 2-5, 2-6, and 2-7 summarize the design criteria for the four barriers.

2.5.1 Design Criteria for the Hanford Barrier

This cover is being considered for the baseline design for WMUs in the 200 Areas containing radionuclides with concentrations and activities corresponding to GTCC LLW and sites where there is a significant inventory of TRU constituents. The Hanford Barrier could also be applied if dangerous constituents are present in addition to these radioactive components. This cover could also be used at sites where risk assessments predict elevated, long-term, environmental risks resulting from the concentrations or mobility of radionuclides present. Of the designs described in this FFS, the Hanford Barrier is intended to provide the maximum available degree of waste isolation and long-term containment, environmental protection, and human intrusion control.

Criteria that pertain to the design of the Hanford Barrier include ARARs and technical guidance for storage and disposal of LLW. Table 2-4 summarizes the design criteria for the Hanford Barrier derived from these sources. A discussion of the radioactive criteria, as they relate to the individual ARARs and technical guidance, is provided below.

ARARs

10 CFR 61.41, WAC 173-480-040, -050, WAC 246-221-060, and WAC 246-247-040.

> The Hanford Barrier is the baseline design for sites with GTCC waste or a significant inventory of TRU constituents. The Hanford Barrier could also be applied if dangerous constituents are present in addition to these radioactive components. This cover could also be used at sites where risk assessments predict elevated, long-term, environmental risks resulting from the concentrations or mobility of radionuclides. Of the designs described in this FFS, the Hanford Barrier is intended to provide the maximum practicable degree of waste isolation and long-term containment, environmental protection, and human intrusion control.
>
> Neither ARARs nor technical guidance provide specific performance or technical standards for the design life of a barrier for such sites. Technical guidance does exist for placement of isolation barriers over Class C LLW sites. Consistent with the intent to provide the maximum practicable degree of protection, the Hanford Barrier should provide protection greater than that offered for Class C LLW sites. The guidance for Class C LLW sites suggests the top of the waste should be at least 5 m (16 ft) below the surface, or that intruder barriers should be designed to protect against inadvertent intrusion for at least 500 years (10 CFR 61.52(a)(2)). A 1,000-year design life approaches the upper range of credible and defensible extrapolations of surface barrier performance results, given the limited understanding of natural phenomena and manmade materials, and relatively limited geotechnical experience. A design life beyond 1,000 years may be beyond normal engineering and scientific capabilities, and tends to be difficult, if not impossible, to prove given the great many uncertainties in the assumptions required to conduct engineering analyses of surface barrier performance over long periods of time. Therefore, to provide the maximum practicable degree of protection and retain defensibility, the Hanford Barrier is designed for a functional life of 1,000 years (Criteria 4, Table 2-4).
>
> The regulations identified above limit radionuclide releases from radiological waste disposal sites to levels that are protective of public health. The cover must be designed to minimize moisture infiltration, prevent plant and animal intrusion and inadvertent human intrusion, and control radioactive air emissions to acceptable levels. The design criteria suggested are to

(1) minimize moisture infiltration through the cover, (2) include appropriate design provisions to limit human intrusion, (3) prevent plants from accessing and mobilizing contamination, and (4) prevent burrowing animals from accessing and mobilizing contamination (Criteria 1, 3, 5, and 6, Table 2-4).

10 CFR 61.42.

For waste-management units containing radioactive waste, the cover must be designed to protect humans from inadvertent contact with waste above acceptable levels at any time after the loss of active institutional controls. This criteria pertains to conceptual and definitive designs of surface barriers for radioactive waste sites. The design criterion suggested is to include appropriate design provisions to limit inadvertent human intrusion (Criterion 7, Table 2-4).

10 CFR 61.44.

This performance ARAR requires that the cover be designed to achieve long-term stability and to eliminate (to the degree practicable) the need for ongoing maintenance. This ARAR can be met with an engineered cover system, supplemented as necessary by stabilization of the site subgrade to minimize settlement. This requirement pertains to both the conceptual and definitive design stages. Settlement issues are site specific and will be addressed during definitive design. The design criteria suggested are as follows: (1) design a multilayer cover of materials that are resistant to natural degradation processes and (2) design a durable cover that needs minimal maintenance during its design life (Criteria 2 and 3, Table 2-4).

TECHNICAL GUIDANCE

10 CFR 61.51.

This technical guidance discusses that the cover be designed to (1) minimize water infiltration, control runoff and run-on of surface water, and otherwise minimize contact between water and waste after disposal and (2) resist degradation by surface geologic processes (i.e., surface erosion) and biotic activity. This criteria pertains to conceptual and definitive design. The design criteria suggested are as follows: (1) minimize moisture infiltration through the cover, (2) design a multilayer cover of materials that resist natural degradation processes, (3) design a durable cover that needs minimal maintenance during its design life, (4) prevent plants from accessing and mobilizing contamination, (5) prevent burrowing animals from accessing and mobilizing contamination, and (6) facilitate drainage and minimize surface erosion by wind and water (Criteria 1, 2, 3, 5, 6, and 8, Table 2-4).

Hanford Plant Standards.

The standards direct that the bottom of foundations for permanent buildings at the Hanford Site to be placed at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade. For frost protection purposes, this criterion will be applied to the lateral drainage layer and the low-permeability asphalt component (Criterion 11, Table 2-4).

In addition to the radioactive performance and design criteria discussed above, it is desired to provide a cover design that can also meet the dangerous waste performance and design criteria. The cover could also be applied to sites with dangerous constituents if the following ARARs and technical guidance are met.

ARARs

40 CFR 264.111, 265.111, and WAC 173-303-610.

> These regulations require that a disposal facility for dangerous and mixed waste be closed in a manner that (1) minimizes the need for further maintenance, (2) controls, minimizes, or eliminates releases of dangerous constituents to the environment, and (3) returns land to the appearance and use of surrounding land to the degree possible, given the nature of previous waste-handling activities. These criteria can best be met by developing a low-maintenance cover constructed of durable materials, that will support perennial vegetative cover similar to vegetation on surrounding land, and be highly effective in limiting moisture infiltration. These standards pertain to conceptual and definitive designs of covers for dangerous waste sites. The design criteria suggested are as follows: (1) minimize moisture infiltration through the cover, (2) design a multilayer cover of materials that are resistant to natural degradation processes, and (3) design a durable cover that needs minimal maintenance during its design life (Criteria 1, 2, and 3, Table 2-4).

40 CFR 264.228, 265.228, 264.310, and 265.310; and WAC 173-303-650 and 173-303-665.

> These six performance ARARs are functionally identical and require that the cover meet the following requirements: (1) minimize moisture infiltration, (2) function with minimum maintenance, (3) promote drainage and minimize erosion, (4) accommodate settlement, and (5) have a permeability less than or equal to any natural subsoils present. These ARARs can best be met by an engineered cover system supplemented, as necessary, by subgrade improvement to minimize settlement. These regulations pertain to conceptual and definitive designs of covers for dangerous waste sites. Determination of appropriate subgrade improvement methods is a site-specific issue to be addressed during definitive design. The following design criteria are suggested by these ARARs: (1) minimize moisture infiltration through the cover, (2) design a durable cover that needs minimal maintenance during its design life, (3) design the cover to promote drainage and minimize surface erosion by wind and water, and (4) design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present (Criteria 1, 3, 8, and 9, Table 2-4).

TECHNICAL GUIDANCE

EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments.

> This technical guidance provides design criteria for specification of soil materials to be used in the construction of graded filter media. These criteria will prevent failure of the drainage layer resulting from clogging with fines. The design criterion suggested is to design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (Criterion 10, Table 2-4).

The criteria identified for radioactive waste and dangerous waste are similar, except for criteria relating to intrusion and design life, and design criteria for dangerous constituents that do not appear in the radioactive criteria. The radioactive criteria includes a need for intrusion protection above and beyond that proposed for the dangerous constituents. However, this barrier is not likely to be proposed for sites with dangerous constituents only. The specific design criteria for dangerous constituents that do not appear in the radioactive performance and design criteria relate to material specifications for the low-permeability layer and the top soil layer. These specific design criteria can be incorporated into the barrier design with no significant change in cost or complexity of design. The specific design criteria relate to issues that would be addressed in detailed design, regardless of whether they are a design criteria (i.e., having a cover with a permeability less than the surrounding soil and ensuring that the drainage system does not clog because of top soil used for the cover; these design considerations must be addressed as part of the detailed engineering phase of the project).

2.5.2 Design Criteria for the Modified RCRA Subtitle C Barrier

The Modified RCRA Subtitle C Barrier is being considered for the baseline design for 200 Area sites having dangerous waste constituents. In addition, the Modified RCRA Subtitle C Barrier is designed to meet or exceed the regulatory requirements for applications at Category 1 and 3 LLW sites because most sites contain radioactive constituents. This section discusses criteria for dangerous waste and LLW and traceability between the ARARs and technical guidance with the conceptual design criteria. Table 2-5 summarizes the design criteria for the Modified RCRA Subtitle C Barrier. Further discussion on what "modifications" were made to the Standard RCRA Subtitle C Barrier are contained in Section 3.4.1. A discussion of the dangerous waste criteria, as they relate to the ARARs and technical guidance, is provided below. The level of dangerous constituent contamination must also be addressed during the site-specific evaluation of waste sites. The ARARs and technical guidance discussed below pertain to RCRA TSDs. A less stringent cover design may be acceptable for waste sites that are not RCRA TSDs.

ARARs

40 CFR 264.111, 265.111, and WAC 173-303-610.

> These two performance ARARs require that a disposal facility for dangerous waste be closed in a manner that (1) minimizes the need for further maintenance; (2) controls, minimizes, or eliminates releases of dangerous constituents to the environment; and (3) returns land to the appearance and use of surrounding land to the degree possible, given the nature of previous waste-handling activities. As in the case of the Hanford Barrier, these requirements can best be met by developing a low-maintenance cover constructed of durable materials that will support perennial vegetative cover similar to vegetation on surrounding land, and be highly effective in limiting moisture infiltration. These ARARs pertain to conceptual and definitive designs of covers for dangerous waste sites. The design criteria suggested are as follows: (1) minimize moisture infiltration through the cover, (2) design a multilayer cover of materials that are resistant to natural degradation processes, (3) design a durable cover that needs minimal maintenance during its design life, (4) prevent plants from accessing and mobilizing contamination, (5) prevent burrowing animals from accessing and mobilizing contamination, and (6) facilitate drainage and minimize surface erosion by wind and water (Criteria 1, 2, 3, 5, 6, and 8, Table 2-6).

40 CFR 264.228, 265.228, 264.310, and 265.310; and WAC 173-303-650 and WAC 173-303-665.

These six performance ARARs are functionally identical and require that the cover meet the following requirements: (1) minimize moisture infiltration, (2) function with minimum maintenance, (3) promote drainage and minimize erosion, (4) accommodate settlement, and (5) have a permeability less than or equal to any natural subsoils present. The two ARARs pertain to conceptual and definitive design. These ARARs can best be met by an engineered cover system supplemented, as necessary, by site subgrade improvement during construction to minimize settlement. Determination of appropriate subgrade improvement methods is a site-specific issue to be addressed during definitive design. The following design criteria are suggested by these ARARs: (1) minimize moisture infiltration through the cover, (2) design a multilayer cover of materials that are resistant to natural degradation processes, (3) design a durable cover that needs minimal maintenance during its design life, (4) facilitate drainage and minimize surface erosion by wind and water, and (5) design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present (Criteria 1, 2, 3, 8, and 9, Table 2-6).

TECHNICAL GUIDANCE

EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments.

This technical guidance provides design criteria for specification of soil materials to be used in the construction of graded filter media. These criteria will prevent failure of the drainage layer resulting from clogging with fines. The design criterion suggested is to design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (Criterion 10, Table 2-5).

Hanford Plant Standards.

The standards require the bottom of foundations for permanent buildings at the Hanford Site to be placed at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade. For frost protection purposes, this criterion will be applied to the lateral drainage layer and the low-permeability asphalt component (Criterion 11, Table 2-5).

In addition to the dangerous waste performance and design criteria discussed above, it is desired to provide a cover design that can also meet the needs for radioactive waste performance and design requirements for Category 3 LLW. The cover could then be used at sites with dangerous waste as well as radioactive constituents (sites with dangerous waste typically include some level of radioactive component; if these two sets of criteria can be grouped, then the cover design can be used in more waste site type applications). The cover design can be used when there is a radioactive component if the following ARARs and technical guidance are met.

ARARs

10 CFR 61.41, WAC 173-480-040, -050, and WAC 246-247-040.

These regulations are functionally equivalent. They limit radionuclide releases from radiological waste disposal sites to levels that provide reasonable expectation that the annual equivalent dose to the public will not exceed 25 mrem to the whole body or 75 mrem to any critical organ. To some degree, the natural system contributes to limiting release rates of contaminants to the accessible environment. However, a conservative approach is to require the cover system to satisfy all performance goals for isolating waste from the accessible environment. Therefore, the cover must be designed to prevent plants and animals from intruding into the waste zone and redistributing contaminants into the accessible environment. These criteria will generally pertain to the definitive design stage, when the significance of specific release limits can be evaluated in the context of individual waste-site conditions. The design criteria suggested are as follows: (1) minimize moisture infiltration through the cover, (2) prevent plants from accessing and mobilizing contamination, and (3) prevent burrowing animals from accessing and mobilizing contamination (Criteria 1, 5, and 6, Table 2-5).

10 CFR 61.42.

For waste-management units containing radioactive waste, the cover must be designed to protect humans from inadvertent contact with waste above acceptable levels at any time after the loss of active institutional controls. This criteria pertains to conceptual and definitive designs of surface barriers for radioactive waste sites. The design criterion suggested is to include appropriate design provisions to limit inadvertent human intrusion (Criterion 7, Table 2-4).

10 CFR 61.44.

This performance ARAR requires that the cover be designed to achieve long-term stability and to eliminate (to the degree practicable) the need for ongoing maintenance. This requirement can be met with an engineered cover system and supplemented, as necessary, by stabilizing the site subgrade to minimize settlement. Settlement issues are site-specific and will be addressed during definitive design. This requirement pertains to conceptual and definitive designs. The design criteria suggested are as follows: (1) design a multilayer cover of materials that are resistant to natural degradation processes and (2) design a durable cover that needs minimal maintenance during its design life (Criteria 2 and 3, Table 2-5).

TECHNICAL GUIDANCE

10 CFR 61.51.

This technical guidance discusses that the cover be designed to (1) minimize water infiltration, control runoff and run-on of surface water, and otherwise minimize contact between water and waste after disposal and (2) resist degradation by surface geologic processes (i.e., surface erosion) and biotic activity. This criteria pertains to conceptual and definitive designs. The design criteria suggested are as follows: (1) minimize moisture infiltration through the cover, (2) design a multilayer cover of materials that are resistant to natural degradation processes, (3) design a durable cover that will require minimal maintenance during its design life, (4) prevent plants from accessing and mobilizing contamination, (5) prevent burrowing animals from accessing and mobilizing contamination, and (6) facilitate drainage and minimize surface erosion by wind and water (Criteria 1, 2, 3, 5, 6, and 8, Table 2-5).

10 CFR 61.52(a)(2).

The NRC Class C LLW (equivalent to DOE Category 3 LLW) must be disposed of so that either the top of the waste is a minimum of 5 m (16.4 ft) below final grade, or the waste is

> covered with a barrier that is designed to protect against inadvertent human intrusion for at least 500 years. This technical guidance pertains to both conceptual and definitive designs. The design criteria suggested are as follows: (1) design cover with a functional life of 500 years, and (2) ensure that the top of the waste is at least 5 m (16.4 ft) below final grade or include appropriate design provisions to limit inadvertent human intrusion (Criteria 4 and 7, Table 2-5).

The criteria identified for the radioactive waste and dangerous waste are similar, except for criteria relating to intrusion and design life. The radioactive criteria includes a timeframe for intrusion protection of a design life of 500 years. These criteria are above and beyond the criteria for the dangerous waste and, thus, adding these criteria to the barrier used for waste sites with dangerous waste enhance the design. The intrusion protection criteria would have no impact if the waste was more than 4.5 m (15 ft) below the surface. Where waste to be left in place was above 4.5 m (15 ft), the intrusion protection criteria could be met by providing additional fill. As a result, combining these criteria is considered appropriate, but would warrant a review in the site-specific evaluation when contamination versus depth information is available at a particular waste site. As a result, the criteria for dangerous waste, as well as the radioactive component, can be incorporated into one generic cover design.

2.5.3 Design Criteria for the Standard RCRA Subtitle C Barrier

The Standard RCRA Subtitle C Barrier may be considered at 200 Area sites containing dangerous waste constituents. However, it is not considered to be the baseline design. This section discusses ARARs and technical guidance for dangerous waste and traceability between the ARARs and technical guidance with the conceptual design criteria.

Table 2-6 summarizes the design criteria for the Standard RCRA Subtitle C Barrier. The pertinent regulatory sources are discussed in the paragraphs that follow.

ARARs

40 CFR 264.111, 265.111, and WAC 173-303-610.

> These regulations require that a disposal facility for dangerous waste be closed in a manner that (a) minimizes the need for further maintenance; (b) controls, minimizes, or eliminates releases of dangerous constituents to the environment; and (c) returns land to the appearance and use of surrounding land to the degree possible, given the nature of previous waste-handling activities. In addition, postclosure care must continue for 30 years in general, although this period may be extended if necessary to protect human health or the environment. These ARARs pertain to conceptual and definitive designs of covers for dangerous and mixed waste sites. The design criteria suggested by these ARARs are as follows: (1) minimize moisture infiltration through the cover, (2) design a durable cover of natural materials that will require minimal maintenance during its design life, (3) prevent plants from accessing and mobilizing contamination, (4) prevent burrowing animals from accessing and mobilizing contamination, (5) facilitate drainage and minimize surface erosion by wind and water, and (6) have a functional design life of at least 30 years (Criteria 1, 2, 3, 4, 5, and 6, Table 2-6).

40 CFR 264.228, 265.228, 264.310, and 265.310; and WAC 173-303-650 and 173-303-665.

These six performance ARARs are functionally identical and require that the cover meet the following requirements: (a) minimize moisture infiltration, (b) function with minimum maintenance, (c) promote drainage and minimize erosion, (d) accommodate settlement, and (e) have a permeability less than or equal to any natural subsoils present. These ARARs pertain to conceptual and definitive design. These ARARs can best be met by an engineered cover system supplemented, as necessary, by site subgrade improvement during construction to minimize settlement. Determination of appropriate subgrade improvement methods is a site-specific issue to be addressed during definitive design. The following design criteria are suggested by these ARARs: (1) minimize moisture infiltration through the cover, (2) design a durable cover of natural materials that needs minimal maintenance during its design life, (3) facilitate drainage and minimize surface erosion by wind and water, and (4) design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present (Criteria 1, 2, 3, 5, 6, and 7, Table 2-6).

TECHNICAL GUIDANCE

EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments.

This technical guidance provides design criteria and technical guidance for this minimum standard surface barrier (Criterion 8, Table 2-6).

Hanford Plant Standards.

The standards require the bottom of foundations for permanent buildings at the Hanford Site to be placed at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade. For frost protection purposes, this criterion will be applied to the drainage layer (Criterion 9, Table 2-6).

2.5.4 Design Criteria for the Modified RCRA Subtitle D Barrier

The Modified RCRA Subtitle D Barrier is being considered for the baseline design for waste sites in the 200 Areas containing nonradiological and nondangerous solid waste. This cover is also designed for LLW sites containing waste with Category 1 activity (equivalent to NRC Class A and Class B LLW). The Modified RCRA Subtitle D Barrier is designed to provide limited hydrologic and biointrusion protection. Because of the nondangerous nature of RCRA Subtitle D waste and because Category 1 LLW decays away to inconsequential activity levels with 100-years, the design includes no human intrusion control provisions.

Regulations that relate to the Modified RCRA Subtitle D Barrier include those pertinent to the disposal of RCRA nonhazardous solid waste and Washington State nondangerous solid waste, as well as regulations that relate to disposal of Category 1 LLW. Table 2-7 summarizes the design criteria for the RCRA Subtitle D cover.

A discussion of ARARs and technical guidance, as they relate to individual design criteria for the Modified RCRA Subtitle D Barrier, is provided below.

ARARs

40 CFR 241.209-1.

This regulation requires that solid waste be covered to minimize fire hazards, minimize moisture infiltration, control odors and blowing litter, control gas venting and vectors, discourage scavenging, and provide a pleasing appearance. An engineered surface barrier constructed of earthen materials will physically isolate the waste, minimize fire hazards, odors, blowing litter, control vectors, and discourage scavenging. Perennial vegetation on the cover surface should provide the site with an acceptable visual appearance. Control of landfill gas is an issue that will be addressed on a site-by-site basis during definitive design. This ARAR pertains to both conceptual and definitive design. Three design criteria are suggested: (1) minimize moisture infiltration through the cover, (2) design the cover to provide limited biointrusion control (i.e., to control scavenging and vector activity), and (3) design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation (Criteria 1, 2, and 5, Table 2-7).

40 CFR 241.209-2.

This regulation requires that surface grades and side slopes be determined such that runoff will be controlled and erosion will be minimized. This ARAR pertains to conceptual and definitive design. The design criterion suggested is to design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface (Criterion 4, Table 2-7).

WAC 173-304-407.

This regulation requires that a solid waste facility be closed in a manner that (1) minimizes the need for further maintenance and (2) controls, minimizes, or eliminates threats to human health and the environment from the postclosure release of harmful substances to the air, surface water, groundwater, or soil. Compliance with this ARAR can be achieved with an engineered cover system that minimizes infiltration and effectively contains the waste within the confines of the cover system. This ARAR pertains to conceptual and definitive cover designs. Four design criteria are suggested by this ARAR: (1) minimize moisture infiltration through the cover, (2) design the cover to provide limited biointrusion control, (3) design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface, and (4) design a durable cover that needs minimal maintenance during its design life (Criteria 1, 2, 4, and 5, Table 2-7).

WAC 173-304-460 (2).

The minimum functional standards for performance of the cover shall consider impacts on groundwater, air quality, and surface water. An engineered surface barrier constructed of material to minimize moisture infiltration and control surface runoff will be provided. The earthen material used to isolate the waste will also serve to control air quality. The design criteria is as follows: (1) minimize moisture infiltration through the cover and (2) design a cover system that includes a surface layer of earthen materials that will control runoff and minimize erosion of the cover surface (Criteria 1 and 6, Table 2-6).

TECHNICAL GUIDANCE

WAC 173-304-460 (3)(e).

> The Hanford Site is located in a section of Washington State that receives less than 30 cm (12 in.) of precipitation annually. Considering the arid climate, this technical guidance provides for solid waste landfill covers at the Hanford Site to (a) be constructed of 60 cm (24 in.) or more of soil with a permeability of 1 x 10^{-5} cm/s or less; (b) have surface slopes of not less than 2%; and (c) have at least 15 cm (6 in.) of topsoil seeded with grass, other shallow-rooted vegetation, or other native vegetation. These criteria pertain to both conceptual and definitive designs. Five design criteria are suggested by this technical guidance: (1) design a multilayer cover system with a combined thickness of at least 60 cm (24 in.), (2) design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface, (3) design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation, (4) design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present, or a permeability that is no greater than 1 x 10^{-5} cm/s (whichever is less), and (5) design a cover with surface slopes of no less than 2% (Criteria 3, 4, 5, 6, and 8, Table 2-7).

The grouping of sites containing Category 1 activity LLW into this design is desirable to allow all low-level contamination sites to also use this generic conceptual cover design. The additional ARARs and technical guidance criteria are contained in the following section.

ARARs

10 CFR 61.41, WAC 173-480-040, and WAC 246-247-040.

> These regulations are functionally equivalent. They limit radionuclide releases from radiological waste disposal sites to levels that provide reasonable expectation that the annual equivalent dose to the public will not exceed 25 mrem to the whole body or 75 mrem to any critical organ. For applications at Category 1 LLW sites, the Modified RCRA Subtitle D Cover will need to satisfy all performance goals for isolating waste from the accessible environment. These requirements pertain to conceptual and definitive designs. Therefore, plants and animals must be prevented from intruding into the waste zone and redistributing contaminants into the accessible environment. The design criteria suggested are as follows: (1) minimize moisture infiltration through the cover and (2) design the cover to provide limited biointrusion control (Criteria 1 and 2, Table 2-7).

10 CFR 61.42.

> The regulation requires that radioactive land disposal facilities be closed such that humans are protected from inadvertent contact with waste above acceptable levels at any time after active institutional controls are removed. The Modified RCRA Subtitle D Barrier is proposed for Category 1 LLW, which by definition is waste that decays to acceptable levels within 100 years. Therefore, the design life for the Modified RCRA Subtitle D Barrier has been set at 100 years (Criterion 9, Table 2-7). This criterion pertains to conceptual and definitive design.

10 CFR 61.44.

This performance ARAR requires that the cover be designed to achieve long-term stability and to eliminate (to the degree practicable) the need for ongoing maintenance. This ARAR can be met with an engineered cover system and supplemented, as necessary, by stabilizing the site subgrade to minimize settlement. As indicated in the previous discussions of the other cover options, settlement issues are site-specific and will be addressed during definitive design. This ARAR pertains to conceptual and definitive designs. The design criteria suggested are as follows: (1) design a multilayer cover system with a combined thickness of at least 60 cm (24 in.); (2) design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface; (3) design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation; and (4) design a durable cover that needs minimal maintenance during its design life (Criteria 3, 4, 5, and 7, Table 2-7).

TECHNICAL GUIDANCE

10 CFR 61.51.

This technical guidance discusses that the cover be designed to (a) minimize water infiltration, control runoff and run-on of surface water, and otherwise minimize contact between water and waste after disposal and (b) resist degradation by surface geologic processes and biotic activity. These requirements pertain to conceptual and definitive designs. The design criteria suggested by this technical guidance are as follows: (1) minimize moisture infiltration through the cover; (2) design the cover to provide limited biointrusion control; (3) design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface; (4) design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation; and (5) design a durable cover that needs minimal maintenance during its design life (Criteria 1, 2, 4, 5, and 7, Table 2-7).

The design life of 100 years for Category 1 LLW is the only additional criteria that exists if the Category 1 LLW sites are incorporated into the criteria for the RCRA Modified Subtitle D Barrier. This criteria would add 15 cm (6 in.) to the previous 46-cm (18-in.) topsoil layer (see Section 3.0 for details). The site-specific evaluation that is needed for all waste sites could further address this issue and evaluate the appropriateness of incorporating this criterion.

Table 2-1. Summary of ARARs.

Waste type	Regulation
LLW[a]	10 CFR 61.41, .42, .44 40 CFR 192.02(b) WAC 173-480-040, -050 WAC 246-247-040
RCRA C	40 CFR 264.111/265.111 40 CFR 264.228/265.228(a)(2)(iii) 40 CFR 264.228/265.228(b)(4) 40 CFR 264.310/265.310(a) 40 CFR 264.310/265.310(b)(5) WAC 173-303-610(2)(a) WAC 173-303-650(6)(a)(ii)(C) WAC 173-303-665(6)(a)(i)-(iv) WAC 173-303-665(6)(b)(v)
RCRA D	40 CFR 241.209-1, .209-2 WAC 173-304-407(3) WAC 173-304-460(2)

RCRA C = *Resource Conservation and Recovery Act*, Subtitle C.
RCRA D = *Resource Conservation and Recovery Act*, Subtitle D.
[a] LLW, including waste with TRU constituents.

Table 2-2. Summary of Technical Guidance Sources.

Waste type	Guidance
LLW[a]	10 CFR 61.51, .52 EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. Hanford Plant Standards.
RCRA C	EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. Hanford Plant Standards.
RCRA D	WAC 173-304-460(3) Hanford Plant Standards.

RCRA C = *Resource Conservation and Recovery Act*, Subtitle C.
RCRA D = *Resource Conservation and Recovery Act*, Subtitle D.
[a] LLW, including waste with TRU constituents.

Table 2-3. Relationships Between Waste Categories and Cover Designs.

Cover type	Waste-site characterization
Hanford Barrier	Sites with significant inventories of TRU constituents, GTCC LLW, and GTCC Mixed LLW
Modified RCRA Subtitle C Barrier	RCRA Subtitle C (Dangerous) Waste Category 3 LLW and Category 3 Mixed LLW Category 1 Mixed LLW
Standard RCRA Subtitle C Barrier	Dangerous Waste
Modified RCRA Subtitle D Barrier	RCRA Subtitle D (Nondangerous and Nonradiological) Waste Category 1 LLW

Table 2-4. Summary of Design Criteria for the Hanford Barrier.

1.	Minimize moisture infiltration through the cover.
2.	Design a multilayer cover of materials that are resistant to natural degradation processes.
3.	Design a durable cover that needs minimal maintenance during its design life.
4.	Design a cover with a functional life of 1,000 years.
5.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).
6.	Prevent burrowing animals from accessing and mobilizing contamination.
7.	Include appropriate design provisions for limiting inadvertent human intrusion.
8.	Facilitate drainage and minimize surface erosion by wind and water.
9.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.
10.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).
11.	For frost protection, the lateral drainage layer and the low-permeability asphalt layer must be located at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade.

Table 2-5. Summary of Design Criteria for the Modified RCRA C Barrier.

1.	Minimize moisture infiltration through the cover.
2.	Design a multilayer cover of materials that are resistant to natural degradation processes.
3.	Design a durable cover that needs minimal maintenance during its design life.
4.	Design a cover with a functional life of 500 years.
5.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).
6.	Prevent burrowing animals from accessing and mobilizing contamination.
7.	Ensure that the top of the waste is at least 5 m (16.4 ft)below final grade or include appropriate design provisions to limit inadvertent human intrusion.
8.	Facilitate drainage and minimize surface erosion by wind and water.
9.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.
10.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).
11.	For frost protection, the lateral drainage layer and the low-permeability asphalt layer must be located at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade.

Table 2-6. Summary of Design Criteria for the Standard RCRA C Barrier.

1.	Minimize moisture infiltration through the cover.
2.	Design a durable cover of natural materials that needs minimal maintenance during its design life.
3.	Design a cover with a functional life of 30 years.
4.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).
5.	Prevent burrowing animals from accessing and mobilizing contamination.
6.	Facilitate drainage and minimize surface erosion by wind and water.
7.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.
8.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).
9.	For frost protection, the lateral drainage layer and the low-permeability layer must be located at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade.

Table 2-7. Summary of Design Criteria for the Modified RCRA D Barrier.

1.	Minimize moisture infiltration through the cover.
2.	Design the cover to provide limited biointrusion control (i.e., to control scavenging and vector activity).
3.	Design a multilayer cover system with a combined thickness of at least 60 cm (24 in.).
4.	Design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface.
5.	Design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation.
6.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoil present, or a permeability that is no greater than 1×10^{-5} cm/s (whichever is less).
7.	Design a durable cover that needs minimal maintenance during its design life.
8.	Design a cover with surface slopes of no less than 2%.
9.	Design a cover with a functional life of 100 years.

3.0 CONCEPTUAL COVER DESIGNS

Based on the review of Hanford Site waste classifications and the pertinent regulations and other criteria relating to waste disposal summarized in Sections 1.0 and 2.0, design needs for four distinct barrier designs for 200 Area WMUs have been developed. The four barriers are listed below in order of overall performance and environmental protection.

- **Hanford Barrier**. This barrier is the baseline design for sites with GTCC LLW or mixed GTCC LLW or significant inventories of TRU constituents. This barrier is designed to remain functional for a performance period of 1,000 years and to provide the maximum available degree of containment and hydrologic protection of the evaluated designs. This barrier includes a layer of coarse, fractured basalt intended to perform the primary biointrusion and human intrusion control functions.

- **Modified RCRA Subtitle C Barrier**. This barrier is the baseline design for sites containing dangerous waste, Category 3 LLW or Category 3 LL mixed waste, and Category 1 LL mixed waste. This barrier is designed to provide long-term containment and hydrologic protection for a performance period of 500 years. This design also incorporates provisions to control biointrusion and human intrusion. However, the provisions are modest compared to the corresponding features in the Hanford Barrier design, reflecting the reduced toxicity of the subject waste and design life of the Modified RCRA Subtitle C Barrier.

- **Standard RCRA Subtitle C Barrier**. This barrier could be considered for sites containing dangerous waste. This barrier provides containment and hydrologic protection for a specified postclosure period of 30 years, to include institutional control consisting of monitoring and necessary maintenance.

- **Modified RCRA Subtitle D Barrier**. This barrier is the baseline design for nonradiological and nonhazardous solid waste sites, as well as Category 1 LLW sites where no dangerous waste constituents are present. It is designed to provide limited biointrusion and limited hydrologic protection (compared to the other two evapotranspiration barrier designs - the Hanford Barrier and Modified RCRA Subtitle C Barrier) for a performance period of 100 years. The performance period is selected based on the length of time for which Category 1 waste presents a hazard.

The four barrier designs are discussed in Sections 3.1, 3.2, 3.3, and 3.4. The designs incorporate all the generic performance and design criteria identified in Section 2.0. Site-specific evaluations are also necessary to establish an appropriate alternative for a specific waste site. The generic cover designs contained in this FFS could be modified as part of the site-specific evaluation. For example, if groundwater protection is not a concern for a specific site, then criteria 1, 8, 9, and 10 for both the Hanford Barrier and the Modified RCRA C Barrier are not needed and a more simplified barrier can be evaluated.

3.1 HANFORD BARRIER DESIGN

This design is described in two subsections: (1) Section 3.1.1 provides background information on development of the Hanford Barrier and (2) Section 3.1.2 provides a more detailed description of the generic design.

3.1.1 Background Information Relating to the Hanford Barrier

The need for a robust, long-term surface barrier design was first formally identified in the *Hanford Waste Management Plan* (DOE-RL 1987) and the *Final Environmental Impact Statement for the Disposal of Hanford Defense High-Level, Transuranic, and Tank Waste* (DOE 1987). The Hanford Site Permanent Isolation Barrier Development Program was organized soon after these documents were published. This program preceded implementation of the Environmental Restoration (ER) Program at the Hanford Site by several years. Since 1987, numerous design concepts have been explored and evaluated while developing the Hanford Barrier's current design configuration. The current design is summarized in a design basis concept document prepared by ICF Kaiser Hanford (Kaiser 1992).

The Hanford Barrier was originally envisioned to provide long-term isolation for high-activity radiological waste sites, such as tank waste residuals (HLW), grout vaults (high-activity LLW), and sites with TRU contamination. As a result of evaluating barrier needs for the ER Program, the Hanford Barrier has been identified as the baseline barrier design to be considered for sites with GTCC LLW, significant inventories of TRU constituents, or cognate mixed waste.

Based on its level of development and because it meets or exceeds any and all identified design criteria, the existing Hanford Barrier design is being considered for the baseline design for cover alternatives at ER sites with waste of this type. Figure 3-1 shows the Hanford Barrier in profile view.

3.1.2 Conceptual Barrier Design

The Hanford Barrier is composed of nine layers of durable material, with a combined thickness of 4.5 m (14.8 ft). The sections that follow describe the functions and design attributes of each layer. The layers are numbered and described in succession from the surface down. Table 3-1 summarizes the cover layers.

3.1.2.1 Topsoil Components - Layer 1 (Topsoil with Pea Gravel Admixture) and Layer 2 (Topsoil without Pea Gravel). Layer 1 consists of 100 cm (40 in.) of sandy silt to silt loam soil containing a 15% (by weight) admixture of pea gravel. The soil in Layer 1 will be placed in a relatively loose condition, with a bulk density of about 1.46 g/cc (91 to 92 lb/ft^3). Layer 1 will be constructed with a surface slope of 2%.

Layer 2 consists of 100 cm (40 in.) of the same topsoil material without pea gravel. Layer 2 will also be placed in a relatively loose condition, with a bulk density of about 1.38 g/cc (86.3 lb/ft^3), which is approximately the same as the in-place condition at the borrow site. The water content of the topsoil material in Layers 1 and 2 will be essentially the same as the in-place value at the borrow site. A minimal amount of moisture will be added at the borrow site for dust control.

The topsoil layers perform several specific functions. First, topsoil must function as a storage medium for retention of moisture arriving as precipitation. Second, topsoil must support growth and propagation of cover vegetation. Both functions relate to water management. Moisture stored at shallow depths in the cover system is subject to removal by direct evaporation. Cover vegetation assists in removing soil moisture by transpiration. Numerical performance assessments performed with the HELP Model and UNSAT-H Model predict that virtually 100% of average annual precipitation will be eliminated from the cover system by evapotranspiration (Appendices C-1 and C-4). By eliminating percolation into the lower portion of the cover system, reliance can be reduced on the performance of Layers 6 and 7 as infiltration barriers, such that Layers 6 and 7 may be regarded more as contingency elements in the overall cover system.

Moisture retention and evapotranspiration within Layers 1 and 2 will be enhanced by a capillary barrier at the base of Layer 2. Conceptually, a capillary barrier develops where a layer of fine-textured soil overlies a layer of coarser-textured soil (e.g., clean sand or gravel) (DOE-RL 1987). The capillary barrier acts as a one-way check valve. Surface tension effects within the pore space of the fine-textured soil exert a negative (suction) pressure on soil moisture. For moisture to drain out of the fine-textured soil, the suction pressure must be overcome by development of an equivalent positive pore pressure (hydraulic head) immediately above the interface. In effect, a portion of the fine-textured soil must approach saturation before moisture can move across the interface.

The long-term effectiveness of the capillary barrier will depend, to some degree, on the efficiency of evapotranspiration processes within the topsoil layers. The topsoil must have sufficiently fine texture to exhibit high water retention characteristics (i.e., high field capacity and porosity values), yet sufficiently coarse texture (i.e., low wilting point) that plants can readily access to extract the moisture from storage. Ideal topsoil materials are silt loams and fine sandy loams. The topsoil material for the Hanford Barrier could be obtained from the McGee Ranch area of the Hanford Site (Skelly and Wing 1992). Fine-textured soils at McGee Ranch have been characterized by preliminary test boring and sampling (Last et al. 1987; Lindberg and Lindsey 1993; Lindberg 1994; Skelly et al. 1994).

Potential susceptibility of the topsoil in Layer 1 to wind erosion is a design issue. The Hanford Site frequently experiences windy weather, resulting from (1) drainage (gravity) winds blowing off the Cascade Range, (2) topographic channeling, and (3) frontal boundaries moving through the region (Stone et al. 1983). Several strategies have been applied to minimize wind erosion of the barrier surface. First, because wind erosion potential is a function of the surface slope, the slope will be limited to 2% (after allowances for settlement and subsidence, as necessary). This value is steep enough to provide for coherent drainage of runoff from the covered area, yet shallow enough to limit exposure of the surface to wind shear. Average annual runoff from the barrier surface is estimated to be 0.001 in. or less according to numerical modeling with the HELP Model and UNSAT-H Model (see Appendices C-1 and C-4). Both models tend to indicate that storm events with associated runoff will be infrequent (perhaps not more than 1 in 10 years). Second, the surface will be planted with perennial vegetation. The shear force exerted by wind on a vegetated soil surface is a small fraction of the shear force on a comparable bare surface. Third, pea gravel will be mixed into Layer 1 to improve its ability to resist wind erosion when the cover is temporarily denuded of vegetation. The effectiveness of pea gravel in controlling wind erosion of Hanford Site soils has been demonstrated in wind tunnel tests (Ligotke and Klopfer 1990). Finally, the combined thickness of Layers 1 and 2 will be sufficient to continue to store and remove moisture by evapotranspiration if significant topsoil losses should occur despite these provisions. Assuming that the topsoil layers are constructed at a bulk density that is approximately the same as the in-place value at the borrow site, and projecting a soil erosion rate of 2 tons per acre per year, the thickness of soil loss over the barrier's 1,000-year design life would be approximately 33 cm (13 in.). Sample wind and water erosion calculations are provided in Appendix D.

Cover vegetation will consist of a mixture of perennial grass species. Specifications for the seed mix, and the methods of seed application, fertilizing, and mulching will be developed during definitive design. Planting of cover vegetation will meet or exceed recommendations in EPA's technical guidance for final covers (EPA 1989).

3.1.2.2 Graded Filter Components - Layer 3 (Sand Filter) and Layer 4 (Gravel Filter). Layers 3 and 4 are components of a two-layer graded filter that will prevent fine-textured soil from moving downward and accumulating in the fractured basalt layer (Layer 5) and/or the lateral drainage layer

(Layer 6). Nominal thicknesses of Layers 3 and 4 are 15 cm (6 in.) and 30 cm (12 in.), respectively. These materials will be clean, screened aggregate materials obtained from a local borrow site on the 200 Areas Plateau.

The design of the graded filter conforms to the criteria published in Cedergren (1989) and Ecology (1987). The criteria are as follows:

Retention Criteria: D_{15} (Filter)/D_{85} (Filtrate) <4 to 5

D_{50} (Filter)/D_{50} (Filtrate) <25

Permeability Criterion: D_{15} (Filter)/D_{15} (Filtrate) >4 to 5

Preliminary gradation data for McGee Ranch silt loam and the two filter layer materials are as follows.

	Particle Size D_{15}	**Particle Size D_{50}**	**Particle Size D_{85}**
Silt Loam	0.005 to 0.020 mm	0.021 to 0.060 mm	0.057 to 0.150 mm
Sand Filter	0.15 to 0.50 mm	0.375 to 1.2 mm	0.70 to 2.5 mm
Gravel Filter	1.5 to 2.0 mm	15 to 20 mm	<37.5 mm

The symbols D_{15}, D_{50}, D_{85} refer to the particle diameters on gradation curves for each material corresponding to designated weight percentages (i.e., 15, 50, and 85% finer). The filter criteria are conservative for this design application because they were developed for applications in earth dams where elevated pore pressure conditions are often present.

3.1.2.3 Layer 5 - Coarse, Fractured Basalt. Layer 5 will be constructed of coarse, quarried basalt (shot rock) with a maximum size of 25 cm (10 in.) and a minimum size of 5 cm (2 in.). This material will be obtained from a quarry location to be determined (Duranceau 1995). Size limits will be controlled by screening material at the quarry site.

The functions of Layer 5 are to control biointrusion and to present an obstacle to inadvertent human intrusion. The intent of biointrusion control is to isolate waste from any contact by plant roots and/or burrowing animals that could result in mobilization or redistribution of contaminants, which would compromise barrier performance. If plant roots penetrate the waste layer, soluble contaminants can be taken up and incorporated into the aboveground biomass. Burrowing animals represent a variety of pathways for contaminant transport. They may transport contaminated soil to the surface directly. Other pathways involve internal contamination (i.e., ingestion, inhalation) or external (skin) contamination of the animal. Animals may spread contamination on the surface via droppings, or they may pass contamination up the food chain if they are consumed by predators.

Layer 5 is designed to preclude moisture retention. The large voids within this layer are designed to ensure that there is negligible storage capability in Layer 5 for any moisture that does move completely through the topsoil component of the barrier (Layers 1 and 2). Liquid moisture entering Layer 5 will drain into Layer 9. Long-term maintenance of extremely dry conditions within Layer 5 are expected to serve as an effective deterrent to plant-root propagation into this layer. The fractured basalt to be placed in this layer has been sized to prevent penetration by burrowing mammals that inhabit the Hanford Site, including large predators such as badgers.

The coarse, fractured basalt in Layer 5 is designed to present an impediment to human intrusion. A subsurface layer consisting of loose, coarse fractured rock represents an adverse ground condition for many types of drilling methods, typically because circulation cannot be maintained, cuttings cannot be removed from the hole, the drill bit does not receive adequate lubrication, and firm contact cannot be maintained between the bit and the rock, all of which contribute to high bit wear and minimal advance of the hole. However, drilling methods exist today that would be minimally affected by the composition of Layer 5, and more effective technologies are likely to be available in the future. Therefore, the effectiveness of Layer 5 as a deterrent to drilling intrusion is likely to decrease over time.

However, passive institutional controls or the intruders' own exploratory procedures can be considered when evaluating adequacy of the intruders to soon detect, or be warned of, the incompatibility of the area with drilling activities. The composition and construction of Layer 5 should be sufficiently unique as to be immediately recognizable to knowledgeable persons engaged in resource exploration as engineered fill material, as opposed to a natural soil deposit of normal geologic origins. Thus, Layer 5 may function either as an impediment to drilling intrusion or as a warning/marker horizon. In either case, Layer 5 will alert intruders to the existence of anomalous subsurface conditions at covered waste sites.

Concrete rubble from demolition of 200 Area canyon buildings and reactor facilities in the 100 Areas is being considered as a substitute for basalt. Technologies for rubblizing concrete are available. The applicability of these technologies to heavily reinforced concrete and the associated cost consequences remain to be determined.

3.1.2.4 Layer 6 - Lateral Drainage Layer. This layer will facilitate the removal of any moisture that moves through the topsoil component of the barrier (Layers 1 and 2). This layer represents a contingency scheme to remove soil moisture in response to extreme climatic events, such as the design storm. The lateral drainage layer will be sloped at 2% to move water to the edge of the cover where it will be collected and/or diverted in an appropriate manner. Layer 6 will be constructed of clean, screened aggregate material with a hydraulic conductivity of at least 1 cm/s. The effective particle size (D_{10}) characteristic of the drainage media needed to achieve the desired permeability value can be estimated using Hazen's approximation (Cedergren 1989), where k is computed in cm/s and D_{10} is in cm:

$$k = 100\, D_{10}^2$$

By this method, the drainage media will need to have a D_{10} of 1 mm or greater. Layer 6 will be approximately 4 m (13 ft) below final grade, which ensures that the layer's performance will be unaffected by frost penetration. Performance simulations with the HELP Model and UNSAT-H Model both indicate little (if any) lateral drainage would actually occur under current climatic conditions (Appendices C-1 and C-4).

3.1.2.5 Layer 7 - Asphalt Layer. This layer will be constructed with a drainage slope of 2% (after allowances for settlement and subsidence), and will function as a low-permeability barrier layer and as a redundant biointrusion barrier. Layer 7 will be 15 cm (6 in.) thick and will be constructed of a durable asphaltic concrete mixture consisting of double-tar asphalt (i.e., twice the tar content of normal highway asphalt) with added sand as binder material, conforming to WSDOT M41-10, Section 9-02.1(4), Grade AR-4000W (WDOT 1991). Laboratory permeability tests on asphaltic concrete cores from the Hanford Barrier prototype yielded values on the order of 10^{-10} cm/s. In-field values, measured by falling-head permeameter testing, ranged between 10^{-7} and 10^{-9} cm/s (DOE-RL 1994). Natural analog studies (Waugh et al. 1994; Freeman and Romine 1994) estimate that asphalt could remain functional for a period of 5,000 years or more, as long as the layer remains covered and protected from ultraviolet radiation and freeze/thaw activity. The natural analogs noted above, were from asphalt specimens from museum collections that range in age from 150 to 5,000 years. This is limited sampling, testing and information for defensibility purposes. Currently, heat-accelerated aging tests are proposed on asphaltic samples fabricated from specifications for the asphalt layer in the barriers; these tests would be more defensible than current analog projections. The top of Layer 7 will be approximately 4.3 m (14 ft) below final grade, well below the design frost depth of 0.6 m, 15 cm (2 ft, 6 in.).

To provide additional assurance against leakage through the asphalt layer, the asphaltic concrete will be coated with a spray-applied asphaltic coating material. This material has gained wide acceptance based on its excellent puncture resistance, retained flexibility, and favorable constructibility attributes. Permeability values on the order of 10^{-11} cm/s have been demonstrated in tests of samples of polymer modified asphalt coating from the Hanford Barrier prototype (Freeman et al. 1994).

Low-permeability asphalt layers like the asphaltic concrete layer in the Hanford Barrier and the Modified RCRA Subtitle C Barrier have been demonstrated to be highly effective in inhibiting the diffusion of radioactive gases with low partial pressures and short half-lives, such as radon. This conclusion is supported by documentation from the *Uranium Mill Tailings Reclamation Act* program, where multilayer barriers, including a low-permeability asphalt layer, have been constructed and evaluated (Wing 1994).

As individual barriers are constructed, field testing will be needed as an aspect of construction quality assurance to ensure that the design hydraulic conductivity performance of the asphalt layer is achieved.

3.1.2.6 Layer 8 - Asphalt Base Course. This layer will provide a stable base for placement of the overlying asphalt layer. The base course will consist of screened, crushed surfacing material, with 100% passing the 32 mm (1.25 in.) sieve, conforming to WSDOT M 41-10, Section 9-03.9(3) (WDOT 1991).

3.1.2.7 Layer 9 - Grading Fill. Grading fill will be placed, as necessary, to establish a smooth, planar-base surface for construction of the overlying layers. The preexisting site surface will be contoured and graded to create uniform surfaces sloped at 2%, as needed for internal lateral drainage and surface runoff control. Grading the site before construction will facilitate accurate and controlled placement of soil lifts and layers. Grading fill will consist of a well-graded granular soil mixture, which may include as much as 20% by volume of cobbles measuring no more than 75 mm (3 in.) in the greatest dimension.

3.2 MODIFIED RCRA SUBTITLE C BARRIER DESIGN

The Modified RCRA Subtitle C Barrier is discussed in two sections: (1) Section 3.2.1 provides background information on development of the conceptual design and (2) Section 3.2.2 provides a more detailed description of each layer in the conceptual barrier design.

3.2.1 Background Information Relating to the Modified RCRA Subtitle C Barrier Design

Extensive guidance has been issued by state and federal regulatory agencies regarding cover designs for dangerous waste sites. Section 2.0 summarizes the current agency guidance. For Standard RCRA Subtitle C Barriers, EPA has developed a set of basic design elements referred to as the MTG (EPA 1989). Although Standard RCRA Subtitle C Barriers vary somewhat in design and construction from one region of the country to another, these elements generally are retained.

The Modified RCRA Subtitle C design is the baseline design to be considered for sites containing not only dangerous waste, but also Category 3 LLW, Category 3 LL mixed waste, and Category 1 LL mixed waste. The barrier is designed to provide containment and hydrologic protection for a performance period of 500 years.

The term "Modified" designates that this design varies in certain key respects from EPA's MTG for RCRA covers. The MTG cover is a 30-year design. The MTG design employs a two-component barrier layer consisting of a 0.6-m (2-ft)-thick compacted clay layer with an overlain geosynthetic membrane material. Neither material appears to be well suited for the Modified RCRA Subtitle C Barrier application. At an arid to semiarid site (such as the Hanford Site), a clay layer can desiccate and develop shrinkage cracks that would compromise the layer's design function. For 30-year design applications, the durability of geomembrane materials in covers is not generally viewed as a design issue. However, in applications where a substantially longer design life may be needed, the long-term durability of geosynthetic materials is open to question. For these reasons, the clay layer and geomembrane materials were eliminated from consideration for the Modified RCRA Subtitle C design.

Before this FFS was conducted, Standard RCRA Subtitle C Barriers had been designed for the following dangerous waste-site applications at the Hanford Site:

- 183-H Solar Evaporation Basins (DOE-RL 1991)
- Low-Level Burial Grounds (DOE-RL 1989)
- Nonradiological Dangerous Waste Landfill (NRDWL) (DOE-RL 1990b).

The three covers are similar in design and materials. The NRDWL design, which is the most recent design of the three, consisted of the following six layers:

- 75 cm (30 in.) - topsoil layer
- 15 cm (6 in.) - sand drainage layer
- Geotextile filter fabric
- Geonet drainage layer
- High-density polyethylene (HDPE) geomembrane
- 60 cm (24 in.) compacted barrier soil layer.

The Modified RCRA Subtitle C Barrier design may be viewed as an evolutionary extension of the NRDWL design. Several significant design changes were made to the NRDWL design to extend the design life for the barrier and otherwise to bring it into conformance with the criteria in Table 2-5. The first change was to increase the thickness of topsoil by 25 cm (10 in.) for increased protection against soil erosion. Second, specifications for the top layer were modified to incorporate pea gravel as in Layer 1 of the Hanford Barrier to further reduce susceptibility to wind erosion. The third change was to eliminate the geosynthetic components (i.e., the geonet and HDPE geomembrane) and replace them with (1) a lateral drainage layer of screened gravel and (2) a low-permeability barrier layer of asphaltic concrete. The asphalt layer will also serve as a biointrusion barrier to prevent plant roots and/or burrowing animals from accessing covered waste. Figure 3-2 shows the Modified RCRA Subtitle C Barrier in profile.

3.2.2 Conceptual Barrier Design

The Modified RCRA Subtitle C Barrier is composed of eight layers with a combined minimum thickness of 1.7 m (5.6 ft). Table 3-2 summarizes each cover layer. A detailed description of the cover layers and their respective functions is provided below, starting with the top layer.

3.2.2.1 Layer 1 (Topsoil with Pea Gravel Admixture) and Layer 2 (Compacted Topsoil without Pea Gravel). Layer 1 consists of 50 cm (20 in.) of sandy silt-to-silt loam soil from the McGee Ranch site containing 15% (by weight) pea gravel. Layer 1 will be placed in a relatively loose condition, with a bulk density value of about 1.46 g/cc (91 to 92 lb/ft^3). Layer 2 consists of 50 cm (20 in.) of the same silt loam soil, without pea gravel, placed in a relatively densified state, approximately 1.76 g/cc (110 lb/ft^3).

The topsoil component (i.e., Layers 1 and 2) of the Modified RCRA Subtitle C Barrier is similar in form and function to the topsoil component in the Hanford Barrier. As in the Hanford Barrier design, the topsoil component must serve as a storage medium for soil moisture, and it must support cover vegetation. Likewise, the purpose of the pea gravel in Layer 1 is to improve the soil's resistance to wind erosion (Ligotke and Klopfer 1990). As in the case of the Hanford Barrier, the surface slope will be limited to 2% (after allowances for settlement and subsidence). This value is steep enough to provide for coherent drainage of runoff from the covered area, yet shallow enough to limit exposure of the surface to wind erosion.

Compaction of Layer 2 during construction will decrease its saturated hydraulic conductivity by three to four orders of magnitude (i.e., from values in the range of 10^{-3} to 10^{-4} cm/s down to values between 10^{-6} to 10^{-7} cm/s). The indicated reduction in conductivity is readily achievable by compacting McGee Ranch silt loam soil to densities in the range of 1.68 to 1.84 (105 to 115 lb/ft^3). Laboratory testing indicates that these results can be accomplished with moderate compactive effort (Skelly et al. 1994). Compaction will retard moisture migration through Layer 2. Moisture retention and evapotranspiration within Layers 1 and 2 will be enhanced by forming a capillary barrier at the base of Layer 2, as explained in Section 3.1.2.1. Numerical performance assessments using the HELP Model and UNSAT-H Model predict that essentially 100% of average annual precipitation will be removed from the barrier by evapotranspiration (Appendices C-2 and C-4).

The combined thickness of Layers 1 and 2 is sufficient to support continued storage and removal of moisture by evapotranspiration even if significant topsoil losses should occur. At a bulk density of 1.38 g/cc (86.3 lb/ft^3) and a projected soil erosion rate of 2 tons per acre per year, the thickness of soil loss over the 500-year design life of the barrier would amount to approximately 16 cm (6.4 in.). Based on numerical simulations, evapotranspiration from the topsoil component of the barrier would only be reduced by soil losses if the losses were to exceed 35 to 40 cm (14 to 16 in.). Appendix D provides sample wind and water erosion calculations.

Cover vegetation will consist of a mixture of perennial grass species. Specifications for the seed mix, and the methods of seed application, fertilizing, and mulching will be developed during definitive design. Planting of cover vegetation will meet or exceed recommendations in EPA's technical guidance for final covers (EPA 1989).

3.2.2.2 Layer 3 (Sand Filter) and Layer 4 (Gravel Filter). These layers are components of a two-layer graded filter designed to prevent topsoil particles from moving downward and accumulating in the lateral drainage layer (Layer 5). Both layers are 15 cm (6 in.) thick. Section 3.1.2.2 provides particle size information for the filter and filtrate materials.

The same graded filter design is employed in the Hanford Barrier and the Modified RCRA Subtitle C Barrier, except that the gravel filter layer in the Subtitle C design is 15 cm (6 in.) thick where the Hanford Barrier design calls for 30 cm (12 in.). A 15-cm (6-in.) thickness is sufficient to achieve the design filtration function, although a 30-cm (12-in.) layer may be somewhat easier to construct. This modification is recommended simply as an economy of material.

3.2.2.3 Layer 5 - Lateral Drainage Layer. This layer will facilitate the removal of any moisture that moves completely through the topsoil component of the barrier (Layers 1 and 2). This layer represents a contingency scheme to remove soil moisture in response to extreme climatic events, such as the design storm. Layer 5 will be sloped at 2% to move water to the edge of the cover where it will be collected and/or diverted in an appropriate manner. Layer 5 will be 15 cm (6 in.) thick and will be constructed of clean, screened aggregate material with a hydraulic conductivity of at least 1 cm/s. As discussed in Section 3.1.2.5, an effective particle size (D_{10}) of 1 mm or greater is needed for the drainage media to achieve the desired permeability value. Layer 5 will be situated approximately 1.32 m (4.33 ft) below final grade, which satisfies the design criterion for frost protection.

The lateral drainage layers in the Hanford Barrier and the Modified RCRA Subtitle C Barrier are similar in design. The Hanford Barrier has a drainage layer that is 30 cm (12 in.) thick, whereas in the Modified RCRA Subtitle C design, the drainage layer is 15 cm (6 in.) thick. This modification is an economy based on the expectation of an extremely small volume of lateral drainage. Performance simulations with the HELP Model and UNSAT-H Model indicate that little (if any) lateral drainage will occur (Appendices C-2 and C-4).

3.2.2.4 Layer 6 - Asphalt Layer. This layer will function as a low-permeability barrier layer and as a biointrusion barrier. Layer 6 will be constructed of a durable asphaltic concrete mixture consisting of double-tar asphalt (i.e., twice the tar content of normal highway asphalt) with added sand as binder material, conforming to WSDOT M41-10, Section 9-02.1(4), Grade AR-4000W (WDOT 1991). Laboratory permeability tests on asphaltic concrete cores from the Hanford Barrier prototype yielded values on the order of 10^{-10} cm/s. In-field values, measured by falling-head permeameter testing, ranged between 10^{-7} and 10^{-9} cm/s (DOE-RL 1994). The asphaltic concrete will be coated with a spray-applied asphaltic material. The same asphalt layer design is incorporated in the Hanford Barrier and the Modified RCRA Subtitle C Barrier. As noted in Section 3.1.2.6, hydraulic conductivity testing will be performed on the asphalt layer in situ to determine the actual in-field value at the time of construction. The asphalt layer will be constructed with a slope of 2% (after allowances for settlement and subsidence).

The low-permeability asphalt layer is expected to be a highly effective deterrent to intrusion by plant roots and burrowing animals. As necessary, it will also function as a human intrusion barrier. The strength of the asphaltic concrete material, the thickness of Layer 6, and its deliberate construction should serve to advise inadvertent intruders that this layer is an intentional barrier. Layer 6 can be breached with mechanical excavation equipment, but intrusion scenarios involving the use of heavy equipment probably would be considered advertent rather than inadvertent.

The 10 CFR 61.42 identifies the need to protect individuals from inadvertent human intrusion into radioactive waste. The guidance contained in 10 CFR 61.52 was used for Class C (DOE Category 3) LLW specifically. This guidance states that protection may take either of the following forms:

- The site may be capped with a combination of earth fill and engineered barrier materials, such that the top of the waste zone is at least 5 m (16.4 ft) below the surface of the cover.
- The engineered barrier must be designed to protect against inadvertent intrusion for the design life of 500 years.

Many radiological sites in the 200 Areas where the Modified RCRA Subtitle C Barrier may be used already have been covered with sufficient fill to satisfy the first option, or would meet option 1 with the additional 1.7 m (5.6 ft) of cover materials in the Modified RCRA Subtitle C Barrier. In other cases, the thicknesses of one or more of the barrier layers (e.g., grading fill [Layer 8] or topsoil [Layers 1 and/or 2]) could be modified (i.e., increased) to conform to option 1 in lieu of designating a human intrusion barrier layer.

Low-permeability asphalt layers, like the asphaltic concrete layer in the Hanford Barrier and the Modified RCRA Subtitle C Barrier, have been demonstrated to be highly effective in inhibiting the diffusion of radioactive gases with low partial pressures and short half-lives, such as radon. This conclusion is supported by documentation from the *Uranium Mill Tailings Reclamation Act* program, where multilayer barriers, including a low-permeability asphalt layer, have been constructed and evaluated (Wing 1994).

As individual barriers are constructed, field testing will be needed as an aspect of construction quality assurance to ensure that the design hydraulic conductivity performance of the asphalt layer is achieved.

3.2.2.5 Layer 7 - Asphalt Base Course. This layer will provide a stable base for placement of the overlying asphalt layer. The base course will consist of screened, crushed-surfacing material, with 100% passing the 32 mm (1.25 in.) sieve, conforming to WSDOT M 41-10, Section 9-03.9(3) (WDOT 1991).

3.2.2.6 Layer 8 - Grading Fill. Grading fill will be placed, as necessary, to establish a smooth, planar-base surface for construction of the overlying layers. The preexisting site surface will be contoured and graded to create uniform surfaces sloped at 2%, as needed for internal lateral drainage and surface runoff control. Grading the site before construction will facilitate accurate and controlled placement of soil lifts and layers. Grading fill will consist of a well-graded granular soil mixture, which may include as much as 20% by volume of cobbles measuring no more than 75 mm (3 in.) in the greatest dimension.

3.2.2.7 Potential Modifications to Design and Application. The Modified RCRA Subtitle C Barrier design could be enhanced by increasing the thickness of the topsoil layers and by including some type of intrusion deterrence layer (similar in function to the fractured basalt layer of the Hanford Barrier) so that it would provide additional protection for sites containing significant inventories of TRU constituents. This is a potential evolutionary direction for the Subtitle C Barrier.

3.3 STANDARD RCRA SUBTITLE C BARRIER DESIGN

The Standard RCRA Subtitle C Barrier is discussed in two subsections. Section 3.3.1 provides background information on development of the conceptual design. Section 3.3.2 describes each layer in the conceptual barrier design.

3.3.1 Background Information Relating to the Standard RCRA Subtitle C Barrier

Background information relating to Standard RCRA Subtitle C Barriers and existing applications at the Hanford Site are presented in Section 3.2. The Standard RCRA Subtitle C Barrier is pertinent to dangerous waste sites. The Standard RCRA Subtitle C Barrier is shown in profile in Figure 3-3.

3.3.2 Conceptual Barrier Design

The Standard RCRA Subtitle C Barrier is composed of a minimum of four layers, with a combined minimum thickness of 165 cm (5.5 ft). Table 3-3 summarizes each cover layer. The cover layers and their respective functions are described below.

3.3.2.1 Layer 1 (Vegetative Layer or Armoring Layer). This layer consists of vegetated silt and gravel admix, to protect the barrier against damage (e.g., erosion) and provide moisture retention and evapotranspiration to decrease infiltration. The top layer consists of two components with a combined minimum thickness of 60 cm (2 ft) consisting of (1) either a vegetated or armored surface component to minimize erosion and, to the extent possible, promote drainage off the cover and (2) a soil component comprised of topsoil and/or fill soil, as appropriate. The surface of the layer should slope uniformly at least 3%, but not more than 5%. A soil component of greater thickness may be required to ensure that the underlying low-permeability layer is below the frost zone.

3.3.2.2 Layer 2 (Filter Layer). This layer consists of sand and/or gravel with a minimum thickness of 15 cm (6 in.) designed to prevent topsoil particles from moving downward and accumulating in the underlying drainage layer. Gradation requirements will depend upon actual topsoil and drainage layer materials.

3.3.2.3 Layer 3 (Drainage Layer). This layer consists of either 30 cm (12 in.) of sand, or a synthetic geonet to divert infiltration away from the covered area and minimize hydraulic head on the infiltration barrier. It provides a soil drainage (and FML-protective bedding) layer with a minimum hydraulic conductivity of 1 x 10^{-2} cm/s that will effectively minimize water infiltration into the low-permeability layer, and will have a final slope of at least 3% after settlement and subsidence; or a drainage layer consisting of geosynthetic materials with equivalent performance characteristics.

3.3.2.4 Layer 4 (Low Permeability Layer). This layer is typically a synthetic membrane over a minimum 60 cm (2 ft) of compacted soil with a permeability no greater than 1 x 10^{-7} cm/s. The synthetic membrane and soil provides a thick barrier capable of self-healing if settling occurs. This two-component, low-permeability layer, lying wholly below the frost zone, provides minimization of water infiltration into the underlying waste, and consists of the following: (1) a 20-mil (0.5 mm) minimum thickness FML component and (2) a compacted soil component with a minimum thickness of at least 60 cm (2 ft) and a maximum in-place saturated hydraulic conductivity of 1 x 10^{-7} cm/s. The soil component typically consist of clay or a soil with admix, such as bentonite.

3.3.2.5 Optional Layers (Site-Specific Design for Gas Venting or Biointrusion). This layer is intended to provide sufficient thickness to minimize the potential for intrusion through the barrier.

These optional layers may be used on a site-specific basis. Two such layers include (1) a gas vent layer to remove gasses that are produced within the waste and/or (2) a biotic barrier layer to protect the cover from animal or plant intrusion. Geosynthetic filter materials may also be used to prevent migration of fine materials from one layer to another or to prevent clogging the drainage layer.

3.4 MODIFIED RCRA SUBTITLE D BARRIER DESIGN

The Modified RCRA Subtitle D Barrier design is discussed in two subsections. Section 3.4.1 provides background information on development of the conceptual design. Section 3.4.2 describes the conceptual barrier design.

3.4.1 Background Information Relating to the Modified RCRA Subtitle D Barrier Design

This design is the baseline design to be considered at nonradiological and nonhazardous solid waste sites, as well as Category 1 LLW sites where no dangerous waste constituents are present. It is designed to provide limited biointrusion and limited hydrologic protection (compared to the other two barrier designs) for a performance period of 100 years. The performance period is selected based on the length of time for which Category 1 waste presents a hazard. Figure 3-4 shows the Modified RCRA Subtitle D Barrier in profile.

Guidance for designing RCRA Subtitle D Barriers is the most explicit of the categories considered in this study. Design criteria for the RCRA Subtitle D Barrier prescribe a minimum number of soil layers, minimum layer thicknesses, and a maximum permeability for the cover.

Before this study, one RCRA Subtitle D Barrier design was prepared for the Hanford Site. This design is described in the permit application for the Hanford Solid Waste Landfill (SWL) (DOE-RL 1993c). The SWL cover was designed to meet the regulatory criteria for both municipal solid waste and asbestos. The SWL cover design consists of a two-layered soil system (76 cm [30 in.] total) with a vegetated surface. It is designed to impede erosion and to remove soil moisture by evapotranspiration.

The Modified RCRA Subtitle D Barrier was developed as an adaptation of the SWL cover design. Two design changes were made to the SWL design to improve its erosion-resistance characteristics and water retention capabilities. The first change was to modify the upper 20 cm (8 in.) of topsoil with a 15% pea gravel admixture. The second change was to increase the thickness of uncompacted topsoil (Layer 1 in the SWL design; the sum of Layers 1 and 2 in the design) from 45 cm (18 in.) to 60 cm (24 in.). Increasing the thickness of the barrier is intended to enhance performance margins relating to soil moisture storage and erosional losses consistent with the extended (100-year) design-life criterion. The term "Modified" designates that this design varies in certain key respects from the MFS design for covers over solid waste sites.

3.4.2 Conceptual Barrier Design

The Modified RCRA Subtitle D Barrier is composed of four layers having a combined thickness of 90 cm (36 in.) minimum. Table 3-4 summarizes the cover layers. In the following subsections, the layers are described in sequence, beginning with the top layer.

3.4.2.1 Topsoil System - Layer 1 (Topsoil with Pea Gravel Admixture), Layer 2 (Topsoil without Pea Gravel), and Layer 3 (Compacted Topsoil). Layer 1 consists of 20 cm (8 in.) of sandy silt-to-silt loam soil with 15% (by weight) admixture of pea gravel. As in the other two designs, the purpose of the pea gravel admix is to reduce the susceptibility of the topsoil surface to wind erosion. The soil in Layer 1 will be placed in a relatively loose condition, with a bulk density of 1.46 g/cc (91 to 92 lb/ft^3).

Layer 2 consists of 40 cm (16 in.) of the same topsoil material without pea gravel. Layer 2 will also be placed in a relatively loose condition, with a bulk density of about 1.38 g/cc (86.3 lb/ft^3), which is approximately the same as the in-place condition at the borrow site.

Layer 3 consists of 30 cm (12 in.) of the same material specified for Layers 1 and 2, but placed in a relatively densified condition of approximately 1.76 g/cc (110 lb/ft^3). Compaction of Layer 3 during construction will decrease its saturated hydraulic conductivity by three to four orders of magnitude (i.e., from values in the range of 10^{-3} to 10^{-4} cm/s down to values between 10^{-6} to 10^{-7} cm/s). The indicated reduction in conductivity is readily achievable by compacting McGee Ranch silt loam soil to densities in the range of 1.68 to 1.84 g/cc (105 to 115 lb/ft^3). Laboratory testing indicates that these results can be accomplished with moderate compactive effort (Skelly et al. 1994). Compaction will retard moisture migration through Layer 3.

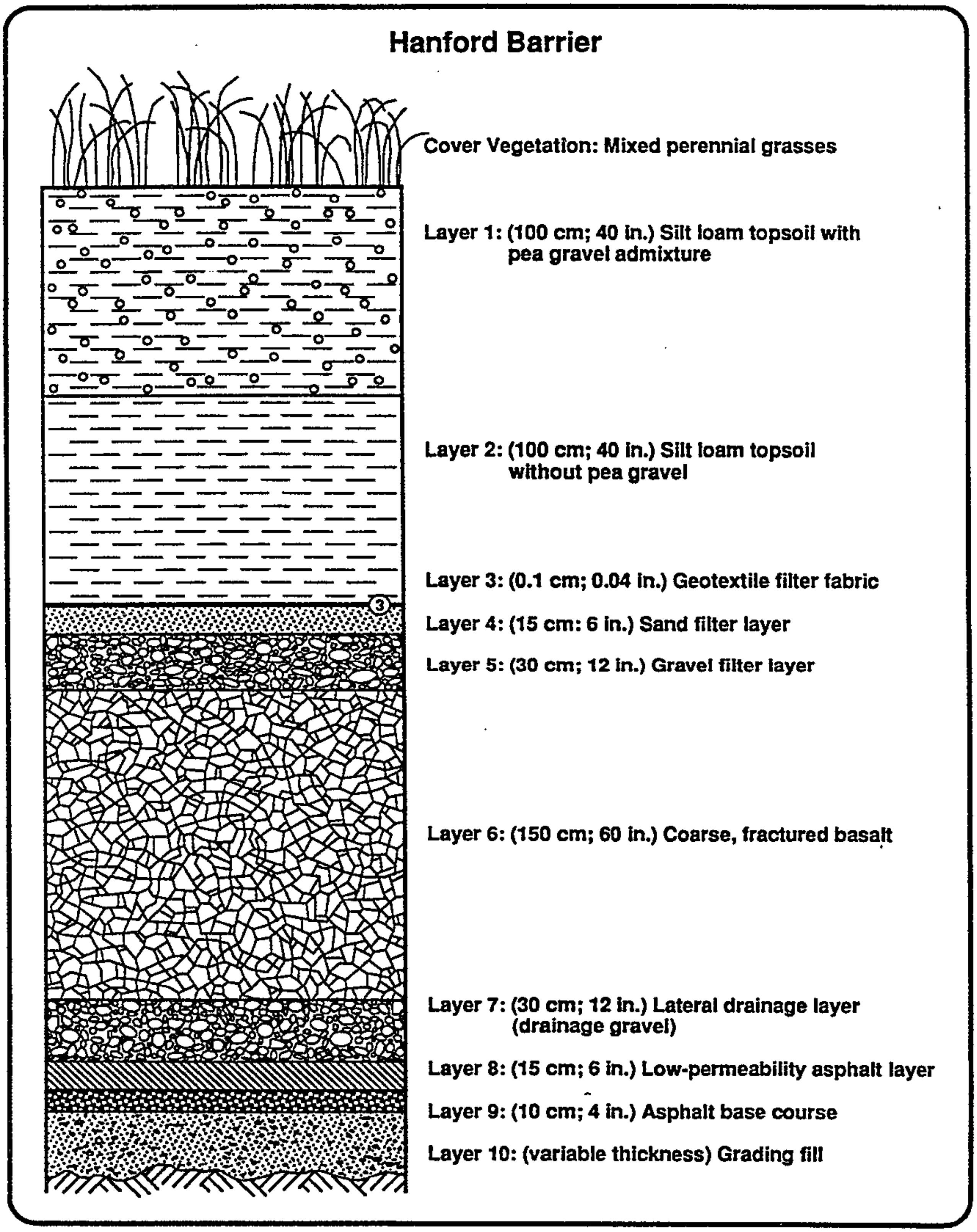
As with the two previous designs, the principal function of the topsoil system is to intercept, temporarily store, and return moisture to the atmosphere by evapotranspiration. The topsoil material must also provide a suitable medium to establish and maintain the cover vegetation that will assist in soil moisture removal and protect the surface from erosion. The compacted soil in Layer 3 will retard moisture migration through the lower part of the cover system, extending the residence time during which soil moisture is available for evaporation and transpiration by plants. Moisture retention and evapotranspiration within the topsoil system will also be enhanced by formatting a capillary barrier at the base of Layer 3. Numerical performance assessments using the HELP Model and UNSAT-H Model predict that essentially 100% of average annual precipitation will be removed from the barrier by evapotranspiration (Appendices C-3 and C-4).

As indicated by the sample calculations in Appendix D, wind erosion potential at the Hanford Site is relatively high, while water erosion potential is almost negligibly small. The Modified RCRA Subtitle D Barrier design calls for the surface of Layer 1 to be constructed with a uniform 2% slope (after allowances for settlement and subsidence). This angle is steep enough to facilitate runoff of excess surface water that may be generated from extreme precipitation events. However, it has been set at a minimum value to limit exposure of the cover surface to wind erosion.

Cover vegetation will consist of a mixture of perennial grass species. Specifications for the seed mix, and the methods of seed application, fertilizing, and mulching will be developed during definitive design. Planting of cover vegetation will meet or exceed recommendations in EPA's technical guidance for final covers (EPA 1989).

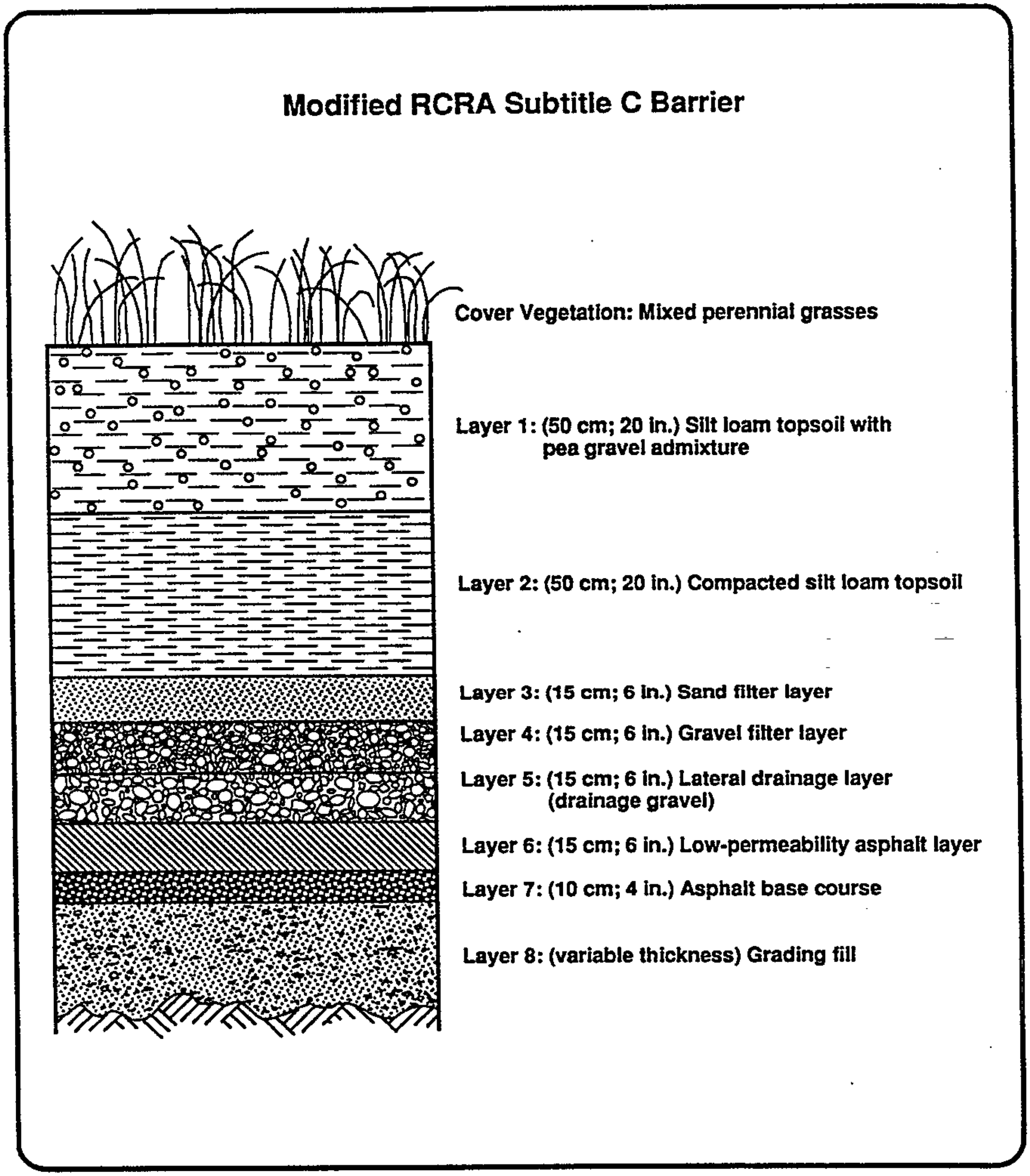
3.4.2.2 Layer 4 - Grading Fill. As in the previous two designs, grading fill must be placed, as necessary, over the preexisting site grade to establish a smooth, planar-base surface for construction of the overlying layers. The preexisting site surface will be contoured and graded to create uniform surfaces sloped at 2%, as needed for internal lateral drainage and surface runoff control. Grading the site before construction will facilitate accurate and controlled placement of soil lifts and layers. Grading fill will consist of a well-graded granular soil mixture, which may include as much as 20% by volume of cobbles measuring no more than 75 mm (3 in.) in the greatest dimension.

Figure 3-1. Hanford Barrier Profile.



H9408029.1

Figure 3-2. Modified RCRA Subtitle C Barrier Profile.



H9408029.2

Figure 3-3. Standard RCRA Subtitle C Barrier Profile.

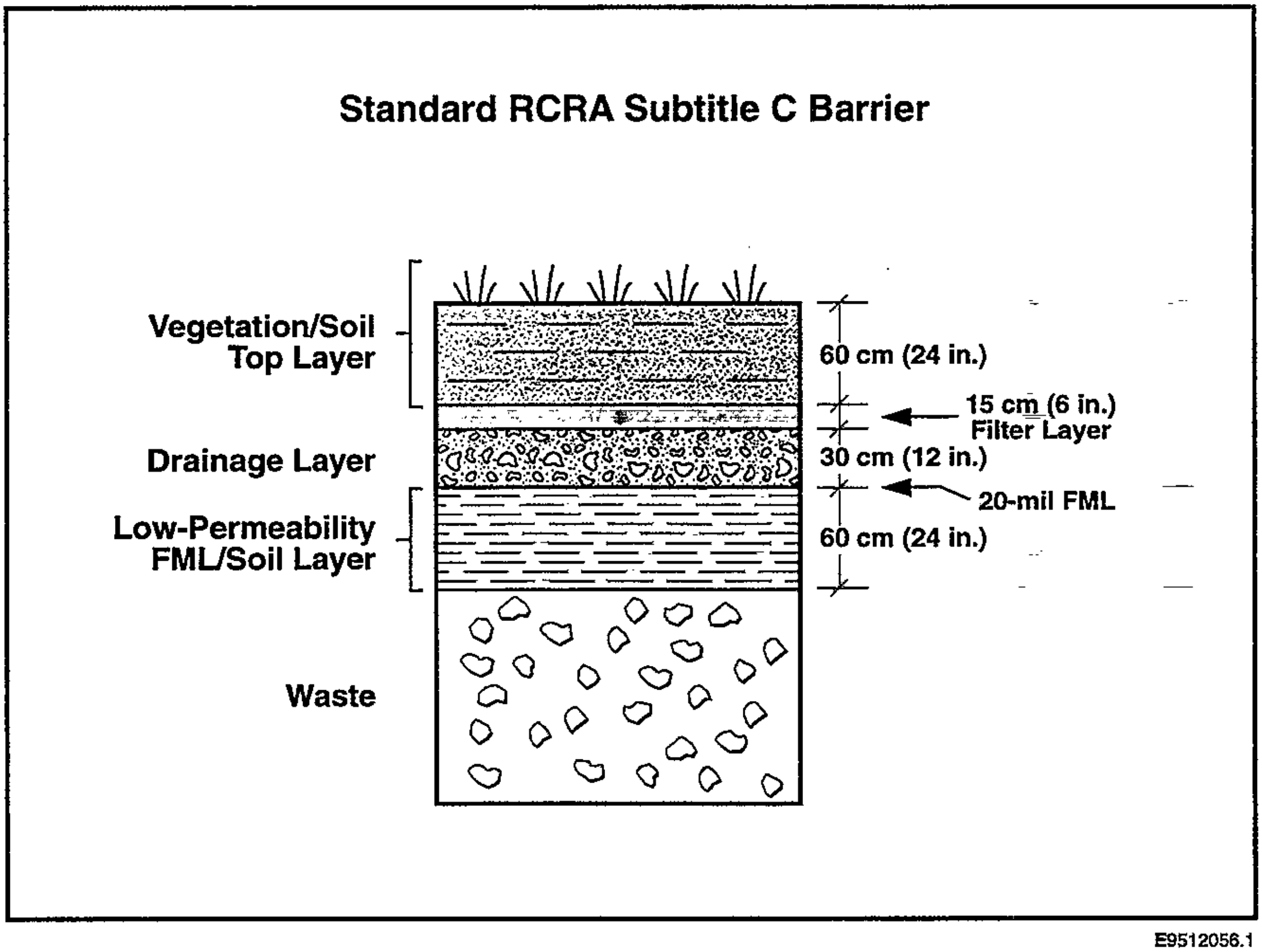
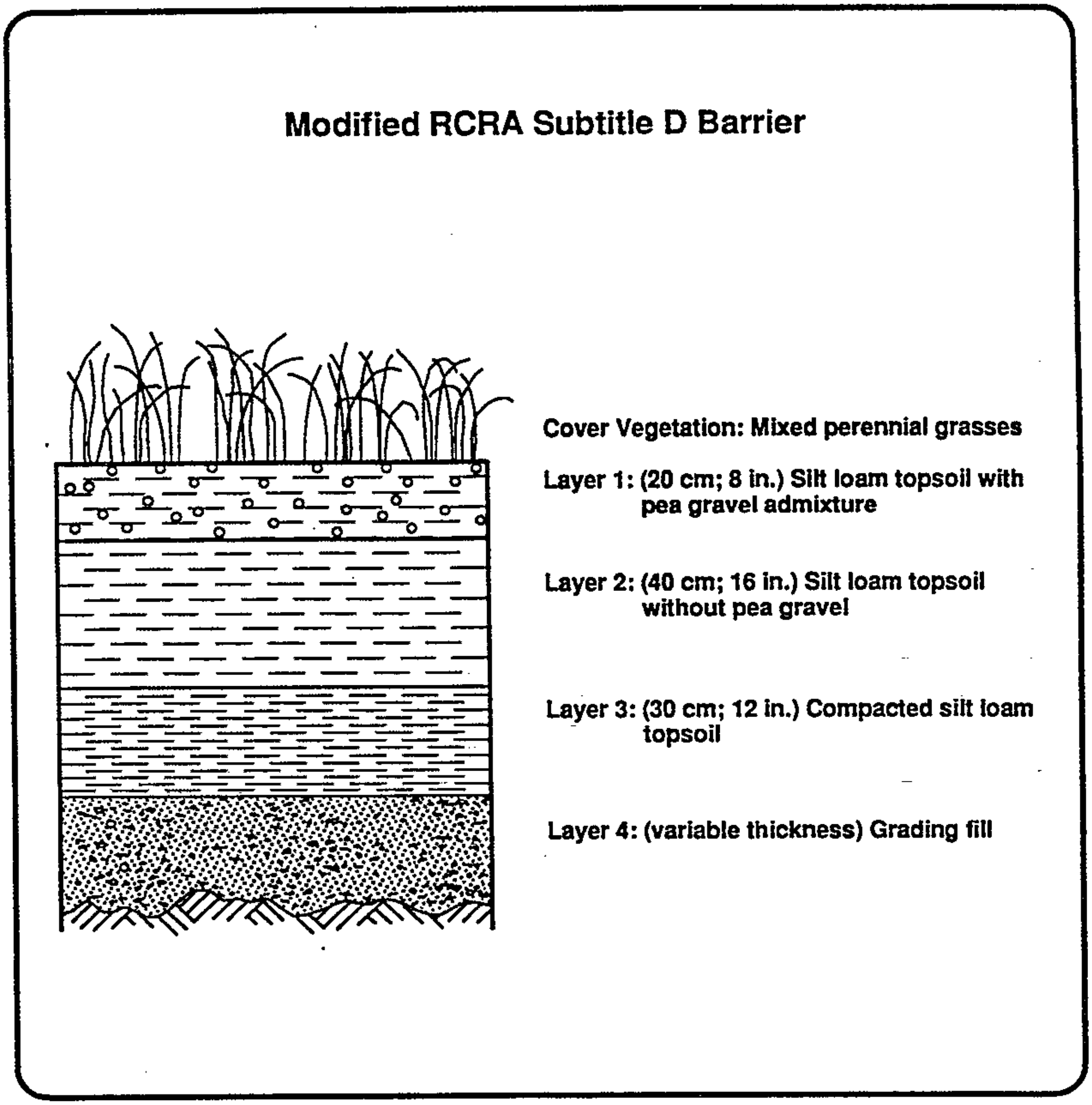


Figure 3-4. Modified RCRA Subtitle D Barrier Profile.



Modified RCRA Subtitle D Barrier

Cover Vegetation: Mixed perennial grasses

Layer 1: (20 cm; 8 in.) Silt loam topsoil with pea gravel admixture

Layer 2: (40 cm; 16 in.) Silt loam topsoil without pea gravel

Layer 3: (30 cm; 12 in.) Compacted silt loam topsoil

Layer 4: (variable thickness) Grading fill

H9408029.3

Table 3-1. Summary of the Hanford Barrier Layers. (Page 1 of 2)

Layer No.[1]	Thickness cm (in.)	Layer description	Specifications	Function
1	100 (40)	Silt loam topsoil with pea gravel admix	McGee Ranch silt loam containing 15% pea gravel by wt., 2.36 to 9.5 mm in diameter, conforming to ASTM D448 No. 8 aggregate; to be placed at a bulk density of approximately 1.46 g/cc.	The topsoil material was identified 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 the silt loam without significantly affecting its moisture retention capabilities.
2	100 (40)	Silt loam topsoil	McGee Ranch silt loam to be placed at a bulk density of approximately 1.38 g/cc.	Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity.
3	15 (6)	Sand filter	Clean, screened sand meeting the following particle sizes: D_{15}= 0.15 to 0.50 mm, D_{50}= 0.375 to 1.2 mm, and D_{85} = 0.70 to 2.5 mm.	This layer is part of a two-layer graded filter designed to prevent the migration of topsoil particles into Layers 6 and 7.
4	30 (25)	Gravel filter	Clean, screened aggregate meeting the following particle sizes: D_{15}= 1.5 to 2.0 mm, D_{50}=15 to 20 mm, and D_{85} <37.5 mm.	Same as Layer 4.
5	150 (60)	Coarse, fractured riprap material	Quarried basalt screened to minus 25 cm (10 in.) plus 5 cm (2 in.).	This layer is specifically designed to perform as a barrier to inadvertent human intrusion (i.e., exploratory drilling). The layer will also prevent plant and animal intrusion into the underlying layers.
6	30 (12)	Lateral drainage aggregate	Naturally occurring aggregate, minus 32-mm (1.25-in.) material, conforming to the grading identified in WDOT M41-10, 9-03.9(3) for base course, with D_{10} >1 mm and k >1 cm/s.	The lateral drainage layer will intercept and divert moisture along a 2% slope to the margin of the cover for collection and/or discharge.

Table 3-1. Summary of the Hanford Barrier Layers. (Page 2 of 2)

Layer No.[1]	Thickness cm (in.)	Layer description	Specifications	Function
7	15 (6)	Asphaltic concrete with spray-applied asphalt coating	Asphaltic concrete, consisting of asphalt conforming to WDOT M41-10, 9-02.1(4) - Grade AR-4000W, and aggregate with particle size gradation conforming to ASTM C 136. Asphalt will make up 7.5 wt. % of total mixture. A spray-applied, styrene-butadiene asphalt material will be sprayed onto the asphaltic concrete surface in two layers, each 100 mils thick minimum.	This layer will function as a hydrologic barrier and will provide additional protection against plant and animal intrusion into the underlying zone of contamination.
8	10 (4)	Asphalt base course	Crushed aggregate, minus 16-mm (5/8-in.) diameter material, conforming to WDOT M41-10, 9-03.9(3) for top course surfacing material.	The function of the material in this layer is to provide a stable base for placing and supporting the asphalt layer.
9	Variable	Grading fill	Clean, bank run sand and gravel conforming to WDOT M41-10, 9-03.18.	This layer will provide a smooth, level subgrade for construction of the overlying layers.

[1] Barrier layers are listed in sequence from top to bottom.

Table 3-2. Summary of Modified RCRA Subtitle C Barrier Layers. (Page 1 of 2)

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
1	50 (20)	Silt loam topsoil with pea gravel admix	McGee Ranch silt loam containing 15 wt. % pea gravel, 2.36 to 9.5 mm in diameter, conforming to ASTM D448 No. 8 aggregate; to be placed at a bulk density of approximately 1.46 g/cc.	The topsoil material was identified 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 the silt loam without significantly affecting its moisture retention capabilities.
2	50 (20)	Compacted topsoil	McGee Ranch silt loam without pea gravel, compacted to 90% of optimum dry density as determined by standard Proctor test; in-place bulk density will be approximately 1.76 g/cc.	Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity. Compaction of this layer is intended to retard the rate of infiltration of soil moisture. The extended residence time of moisture in Layer 2 will increase the amount of moisture removed by evapotranspiration.
3	15 (6)	Sand filter	Clean, screened sand meeting the following particle sizes: D_{15} = 0.15 to 0.50 mm, D_{50} = 0.375 to 1.2 mm, and D_{85} = 0.70 to 2.5 mm.	This layer is part of a two-layer graded filter designed to prevent the migration of topsoil particles into Layer 5.
4	15 (6)	Gravel filter	Clean, screened aggregate meeting the following particle sizes: D_{15} = 1.5 to 2.0 mm, D_{50} =15 to 20 mm, and D_{85} <37.5 mm.	Same as Layer 3.
5	15 (6)	Lateral drainage aggregate	Naturally occurring aggregate, minus 32-mm (1 1/4-in.) material, conforming to the grading identified in WDOT M41-10, 9-03.9(3) for base course, with D_{10} >1 mm and k >1 cm/s.	The lateral drainage layer will intercept and divert moisture along a 2% slope to the margin of the cover for collection and/or discharge.

Table 3-2. Summary of Modified RCRA Subtitle C Barrier Layers. (Page 2 of 2)

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
6	15 (6)	Asphaltic concrete with spray-applied asphalt coating	Asphaltic concrete, consisting of asphalt conforming to WDOT M41-10, 9-02.1(4) - Grade AR-4000W, and aggregate with particle size gradation conforming to ASTM C 136. Asphalt will make up 7.5 wt. % of total mixture. A spray-applied, styrene-butadiene asphalt material will be sprayed onto the asphaltic concrete surface in two layers, each 100 mils thick minimum.	This layer will function as a hydrologic barrier and as a biointrusion barrier.
7	10 (4)	Asphalt base course	Crushed aggregate, minus 16-mm (5/8-in.) diameter material, conforming to WDOT M41-10, 9-03.9(3) for top course surfacing material.	The function of the material in this layer is to provide a stable base for placing and supporting the asphalt layer.
8	Variable	Grading fill	Clean, bank run sand and gravel conforming to WDOT M41-10, 9-03.18.	This layer will provide a smooth, level subgrade for construction of the overlying layers.

[1] Barrier layers are listed in sequence from top to bottom.

Table 3-3. Summary of Standard RCRA Subtitle C Barrier Layers.

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
1	60 (24)	Silty-to-sandy loam topsoil with pea gravel admix	Available, native, silty-to-sandy loam topsoil, with pea gravel to gravel mix. Grain size requirements vary per site/available materials.	Provide a good rooting medium for cover vegetation. Pea gravel admix and vegetation for wind erosion mitigation.
2	15 (6)	Sand and/or gravel filter	Native/local or imported sand and/or gravel. Grain size requirements vary per topsoil type.	Filter designed to prevent the migration of topsoil particles into Layer 3.
3	30 (12)	Lateral drainage aggregate	Import or naturally occurring aggregate. Grain size requirements vary per overlying topsoil and filter sizes.	The lateral drainage layer will intercept and divert moisture along a minimum 3% slope to the margin of the cover for collection and/or discharge.
4	60 (24)	Low permeability FML/soil layer	20-mil minimum thickness FML. Bentonite admix with available silty to sandy native soils; admix range from approximately 8 to 12%.	This layer will function as a hydrologic barrier.

[1] Barrier layers are listed in sequence from top to bottom.

Table 3-4. Summary of Modified RCRA Subtitle D Barrier Layers.

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
1	20 (8)	Silt loam topsoil with pea gravel admix	McGee Ranch silt loam containing 15 wt. % pea gravel, 2.36 to 9.5 mm in diameter, conforming to ASTM D448 No. 8 aggregate; to be placed at a bulk density of approximately 1.46 g/cc.	The topsoil material 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 the silt loam without significantly affecting its moisture retention capabilities.
2	40 (16)	Silt loam topsoil	McGee Ranch silt loam without pea gravel, to be placed at a bulk density of approximately 1.38 g/cc.	Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity.
3	30 (12)	Compacted topsoil	McGee Ranch silt loam compacted to 90% of optimum dry density as determined by standard Proctor test; in-place bulk density will be approximately 1.76 g/cc.	Same as Layer 1. Compaction of this layer is intended to retard the rate of infiltration of soil moisture. The extended residence time of moisture in Layer 3 will increase the amount of moisture removed by evapotranspiration.
4	Variable	Grading fill	Clean, bank run sand and gravel conforming to WDOT M41-10, 9-03.18.	This layer will provide a smooth, level subgrade for construction of the overlying layers.

[1] Barrier layers are listed in sequence from top to bottom.

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4.0 EVALUATION OF ENGINEERED SURFACE BARRIER DESIGNS

In this section, the four conceptual surface barrier designs presented in Section 3.0 are evaluated against two sets of criteria: (1) the design criteria developed for each barrier in Section 2.0 and (2) the nine evaluation criteria applied by EPA to demonstrate satisfaction of the statutory requirements of CERCLA in evaluating appropriate remedial actions, as described in Chapter 6 of EPA 1988. The first evaluation verifies the technical adequacy of the designs in terms of conformance of each design to its design criteria. The second evaluation provides preliminary information to evaluate surface barriers against other remedial alternatives during the site-specific evaluation.

4.1 CONFORMANCE TO DESIGN CRITERIA

This section reviews the four cover designs (Hanford Barrier, Modified RCRA Subtitle C Barrier, Standard RCRA Subtitle C Barrier, and Modified RCRA Subtitle D Barrier) for conformance with the design criteria identified for each cover in Section 2.5. In Tables 4-1 through 4-4, each design criterion has been addressed individually; the criteria and corresponding conformance attributes are listed in adjacent columns. Layer numbers referenced in the tables refer to the corresponding cover layers shown in Figures 3-1 through 3-4.

The results of the conformance assessment for the Hanford Barrier are tabulated in Table 4-1; Table 4-2 presents results for the Modified RCRA Subtitle C Barrier; Table 4-3 presents results for the Standard RCRA Subtitle C Barrier; and Table 4-4 presents results for the RCRA Subtitle D Barrier.

The EPA MTGs for the Standard RCRA Subtitle C Barrier are presented in EPA 1989, adapted herein with modifications, as noted in Section 3.0 for site-specific conditions.

The Hanford Barrier, the Modified RCRA Subtitle C Barrier, and the Standard RCRA Subtitle C Barrier are designed for application at the site containing dangerous waste. Therefore, the EPA's MTG is evaluated for these three barriers.

1. A vegetated or armored topsoil surface component with a minimum thickness of 60 cm (24 in.), with a surface slope of at least 3% but not more than 5%.

2. A lateral drainage layer with a minimum thickness of 30 cm (12 in.) and a minimum hydraulic conductivity of 1×10^{-2} cm/s, and a minimum final slope (after settlement and subsidence) of at least 3%.

3. A two-component low-permeability layer, consisting of (1) a flexible membrane liner with a minimum thickness of 20 mils (0.5 mm) and (2) a compacted soil component with a minimum thickness of 60 cm (24 in.) and a maximum in-place saturated hydraulic conductivity of 1×10^{-7} cm/s.

The MTG is not a regulation. The EPA recognizes that other design configurations (e.g., with fewer layers or optional layers) may be appropriate for site-specific applications. However, EPA states that alternative designs should provide long-term performance that is equivalent to that implied in the MTG design (EPA 1989).

The Hanford Barrier and the Modified RCRA Subtitle C Barrier both include a vegetated topsoil layer, a lateral drainage layer, and a two-component low-permeability layer. The designs depart from the MTG in the following respects:

- The surface slope and the slopes of internal layers are specified at 2%.
- The thickness of the lateral drainage layer in the Modified RCRA Subtitle C Barrier is 15 cm (6 in.).
- The two-component low-permeability layer will be constructed of 15 cm (6 in.) of low-permeability asphalt with a spray-applied asphaltic coating material.

The provision in the MTG for slopes between 3 and 5% encourage runoff and minimize or eliminate any tendency for ponding of rainwater on the barrier surface. Because the climate at the Hanford Site is semiarid, nearly all precipitation arriving at the site infiltrates into the soil column regardless of the surface slope. As shown in performance simulations in Appendix C, precipitation events resulting in excess surface water (i.e., runoff or standing water) are relatively rare at the Hanford Site. Even in design-storm simulations and analyses where precipitation is modeled at twice the actual ambient values, relatively little runoff is generated. Estimates of potential losses of topsoil caused by water erosion are small (Appendix D, Section 3.0). For these reasons, water erosion of the barrier surface from stormwater runoff and ponding of surface water are not viewed as consequential issues at the Hanford Site.

Conversely, wind erosion is a potentially significant problem. The Hanford Site is situated in a particularly adverse location within Washington State with respect to wind erosion potential, as illustrated in Appendix D (Figure D-3). Estimates of topsoil losses to wind erosion (Appendix D, Section 2.0) indicate that losses would be expected to exceed 2.0 tons per acre per year for surface slopes of 3%. If slopes are limited to 2%, soil losses are predicted to be acceptable.

The lateral drainage layer of both the Hanford Barrier and the Modified RCRA Subtitle C Barrier will be sloped at 2% rather than the 3% recommended in the MTG. In part, this departure reflects the assessment from performance simulations in Appendix C that the amount of lateral drainage will be small and sporadic. Additionally, barrier construction is simplified if all layers are parallel and of constant thickness. Lowering the gradient will have the net effect of reducing drainage efficiency. The reduced gradient and the reduced layer thickness (in the case of the Modified RCRA Subtitle C Barrier) will be more than offset by constructing the layer of drainage gravel with a saturated hydraulic conductivity of 1 cm/s (100 times higher than the value specified in the MTG).

The substitution of materials for the low-permeability layer was made because (1) the design-life criteria for the Hanford Barrier and the Modified RCRA Subtitle C Barrier call for materials with long-term durability that cannot presently be demonstrated for geosynthetic materials and (2) compacted clay soils in arid environments may be subject to desiccation cracking and may develop secondary (i.e., fracture) permeability. The use of asphaltic materials will substantially eliminate concerns over long-term durability, stability, and retention of function. Research needs relating to the issue of long-term durability of asphaltic materials are discussed in Section 5.0.

Ecology has implemented MFS guidance for final covers on solid waste landfills based on criteria in WAC 173-304. The MFS design is a two-layer cover system with the following specifications:

- Topsoil layer: A minimum of 15 cm (6 in.) of loamy topsoil material capable of supporting vegetation, with a surface slope of at least 2%, but no more than 33%.
- Barrier layer: A minimum of 60 cm (24 in.) of soil with a maximum permeability of 10^{-5} cm/s for arid regions within the state.

Ecology recognizes that other designs that meet or exceed the MFS specifications may be appropriate. The Modified RCRA Subtitle D Barrier includes three layers of topsoil materials. The combined thickness of Layer 1 (topsoil with pea gravel) and Layer 2 (topsoil without pea gravel) is 60 cm (24 in.), which exceeds the specifications for the topsoil component in the MFS design. Layer 3 (compacted topsoil) in the design is only 30 cm (12 in.) thick, but the permeability of this layer is expected to be almost an order of magnitude lower than the value specified in the guidance; therefore, the design is considered to satisfy all functional equivalence requirements relative to the MFS design.

4.2 ASSESSMENT AGAINST EPA EVALUATION CRITERIA

The EPA has developed nine criteria for comparing remedial alternatives under CERCLA (EPA 1988). In a typical site-specific CERCLA FS, these criteria are applied to compare between specific remedial options, including barrier and nonbarrier options. This FFS focuses exclusively on engineered surface barriers as generic remedial alternatives. This study does not provide a basis for comparing barrier and nonbarrier alternatives for a specific waste site. The following discussion documents the evaluation of the conceptual designs from Section 3.0 against the nine criteria, for use or reference in conjunction with future FS applications.

The nine EPA criteria are based on regulatory guidance that originally appeared in the National Contingency Plan (40 CFR 300.430 (e)(9)) in 1985. The criteria can be subdivided into threshold, balancing, and modifying criteria as follows:

Threshold criteria:

1. Overall protection of human health and the environment
2. Compliance with ARARs

Balancing criteria:

3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume
5. Short-term effectiveness
6. Implementability
7. Cost

Modifying criteria:

8. State acceptance
9. Community acceptance.

4.2.1 Overall Protection of Human Health and the Environment

Because it is a threshold criterion, this evaluation criterion must be satisfied by the remedial alternative. This criterion provides a final check to assess whether a given alternative will provide adequate protection of human health and the environment. The overall assessment of conformance to this criterion draws on the assessments conducted under other evaluation criteria, specifically long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs (i.e., this criterion is not independent and can be considered to be evaluated in terms of the other eight criteria).

4.2.2 Compliance With ARARs

Section 2.2 presented an evaluation of ARARs as sources of performance and design criteria for surface barriers. Conceptual design criteria for the Hanford Barrier, the Modified RCRA Subtitle C Barrier, the Standard RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier were developed in Sections 2.5.1, 2.5.2, 2.5.3, and 2.5.4, respectively. The criteria, which are summarized in Tables 2-4, 2-5, 2-6, and 2-7, reflect the identified ARARs and technical guidance document considerations.

Three categories of ARARs are distinguished: (1) chemical-specific, (2) location-specific, and (3) action-specific. The initial screening of ARARs described in Section 2.0 produced the following conclusions.

- The only chemical-specific ARARs identified that relate to the generic conceptual cover designs are those that address releases of radon. Others, such as regulations that limit radioactive dose to individuals, could not be related to the conceptual design in the absence of specific knowledge of the contaminants at individual waste sites. Chemical-specific ARARs must be considered during the site-specific evaluation.

- No location-specific ARARs were identified for the generic conceptual cover designs. Location-specific criteria should be considered on a site-by-site basis during the site-specific evaluation.

- A number of action-specific ARARs were identified that relate to barrier design or performance. These requirements address factors such as maintenance, run-on/runoff control, infiltration, and other considerations relating to long-term waste isolation and overall barrier performance.

Each barrier design described in Section 3.0 has been evaluated for conformance to design criteria in Section 4.1. The criteria were related to individual ARARs and technical guidance sources in Section 2.5 and Tables 2.4, 2.5, 2.6, and 2-7. Based on this information, it is established that the barrier designs comply with ARARs and conform to the criteria relating to these ARARs.

The requirements associated with the radioactive component of the barrier design criteria are contained in 40 CFR 61, WAC 173-480, and WAC 246-247 (see Table 2-1 for specific sections of these regulations that are ARARs). The design of the Hanford Barrier, Modified RCRA C Barrier, and Modified RCRA D Barrier all satisfy the requirements contained in those regulations.

The pertinent dangerous waste regulations (sections of 40 CFR 264, 265, WAC 173-303, and WAC 173-304, as shown in Table 2-1) are met or exceeded by the design criteria used for the Hanford Barrier, the Modified RCRA C Barrier, and the Standard RCRA C Barrier. The Modified Subtitle D Barrier meets the requirements contained in the pertinent sections of 40 CFR 241 and WAC 173-304 (Table 2-1). These requirements can be either applicable (as would be the case of a TSD complying with WAC 173-303 requirements) or relevant and appropriate (dangerous waste sites sufficiently similar to TSDs) and the conceptual design meets these ARARs.

4.2.3 Long-Term Effectiveness and Permanence

This criterion addresses the residual health and environmental risks at a site after a remedial alternative has been implemented. This assessment focuses on the extent, effectiveness, and reliability of environmental control attained by the remedy.

In remedial investigations conducted thus far in the 200 Areas (DOE-RL 1993d), direct exposure and groundwater contamination have been identified as the exposure pathways that pose significant long-term human health and environmental risks. In response to these findings, the following RAOs were specified for the 200-BP-1 Operable Unit:

- Reduce the potential for intrusion and (direct) exposure to contaminants
- Minimize future groundwater contamination.

Based on broad similarities in the nature and extent of contamination and commonality in vadose zone and groundwater geology among waste sites in the 200 Areas, it is expected that these two RAOs will also apply to the majority of other sites in the 200 Areas that are candidates for remediation with surface barriers. Accordingly, the following conformance measures are recommended for evaluating the long-term effectiveness and permanence criterion with respect to barriers: (1) intrusion control, (2) moisture infiltration control, and (3) long-term durability.

4.2.3.1 Intrusion Control. The Hanford Barrier is the baseline design for sites containing GTCC waste and significant inventories of TRU constituents (if any). In these applications, the Hanford Barrier includes provisions to control biointrusion and inadvertent human intrusion. The Modified RCRA Subtitle C Design, which is the baseline design for sites containing Category 3 LLW, also provides intrusion control.

Two separate features of the Hanford Barrier will function as intrusion controls. The primary provision is a 1.5-m (60-in.)-thick layer of coarse, fractured basalt designed to deter animal burrowing, root penetration, and unintentional intrusion by humans. Individual rock fragments in this layer are too large and heavy to be excavated by any indigenous burrowing animals at the Hanford Site. The overlying capillary barrier will generally prevent moisture from entering the fractured basalt layer, and the coarseness of the material basalt will severely limit moisture retention. Consequently, extremely dry conditions are expected to be sustained within this layer, which should effectively discourage root penetration. The fractured basalt layer is also designed to present difficult drilling conditions to inadvertent human intruders engaged in exploratory drilling for mineral resources or water-well development.

The second control provision of the Hanford Barrier design is the 15-cm (6-in.)-thick low-permeability asphalt layer. The asphalt layer will be a highly effective deterrent to plant and animal intrusion (although it will not deter drilling intrusion). The asphalt layer will be particularly effective in thwarting intrusion by insects (e.g., carpenter ants).

The same asphalt layer design is used in the Modified RCRA Subtitle C design. Intrusion control is provided by the combined thickness of cover materials, earth-fill placed directly over the waste, and the asphalt layer.

The Standard RCRA Subtitle C Barrier does not provide long-term protection against penetration of deep-rooting plants into the waste (other than protection caused by thickness of the barrier). If maintenance of the facility included removal of deep-rooting plants before they penetrate the waste, the effectiveness of this type of barrier could be enhanced. Monitoring and maintenance will be required for the Standard RCRA Subtitle C Barrier to maintain effectiveness. Animal and human intrusion prevention is by way of institutional control.

The Modified RCRA Subtitle D Barrier provides modest biointrusion control in the form of the thickness of the barrier layers combined with the thickness of existing fill materials. The design of the Modified RCRA Subtitle D Barrier does not address provisions for human intrusion control.
The Subtitle D barrier has a design life of 100 years. Control of inadvertent human intrusion will be placed on existing institutional controls (e.g., signage, fencing, surface markers).

4.2.3.2 Moisture Infiltration Control. The Hanford, Modified RCRA Subtitle C, and Modified RCRA Subtitle D Barriers are principally designed to maximize shallow moisture infiltration and storage within the topsoil layers, removal of the stored moisture by evapotranspiration, and minimize to eliminate deep infiltration completely through the barrier. Moisture stored at shallow depths in the cover system is subject to removal by direct evaporation. Cover vegetation assists in removing soil moisture by transpiration. Numerical performance assessments for these three barriers were performed to estimate infiltration resulting from various precipitation conditions, to include 24-hour design-storm events, with estimated return periods equal to the barrier's design life (1,000, 500, and 100 years, respectively). The numerical performance assessments were made with the HELP Model (Version 2.0) and the UNSAT-H Model (Version 2.0). Results and details of the numerical performance assessments are presented in Appendix C of this FFS. The design-storm simulations show indirectly that during large storm events at the Hanford Site, the majority of precipitation (60% or more) will infiltrate into the topsoil layers of the barrier, where moisture would be retained in storage until it is removed by the combination action of evapotranspiration processes. The balance of the precipitation from the design-storm is runoff. The design-storm simulations indicate that runoff is not a significant design issue because precipitation events that produce surface runoff are infrequent, and the volume of runoff is small. The barriers are all sloped at 2% to provide drainage toward the perimeter of covered areas, where runoff would be permitted to infiltrate into the soil column at a distance from the contaminated media.

The Standard RCRA Subtitle C Barrier is designed to optimize surface runoff and shed water away from underlying waste, by way of a low permeability, composite, flexible membrane liner and compacted soil layer within the barrier. An inherent, site-specific design factor for this barrier is consideration of runoff collection and diversion systems. The compacted soil component of the low permeability layer would need to achieve a hydraulic conductivity of no greater than 1 x 10^{-7} cm/s. This is typically accomplished with silty and clay soils, or use of a soil admix, such as bentonite, to amend native borrow soils with little to no silt and clay. In wet climates, clay covers or liners can be generally effective and reliable. However, the arid climate at the Hanford Site increases the likelihood of drying, which can cause cracking and raise permeability significantly of such compacted soils. This can be mitigated by continual maintenance and monitoring, as well as likely repair and replacement. The repair and replacement requirements are one reason why the Standard RCRA Subtitle C Barrier has limited utility for Hanford Site projects. A detailed hydrologic analysis of surface infiltration for a generic, MTG compliant Standard RCRA Subtitle C Barrier was not performed for this FFS. Numerical performance assessments for a Standard RCRA Subtitle C Barrier have been performed for application at two specific sites at Hanford, and the results are summarized in Appendix C. In summary, both studies used current ambient precipitation and meteorological conditions as input parameters, consistent with a 30-year design life. The results of the analysis indicated that the majority of the precipitation was stored and evaporated in the upper vegetative/armoring layer; only a small percentage of the total precipitation infiltrated to and through the low permeability soil admix and flexible membrane.

4.2.3.3 Long-Term Durability. The principal issues associated with long-term durability of surface barriers are (1) potential changes in barrier morphology (thickness) caused by erosion and (2) potential chemical or physical alteration (weathering) of barrier materials.

If an excessive amount of topsoil material is removed from the barrier surface by erosion, hydrologic performance would be adversely affected. In all barrier options, the topsoil system is designed to perform the key role in moisture management. The topsoil layers will serve as a storage medium for moisture received as precipitation. Storage will be enhanced by developing a capillary barrier at the base of the topsoil system. Increasing the storage capacity and the residence time for soil moisture within the topsoil system will facilitate moisture removal by evapotranspiration processes. Performance simulations in Appendix C indicate that, as designed, the topsoil systems of the Hanford Barrier, Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier can be expected to store and remove essentially 100% of average annual moisture receipts. Numerical sensitivity studies indicate that a minimum thickness of topsoil (61 to 66 cm [24 to 26 in.]) is needed to sustain moisture removal at this level of efficiency.

The Standard RCRA Subtitle C Barrier is intended to provide a 30-year, postclosure design life, with expected maintenance, operations and repairs. Long-term durability beyond 30 years is not an intended design feature of the Standard RCRA Subtitle C Barrier. Long-term durability beyond 30 years is an intended design feature of the Hanford Barrier, the Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier.

Several provisions have been incorporated into the Hanford Barrier, the Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier designs to protect the topsoil system from and/or otherwise compensate for the effects of erosion. The top layer of each barrier includes an admixture of pea gravel that will assist in armoring the barrier surface to protect it from wind erosion. Cover vegetation will be cultivated to further assist in reducing exposure of barrier surfaces to wind. Third, and perhaps most importantly, each barrier design includes excess thickness in the topsoil layers to provide performance margins against long-term wind erosion and long-term climate change. Sample calculations of potential wind and water erosion rates are provided in Appendix D and Sections 2.0 and 3.0. Projected soil losses for the three barrier options over their respective design lives are reported in Appendix D, Section 4.0. For the Hanford Barrier (1,000-year design life), the thickness allowance for wind erosion is 30 cm (12.1 in.). For the Modified RCRA Subtitle C Barrier (500-year design life), the allowance for wind erosion is 15 cm (6 in.). And for the Modified RCRA Subtitle D Barrier (100-year design life), the allowance for wind erosion is 3 cm (1.2 in.). These losses are all tolerable (i.e., soil losses of these magnitudes would not reduce the composite thickness of topsoil components into the range of 61 to 66 cm [24 to 26 in.]). The beneficial effect of the pea gravel admixture in limiting wind erosion is not considered in the calculations in Appendix D, Section 4.0.

Aside from the low-permeability asphalt layer specified in the Hanford Barrier and the Modified RCRA Subtitle C Barrier, the three long-term durability barriers will be constructed entirely of natural rock and soil materials. Chemical and physical weathering rates for these materials are low relative to the performance periods of interest; it is known that these materials will not experience any significant deterioration during the respective performance periods. The low-permeability asphalt layer is also expected to provide adequate durability, based on studies of naturally occurring asphaltic materials. It is anticipated that additional studies of long-term durability of asphalt will be performed. The asphalt layer and lateral drainage layer in the Hanford Barrier and the Modified RCRA Subtitle C Barrier are both situated at sufficient depths below the surface to ensure permanent protection from frost damage.

4.2.4 Reduction of Toxicity, Mobility, or Volume

This criterion addresses the statutory preference in the CERCLA process for remedial actions that employ treatment technologies (i.e., technologies that will permanently and significantly reduce the toxicity, mobility, or volume of contaminants). This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of contaminants, irreversible reduction in contaminant mobility, reduction of the total mass of contaminants, or reduction of the total volume of contaminated media.

The principal contaminants of concern at most 200 Area waste sites are radionuclides. The activity or toxicity of radionuclides cannot be reduced by any means other than natural decay; therefore, treatment options for radionuclides are limited to technologies intended to reduce volume or mobility.

The evaluated surface barriers primarily function as hydrologic barriers, reducing contaminant mobility through containment. Mobility is reduced by minimizing or eliminating moisture infiltration into and through the zone of contamination. Moisture infiltration provides the principal mechanism for contaminant transport in the vadose zone. The barriers also control biointrusion, as well as inadvertent intrusion by humans. Activity or toxicity of radionuclides gradually diminishes naturally over time because of radionuclide decay. Use of surface barriers is considered a containment technology that does not satisfy the preference for reduction of toxicity, mobility, or volume through treatment. Use of surface barriers will, however, prevent further spread of contaminants and accommodate treatment of radionuclides in situ via natural decay.

4.2.5 Short-Term Effectiveness

This criterion addresses the human health and environmental consequences of a given remedial alternative during the construction and implementation phase. The following subcriteria normally are considered under short-term effectiveness.

- **Risk to the community**. This issue addresses potential risks to the public resulting from implementation of the remedial action, such as fugitive emissions of contaminated dust or transportation of contaminated materials over public roads.

- **Risk to workers**. This issue addresses potential health and accident risks to workers from implementation of the remedial action, such as radiation exposure, and the reliability of protective measures.

- **Environmental impacts**. This issue deals with potential adverse environmental consequences that may result from the remedial action and the reliability of mitigation measures.

- **Time until RAOs are achieved**. This consideration estimates the time needed to complete the remedial action and short-term health effects consequences (if any) associated with the timing of remedial activities.

The exposure pathway of any significance to the offsite public, related to construction of surface barriers, is the air pathway. Barrier construction activities are not expected to generate contaminated particulate in rates or quantities of any consequence to the offsite public. For example, the RI report for the 200-BP-1 Operable Unit (DOE-RL 1993a) concluded that the worst-case air release scenario (assuming direct surface exposure of all subsurface contaminated soils within the operable unit) would result in an incremental life-time cancer risk (for the residential or agricultural land-use cases) at the site of less than 10^{-6}. Risk factors were not reported for offsite locations because of the low onsite risk and the dispersion that would necessarily occur between the onsite location and the nearest offsite receptor. Based on the RI results, it is expected that baseline risk assessments for other 200 Area waste sites will also show that risk to the offsite public from barrier construction is low in relation to onsite worker risk and low in absolute terms.

Barrier construction activities at 200 Area waste sites will be performed on surfaces where radiological contamination is demonstrably below levels of concern with regard to worker health and safety. Most waste sites identified in Appendix B already have undergone surface stabilization. This practice involves placing a blanket of a few feet to several feet of clean fill over a radiological site. The fill provides shielding that eliminates direct exposure hazards to workers and reduces short-term problems associated with biointrusion. Radiological surveys are used to verify that surface contamination has been reduced to acceptably low levels as a result of stabilization activities. In any case where a surface barrier is to be built at a site with residual surface radiological contamination, the site would be stabilized with grading fill before barrier construction activities are initiated to ensure that shielding is adequate to protect construction workers. After a site has been stabilized, the risk of coming into contact with subsurface waste or releasing contaminants into the air during barrier construction activities is considered low. Radiological monitoring will be performed during construction to verify that contamination is not disturbed or released.

Concerning surface stabilization activities, work inside radiological areas on the Hanford Site is subject to rigorous procedural controls that ensure that appropriate training, protective clothing, equipment and support are provided to workers, and that the activities are managed and performed to maintain worker exposures as low as reasonably achievable.

Most or all waste sites in the 200 Areas that have been identified as candidates to be evaluated for remediation with surface barriers are already disturbed areas and do not support any unique or significant ecological resources (i.e., candidate, threatened, or endangered plant or animal species). Therefore, construction of surface barriers is not known to represent a potentially significant environmental consequence (e.g., habitat destruction) at any of these sites.

The amount of time needed to achieve RAOs is a factor only in cases where current risks are significant. Because 200 Area waste sites are all under active institutional control, short-term risks are low.

In summary, worker risk is the one potentially significant short-term effectiveness issue identified in the context of constructing surface barriers. Risks associated with direct radiological exposures will be minimal. Consequently, health and accident risks to workers engaged in barrier construction are expected to be comparable to other types of earth work construction where contamination is not a consideration. Considering short-term worker risk alone, remedial alternatives involving construction of surface barriers for 200 Area waste sites should consistently be preferred over alternatives that would involve excavation and transportation of contaminated soil.

4.2.6 Implementability

The implementability criterion can be divided into technical feasibility, administrative feasibility, and availability of services and materials. Implementability issues are significant in that they focus on factors that directly affect schedule, cost, public opinion, and the likelihood of success or failure. Implementability issues acquire greater significance as remedial options increase in complexity or reliance on innovative technologies.

4.2.6.1 Technical Feasibility. Technical feasibility is determined by constructibility, reliability, and ease of undertaking additional remedial actions. Monitoring considerations were not assessed because the activity will be determined on a site-specific basis.

- **Constructibility**. In terms of complexity and expertise, surface barrier construction is similar to other types of earth work such as highway construction. Remedial alternatives that involve capping sites with any of the four barrier designs presented in this FFS would be expected to receive high ratings for constructibility.

- **Reliability**. The Hanford Barrier, Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier designs are predicted to perform as designed in terms of limiting moisture infiltration and resisting erosion by wind and water for their respective design lives, based on the computational methods documented in Appendices C and D. Performance margins are expected to be sufficient to accommodate a wide variety of transient conditions. The Standard RCRA Subtitle C Barrier is designed for a 30-year period under institutional control, with expected maintenance, monitoring, and necessary repairs to provide reliability.

One surface barrier has already been built at the Hanford Site (the Hanford Barrier prototype at the 200-BP-1 Operable Unit). Design, materials, and construction issues that were identified during that project have been summarized and evaluated for future reference (DOE-RL 1994). Monitoring and testing activities are ongoing to identify and evaluate any unresolved issues relating to barrier performance. Most materials of construction consist of natural soil and rock materials that are available on the Hanford Site. Asphalt, flexible membrane liner, and bentonite (or other) admix materials are the only essential material that must be brought to the site. Consequently, it is not likely that significant schedule impacts would be experienced because of nonavailability of materials. As experience with barrier-type construction accumulates, the likelihood of encountering significant technical problems, schedule delays, or cost overruns will be reduced. The ERDF project is in progress of large-scale production of admixing and placing bentonite-amended soil for impermeable liner materials.

- **Ease of undertaking additional remedial actions**. For the Hanford Barrier, Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier, minimal needs for maintenance and repairs are anticipated. Only the surface of the barrier is accessible to damage. Repairs to the surface layer(s) are easily performed by replacing eroded or deliberately removed soil material with similar material. Maintenance, monitoring, and repairs to the Standard RCRA Subtitle C Barrier would be expected in arid climate conditions.

Should performance monitoring indicate that a barrier is not performing as designed for some unforeseen reason, remedial action could simply take the form of adding another lift of topsoil to the existing structure.

The existence of a surface barrier at a given waste site would complicate efforts to implement many other types of remedial actions at a later date. This may be a significant disadvantage, particularly in situations where capping a site is recommended as an interim action.

4.2.6.2 Administrative Feasibility. Administrative feasibility issues relate to the need for coordinating with or between various agencies of government for concurrence, approvals, or variance actions. A procedural framework has been negotiated between the DOE, EPA, and Ecology for developing, prioritizing, implementing, and monitoring ER and remediation activities on the Hanford Site (Tri-Party Agreement [Ecology et al. 1994]). Administrative issues at the Hanford Site are primarily resolved through this agreement. Surface barriers as remedial alternatives do not represent any unique or unusual requirements for regulatory approvals.

4.2.6.3 Availability of Services and Materials. Barrier construction will not require any specialized construction equipment or personnel with unique skills or education not available to local contractors. No specific issues are anticipated in seeking or obtaining competitive bids from contractors to do this work.

The silt loam soil at the McGee Ranch site has been characterized for use as topsoil material in barrier construction, as indicated in Section 3.1.2.1. The site contains approximately 30.6 million m^3 (40 million yd^3) of suitable material (Lindberg 1994). The McGee Ranch site has been reserved as a borrow site to support ER activities at the Hanford Site (Skelly and Wing 1992).

Parallel efforts are ongoing to evaluate potential borrow sources for basalt riprap (i.e., coarse, fractured basalt) and aggregate materials (pea gravel, filter sand and gravel, and drainage gravel) at the Hanford Site (Duranceau 1995). These materials exist on site in sufficient quantities, but specific borrow locations have not been established.

4.2.7 Cost

Cost estimates are reported in Appendix E for the conceptual Hanford Barrier, Modified RCRA Subtitle C Barrier, and Modified RCRA Subtitle D Barrier designs for an actual waste site in the 200 East Area. The subject site is an area 126 by 162 m (415 by 530 ft) (5.05 acres) within the 200-BP-1 Operable Unit, consisting of eight adjacent cribs (216-B-43 through 216-B-50). These cribs received low-level radioactive liquid waste from U Plant uranium recovery operations and condensate from the adjacent 241-BY Tank Farm. Construction of a Modified RCRA Subtitle C Barrier over this site has been recommended (DOE-RL 1993d).

The three cost estimates in Appendix E have been prepared to a conceptual level of detail. The estimates address costs related to barrier construction only. Costs for inspection and maintenance of the barrier after construction were not estimated. The cost estimates also do not include costs related to cover vegetation. Vegetation costs (i.e., for disking, fertilizing, seeding, and mulching) are minor ($1,000 to 2,000 per acre) compared to the earth work involved. The three estimates in Appendix E are summarized in Table 4-5.

Regarding the three estimates in Appendix E, significant costs are identified for site grading, reflecting the existing irregular site surface over the eight cribs. Costs such as these vary widely as a percentage of total project cost depending on site-specific conditions. Another significant cost in the estimates relates to costs for constructing the low-permeability asphalt layer. Based on the available information, a disproportionately high cost is associated with the fluid-applied asphalt top coat material that is currently specified for the Hanford Barrier and the Modified RCRA Subtitle C Barrier. Further engineering work on this topic is necessary.

A detailed cost study for the Standard RCRA Subtitle C Barrier was not performed for this FFS. Comparative construction cost studies for various surface barriers were included in the RI/FS for ERDF (DOE-RL 1993f). For the Standard RCRA Subtitle C Barrier, which included a vegetative and general fill layer several feet thick, unit construction costs were estimated at \$59/m^2 (\$5.5/ft^2). Construction cost for the Hanford Barrier was estimated at \$135/m^2 (\$12.6/ft^2); and construction cost for a barrier similar to the Modified RCRA Subtitle C Barrier was estimated at $79/m^2 ($7.3/ft^2). The cost differences between the Hanford Barrier and the Modified RCRA Subtitle C Barrier are consistent with those presented in this FFS (Appendix E).

Not presented in this FFS are institutional control, maintenance and operations, and repair and replacement costs for any of the barrier alternatives. As noted in previous sections of this FFS, implementation of these factors are critical to the short- and long-term performance of low permeability barriers, such as the Standard RCRA Subtitle C Barrier, particularly in arid to semiarid regions. Categories for maintenance, operations, repair and replacement costs for a low permeability barrier, such as the Standard RCRA Subtitle C Barrier, that would differ from evapotranspiration barriers (Hanford, Modified RCRA Subtitle C and Modified RCRA Subtitle D) include the following:

- Ensure functional performance of surface water run-on and runoff controls, collection, and discharge devices
- Ensure the integrity of a flexible membrane liner
- Ensure the integrity of a low permeability, compacted soil layer.

4.2.8 State Acceptance

This criterion makes provision for resolution of state technical and administrative issues and concerns raised regarding the evaluation and recommendation of a remedial alternative. This criterion will be addressed after the state has had the opportunity to review and comment on the site-specific evaluation of alternatives and recommendations identified in decision documents.

4.2.9 Community Acceptance

This criterion provides for public input on recommended remedial action plans. Public comments regarding the site-specific evaluation will satisfy this requirement.

Table 4-1. Conformance Assessment of Hanford Barrier to Design Criteria. (Page 1 of 3)

	Design Criteria	Assessment of Conformance
1.	Minimize moisture infiltration through the cover.	The Hanford Barrier design facilitates moisture retention in the topsoil layers for removal by evaporation and plant transpiration. Capillary barrier interface at the base of the topsoil will restrict drainage and increase moisture storage capacity in the topsoil layers. A high saturated hydraulic conductivity value (1 cm/s) is specified for the lateral drainage layer to prevent buildup of hydraulic head within the layer. The low-permeability (approximately 10^{-8} cm/s) asphalt layer will be highly impervious to moisture infiltration. Numerical performance assessments in Appendix C predict that infiltration through the barrier will be negligible (i.e., less than 0.1% of annual precipitation). The Hanford Barrier is designed to accommodate significant increases in annual precipitation (up to twice ambient) with no significant adverse effects on performance.
2.	Design a multilayer cover of materials that are resistant to natural degradation processes.	Long-term durability of asphalt is being evaluated through natural analog studies. Preliminary information indicates that asphalt offers adequate durability over periods in excess of 5,000 years. The geotextile filter fabric in Layer 3 is a construction aid only. It has no long-term function (i.e., no durability requirements). Except for the asphalt layer and the geotextile, the barrier is designed entirely of natural soil and rock materials that will provide appropriate long-term resistance to chemical and physical weathering.

Table 4-1. Conformance Assessment of Hanford Barrier to Design Criteria. (Page 2 of 3)

	Design Criteria	Assessment of Conformance
3.	Design a durable cover that needs minimal maintenance during its design life.	Perennial vegetation will be cultivated on the cover surface to minimize susceptibility to wind and water erosion. The topsoil in Layer 1 will contain 15 wt.% pea gravel. As silt particles are eroded from the surface, pea gravel will form a lag deposit that will tend to protect the surface from further erosion. The surface slope has been limited to 2% to limit wind erosion.
4.	Design a barrier with a functional life of 1,000 years.	The thickness of topsoil in the Hanford Barrier is sufficient to accommodate soil losses at a rate of 2 tons per acre per year for 1,000 years with no significant adverse effect on performance. The Hanford Barrier is designed to accommodate substantial increases in annual precipitation (up to twice ambient) with no significant adverse effect on performance. The 1,000-year, 24-hr storm has been evaluated (Appendix C-4). Although the design storm delivers 6.8 cm (2.68 in.) of precipitation, runoff during the 24-hr period is less than 2.5 cm (1 in.) (i.e., runoff is not excessive, and the design storm is unlikely to cause severe erosion of the cover surface).
5.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).	Extremely low soil moisture conditions are expected to be maintained in the coarse-textured soil layers (i.e., Layers 4, 5, 6, and 7) below the capillary barrier interface. These conditions are expected to deter root zone development below the topsoil layers. The low-permeability asphalt in Layer 8 is expected to present an impenetrable barrier to plant roots.
6.	Prevent burrowing animals from accessing and mobilizing contamination.	The coarse, fractured basalt rip-rap in Layer 6 will contain material that is too heavy and bulky to be excavated and moved by indigenous burrowing animals at the Hanford Site. The low-permeability asphalt in Layer 8 is expected to present an impenetrable barrier to burrowing animals.

Table 4-1. Conformance Assessment of Hanford Barrier to Design Criteria. (Page 3 of 3)

	Design Criteria	Assessment of Conformance
7.	Include appropriate design provisions for limiting inadvertent human intrusion.	Drilling is considered the most potentially adverse human intrusion scenario for waste sites. The coarse, fractured basalt rip-rap in Layer 6 is designed to constitute an obstacle to drilling because of its loose, porous, and fragmented condition. Layer 8 could be excavated, but only with the aid of mechanized equipment. Layer 8 constitutes a second obstacle to inadvertent intrusion.
8.	Facilitate drainage and minimize surface erosion by wind and water.	The surface slope is specified at 2% to provide for coherent drainage off the barrier surface while limiting wind erosion potential. Perennial vegetation will be cultivated on the cover surface to minimize susceptibility to wind and water erosion. The topsoil in Layer 1 will contain 15 wt.% pea gravel. As silt particles are eroded from the surface, pea gravel will form a lag deposit that will tend to protect the surface from further erosion.
9.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.	The low-permeability asphalt layer is expected to demonstrate an in-field saturated hydraulic conductivity value on the order of 10^{-8} cm/s. This value is several orders of magnitude lower than the conductivity values of natural subsoils in the 200 Areas.
10.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).	A two-layer graded filter (Layers 4 and 5) separates the topsoil layers from the underlying layers of coarse-textured aggregate materials that will perform the biointrusion and drainage functions. Design specifications for the two graded filter layers to conform to standard filter criteria.
11.	For frost protection, locate the lateral drainage layer and the low-permeability asphalt layer at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade.	The top of the lateral drainage layer will be situated approximately 3.95 m (13 ft, 2 in.) below final grade.

Table 4-2. Conformance Assessment of Modified RCRA Subtitle C Barrier to Design Criteria. (Page 1 of 3)

	Design Criteria	Assessment of Conformance
1.	Minimize moisture infiltration through the cover.	Design facilitates moisture retention in the topsoil layers for removal by evaporation and plant transpiration. Capillary barrier interface at the base of the topsoil will restrict drainage and increase moisture storage capacity in the topsoil layers. A high saturated hydraulic conductivity value (1 cm/s) is specified for the lateral drainage layer to prevent significant hydraulic head buildup within the layer. The low-permeability (approximately 10^{-8} cm/s) asphalt layer will be highly impervious to moisture infiltration. Numerical performance assessments in Appendix C predict that infiltration through the barrier will be negligible (i.e., less than 0.2% of precipitation). The Modified RCRA Subtitle C Barrier can accommodate significant increases in annual precipitation (up to twice ambient) with no significant adverse effect on performance.
2.	Design a multilayer cover of materials that are resistant to natural degradation processes.	Long-term durability of asphalt is being evaluated through natural analog studies. Preliminary information indicates that asphalt offers adequate durability over periods in excess of 5,000 years. Except for the asphalt layer, the Modified RCRA Subtitle C Barrier is designed entirely of natural soil and rock materials that will provide appropriate long-term resistance to chemical and physical weathering.
3.	Design a durable cover that will need minimal maintenance during its design life.	Perennial vegetation will be cultivated on the cover surface to minimize susceptibility to wind and water erosion. The topsoil in Layer 1 will contain 15 wt.% pea gravel. As silt particles are removed from the surface by erosion, pea gravel will form a lag deposit that will tend to protect the surface from further erosion. The surface slope has been limited to 2% to limit wind erosion.

Table 4-2. Conformance Assessment of Modified RCRA Subtitle C Barrier to Design Criteria. (Page 2 of 3)

	Design Criteria	Assessment of Conformance
4.	Design a cover with a functional life of 500 years.	The thickness of topsoil in the Modified RCRA Subtitle C Barrier is sufficient to accommodate soil losses at a rate of 2 tons per acre per year for 500 years with no significant adverse effect on performance. The Modified RCRA Subtitle C Barrier can accommodate substantial increases in annual precipitation (up to twice ambient) with no significant adverse effect on performance. The 500-year, 24-hr storm has been evaluated (Appendix C-4). Although the design storm delivers 6.2 cm (2.47 in.) of precipitation, runoff during the 24-hr period is less than 2.5 cm (1 in.) (i.e., runoff is not excessive, and the design storm is unlikely to cause severe erosion of the cover surface).
5.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).	Extremely low soil moisture conditions are expected to be maintained in the coarse-textured soil layers (i.e., Layers 3, 4, and 5) below the capillary barrier interface. These conditions are expected to deter root zone development below the topsoil layers. The low-permeability asphalt in Layer 6 is expected to present an impenetrable barrier to plant roots.
6.	Prevent burrowing animals from accessing and mobilizing contamination.	The low-permeability asphalt in Layer 6 is expected to present an impenetrable barrier to burrowing animals.
7.	Ensure that the top of the waste zone is at least 5 m (16.4 ft) below final grade or include appropriate design provisions for limiting inadvertent human intrusion.	Human habitation of the site surface is considered the most potentially adverse human intrusion scenario for LLW sites. Many radiological waste sites in the 200 Areas have already been stabilized with coarse fill that would approach or exceed this criteria. At other sites, the criteria could be met by placement of additional grading fill (same material as in Layer 8). Layer 6 represents a substantial barrier to inadvertent human intrusion. Layer 6 could be excavated, but only with the aid of mechanized equipment.

Table 4-2. Conformance Assessment of Modified RCRA Subtitle C Barrier to Design Criteria. (Page 3 of 3)

	Design Criteria	Assessment of Conformance
8.	Facilitate drainage and minimize surface erosion by wind and water.	The surface slope is specified at 2% to provide for coherent drainage off the barrier surface while limiting wind erosion potential. Perennial vegetation will be cultivated on the cover surface to minimize susceptibility to wind and water erosion. The topsoil in Layer 1 will contain 15 wt.% pea gravel. As silt particles are eroded from the surface, pea gravel will form a lag deposit that will tend to protect the surface from further erosion.
9.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.	The low-permeability asphalt layer is expected to demonstrate an in-field saturated hydraulic conductivity value on the order of 10^{-8} cm/s. This value is several orders of magnitude lower than the conductivity values of natural subsoils in the 200 Areas.
10.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).	A two-layer graded filter (Layers 3 and 4) separates the topsoil layers from the underlying layers of coarse-textured aggregate materials that will perform the biointrusion and drainage functions. Design specifications for the two graded filter layers conform to standard filter criteria.
11.	For frost protection, the lateral drainage layer and the low-permeability asphalt layer are to be located at least 0.6 m, 15 cm (2 ft, 6 in.) below final grade.	The top of the lateral drainage layer will be situated approximately 1.3 m (4 ft, 4 in.) below final grade.

Table 4-3. Conformance Assessment of Standard RCRA Subtitle C Barrier to Design Criteria. (Page 1 of 2)

	Design Criteria	Assessment of Conformance
1.	Minimize moisture infiltration through the cover.	Design facilitates: (1) over land flow, or runoff of precipitation directed to periphery of surface cover where runoff is collected and discharged through percolation into adjacent ground, or other basin/piping facility and (2) a two-component low permeability layer (Layers 3 and 4).
2.	Design a durable cover of natural materials that will need minimal maintenance during its design life.	Design includes a top layer consisting of two natural components: (1) either a vegetated or armored surface component to minimize erosion and, to the extent possible, promote drainage off the cover and (2) a soil component with a minimum total thickness of 60 cm (24 in.). This top layer should be comprised of topsoil and/or local fill soil, as appropriate, the surface of which slopes uniformly at least 3%, but not more than 5% (Layer 1).
3.	Design a cover with a functional life of 30 years.	Adequate performance can be expected with suitable maintenance, monitoring, and any necessary repairs/replacement.
4.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).	Where revegetation is used for erosion control, shallow-rooted vegetation is used. Selective planting, monitoring, and any necessary removal of deep-rooted vegetation will meet this criteria.
5.	Prevent burrowing animals from accessing and mobilizing contamination.	Mitigation of burrowing animals can be provided by surveillance, engineering controls, and any necessary maintenance and repairs during the 30-year life of the cover.
6.	Facilitate drainage and minimize surface erosion by wind and water.	A soil drainage (and FML-protective bedding) layer is provided with a minimum thickness of 30 cm (12 in.) and a minimum hydraulic conductivity of 1 x 10^{-2} cm/s that will effectively minimize water infiltration into the low-permeability layer, and will have a final slope of at least 3% after settlement and subsidence; or a drainage layer consisting of geosynthetic materials with equivalent performance characteristics (Layer 3).

Table 4-3. Conformance Assessment of Standard RCRA Subtitle C Barrier to Design Criteria. (Page 2 of 2)

	Design Criteria	Assessment of Conformance
7.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.	Design includes a two-component low-permeability layer, lying wholly below the frost zone, that provides long-term minimization of water infiltration into the underlying waste, consisting of (1) a 20-mil (0.5-mm) minimum thickness FML component and (2) a compacted soil component with a minimum thickness of at least 60 cm (24 in.) and a maximum inplace saturated hydraulic conductivity of 1 x 10^{-7} cm/s (Layer 4).
8.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).	Design includes a filter layer to prevent migration of fine materials from the upper surface layers to the underlying soil drainage layer.
9.	For frost protection, the lateral drainage layer and the low-permeability layer must be located at least 0.6 m, 15 cm (2 ft, 6 in.) below the final grade.	The minimum design thickness of the overlying layers places the lateral drainage layer and the low-permeability layer at least 0.6 m, 15 cm (2 ft, 6 in.) below the final grade.

Table 4-4. Conformance Assessment of Modified RCRA Subtitle D Barrier to Design Criteria. (Page 1 of 3)

	Design Criteria	Assessment of Conformance
1.	Minimize moisture infiltration through the cover.	The Modified RCRA Subtitle D Barrier facilitates moisture retention in the topsoil layers for removal by evaporation and plant transpiration. Capillary barrier interface at the base of the topsoil will restrict drainage and increase moisture storage capacity in the topsoil layers. Numerical performance assessments in Appendix C predict that infiltration through the barrier will be negligible (i.e., less than 0.5% of annual precipitation). Because of its shorter design life, the Modified RCRA Subtitle D Barrier is not designed to accommodate wide deviations in average annual precipitation.
2.	Design the cover to provide limited biointrusion control (i.e., to control scavenging and vector activity).	Limited biointrusion control will be provided by adding soil layers over existing fill and by compacting topsoil in Layer 3. Compaction will provide increased resistance to burrowing activity and root penetration. Solid waste sites in the 200 Areas do not contain putrescible waste that attract vectors. Modified RCRA Subtitle D Barrier does not address human intrusion. The 100-year design life corresponds to the minimum limit of active institutional control.
3.	Design a multilayer cover system with a combined thickness of at least 60 cm (24 in.).	Discounting grading fill (Layer 4), the combined thickness of Layers 1, 2, and 3 is 90 cm (36 in.).

Table 4-4. Conformance Assessment of Modified RCRA Subtitle D Barrier to Design Criteria. (Page 2 of 3)

	Design Criteria	Assessment of Conformance
4.	Design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control runoff and minimize erosion of the cover surface.	Perennial vegetation will be cultivated on the cover surface to minimize susceptibility to wind and water erosion. The topsoil in Layer 1 will contain 15 wt.% pea gravel. As silt particles are removed from the surface by erosion, pea gravel will form a lag deposit that will tend to protect the surface from further erosion. The surface slope has been limited to 2% to limit wind erosion. Layer 1 of the Modified RCRA Subtitle D Barrier has a design thickness of 20 cm (8 in.).
5.	Design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation.	The combined thickness of topsoil materials of 90 cm (36 in.) will provide adequate thickness to establish and maintain cover vegetation of perennial grass species.
6.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoil present, or a permeability that is no greater than 1 x 10^{-5} cm/s (whichever is less).	The compacted topsoil in Layer 3 is expected to have a saturated hydraulic conductivity value of between 10^{-6} and 10^{-7} cm/s. This value is less than the permeabilities of native subsoils in the 200 Areas.
7.	Design a durable cover that will need minimal maintenance during its design life.	Perennial vegetation will be cultivated on the cover surface to minimize susceptibility to wind and water erosion. The topsoil in Layer 1 will contain 15 wt.% pea gravel. As silt particles are removed from the surface by erosion, pea gravel will form a lag deposit that will tend to protect the surface from further erosion. The surface slope has been limited to 2% to limit wind erosion.
8.	Design a cover with surface slopes of no less than 2%.	The surface slope is specified in the design at 2%.

Table 4-4. Conformance Assessment of Modified RCRA Subtitle D Barrier to Design Criteria. (Page 3 of 3)

	Design Criteria	Assessment of Conformance
9.	Design a cover with a functional life of 100 years.	The thickness of topsoil in the Modified RCRA Subtitle D Barrier will accommodate soil losses at a rate of 2 tons per acre per year for 100 years with no significant adverse effect on performance. The barrier is designed entirely of natural soil and aggregate materials that will provide appropriate long-term resistance to chemical and physical weathering. The 100-year, 24-hr storm has been evaluated (Appendix C-4). Although the design storm delivers 5.05 cm (1.99 in.) of precipitation, runoff during the 24-hr period is less than 2.5 cm (1 in.) (i.e., runoff is not excessive, and the design storm is unlikely to cause severe erosion of the cover surface).

Table 4-5. Sample Barrier Cost Estimates Based on Actual Estimated Costs for Barriers over 216-B-43/50 Cribs.

Cost Items	Hanford Barrier	Modified RCRA Subtitle C Barrier	Modified RCRA Subtitle D Barrier
Engineering			
Definitive Design (Technical Services)	287,500	139,150	23,000
Engineering/Inspection (Technical Services)	575,000	278,300	46,000
SDRI Test on Asphalt Layer (Technical Services)	20,700	20,700	0
Engineering Totals	883,200	438,150	69,000
Improvements to Land			
Site grading, compaction, and fill	618,728	534,213	534,213
Placement of base course	86,454	71,046	0
Placement of asphalt layer	2,141,519	1,766,573	0
Placement of gravel drainage layer	165,770	66,670	0
Placement of coarse basalt layer and side slope surfacing material	2,565,267	68,407	68,407
Placement of side-slope fill	0	50,030	0
Placement of sand/gravel filter layers	257,263	157,663	0
Placement of lower silt layer	335,017	220,101	168,194
Placement of middle silt layer	0	0	222,439
Placement of silt/pea gravel admix layer	411,276	249,221	121,088
Base material for perimeter access road	27,399	0	0
Improvements to Land Totals	6,608,693	3,183,924	1,114,341
Project Totals	7,491,893	3,622,074	1,183,341

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 COVER FEASIBILITY - CONCLUSIONS

The results of the detailed assessments in Section 4.0, in which each of the four presented surface barrier designs was assessed against its design criteria and the EPA evaluation criteria, demonstrate that the barrier designs constitute potential generic remedial alternatives for 200 Area waste sites. A site-specific evaluation can then compare the single surface barrier alternative to other alternatives proposed for the individual waste site. The designs presented in this FFS are as follows:

- **Hanford Barrier**. Designed to provide 1,000-year isolation of waste sites containing GTCC LLW, GTCC mixed waste, and significant inventories of TRU constituents.
- **Modified RCRA Subtitle C Barrier**. Designed to provide 500-year isolation of waste sites with dangerous waste, Category 3 LLW, Category 3 LL mixed waste, and Category 1 LL mixed waste.
- **Standard RCRA Subtitle C Barrier**. Designed to provide 30-year isolation of dangerous waste sites.
- **Modified RCRA Subtitle D Barrier**. Designed to provide 100-year isolation of waste sites with Category 1 LLW and nonhazardous/nonradioactive solid waste.

Performance simulations indicate that the barriers can be relied upon to perform as designed and to provide effective short- and long-term protection of human health and the environment. From an implementability perspective, surface barriers are readily constructable, are viewed as reliable remedial measures, and are not constrained by administrative issues or the availability of labor or materials. Sample engineering and construction costs are presented in Section 4.2.7 and Appendix E.

The Standard RCRA Subtitle C Barrier has limited applications and use at the Hanford Site, individual project sites. Limitations include the following: (1) limited design life and (2) anticipated high surveillance, maintenance and operations cost caused by low-permeability layer design features, and implementation of such in arid climate conditions and maintenance and operations cost caused by surface water run-on and runoff control, collection, and discharge facilities. Because of these limitations, the Standard RCRA Subtitle C Barrier is not recommended for use on Hanford Site ER projects.

The Modified RCRA Subtitle C Barrier is considered to be the baseline design in lieu of the Standard RCRA Subtitle C Barrier. Advantages of the Modified RCRA Subtitle C Barrier include the following:

- Design for operation and low maintenance in arid climate conditions
- Elimination of need for surface water run-on and runoff control, collection and discharge devices.

5.2 SITE-SPECIFIC EVALUATION AND DEFINITIVE DESIGN

The four surface barrier designs in this FFS report have been developed as generic conceptual designs based on ARARs and technical guidance that may relate to the 200 Area waste sites. The design process has incorporated all of the criteria except for site-specific items. Site-specific requirements and criteria, as well as tailoring the ARARs and technical guidance developed here to site-specific conditions, will be considered during the site-specific evaluation and subsequent definitive design of barriers for individual 200 Area waste sites. Site-specific requirements and criteria include the following items.

- ARARs, including design-specific ARARs that were not addressed in the conceptual design, together with contaminant- and location-specific ARARs that were not evaluated in detail in Section 2.0.
- Results of site characterization studies, including chemical, radiological, and physical characteristics.
- Adaptation and/or detailing of conceptual designs to address side-slope design, crown slope geometry, drainage, the size and shape of the cover footprint, and edge effects.
- Settlement and subsidence issues and control measures, including void reduction and subgrade compaction specifications.
- Gas control.
- Evaluations of seismic susceptibility.
- Thickness of barrier layers and materials with respect to shielding needs.
- Availability of construction materials.
- Safety and construction quality assurance plans.
- Specification of suitable cover vegetation.
- Monitoring and maintenance plans.

Research and engineering activities are ongoing to refine barrier materials and specifications. These activities include work associated with the monitoring and testing of the Hanford Barrier prototype and the work described in Sections 5.3.2 and 5.3.3, which is related to implementing remedial actions for units within the 200-BP-1 Operable Unit. Refinements will be incorporated into definitive cover designs as they become available.

Seismic susceptibility of the Hanford Barrier prototype has been evaluated (Wing et al. 1995). The results indicated that potential damage to the barrier from the design earthquake was confined to the 2:1 sideslope. The sideslope was susceptible to a sliding wedge failure mode, with sliding occurring on top of the fluid-applied asphalt layer. Seismic evaluations have not been carried out to date for the other two barrier designs described in this FFS. However, it is anticipated that results for the other designs will also demonstrate that seismic susceptibility is confined to the sideslopes and is readily controllable by design.

5.3 RECOMMENDATIONS FOR FURTHER WORK

The following subsections highlight several design issues recommended as priority topics for further barrier development work. Recommendations made within this FFS should be dispositioned before implementation (except for the materials data base, Section 5.3.6).

5.3.1 Prototype Testing

Plans to monitor and test the Hanford Barrier prototype over the 216-B-57 Crib are summarized in *Treatability Test Plan for the 200-BP-1 Prototype Surface Barrier* (DOE-RL 1993e). After construction, the barrier is expected to take approximately 1 year to stabilize. Barrier performance will be evaluated for an additional 2-year period (i.e., active monitoring and testing are planned for 3 years). Because this timeframe is limited compared to the barrier's 1,000-year design life, the program emphasizes stress testing (i.e., imposition of harsher environmental conditions on the barrier than those that occur naturally). Monitoring and testing activities will focus on the following performance issues:

- Water infiltration control
- Water erosion
- Wind erosion
- Biointrusion
- Asphalt performance.

The barrier's ability to control moisture infiltration and to resist mass wasting will be evaluated from the data to be obtained.

5.3.2 Asphalt Durability Assessment

Durability of the low-permeability asphalt layer in the Hanford Barrier and the Modified RCRA Subtitle C Barrier is a design issue. Preliminary information from analog studies of natural asphaltic materials (Waugh et al. 1994) indicates that asphaltic materials are likely to exhibit adequate durability for surface barriers with design life criteria of 500 or 1,000 years. Additional investigations are planned (Freeman and Romine 1994) to obtain defensible data on the long-term performance of asphaltic materials for barrier applications. These investigations will (1) develop and perform a defensible accelerated aging test procedure to measure asphalt properties over 1,000 years and (2) supplement and validate laboratory aging data by comparisons to asphalt artifacts from archaeological sites. The scope of work recommended by Freeman and Romine (1994) has been initiated.

5.3.3 Alternative to Fluid-Applied Asphalt Top Coat

The Hanford Barrier and Modified RCRA Subtitle C Barrier designs both include a low-permeability asphalt layer consisting of 15 cm (6 in.) of "double-tar" asphaltic concrete with a seal coating of spray-applied polymer-modified asphalt. The specification calls for the fluid-applied asphalt to be applied in two coats, each approximately 100 mil thick. During construction of the Hanford Barrier prototype at the 216-B-57 Crib, constructibility problems were experienced with the fluid-applied asphalt (DOE-RL 1994). When the material was applied in 100 mil thickness as specified, it tended to develop bubbles up to 1 cm (0.4 in.) in diameter. Remedial measures were implemented to detect and eliminate bubbles while the material was hot. Other bubbles, which were not identified until after the material had cooled, were repaired by remelting the material with a propane torch. The tendency for bubbling was reduced by applying the material in thinner layers. It is reported that, ultimately, it was necessary to apply five to seven thin layers of the polymer-modified asphalt to get acceptable results.

In view of the constructibility problems, there is an apparent need to reevaluate the specification of polymer-modified asphalt in the two designs. Moreover, this is a disproportionately expensive material. In initial permeability tests (DOE-RL 1994), the asphaltic concrete layer exceeded design criteria. Therefore, it may be appropriate either to identify an appropriate substitute for the fluid-applied asphalt coating or to eliminate it altogether.

5.3.4 Biointrusion Barrier

During this FFS, there was extended consideration of a fourth barrier option, a so-called "biointrusion barrier." The biointrusion barrier was envisioned for waste sites containing only dangerous, LLW, or LL mixed waste constituents that are strongly sorbed onto the soil column (i.e., constituents that are highly immobile in the calcic vadose zone environment of the 200 Areas). In such cases, it is expected that risk assessments would generally show that moisture infiltration does not pose a significant risk to groundwater quality. Consequently, the biointrusion barrier was conceptualized as a design consisting of multiple layers of coarse-textured soil materials that would isolate waste physically, but not hydrologically.

This concept was considered to best be addressed in the site-specific evaluation for the individual waste sites. The ARARs delineated in this FFS indicate which performance and design criteria are pertinent when certain contaminants exist at the site. If these contaminants do not pose a threat to groundwater, then the performance and design criteria relating to groundwater protection may not be relevant and appropriate and can be eliminated in the site-specific evaluation. This would then result in a barrier criteria that is dominated by the biointrusion scenario. If an alternate design is then desired, that design can be best developed by factoring in all other site-specific ARARs information.

5.3.5 Settlement and Subsidence

Settlement and subsidence refer to various forms of soil response to surcharge loading of the site surface. In the context of engineered barriers, surcharge loading refers to the combined weight of materials placed in various cover layers per unit area of the site surface. Settlement refers to a change in elevation of a structure or the ground surface caused by compressive stresses acting on the subgrade, leading to densification (void volume reduction) within the soil. Subsidence generally refers to localized anomalous settlement patterns produced by collapse of large individual voids within the subgrade or the cumulative densification of low-density fill material.

Earth structures, such as surface barriers, generally can tolerate a significant amount of settlement, provided the settlement is short-term and relatively uniform. However, localized or uneven settlement is a potential performance issue for barriers.

This FFS does not address settlement and subsidence issues as they relate to the surface barriers evaluated in this FFS. To deal effectively with this issue, the engineering focus must be redirected from the barrier to the subgrade. A follow-on engineering study is recommended to address settlement and subsidence issues associated with various types of waste sites in the 200 Areas. This study will be performed in two parts.

1. Conventional foundation engineering methods will be used to make estimates of normal settlement for surface barriers on sites with undisturbed subgrade. Estimates will be prepared for a range of barrier sizes (i.e., 9.3-, 46.5-, and 93-m^2 [100-, 500-, and 1,000-ft^2] areas), and

separate estimates will be prepared for sites in the 200 East Area (where the shallow subgrade generally consists of coarse alluvium) and the 200 West Area (where the subgrade includes finer alluvial materials).

2. The remainder of the study will address subsidence issues associated with specific waste site types (e.g., cribs, trenches and ditches, ponds, burial grounds) and make specific recommendations on appropriate subgrade modification methods for eliminating subsidence potential in advance of barrier construction.

5.3.6 Barrier Materials Data Base

The information in Appendix B could serve as the basis for a spreadsheet or data base for accumulating and correlating data on material quantity and scheduling needs for barrier construction. Such a data base would be useful in budgeting and planning for tracking material quantity needs, scheduling borrow site operations, planning capital expenditures, and other related tasks.

5.4 IMPLEMENTATION LOGIC FOR GRADED BARRIERS

This FFS provides a sequence of generic conceptual designs of surface barriers for 200 Area waste sites. These generic conceptual designs can be used as a baseline cover design to evaluate various remedial alternatives during a site-specific evaluation. During this site-specific evaluation, the tailoring of the cover design can be accomplished factoring in specific location, contaminants, risk levels, etc. The generic design provided here reflects a barrier that meets potential design criteria and can be simplified or reduced if not all the design criteria is needed for the specific site. Figure 5-1 represents the logic for determining the barrier to be evaluated in the site-specific evaluation and for implementation of the "graded approach" to surface barriers for the 200 Areas. Decision gates numbered in the figure correspond to the following questions and statements.

1. Does the WMU contain significant inventories of TRU constituents?

2. Does the WMU contain LLW with GTCC activity (i.e., does waste activity exceed Category 3 limits)?

3. Does the WMU contain waste regulated as dangerous waste?

4. Does the WMU contain LLW with Category 3 activity?

5. Does the WMU contain LLW with Category 1 activity?

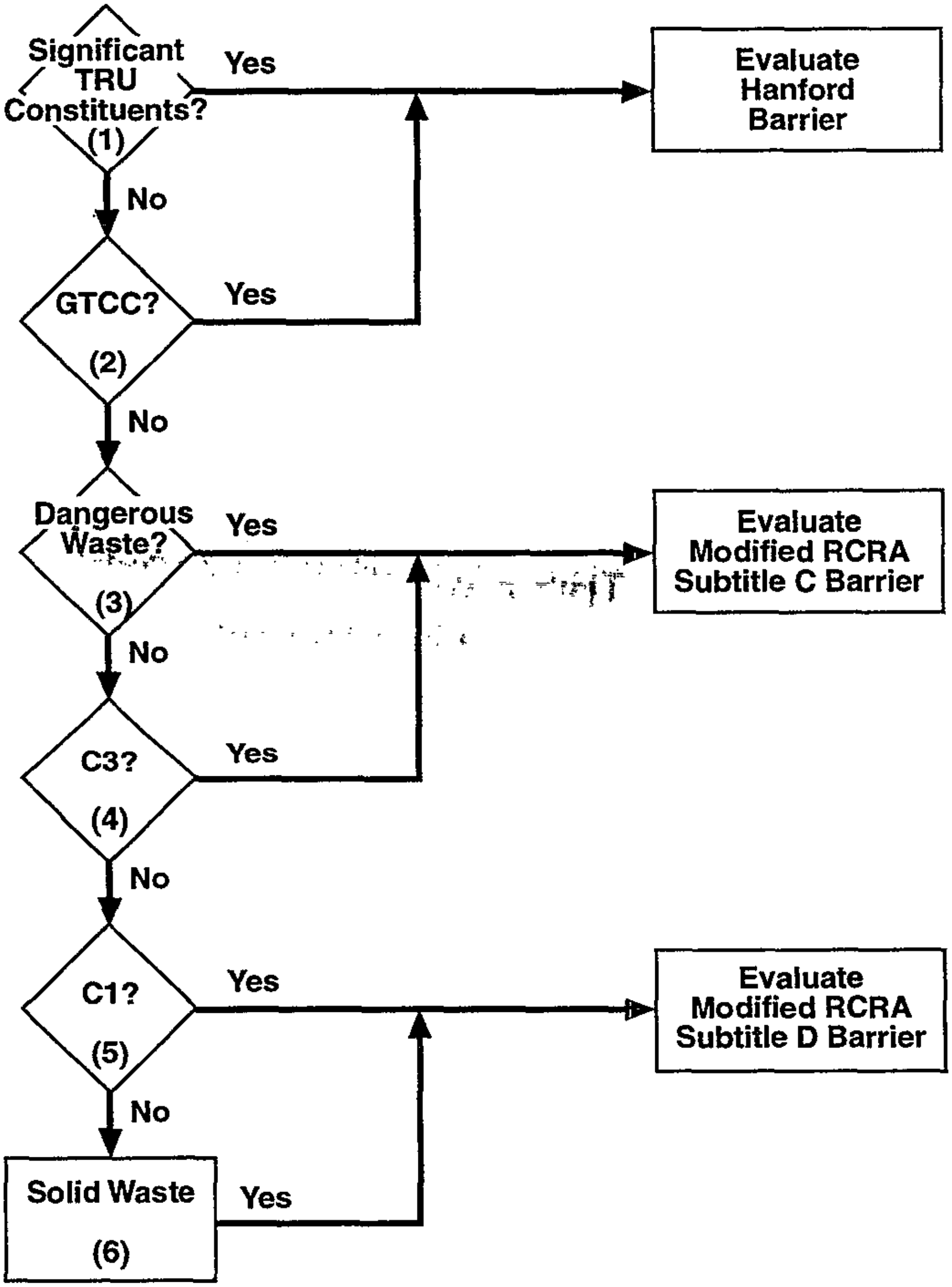
6. Only nonradiological, nonhazardous solid waste is present.

Applying the logic requires that sufficient information is available regarding contaminant constituents and concentrations to classify the radiological component of the waste against the activity limits in Appendix A and to determine whether dangerous constituents are present at levels of regulatory concern.

According to the waste-site information in Appendix B and the summary in Table 1-1, there are 30 waste sites (predominantly in the 200 West Area) with TRU constituents. According to Figure 5-1, these sites will be evaluated to determine if any are candidates for the Hanford Barrier.

Table 1-1 indicates there are 239 LLW and LL mixed waste sites included in Appendix B and another 8 dangerous waste-only sites. Characterization and/or waste inventory data are currently insufficient to provide a breakdown of these sites with respect to radiological activity. However, according to the logic in Figure 5-1, sites with GTCC activity (if any) would be candidate sites for the Hanford Barrier, and Category 3 sites and dangerous waste-only sites would be candidates for the Modified RCRA Subtitle C Barrier. The Subtitle C Barrier would also be evaluated for Category 1 - mixed waste sites, in consideration of the dangerous component. Sites with Category 1 LLW and nonradiological, nonhazardous solid waste would be candidates for the Modified RCRA Subtitle D Barrier. Table 1-1 indicates there are 14 nonradiological, nonhazardous waste sites included in Appendix B.

Figure 5-1. Implementation Logic for the Graded Barrier Approach (the numbered notes refer to statements listed in Section 5.4).



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APPENDIX A

LOW-LEVEL WASTE ACTIVITY LIMITS

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The LLW is divided into three categories at the Hanford Site: Category 1 (analogous to NRC Classes A and B), Category 3 (analogous to NRC Class C), and GTCC as defined by NRC in 10 CFR 61.55(a)(2). The DOE Categories 1 and 3 waste are defined according to the radiological constituents and corresponding activity limits tabulated in Section 3.0 of WHC (1993). The information in this appendix is reproduced from that source. Waste with multiple constituents are characterized according to a "sum-of-fractions" rule derived from 10 CFR 61.55(a)(7).

**Categories 1 and 3 Activity
Limits for Disposal. (Page 1 of 3)**

Nuclide	Activity limits (Ci/m^{3})	
	Category 1	Category 3
^{3}H	5.0 E+06	--
^{10}Be	1.0 E+00	2.2 E+02
^{14}C	4.0 E-02	9.1 E+00
^{14}C[a]	4.0 E-01	9.1 E+01
^{36}Cl	4.0 E-04	8.3 E-02
^{40}K	1.7 E-03	3.4 E-01
^{60}Co	7.7 E+01	--
^{59}Ni	4.0 E+00	8.3 E+02
^{59}Ni[a]	4.0 E+01	8.3 E+03
^{63}Ni	4.8 E+00	1.7 E+04
^{63}Ni[a]	4.8 E+01	1.7 E+05
^{79}Se	3.8 E-01	8.3 E+01
^{90}Sr	4.3 E-03	1.5 E+04
^{93}Zr	2.7 E+00	5.9 E+02
^{94}Nb	2.6 E-04	5.6 E-02
^{94}Nb[a]	2.6 E-03	5.6 E-01
^{93}Mo	3.0 E-01	7.1 E+01
^{99}Tc	5.6 E-03	1.2 E+00
^{99}Tc	5.6 E-03	1.2 E+00
^{107}Pd	4.8 E+00	1.0 E+03
^{113m}Cd	2.0 E-01	--
^{121m}Sn	6.3 E+00	2.0 E+05
^{126}Sn	1.8 E-04	--
^{129}I	2.9 E-03	5.9 E-01

Categories 1 and 3 Activity Limits for Disposal. (Page 2 of 3)

Nuclide	Activity limits (Ci/m³)	
	Category 1	Category 3
^{133}Ba	7.7 E-01	--
^{135}Cs	1.9 E-01	4.2 E+01
^{137}Cs	6.3 E-03	1.3 E+04
^{147}Sm	1.6 E-02	3.4 E+00
^{151}Sm	3.8 E+01	1.8 E+05
^{150}Eu	1.6 E-03	7.7 E+02
^{152}Eu	5.3E-02	--
^{154}Eu	8.3E-01	--
^{152}Gd	6.3 E-03	1.3 E+00
^{187}Re	5.3 E+00	1.1 E+03
^{209}Po	2.9 E-02	7.7 E+01
^{210}Pb	1.0 E-02	5.6 E+05
^{226}Ra	1.4 E-04	3.6 E-02
^{228}Ra	1.9 E+01	--
^{227}Ac	4.5 E-03	3.2 E+05
^{229}Th	4.8 E-04	1.1 E-01
^{230}Th	2.1 E-03	1.3 E-01
^{232}Th	1.2 E-04	2.2 E-02
^{231}Pa	1.6 E-04	3.3 E-02
^{232}U	5.3 E-04	4.0 E+00
^{233}U^{b}	7.7 E-03	1.1 E+00
^{234}U	9.1 E-03	2.1 E+00
^{235}U	3.2 E-03	5.9 E-01
^{236}U	1.0 E-02	2.2 E+00
^{238}U	6.3 E-03	1.4 E+00

Categories 1 and 3 Activity Limits for Disposal. (Page 3 of 3)

Nuclide	Activity limits (Ci/m^3)	
	Category 1	Category 3
^{237}Np[b]	1.9 E-04	4.0 E-02
^{238}Pu[b]	9.1 E-03	4.5 E+01
^{239}Pu[b]	3.6 E-03	7.7 E-01
^{240}Pu[b]	3.6 E-03	7.7 E-01
^{241}Pu[b]	7.7 E-02	3.1 E+01
^{242}Pu[b]	3.8 E-03	8.3 E-01
^{244}Pu[b]	8.3 E-04	1.7 E-01
^{241}Am[b]	2.6 E-03	1.1 E+00
^{242m}Am[b]	2.6 E-03	2.4 E+00
^{243}Am[b]	1.3 E-03	2.8 E-01
^{243}Cm[b]	2.5 E-02	6.3 E+02
^{244}Cm[b]	2.3 E-01	2.9 E+02
^{245}Cm[b]	2.1 E-03	3.3 E-01
^{246}Cm[b]	3.3 E-03	7.7 E-01
^{247}Cm[b]	7.1 E-04	1.5 E-01
^{248}Cm[b]	9.1 E-04	2.0 E-01

[a] Limit for isotope in activated metal.

[b] Category 3 limit is the lower of this value and 100 nCi/g.

APPENDIX B

WASTE-MANAGEMENT UNITS IN THE 200 AGGREGATE AREA DESIGNATED IN THE AGGREGATE AREA MANAGEMENT STUDY REPORTS AS CANDIDATES FOR REMEDIATION WITH SURFACE BARRIERS

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Table B-1. Candidates for Remediation with Surface Barriers. (Page 1 of 12)

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-PO-2	216-A-2	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-3	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-4	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-5	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-9	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-10	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-11	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-12	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-13	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-14	French Drain	LL/Mixed Waste	Y
200-PO-2	216-A-15	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-21	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-22	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-26	French Drain	LLW	N
200-PO-2	216-A-26A	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-27	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-28	French Drain	LL/Mixed Waste	Y
200-PO-2	216-A-31	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-32	Crib	LLW	Y
200-PO-2	216-A-33	French Drain	LLW	N
200-PO-2	216-A-35	French Drain	LL/Mixed Waste	N
200-PO-2	216-A-36A	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-36B	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-38-1	Crib	Nonhazardous/ Nonradiological	N
200-PO-2	216-A-40	Trench	LL/Mixed Waste	Y
200-PO-2	216-A-41	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-45	Crib	LLW	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 2 of 12)

200-PO-2	218-E-1	Burial Ground	Pre-1970 TRU Constituents/ Mixed Waste	N
200-PO-2	218-E-13	Burial Ground	LL/Mixed Waste	N
200-PO-2	299-E24-111	Injection Well	LLW	N
200-PO-4	216-A-6	Crib	LL/Mixed Waste	Y
200-PO-4	216-A-30	Crib	LLW	Y
200-PO-4	216-A-37-1	Crib	LLW	Y
200-PO-4	216-A-37-2	Crib	LLW	Y
200-PO-4	216-A-42	Retention Basin	LL/Mixed Waste	Y
200-PO-5	207-A-NORTH	Retention Basin	Nonhazardous/ Nonradiological	N
200-PO-5	207-A-SOUTH	Retention Basin	Hazardous Waste	N
200-PO-5	216-A-1	Crib	LL/Mixed Waste	Y
200-PO-5	216-A-7	Crib	LL/Mixed Waste	Y
200-PO-5	216-A-8	Crib	LLW	Y
200-PO-5	216-A-18	Trench	LL/Mixed Waste	N
200-PO-5	216-A-19	Trench	LL/Mixed Waste	N
200-PO-5	216-A-20	Trench	LL/Mixed Waste	N
200-PO-5	216-A-24	Crib	LL/Mixed Waste	Y
200-PO-5	216-A-29	Ditch	LL/Mixed Waste	Y
200-PO-5	216-A-34	Ditch	LL/Mixed Waste	N
200-PO-6	218-E-8	Burial Ground	LL/Mixed Waste	N
200-PO-6	218-E-12A	Burial Ground	LL/Mixed Waste	Y
200-BP-1	216-B-43	Crib	LL/Mixed Waste	N
200-BP-1	216-B-44	Crib	LL/Mixed Waste	N
200-BP-1	216-B-45	Crib	LL/Mixed Waste	N
200-BP-1	216-B-46	Crib	LL/Mixed Waste	N
200-BP-1	216-B-47	Crib	LL/Mixed Waste	N
200-BP-1	216-B-48	Crib	LL/Mixed Waste	N
200-BP-1	216-B-49	Crib	LL/Mixed Waste	N

Table B-1. Candidates for Remediation with Surface Barriers. (Page 3 of 12)

200-BP-1	216-B-50	Crib	LL/Mixed Waste	N
200-BP-1	216-B-57	Crib	LL/Mixed Waste	N
200-BP-1	216-B-61	Crib	Nonhazardous/ Nonradiological	N
200-BP-2	216-B-14	Crib	LL/Mixed Waste	Y
200-BP-2	216-B-15	Crib	LL/Mixed Waste	Y
200-BP-2	216-B-16	Crib	LL/Mixed Waste	Y
200-BP-2	216-B-17	Crib	LL/Mixed Waste	Y
200-BP-2	216-B-18	Crib	LL/Mixed Waste	Y
200-BP-2	216-B-19	Crib	LL/Mixed Waste	Y
200-BP-2	216-B-20	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-21	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-22	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-23	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-24	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-25	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-26	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-27	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-28	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-29	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-30	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-31	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-32	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-33	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-34	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-52	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-53A	Trench	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-BP-2	216-B-53B	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-54	Trench	LL/Mixed Waste	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 4 of 12)

200-BP-2	216-B-58	Trench	LL/Mixed Waste	Y
200-BP-3	216-B-35	Trench	LL/Mixed Waste	N
200-BP-3	216-B-36	Trench	LL/Mixed Waste	N
200-BP-3	216-B-37	Trench	LL/Mixed Waste	N
200-BP-3	216-B-38	Trench	LL/Mixed Waste	N
200-BP-3	216-B-39	Trench	LL/Mixed Waste	N
200-BP-3	216-B-40	Trench	LL/Mixed Waste	N
200-BP-3	216-B-41	Trench	LL/Mixed Waste	N
200-BP-3	216-B-42	Trench	LL/Mixed Waste	N
200-BP-4	216-B-7A	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-BP-4	216-B-7B	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-BP-4	216-B-8	Crib	LL/Mixed Waste	Y
200-BP-4	216-B-11A	Reverse Well	LL/Mixed Waste	Y
200-BP-4	216-B-11B	Reverse Well	LL/Mixed Waste	Y
200-BP-4	216-B-51	French Drain	LL/Mixed Waste	Y
200-BP-6	216-B-4	Reverse Well	LL/Mixed Waste	Y
200-BP-6	216-B-5	Reverse Well	TRU Constituents/ Mixed Waste Contaminated Soil	N
200-BP-6	216-B-6	Reverse Well	LL/Mixed Waste	Y
200-BP-6	216-B-9	Crib	LL/Mixed Waste	Y
200-BP-6	216-B-10A	Crib	LL/Mixed Waste	Y
200-BP-6	216-B-10B	Crib	LL/Mixed Waste	Y
200-BP-6	216-B-13	French Drain	LL/Mixed Waste	N
200-BP-6	216-B-56	Crib	Nonhazardous/ Nonradiological	N
200-BP-6	216-B-59B	Retention Basin	LLW	N
200-BP-6	216-B-60	Crib	LL/Mixed Waste	N

Table B-1. Candidates for Remediation with Surface Barriers. (Page 5 of 12)

200-BP-6	218-E-6	Burial Ground	Nonhazardous/ Nonradiological Solid Waste	N
200-BP-6	218-E-7	Burial Ground	LL/Mixed Waste	N
200-BP-8	216-B-2-1	Ditch	LL/Mixed Waste	Y
200-BP-8	216-B-2-2	Ditch	LL/Mixed Waste	Y
200-BP-8	216-B-2-3	Ditch	LLW	Y
200-BP-8	216-B-63	Ditch	LL/Mixed Waste	Y
200-BP-8	207-B	Retention Basin	LLW	Y
200-BP-9	216-B-12	Crib	LL/Mixed Waste	Y
200-BP-9	216-B-55	Crib	LLW	Y
200-BP-9	216-B-62	Crib	LLW	N
200-BP-9	216-B-64	Retention Basin	LLW	Y
200-BP-9	200 Area Construction Pit	Pit	Nonhazardous/ Nonradiological Solid Waste	N
200-BP-10	218-E-2	Burial Ground	LL/Mixed Waste	Y
200-BP-10	218-E-2A	Burial Ground	LL/Mixed Waste	N
200-BP-10	218-E-4	Burial Ground	LL/Mixed Waste	Y
200-BP-10	218-E-5	Burial Ground	LL/Mixed Waste	Y
200-BP-10	218-E-5A	Burial Ground	Pre-1970 TRU Constituents/ Mixed Waste	Y
200-BP-10	200-E-8 Borrow Pit Demolition Site	Ash Pit	Hazardous Waste	N
200-BP-10	218-E-9	Burial Ground	LL/Mixed Waste	Y
200-BP-10	218-E-10	Burial Ground	LL/Mixed Waste	N
200-BP-11	216-B-3	Pond	LL/Mixed Waste	Y
200-BP-11	216-B-3A	Pond	LL/Mixed Waste	Y
200-BP-11	216-B-3B	Pond	LL/Mixed Waste	Y
200-BP-11	216-B-3C	Pond	LL/Mixed Waste	Y
200-BP-11	216-B-3-1	Ditch	LL/Mixed Waste	Y
200-BP-11	216-B-3-2	Ditch	LL/Mixed Waste	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 6 of 12)

200-BP-11	216-B-3-3	Ditch	LLW	Y
200-BP-11	216-E-28	Pond	Nonhazardous/ Nonradiological	N
200-SS-1	218-E-3	Burial Ground	LL/Mixed Waste	N
200-IU-6	216-A-25	Pond	LLW	Y
200-SO-1	216-C-1	Crib	LL/Mixed Waste	Y
200-SO-1	216-C-2	Reverse Well	LLW	N
200-SO-1	216-C-3	Crib	LL/Mixed Waste	Y
200-SO-1	216-C-4	Crib	LL/Mixed Waste	Y
200-SO-1	216-C-5	Crib	LL/Mixed Waste	Y
200-SO-1	216-C-6	Crib	LL/Mixed Waste	Y
200-SO-1	216-C-7	Crib	LLW	Y
200-SO-1	216-C-9	Pond	LLW	N
200-SO-1	216-C-10	Crib	LL/Mixed Waste	Y
200-SO-1	218-C-9	Burial Ground	LLW	N
200-SO-1	200-E Powerhouse Ditch	Ditch	Nonhazardous/ Nonradiological	N
200-NO-1	216-N-1	Pond	LLW	Y
200-NO-1	216-N-2	Trench	LLW	Y
200-NO-1	216-N-3	Trench	LLW	Y
200-NO-1	216-N-4	Pond	LLW	Y
200-NO-1	216-N-5	Trench	LLW	Y
200-NO-1	216-N-6	Pond	LLW	Y
200-NO-1	216-N-7	Trench	LLW	Y
200-RO-1	216-S-5	Crib	LL/Mixed Waste	Y
200-RO-1	216-S-6	Crib	LL/Mixed Waste	Y
200-RO-1	216-S-10D	Ditch	LL/Mixed Waste	Y
200-RO-1	216-S-10P	Pond	LL/Mixed Waste	Y
200-RO-1	216-S-11	Pond	LL/Mixed Waste	Y
200-RO-1	216-S-16D	Ditch	LL/Mixed Waste	Y
200-RO-1	216-S-16P	Pond	LL/Mixed Waste	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 7 of 12)

200-RO-1	216-S-17	Pond	LL/Mixed Waste	Y
200-RO-1	216-S-19	Pond	LL/Mixed Waste	Y
200-RO-1	216-S-25	Crib	LLW	Y
200-RO-1	216-U-9	Ditch	LL/Mixed Waste	Y
200-RO-2	207-S	Retention Basin	LLW	N
200-RO-2	216-S-1	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-RO-2	216-S-2	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-RO-2	216-S-3	French Drain	LL/Mixed Waste	Y
200-RO-2	216-S-7	Crib	LL/Mixed Waste	Y
200-RO-2	216-S-8	Trench	LL/Mixed Waste	N
200-RO-2	216-S-9	Crib	LL/Mixed Waste	Y
200-RO-2	216-S-13	Crib	LL/Mixed Waste	Y
200-RO-2	216-S-15	Pond	LL/Mixed Waste	Y
200-RO-2	216-S-18	Trench	LL/Mixed Waste	N
200-RO-2	216-S-23	Crib	LL/Mixed Waste	Y
200-RO-2	218-W-9	Burial Ground	LL/Mixed Waste	N
200-RO-3	207-SL	Retention Basin	LL/Mixed Waste	N
200-RO-3	216-S-12	Trench	LL/Mixed Waste	N
200-RO-3	216-S-14	Trench	LL/Mixed Waste	N
200-RO-3	216-S-20	Crib	LL/Mixed Waste	Y
200-RO-3	216-S-22	Crib	LL/Mixed Waste	Y
200-RO-3	216-S-26	Crib	LLW	Y
200-RO-3	218-W-7	Burial Ground	LL/Mixed Waste	N
200-SS-2	216-W-LWC	Crib	LLW	Y
200-SS-2	200-W Powerhouse Ash Pit	Ash Pit	Nonhazardous/ Nonradiological Solid Waste	N
200-SS-2	200-W Ash Disposal Basin	Ash Pit	Hazardous Waste	N

Table B-1. Candidates for Remediation with Surface Barriers. (Page 8 of 12)

200-SS-2	200-W Burn Pit	Pit	Hazardous Waste	N
200-TP-1	216-T-5	Trench	LL/Mixed Waste	Y
200-TP-1	216-T-7TF	Crib and Tile Field	LL/Mixed Waste	Y
200-TP-1	216-T-21	Trench	LL/Mixed Waste	Y
200-TP-1	216-T-22	Trench	LL/Mixed Waste	Y
200-TP-1	216-T-23	Trench	LL/Mixed Waste	Y
200-TP-1	216-T-24	Trench	LL/Mixed Waste	Y
200-TP-1	216-T-25	Trench	LL/Mixed Waste	Y
200-TP-1	216-T-36	Crib	LL/Mixed Waste	Y
200-TP-1	216-T-32	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-TP-2	216-T-13	Trench	LL/Mixed Waste	N
200-TP-2	216-T-18	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-TP-2	216-T-19TF	Crib and Tile Field	LL/Mixed Waste	Y
200-TP-2	216-T-20	Trench	LL/Mixed Waste	Y
200-TP-2	216-T-26	Crib	LL/Mixed Waste	Y
200-TP-2	216-T-27	Crib	LL/Mixed Waste	Y
200-TP-2	216-T-28	Crib	LL/Mixed Waste	Y
200-TP-2	216-T-31	French Drain	LL/Mixed Waste	N
200-TP-3	207-T	Retention Basin	LLW	Y
200-TP-3	216-T-4A	Pond	LL/Mixed Waste	N
200-TP-3	216-T-4B	Pond	LLW	N
200-TP-3	216-T-4-1D	Ditch	LL/Mixed Waste	Y
200-TP-3	216-T-4-2	Ditch	LLW	Y
200-TP-3	216-T-6	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-TP-3	216-T-12	Trench	LL/Mixed Waste	Y
200-TP-3	216-T-14	Trench	LL/Mixed Waste	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 9 of 12)

200-TP-3	216-T-15	Trench	LL/Mixed Waste	Y
200-TP-3	216-T-16	Trench	LL/Mixed Waste	Y
200-TP-3	216-T-17	Trench	LL/Mixed Waste	Y
200-TP-4	216-T-1	Ditch	LLW	Y
200-TP-4	216-T-2	Reverse Well	LL/Mixed Waste	N
200-TP-4	216-T-3	Reverse Well	TRU Constituents/ Mixed Waste Contaminated Soil	N
200-TP-4	216-T-8	Crib	LL/Mixed Waste	Y
200-TP-4	216-T-9	Trench	Nonhazardous/ Nonradiological	Y
200-TP-4	216-T-10	Trench	Nonhazardous/ Nonradiological	N
200-TP-4	216-T-11	Trench	Nonhazardous/ Nonradiological	N
200-TP-4	216-T-29	Crib	LL/Mixed Waste	Y
200-TP-4	216-T-33	Crib	LL/Mixed Waste	Y
200-TP-4	216-T-34	Crib	LL/Mixed Waste	Y
200-TP-4	216-T-35	Crib	LL/Mixed Waste	Y
200-TP-4	218-W-8	Burial Ground	LL/Mixed Waste	N
200-TP-4	241-T-361	Settling Tank	LL/Mixed Waste	Y
200-UP-2	216-S-4	French Drain	LL/Mixed Waste	Y
200-UP-2	216-S-21	Crib	LL/Mixed Waste	Y
200-UP-2	207-U	Retention Basin	LL/Mixed Waste	Y
200-UP-2	216-U-1	Crib	LL/Mixed Waste	Y
200-UP-2	216-U-2	Crib	LL/Mixed Waste	Y
200-UP-2	216-U-3	French Drain	LL/Mixed Waste	Y
200-UP-2	216-U-4	Reverse Well	LL/Mixed Waste	Y
200-UP-2	216-U-4A	French Drain	LL/Mixed Waste	Y
200-UP-2	216-U-4B	French Drain	LL/Mixed Waste	Y
200-UP-2	216-U-5	Trench	LL/Mixed Waste	N
200-UP-2	216-U-6	Trench	LL/Mixed Waste	N

Table B-1. Candidates for Remediation with Surface Barriers. (Page 10 of 12)

200-UP-2	216-U-7	French Drain	LL/Mixed Waste	Y
200-UP-2	216-U-8	Crib	LL/Mixed Waste	Y
200-UP-2	216-U-10	Pond	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-UP-2	216-U-11	Ditch	LL/Mixed Waste	Y
200-UP-2	216-U-12	Crib	LL/Mixed Waste	Y
200-UP-2	216-U-13	Trench	LL/Mixed Waste	N
200-UP-2	216-U-14	Ditch	LL/Mixed Waste	Y
200-UP-2	216-U-15	Trench	LL/Mixed Waste	N
200-UP-2	216-U-16	Crib	LLW	Y
200-UP-2	216-U-17	Crib	LLW	Y
200-UP-2	241-U-361	Settling Tank	LL/Mixed Waste	Y
200-UP-2	200-W-5	Burial Ground	LLW	N
200-UP-2	200-W Construction Surface Laydown Area	Burial Ground	Hazardous Waste	N
200-UP-2	216-Z-1D	Ditch	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-UP-2	216-Z-11	Ditch	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-UP-2	216-Z-19	Ditch	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-UP-2	216-Z-20	Crib	LLW	Y
200-UP-2	200-W Powerhouse Pond	Pond	Nonhazardous/ Nonradiological	N
200-UP-3	200-W-4	Demolition and Inert Waste Landfill	Hazardous Waste	Y
200-ZP-2	207-Z	Retention Basin	LL/Mixed Waste	Y
200-ZP-2	216-Z-1&2	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-1A	Tile Field	LL/Mixed Waste	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 11 of 12)

200-ZP-2	216-Z-3	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-4	Trench	LL/Mixed Waste	Y
200-ZP-2	216-Z-5	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-6	Crib	LL/Mixed Waste	Y
200-ZP-2	216-Z-7	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-8	French Drain	TRU Constituents/ Mixed Waste Contaminated Soil	N
200-ZP-2	216-Z-8	Settling Tank	TRU Constituents/ Mixed Waste	Y
200-ZP-2	216-Z-9	Trench	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-10	Reverse Well	TRU Constituents/ Mixed Waste Contaminated Soil	N
200-ZP-2	216-Z-12	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-13	French Drain	LLW	N
200-ZP-2	216-Z-14	French Drain	LLW	N
200-ZP-2	216-Z-15	French Drain	LLW	N
200-ZP-2	216-Z-16	Crib	LLW	Y
200-ZP-2	216-Z-17	Trench	LLW	Y
200-ZP-2	216-Z-18	Crib	TRU Constituents/ Mixed Waste Contaminated Soil	Y
200-ZP-2	241-Z-361	Settling Tank	LL/Mixed Waste	Y
200-ZP-3	218-W-1	Burial Ground	Pre-1970 TRU Constituents/ Mixed Waste	Y
200-ZP-3	218-W-1A	Burial Ground	LL/Mixed Waste	Y

Table B-1. Candidates for Remediation with Surface Barriers. (Page 12 of 12)

200-ZP-3	218-W-2	Burial Ground	Pre-1970 TRU Constituents/ Mixed Waste	Y
200-ZP-3	218-W-3	Burial Ground	Pre-1970 TRU Constituents/ Mixed Waste	Y
200-ZP-3	218-W-4A	Burial Ground	LL and Pre-1970 TRU Constituents/ Mixed Waste	Y
200-ZP-3	218-W-11	Burial Ground	LL/Mixed Waste	Y
200-ZP-3	Z Plant Burn Pit	Burn Pit	Hazardous Waste	N
200-IU-3	Old Central Landfill	Landfill	LLW	(b)
200-IU-3	Solid Waste Landfill	Landfill	Nonhazardous/ Nonradiological Solid Waste	(b)
200-IU-3	NRDWL	Landfill	Hazardous Waste	(b)

[a] As indicated in Tables 9-1 and 9-2 of the AAMS reports. Units that are not candidates for the IRM or LFI paths are subject to final remedy selection.

[b] No remediation path has been designated for these units to date because they were not addressed within the AAMS process. They are listed in this table because they are situated in the 200 Areas NPL site and should be evaluated for potential capping with surface barriers.

APPENDIX C

NUMERICAL PERFORMANCE ASSESSMENTS

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1.0 CONTENTS AND ORGANIZATION OF THIS APPENDIX

This appendix presents information concerning numerical performance assessments of three surface barrier designs (Hanford Barrier, Modified RCRA Subtitle C Barrier, and Modified RCRA Subtitle D Barrier) evaluated as remedial action alternatives for WMUs in the 200 Areas. These simulations were conducted to evaluate the hydrologic performance of the barriers under long-term ambient precipitation conditions, multiyear periods of elevated (twice ambient) precipitation, and the design storm.

Performance of the three barrier designs was evaluated using both the HELP (Version 2.0) and UNSAT-H (Version 2.0) Models. The HELP Model is recommended by EPA to evaluate hydrologic performance of surface barrier designs. However, for arid site applications, the HELP Model has two significant limitations. The HELP Model requires the assumption of a constant evaporative zone depth through the year. In actuality, evaporative depth varies considerably through the year at arid sites, tending toward a maximum value during the summer months when soil moisture is typically low, and a minimum value in the winter months when the majority of annual precipitation is often received. Secondly, moisture movement in the unsaturated state is calculated by algorithms in the HELP Model that are computationally efficient, but do not accurately represent unsaturated flow. As a result, the HELP Model tends to overestimate drainage across a capillary barrier interface. The capillary barrier is an advantageous design concept for barriers in arid locations, and it is used in three of the barriers evaluated in this FFS.

Because of the importance of hydrologic performance in the context of the long-term effectiveness of each design, several different approaches were taken to prepare these calculations. The approaches were as follows.

1. The HELP Model simulations were performed for each barrier using measured and calculated parameter values for the fine-textured soil layers and default data for the layers of coarse-textured material. A value of 90 cm (36 in.) was used for the evaporative zone depth. A 10-year climate data set consisting of actual Hanford Site meteorological records was used in the simulations. The results are reported in Appendices C-1, C-2, and C-3.

2. The three barriers were reevaluated using the UNSAT-H Model. Material properties for the various layers were assigned, based on actual data for the fine-textured soil components (from laboratory and literature sources) and presumptive information (from literature sources) for the coarse-textured soils. Hanford Site weather records for the same 10-year period were used.

3. The HELP Model was "calibrated" using water-balance data from the Field Lysimeter Test Facility at the Hanford Site. The objective of calibration was to minimize the effects of the assumption of constant evaporative depth and the approximations in calculating unsaturated flow and moisture retention. The three barrier designs were then reevaluated using best-fit input parameters from the calibration. Evaporative zone depth was determined separately for each barrier, using averaged annual values from the UNSAT-H modeling. The same 10-year climate data set was used. Results of the UNSAT-H Model simulations and the "calibrated" HELP Model simulations are reported and compared in Appendix C-4.

Selection and assembly of the input files for the "uncalibrated" HELP Model runs is discussed in Section 2.0. Selection of input information for the UNSAT-H Model simulations and the "calibrated" HELP Model simulations is described separately in Appendix C-4.

A detailed hydrologic analysis of surface infiltration for a generic, MTG compliant Standard RCRA Subtitle C Barrier was not performed for this FFS. However, comparative hydrologic studies were performed for site-specific applications at the Hanford Site. Hydrologic Evaluation of Landfill Performance (HELP) computer modeling and analyses were performed for a Standard RCRA Subtitle C Barrier for the low-level burial grounds in the 200 East and 200 West Areas, as presented in *Low Level Burial Grounds Dangerous Waste Permit Application* (DOE-RL 1989). In addition, for the 183-H Solar Basins in the 100 Area, HELP computer modeling and analyses were performed for a Standard RCRA Subtitle C Barrier, as presented in *183-H Solar Evaporation Basin Closure/Post Closure Plan* (DOE-RL 1991). In summary, both studies used current ambient precipitation and meteorological conditions as input parameters, and as can be expected, the majority of the precipitation was evaporated in the upper vegetative/armoring layer. For both studies, only a small percentage of the total precipitation infiltrated to and through the admix and flexible membrane liner. Infiltration through the low permeability admix and flexible membrane liner was estimated at 0.001 in. annually (0.018% of 7.08 total in. annually) for the Low-Level Burial Grounds Project. Infiltration through the low permeability admix and flexible membrane liner was estimated at 0.07 in. (0.85% of 8.22 total in. annually) for the 183-H Solar Basin, assuming a 10% geomembrane failure.

Performance predictions for ambient precipitation conditions are summarized below for the three barrier designs. Average annual precipitation for the 10-year period of interest is 18 cm (7 in.). Runoff refers to the percentage of precipitation that drains off of the barrier surface without being absorbed. Evaporation and transpiration, also shown collectively as evapotranspiration, are the percentages of precipitation that are absorbed into storage in the topsoil layers of the barrier, where they are subsequently removed by direct evaporation and plant transpiration. Lateral drainage is the percentage of precipitation that infiltrates to the level of the lateral drainage layer of the barrier, where it is intercepted and diverted to the perimeter of the barrier. Deep infiltration represents the percentage of precipitation that is able to infiltrate completely through the barrier system, such that it could come into contact with buried waste or contaminated soil.

Water Balance Summary - Ambient Precipitation, Steady State HELP Model, Uncalibrated (in Percent of Average Annual Precipitation)

Barrier	Runoff	Evapotranspiration	Lateral drainage	Deep infiltration
Hanford Barrier	0.01	99.30	0.03	0.66
Mod. RCRA C Barrier	0.01	99.99	0.00	0.00
Mod. RCRA D Barrier	0.01	99.99	N.E.	0.00

N.E. = Not evaluated.

One of the inherent limitations with the HELP Model is the unrealistic assumption that the depth of the evaporative zone is static through time. For the uncalibrated HELP Model simulations of the three barrier designs in Appendices C-1 through C-3, a constant 91-cm (36-in.) evaporative zone depth value was specified. The HELP Model calibration (see Appendix C-4) helped determine that separate evaporative depth values should be identified for the three individual barriers. In the case of the Hanford Barrier simulation, the calibrated evaporative zone depth was 175 cm (69.2 in.) (nearly double the value used in the uncalibrated simulation). This change significantly improved performance predictions for the Hanford Barrier, as indicated below. Evaporative zone depth values were less affected by calibration for the other two designs.

Water Balance Summary - Ambient Precipitation, Steady State HELP Model, Calibrated (in Percent of Average Annual Precipitation)

Barrier	Runoff	Evapotranspiration	Lateral drainage	Deep infiltration
Hanford Barrier	0.01	99.85	0.00	<0.15
Mod. RCRA C Barrier	0.01	99.85	0.00	<0.15
Mod. RCRA D Barrier	0.01	99.85	N.E.	<0.15

N.E. = Not evaluated.

Water Balance Summary - Ambient Precipitation, Steady State UNSAT-H (in Percent of Average Annual Precipitation)

Barrier	Runoff	Evaporation	Transpiration	Lateral drainage and deep infiltration
Hanford Barrier	0.00	97.71	2.24	<0.06
Mod. RCRA C Barrier	0.00	90.43	9.54	<0.04
Mod. RCRA D Barrier	0.00	90.43	9.57	<0.02

The HELP Model is not configured to provide separate reporting of evaporation and transpiration totals. The UNSAT-H Model simulations do not distinguish between lateral drainage and vertical drainage through the low-permeability asphalt layer. In the Modified RCRA Subtitle D design, there is no lateral drainage layer.

In spite of the different assumptions and computational methods employed in the two simulation methods, the results listed above all indicate that the three barriers should perform as designed under ambient precipitation conditions (i.e., virtually all precipitation will be eliminated by evapotranspiration).

In consideration of the relatively long performance periods specified in this FFS for the Hanford Barrier and the Modified RCRA Subtitle C Barrier, hydrologic performance was also modeled for the hypothetical "twice ambient" climate condition. For these simulations, all recorded daily precipitation values in the 10-year data set were doubled. These simulations indicate the capabilities of the three designs to accommodate multiyear periods of above-average rainfall. The "twice ambient" simulations were performed using the UNSAT-H Model and the calibrated HELP Model (Appendix C-4).

Water Balance Summary - Twice Ambient Precipitation, Steady State UNSAT-H (in Percent of Twice Ambient Annual Precipitation)

Barrier	Runoff	Evaporation	Transpiration	Lateral drainage and deep infiltration
Hanford Barrier	0.00	98.49	1.51	0.00
Mod. RCRA C Barrier	0.00	92.74	7.26	0.00
Mod. RCRA D Barrier	0.00	92.64	5.36	2.00

Water Balance Summary - Twice Ambient Precipitation, Steady State HELP Model, Calibrated (in Percent of Twice Ambient Annual Precipitation)

Barrier	Runoff	Evapotranspiration	Lateral drainage	Deep infiltration
Hanford Barrier	1.29	98.57	0.00	<0.15
Mod. RCRA C Barrier	1.66	87.29	10.07	0.98
Mod. RCRA D Barrier	1.50	97.57	N.E.	0.93

N.E. = Not evaluated.

In the "twice ambient" simulations, the HELP Model predicts that a slight amount of runoff will be observed, whereas the UNSAT-H Model predicts no runoff. For the Modified RCRA Subtitle C Barrier, a significant increase in lateral drainage is predicted over the ambient precipitation case, but deep infiltration is still predicted to average less than 1% of "twice ambient" precipitation. Deep infiltration for the Modified RCRA Subtitle D Barrier is about 2% of "twice ambient" precipitation in the UNSAT-H Model simulation and about 1% according to the HELP Model.

One additional group of simulations was conducted to assess runoff production from the design storm. The design-storm analyses are reported in Appendix C-4. Results of the analysis are summarized below. The design-storm is the maximum precipitation event that would be expected to occur during the design life of each barrier. The design-storm amount is based on a storm of maximum intensity and given duration occurring once within a specified return period and is determined from statistical analysis of historic precipitation data for a given locale.

Design Storm Analyses - HELP Model, Calibrated

Barrier	Return period and duration (yrs and hrs)	Design storm amount (in.) [a]	Runoff amount (in.)	Runoff (% storm amt.)
Hanford Barrier	1,000/24	2.68	0.85	31.6
Modified RCRA C Barrier	500/24	2.47	0.91	36.8
Modified RCRA D Barrier	100/24	1.99	0.60	30.1

[a] From Stone et al. (1983), Table 61.

Reflecting the Hanford Site's arid climate, the design-storm amounts are comparatively small. In more humid parts of the United States, storms of this magnitude are likely to have return periods on the order of 2 to 5 years. The design-storm simulations predict that runoff would be less than 2.54 cm (1 in.) in all cases. Because this amount of runoff takes place over a 24-hr period, it is unlikely that the design storm would induce significant erosion of the barrier surface. The simulations also show indirectly that during even the largest storm events at the Hanford Site, the majority of precipitation (60% or more) will infiltrate into the topsoil layers of the barrier, where moisture would be retained in storage until it is removed by the combined action of evapotranspiration processes.

2.0 NOTES ON HELP MODEL SIMULATIONS REPORTED IN APPENDICES C-1, C-2, AND C-3

The HELP Model computes runoff, lateral drainage, and infiltration through a multilayer soil liner and/or cover system for a user-specified location, using actual or stochastically generated daily rainfall data and stochastically generated temperature and solar radiation parameters for that location. To model the barrier designs, each layer must be characterized in terms of thickness, degree of compaction, porosity, field capacity, wilting point, and saturated hydraulic conductivity. The HELP Model contains a look-up table with default characteristics for various representative soil textural types. Climate input information for HELP Model applications at the Hanford Site is documented in WHC-SD-EN-CSWD-028 (Skelly 1990). The Hanford Site data set includes 10 years of daily precipitation values (for the period January 1, 1979, to December 31, 1988). The data set also includes site-specific stochastic parameters for temperature and solar radiation, beginning and end dates for the growing season, and a maximum leaf area index parameter.

For the simulations reported in Appendices C-1, C-2, and C-3, the cover area was defined as 1 acre 4,501 m^2 (43,560 ft^2) so that runoff, drainage, and infiltration values in the output file are directly assessable on a "per acre" basis. The runoff curve number of 87.21 was assigned by the program. A value of
90 cm (36 in.) was assumed for the simulations as the limiting depth of evapotranspiration.

Each model was rerun until quasi-steady state moisture conditions were identified. This was accomplished by redefining the final moisture content values for individual layers from one run as the initial values for the next run until the initial and final values became invariant. This procedure eliminates the effects of overstating soil moisture conditions at the beginning of a simulation.

Input Parameters for the Hanford Barrier (Appendix C-1). The Hanford Barrier design was modeled as seven layers with the following material properties:

Layer 1--upper silt layer with pea gravel admixture: 102 cm (40 in.) thick. Material properties for McGee Ranch silt for this simulation are the same as specified below for Layer 2; however, porosity, field capacity, and wilting point values were reduced by 7.9% to reflect the reduced void volume attributable to the pea gravel admixture. (The void volume reduction factor was calculated based on a mixture consisting of 15 wt.% pea gravel [125 lb/ft^3 dry unit weight and 25% porosity] and 85 wt.% silt [85 lb/ft^3 dry unit weight and 51.4% porosity]).

Porosity = 0.4734
Field Capacity = 0.2381
Wilting Point = 0.0629
Saturated Hydraulic Conductivity = 9.9×10^{-4} cm/s

A "poor" grass cover was specified.

Layer 2--lower silt layer: 102 cm (40 in.) thick. Material properties for uncompacted McGee Ranch silt for this simulation are from DOE-RL (1990a); field capacity and wilting point values are based on moisture retention data in Figures 5-10 and 5-11 of Gee et al. (1989), and saturated hydraulic conductivity is from Table 5-5 (same source).

Porosity = 0.5140
Field Capacity = 0.2585
Wilting Point = 0.0681
Saturated Hydraulic Conductivity = 9.9×10^{-4} cm/s

Layer 3--sand filter layer: The layer was modeled as consisting of 15 cm (6 in.) of HELP Model default textural type 3 soil (fine sand). Layer 3 was modeled as a compacted soil layer.

Layer 4--gravel filter layer: The layer was modeled as 30 cm (12 in.) of HELP Model default textural type 1 soil (sand and gravel). This layer was also modeled as a compacted soil layer.

Layer 5--crushed basalt biointrusion layer: Modeled as 152 cm (60 in.) of HELP Model default type 1 soil, uncompacted. A saturated hydraulic conductivity value of 0.1 cm/s was input to override the default k value. This material will be minus 25 cm (10 in.) of material with a D_{50} of 10 cm (4 in).

Layer 6--lateral drainage layer: The lateral drainage layer was modeled as a 30-cm (12-in.) layer of uncompacted HELP Model default type 1 soil (sand and gravel), sloping at 2%. Specifications call for this material to be a screened product that is substantially free of fines with a relatively high saturated hydraulic conductivity (> 1 cm/s).

Layer 7--asphalt layer: The asphalt was modeled as a barrier soil layer with a saturated hydraulic conductivity of 1×10^{-8} cm/s and arbitrarily assigned low porosity (0.022), field capacity (0.021), and wilting point (0.020) values. Actual asphalt porosity should be well below 2%. However, the HELP Model will not accept lower values. Because the layer is identified as a barrier soil layer, the HELP Model operates on the assumption that the layer is saturated at all times and computes flow according to the Darcy equation (i.e., unsaturated hydraulic properties for Layer 6 do not enter into the analysis).

Input Parameters for the Modified RCRA Subtitle C Barrier (Appendix C-2). The Barrier was modeled as follows:

Layer 1--upper silt layer with pea gravel admixture: 51 cm (20 in.) thick. Material properties for McGee Ranch silt for this simulation are the same as specified for Layer 1 of the Hanford Barrier. A "poor" grass cover was specified.

Layer 2--lower (compacted) silt layer: 51 cm (20 in.) thick. The following adjustments were made to reflect compaction of Layer 2:

- Porosity: reduced by 25% relative to Layer 1.
- Field capacity: reduced by 25% of the difference between the uncompacted field capacity and wilting point values.
- Saturated hydraulic conductivity: 1.6×10^{-6} cm/s (based on laboratory data from compacted samples reported in DOE-RL 1990a).

These modifications to properties are consistent with the algorithm within the HELP Model that modifies default soil properties to account for the effects of compaction (Schroeder et al. 1988).

Layer 3--sand filter layer: The layer was modeled as consisting of 15 cm (6 in.) of HELP Model default textural type 3 soil (fine sand). Layer 3 was modeled as a compacted soil layer.

Layer 4--gravel filter layer: The layer was modeled as 15 cm (6 in.) of HELP Model default textural type 1 soil (sand and gravel). This layer was also modeled as a compacted soil layer.

Layer 5--lateral drainage layer: The lateral drainage layer was modeled as a 15-cm (6-in.) layer of uncompacted HELP Model default type 1 soil (sand and gravel), sloping at 2%. Specifications call for this material to be a screened product, substantially free of fines, with a relatively high saturated hydraulic conductivity (>1 cm/s).

Layer 6--asphalt layer: The asphalt was modeled as a 15-cm (6-in.) barrier soil layer with a saturated hydraulic conductivity of 1×10^{-8} cm/s and arbitrarily assigned low porosity (0.022), field capacity (0.021), and wilting point (0.020) values. These are the same values used in the Hanford Barrier simulation.

Input Parameters for the Modified RCRA Subtitle D Barrier (Appendix C-3). The RCRA Subtitle D Barrier design was modeled as consisting of the following three layers:

Layer 1--upper silt layer with pea gravel admixture: 20 cm (8 in.) thick. Material properties for McGee Ranch silt for this simulation are the same as specified for

Layer 1 of the Hanford Barrier and Layer 1 of the Modified RCRA Subtitle C Design. A "poor" grass cover was specified.

Layer 2--middle (uncompacted) silt layer: 41 cm (16 in.) thick. Material properties for uncompacted McGee Ranch silt for this simulation are the same as specified for Layer 2 of the Hanford Barrier.

Porosity = 0.5140
Field Capacity = 0.2585
Wilting Point = 0.0681
Saturated Hydraulic Conductivity = 9.9 x 10^{-4} cm/s

The hydraulic conductivity value is based on field and laboratory measurements.

Layer 3--lower (compacted) silt layer: 30 cm (12 in.) thick. The values cited here are the same as values used for compacted McGee Ranch silt in Layer 2 of the Modified RCRA Subtitle C Barrier design.

APPENDIX C-1

HANFORD BARRIER DESIGN
PRELIMINARY PERFORMANCE ASSESSMENT FOR STEADY-STATE CONDITIONS (HELP VERSION 2.0 RESULTS)

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APPENDIX C-1

HANFORD BARRIER DESIGN
PRELIMINARY PERFORMANCE ASSESSMENT FOR STEADY-STATE CONDITIONS
(HELP VERSION 2.0 RESULTS)

```
                          LAYER  1 -- POOR GRASS COVER
                          -----------------------------

                          VERTICAL PERCOLATION LAYER

   THICKNESS                            =      40.00 INCHES
   POROSITY                             =       0.4734 VOL/VOL
   FIELD CAPACITY                       =       0.2381 VOL/VOL
   WILTING POINT                        =       0.0627 VOL/VOL
   INITIAL SOIL WATER CONTENT           =       0.0834 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY     =       0.000989999971 CM/S

                                   LAYER  2
                                   --------

                          VERTICAL PERCOLATION LAYER

   THICKNESS                            =      40.00 INCHES
   POROSITY                             =       0.5140 VOL/VOL
   FIELD CAPACITY                       =       0.2585 VOL/VOL
   WILTING POINT                        =       0.0681 VOL/VOL
   INITIAL SOIL WATER CONTENT           =       0.1171 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY     =       0.000989999971 CM/S

                                   LAYER  3
                                   --------

                          VERTICAL PERCOLATION LAYER

   THICKNESS                            =       6.00 INCHES
   POROSITY                             =       0.4570 VOL/VOL
   FIELD CAPACITY                       =       0.0830 VOL/VOL
   WILTING POINT                        =       0.0330 VOL/VOL
   INITIAL SOIL WATER CONTENT           =       0.0922 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY     =       0.003100000089 CM/S
```

```
                              LAYER  4
                              --------

                      VERTICAL PERCOLATION LAYER

     THICKNESS                          =      12.00 INCHES
     POROSITY                           =       0.4170 VOL/VOL
     FIELD CAPACITY                     =       0.0450 VOL/VOL
     WILTING POINT                      =       0.0200 VOL/VOL
     INITIAL SOIL WATER CONTENT         =       0.0442 VOL/VOL
     SATURATED HYDRAULIC CONDUCTIVITY   =       0.009999999776 CM/S

                              LAYER  5
                              --------

                      VERTICAL PERCOLATION LAYER

     THICKNESS                          =      60.00 INCHES
     POROSITY                           =       0.4170 VOL/VOL
     FIELD CAPACITY                     =       0.0450 VOL/VOL
     WILTING POINT                      =       0.0200 VOL/VOL
     INITIAL SOIL WATER CONTENT         =       0.0350 VOL/VOL
     SATURATED HYDRAULIC CONDUCTIVITY   =       0.100000001490 CM/S

                              LAYER  6
                              --------

                        LATERAL DRAINAGE LAYER

     THICKNESS                          =      12.00 INCHES
     POROSITY                           =       0.4170 VOL/VOL
     FIELD CAPACITY                     =       0.0450 VOL/VOL
     WILTING POINT                      =       0.0200 VOL/VOL
     INITIAL SOIL WATER CONTENT         =       0.0450 VOL/VOL
     SATURATED HYDRAULIC CONDUCTIVITY   =       1.000000000000 CM/S
     SLOPE                              =       2.00 PERCENT
     DRAINAGE LENGTH                =     295.0 FEET

                              LAYER  7
                              --------

                          BARRIER SOIL LINER

     THICKNESS                          =       6.00 INCHES
     POROSITY                           =       0.0220 VOL/VOL
     FIELD CAPACITY                     =       0.0210 VOL/VOL
     WILTING POINT                      =       0.0200 VOL/VOL
     INITIAL SOIL WATER CONTENT         =       0.0210 VOL/VOL
     SATURATED HYDRAULIC CONDUCTIVITY   =       0.000000010000 CM/S
```

```
                         GENERAL SIMULATION DATA
                         -----------------------

   SCS RUNOFF CURVE NUMBER              =      87.21
   TOTAL AREA OF COVER                  =   43560. SQ FT
   EVAPORATIVE ZONE DEPTH               =      36.00 INCHES
   UPPER LIMIT VEG. STORAGE             =      17.0424 INCHES
   INITIAL VEG. STORAGE                 =       3.0024 INCHES
   INITIAL SNOW WATER CONTENT           =       0.0000 INCHES
   INITIAL TOTAL WATER STORAGE IN
     SOIL AND WASTE LAYERS              =      11.8696 INCHES

              SOIL WATER CONTENT INITIALIZED BY USER.

                         CLIMATOLOGICAL DATA
                         -------------------

   USER SPECIFIED RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
   SOLAR RADIATION FOR HANFORD SITE, WASHINGTON STATE.


   MAXIMUM LEAF AREA INDEX                 = 1.60
   START OF GROWING SEASON (JULIAN DATE)   =  113
   END OF GROWING SEASON (JULIAN DATE)     =  288


         NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------

   29.30       36.30       45.10       53.10       61.50       69.30
   76.40       74.30       65.20       53.00       39.80       32.70
```

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                        MONTHLY TOTALS FOR YEAR 1979
------------------------------------------------------------------------------

                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)    0.54    0.17    0.54    0.52    0.10    0.00
                           0.09    0.38    0.20    0.67    1.36    0.99

 RUNOFF (INCHES)           0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION        0.778   0.304   0.208   0.452   0.611   0.262
      (INCHES)             0.090   0.285   0.295   0.137   0.350   0.531

 LATERAL DRAINAGE FROM     0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)       0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM          0.0040  0.0036  0.0040  0.0039  0.0040  0.0039
   LAYER  7 (INCHES)       0.0041  0.0041  0.0039  0.0041  0.0040  0.0041

 ----------------------------------------------------------------------------
                       ANNUAL TOTALS FOR YEAR 1979
 ----------------------------------------------------------------------------

                                        (INCHES)   (CU. FT.)   PERCENT
                                        --------   ---------   -------

   PRECIPITATION                          5.56       20183.    100.00

   RUNOFF                                 0.000          0.      0.00

   EVAPOTRANSPIRATION                     4.303      15622.     77.40

   LATERAL DRAINAGE FROM LAYER  6         0.0025         9.      0.04

   PERCOLATION FROM LAYER  7              0.0477       173.      0.86

   CHANGE IN WATER STORAGE                1.206       4379.     21.70

   SOIL WATER AT START OF YEAR           11.87       43087.

   SOIL WATER AT END OF YEAR             13.08       47466.

   SNOW WATER AT START OF YEAR            0.00           0.

   SNOW WATER AT END OF YEAR              0.00           0.

   ANNUAL WATER BUDGET BALANCE            0.00           0.      0.00

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                        MONTHLY TOTALS FOR YEAR 1980
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                           JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                           ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)      1.32    1.30    0.30    0.86    1.41    0.96
                             0.00    0.02    0.85    0.33    0.44    1.89

 RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                             0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION          0.487   1.188   1.943   0.511   1.681   2.054
       (INCHES)              0.285   0.020   0.383   0.364   0.293   0.324

 LATERAL DRAINAGE FROM       0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)         0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM            0.0041  0.0038  0.0041  0.0040  0.0041  0.0040
   LAYER  7 (INCHES)         0.0041  0.0041  0.0040  0.0041  0.0040  0.0041

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1980
-------------------------------------------------------------------------------

                                       (INCHES)     (CU. FT.)    PERCENT
                                       --------     ----------   -------

  PRECIPITATION                          9.68         35138.      100.00

  RUNOFF                                 0.001            2.        0.01

  EVAPOTRANSPIRATION                     9.533        34606.       98.49

  LATERAL DRAINAGE FROM LAYER  6         0.0026           9.        0.03

  PERCOLATION FROM LAYER  7              0.0484         176.        0.50

  CHANGE IN WATER STORAGE                0.095          345.        0.98

  SOIL WATER AT START OF YEAR           13.08         47466.

  SOIL WATER AT END OF YEAR             13.17         47810.

  SNOW WATER AT START OF YEAR            0.00             0.

  SNOW WATER AT END OF YEAR              0.00             0.

  ANNUAL WATER BUDGET BALANCE            0.00             0.        0.00

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                        MONTHLY TOTALS FOR YEAR 1981
-------------------------------------------------------------------------------

                           JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                           -------  -------  -------  -------  -------  -------

 PRECIPITATION (INCHES)     0.56     0.60     0.70     0.02     0.99     0.43
                            0.19     0.03     0.60     0.39     1.08     1.45

 RUNOFF (INCHES)            0.000    0.000    0.000    0.000    0.000    0.000
                            0.000    0.000    0.000    0.000    0.000    0.000

 EVAPOTRANSPIRATION         0.698    1.506    0.949    0.394    0.336    1.571
       (INCHES)             0.182    0.030    0.102    0.347    0.538    0.558

 LATERAL DRAINAGE FROM      0.0002   0.0002   0.0002   0.0002   0.0002   0.0002
   LAYER  6 (INCHES)        0.0002   0.0002   0.0002   0.0002   0.0002   0.0002

 PERCOLATION FROM           0.0041   0.0037   0.0041   0.0040   0.0041   0.0040
   LAYER  7 (INCHES)        0.0041   0.0041   0.0039   0.0041   0.0039   0.0041

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1981
-------------------------------------------------------------------------------

                                          (INCHES)    (CU. FT.)     PERCENT
                                          --------    ---------     -------
  PRECIPITATION                             7.04        25555.      100.00

  RUNOFF                                    0.000           0.        0.00

  EVAPOTRANSPIRATION                        7.211       26175.      102.42

  LATERAL DRAINAGE FROM LAYER  6            0.0025          9.        0.04

  PERCOLATION FROM LAYER  7                 0.0481        174.        0.68

  CHANGE IN WATER STORAGE                  -0.221        -803.       -3.14

  SOIL WATER AT START OF YEAR              13.17        47810.

  SOIL WATER AT END OF YEAR                12.95        47007.

  SNOW WATER AT START OF YEAR               0.00            0.

  SNOW WATER AT END OF YEAR                 0.00            0.

  ANNUAL WATER BUDGET BALANCE               0.00            0.        0.00

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                        MONTHLY TOTALS FOR YEAR 1982
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                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)      0.33    0.57    0.30    0.75    0.28    0.75
                            0.22    0.20    0.55    1.33    0.91    1.79

RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                            0.000   0.000   0.000   0.008   0.000   0.000

EVAPOTRANSPIRATION          0.688   1.161   0.866   0.588   0.697   0.472
     (INCHES)               0.704   0.196   0.295   0.402   1.036   0.568

LATERAL DRAINAGE FROM       0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
  LAYER  6 (INCHES)         0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

PERCOLATION FROM            0.0040  0.0037  0.0040  0.0039  0.0040  0.0039
  LAYER  7 (INCHES)         0.0040  0.0040  0.0039  0.0040  0.0038  0.0040

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1982
-------------------------------------------------------------------------------

                                          (INCHES)     (CU. FT.)    PERCENT
                                          --------     ---------    -------
  PRECIPITATION                             7.98         28967.     100.00

  RUNOFF                                    0.008           28.       0.09

  EVAPOTRANSPIRATION                        7.672        27848.      96.14

  LATERAL DRAINAGE FROM LAYER  6            0.0024           9.       0.03

  PERCOLATION FROM LAYER  7                 0.0472         171.       0.59

  CHANGE IN WATER STORAGE                   0.251          912.       3.15

  SOIL WATER AT START OF YEAR              12.95         47007.

  SOIL WATER AT END OF YEAR                13.20         47919.

  SNOW WATER AT START OF YEAR               0.00             0.

  SNOW WATER AT END OF YEAR                 0.00             0.

  ANNUAL WATER BUDGET BALANCE               0.00             0.       0.00

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                      MONTHLY TOTALS FOR YEAR 1983
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                         JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                         ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)    1.44    1.36    1.00    0.42    0.52    0.68
                           0.31    0.12    0.46    0.52    2.12    2.12

 RUNOFF (INCHES)           0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION        0.596   0.998   2.199   0.870   0.605   1.791
      (INCHES)             0.747   0.123   0.460   0.157   0.703   0.461

 LATERAL DRAINAGE FROM     0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)       0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM          0.0039  0.0036  0.0039  0.0038  0.0039  0.0038
   LAYER  7 (INCHES)       0.0039  0.0039  0.0037  0.0039  0.0037  0.0038

-------------------------------------------------------------------------------
                       ANNUAL TOTALS FOR YEAR 1983
-------------------------------------------------------------------------------

                                       (INCHES)    (CU. FT.)    PERCENT
                                       --------    ---------    -------

   PRECIPITATION                        11.07         40184.    100.00

   RUNOFF                                0.000           0.      0.00

   EVAPOTRANSPIRATION                    9.711        35250.     87.72

   LATERAL DRAINAGE FROM LAYER  6        0.0023          8.      0.02

   PERCOLATION FROM LAYER  7             0.0458        166.      0.41

   CHANGE IN WATER STORAGE               1.311        4759.     11.84

   SOIL WATER AT START OF YEAR          13.20         47919.

   SOIL WATER AT END OF YEAR            14.51         52678.

   SNOW WATER AT START OF YEAR           0.00            0.

   SNOW WATER AT END OF YEAR             0.00            0.

   ANNUAL WATER BUDGET BALANCE           0.00            0.      0.00

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                     MONTHLY TOTALS FOR YEAR 1984
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                            JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                            ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)      0.23    0.94    1.01    0.60    0.55    0.99
                             0.06    0.00    0.42    0.07    1.83    0.57

 RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                             0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION          0.467   1.340   1.959   0.510   0.729   2.337
       (INCHES)              0.162   0.000   0.214   0.269   0.468   0.601

 LATERAL DRAINAGE FROM       0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)         0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM            0.0038  0.0036  0.0038  0.0037  0.0038  0.0036
   LAYER  7 (INCHES)         0.0038  0.0037  0.0036  0.0037  0.0036  0.0037

------------------------------------------------------------------------------
                      ANNUAL TOTALS FOR YEAR 1984
------------------------------------------------------------------------------

                                       (INCHES)    (CU. FT.)    PERCENT
                                       --------    ---------    -------

  PRECIPITATION                          7.27        26390.     100.00

  RUNOFF                                 0.000           0.       0.00

  EVAPOTRANSPIRATION                     9.057       32877.     124.58

  LATERAL DRAINAGE FROM LAYER  6         0.0021          8.       0.03

  PERCOLATION FROM LAYER  7              0.0444        161.       0.61

  CHANGE IN WATER STORAGE               -1.833       -6655.     -25.22

  SOIL WATER AT START OF YEAR           14.51        52678.

  SOIL WATER AT END OF YEAR             12.68        46023.

  SNOW WATER AT START OF YEAR            0.00            0.

  SNOW WATER AT END OF YEAR              0.00            0.

  ANNUAL WATER BUDGET BALANCE            0.00            0.       0.00

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                     MONTHLY TOTALS FOR YEAR 1985
-------------------------------------------------------------------------------

                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)     0.34    0.82    0.36    0.01    0.12    0.15
                            0.12    0.01    0.63    0.46    1.24    0.84

 RUNOFF (INCHES)            0.000   0.000   0.000   0.000   0.000   0.000
                            0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION         0.681   1.218   0.921   0.010   0.144   0.165
      (INCHES)              0.026   0.104   0.335   0.262   0.281   0.630

 LATERAL DRAINAGE FROM      0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)        0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM           0.0037  0.0033  0.0037  0.0036  0.0037  0.0035
   LAYER  7 (INCHES)        0.0037  0.0037  0.0035  0.0037  0.0035  0.0037

-------------------------------------------------------------------------------
                      ANNUAL TOTALS FOR YEAR 1985
-------------------------------------------------------------------------------

                                        (INCHES)     (CU. FT.)     PERCENT
                                        ---------    ---------     -------
   PRECIPITATION                          5.10         18513.      100.00

   RUNOFF                                 0.000           0.         0.00

   EVAPOTRANSPIRATION                     4.776        17335.       93.64

   LATERAL DRAINAGE FROM LAYER  6         0.0020          7.         0.04

   PERCOLATION FROM LAYER  7              0.0432        157.         0.85

   CHANGE IN WATER STORAGE                0.279        1014.         5.48

   SOIL WATER AT START OF YEAR           12.68        46023.

   SOIL WATER AT END OF YEAR             12.96        47036.

   SNOW WATER AT START OF YEAR            0.00            0.

   SNOW WATER AT END OF YEAR              0.00            0.

   ANNUAL WATER BUDGET BALANCE            0.00            0.         0.00

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                        MONTHLY TOTALS FOR YEAR 1986
-------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------

 PRECIPITATION (INCHES)    1.76     1.37     0.76     0.00     0.30     0.00
                           0.21     0.02     0.96     0.29     0.65     0.77

 RUNOFF (INCHES)           0.000    0.000    0.000    0.000    0.000    0.000
                           0.000    0.000    0.000    0.000    0.000    0.000

 EVAPOTRANSPIRATION        0.535    1.400    1.859    0.287    0.363    0.420
      (INCHES)             1.165    0.020    0.328    0.270    0.236    0.273

 LATERAL DRAINAGE FROM     0.0002   0.0002   0.0002   0.0002   0.0002   0.0002
   LAYER  6 (INCHES)       0.0002   0.0002   0.0002   0.0002   0.0002   0.0002

 PERCOLATION FROM          0.0037   0.0033   0.0037   0.0036   0.0037   0.0036
   LAYER  7 (INCHES)       0.0037   0.0037   0.0036   0.0037   0.0036   0.0037

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1986
-------------------------------------------------------------------------------

                                         (INCHES)     (CU. FT.)    PERCENT
                                         --------     ---------    -------
  PRECIPITATION                            7.09         25737.     100.00

  RUNOFF                                   0.000            0.       0.00

  EVAPOTRANSPIRATION                       7.156        25978.     100.94

  LATERAL DRAINAGE FROM LAYER  6           0.0021           7.       0.03

  PERCOLATION FROM LAYER  7                0.0435         158.       0.61

  CHANGE IN WATER STORAGE                 -0.112         -407.      -1.58

  SOIL WATER AT START OF YEAR             12.96         47036.

  SOIL WATER AT END OF YEAR               12.85         46630.

  SNOW WATER AT START OF YEAR              0.00             0.

  SNOW WATER AT END OF YEAR                0.00             0.

  ANNUAL WATER BUDGET BALANCE              0.00             0.       0.00

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                        MONTHLY TOTALS FOR YEAR 1987
-------------------------------------------------------------------------------

                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)    0.80    0.19    1.05    0.14    0.17    0.11
                           0.50    0.07    0.01    0.00    0.40    1.63

 RUNOFF (INCHES)           0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION        0.276   1.031   0.775   0.405   0.594   0.941
      (INCHES)             0.500   0.070   0.010   0.000   0.224   0.389

 LATERAL DRAINAGE FROM     0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)       0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM          0.0037  0.0034  0.0038  0.0037  0.0038  0.0037
   LAYER  7 (INCHES)       0.0038  0.0038  0.0037  0.0039  0.0037  0.0039

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1987
-------------------------------------------------------------------------------
                                          (INCHES)     (CU. FT.)    PERCENT
                                          --------     ---------    -------
   PRECIPITATION                            5.07         18404.      100.00

   RUNOFF                                   0.000            0.        0.00

   EVAPOTRANSPIRATION                       5.217        18936.      102.89

   LATERAL DRAINAGE FROM LAYER  6           0.0022           8.        0.04

   PERCOLATION FROM LAYER  7                0.0449         163.        0.89

   CHANGE IN WATER STORAGE                 -0.194         -703.       -3.82

   SOIL WATER AT START OF YEAR             12.85         46630.

   SOIL WATER AT END OF YEAR               12.65         45927.

   SNOW WATER AT START OF YEAR              0.00             0.

   SNOW WATER AT END OF YEAR                0.00             0.

   ANNUAL WATER BUDGET BALANCE              0.00             0.        0.00

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                       MONTHLY TOTALS FOR YEAR 1988
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                              JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                              ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)        0.48    0.00    0.39    1.12    0.33    0.11
                               0.13    0.00    0.39    0.01    0.82    0.40

 RUNOFF (INCHES)               0.000   0.000   0.000   0.000   0.000   0.000
                               0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION            0.818   0.642   0.531   0.483   0.582   0.791
      (INCHES)                 0.130   0.000   0.165   0.205   0.289   0.279

 LATERAL DRAINAGE FROM         0.0002  0.0002  0.0002  0.0002  0.0002  0.0002
   LAYER  6 (INCHES)           0.0002  0.0002  0.0002  0.0002  0.0002  0.0002

 PERCOLATION FROM              0.0039  0.0037  0.0039  0.0038  0.0039  0.0038
   LAYER  7 (INCHES)           0.0040  0.0040  0.0039  0.0040  0.0039  0.0040

-------------------------------------------------------------------------------
                        ANNUAL TOTALS FOR YEAR 1988
-------------------------------------------------------------------------------

                                          (INCHES)    (CU. FT.)    PERCENT
                                          --------    ---------    -------
  PRECIPITATION                             4.18        15173.     100.00

  RUNOFF                                    0.000           0.       0.00

  EVAPOTRANSPIRATION                        4.914       17838.     117.56

  LATERAL DRAINAGE FROM LAYER  6            0.0024          9.       0.06

  PERCOLATION FROM LAYER  7                 0.0468        170.       1.12

  CHANGE IN WATER STORAGE                  -0.783       -2843.     -18.74

  SOIL WATER AT START OF YEAR              12.65        45927.

  SOIL WATER AT END OF YEAR                11.87        43083.

  SNOW WATER AT START OF YEAR               0.00            0.

  SNOW WATER AT END OF YEAR                 0.00            0.

  ANNUAL WATER BUDGET BALANCE               0.00            0.       0.00

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-------------------------------------------------------------------------------
          AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1979 THROUGH 1988
-------------------------------------------------------------------------------

                      JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                      -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS               0.78     0.73     0.64     0.44     0.48     0.42
                        0.18     0.09     0.51     0.41     1.09     1.24

   STD. DEVIATIONS      0.54     0.51     0.30     0.40     0.42     0.40
                        0.14     0.12     0.28     0.39     0.57     0.60

 RUNOFF
 ------
   TOTALS               0.000    0.000    0.000    0.000    0.000    0.000
                        0.000    0.000    0.000    0.001    0.000    0.000

   STD. DEVIATIONS      0.000    0.000    0.000    0.000    0.000    0.000
                        0.000    0.000    0.000    0.002    0.000    0.000

 EVAPOTRANSPIRATION
 ------------------
   TOTALS               0.602    1.079    1.221    0.451    0.634    1.080
                        0.399    0.085    0.259    0.241    0.442    0.462

   STD. DEVIATIONS      0.164    0.364    0.701    0.218    0.411    0.795
                        0.370    0.095    0.136    0.121    0.258    0.136

 LATERAL DRAINAGE FROM LAYER  6
 ------------------------------
   TOTALS               0.0002   0.0002   0.0002   0.0002   0.0002   0.0002
                        0.0002   0.0002   0.0002   0.0002   0.0002   0.0002

   STD. DEVIATIONS      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

 PERCOLATION FROM LAYER  7
 -------------------------
   TOTALS               0.0039   0.0036   0.0039   0.0038   0.0039   0.0038
                        0.0039   0.0039   0.0038   0.0039   0.0038   0.0039

   STD. DEVIATIONS      0.0002   0.0002   0.0002   0.0002   0.0002   0.0002
                        0.0002   0.0002   0.0002   0.0002   0.0002   0.0002

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1979 THROUGH 1988

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	7.00	(2.164)	25425.	100.00
RUNOFF	0.001	(0.002)	3.	0.01
EVAPOTRANSPIRATION	6.955	(2.062)	25247.	99.30
LATERAL DRAINAGE FROM LAYER 6	0.0023	(0.0002)	8.	0.03
PERCOLATION FROM LAYER 7	0.0460	(0.0019)	167.	0.66
CHANGE IN WATER STORAGE	0.000	(0.907)	0.	0.00

PEAK DAILY VALUES FOR YEARS 1979 THROUGH 1988

	(INCHES)	(CU. FT.)
PRECIPITATION	0.93	3375.9
RUNOFF	0.008	27.5
LATERAL DRAINAGE FROM LAYER 6	0.0000	0.0
PERCOLATION FROM LAYER 7	0.0001	0.5
HEAD ON LAYER 7	0.0	
SNOW WATER	0.76	2743.4
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.1626	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0625	

FINAL WATER STORAGE AT END OF YEAR 1988

LAYER	(INCHES)	(VOL/VOL)
1	3.34	0.0834
2	4.68	0.1171
3	0.55	0.0922
4	0.53	0.0442
5	2.10	0.0350
6	0.54	0.0450
7	0.13	0.0210
SNOW WATER	0.00	

APPENDIX C-2

MODIFIED RCRA SUBTITLE C BARRIER DESIGN PRELIMINARY PERFORMANCE ASSESSMENT FOR STEADY-STATE CONDITIONS

(HELP VERSION 2.0 RESULTS)

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APPENDIX C-2

MODIFIED RCRA SUBTITLE C BARRIER DESIGN PRELIMINARY PERFORMANCE ASSESSMENT FOR STEADY-STATE CONDITIONS (HELP VERSION 2.0 RESULTS)

```
                     LAYER  1 -- POOR GRASS COVER
                     ----------------------------

                       VERTICAL PERCOLATION LAYER

THICKNESS                          =     20.00 INCHES
POROSITY                           =      0.4734 VOL/VOL
FIELD CAPACITY                     =      0.2381 VOL/VOL
WILTING POINT                      =      0.0627 VOL/VOL
INITIAL SOIL WATER CONTENT         =      0.0977 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY   =      0.000989999971 CM/S

                              LAYER  2
                              --------

                       VERTICAL PERCOLATION LAYER

THICKNESS                          =     20.00 INCHES
POROSITY                           =      0.3470 VOL/VOL
FIELD CAPACITY                     =      0.2109 VOL/VOL
WILTING POINT                      =      0.0681 VOL/VOL
INITIAL SOIL WATER CONTENT         =      0.0677 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY   =      0.000001600000 CM/S

                              LAYER  3
                              --------

                       VERTICAL PERCOLATION LAYER

THICKNESS                          =      6.00 INCHES
POROSITY                           =      0.4570 VOL/VOL
FIELD CAPACITY                     =      0.0830 VOL/VOL
WILTING POINT                      =      0.0330 VOL/VOL
INITIAL SOIL WATER CONTENT         =      0.0476 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY   =      0.003100000089 CM/S

                              LAYER  4
                              --------

                       VERTICAL PERCOLATION LAYER

THICKNESS                          =      6.00 INCHES
POROSITY                           =      0.4170 VOL/VOL
FIELD CAPACITY                     =      0.0450 VOL/VOL
WILTING POINT                      =      0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT         =      0.0259 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY   =      0.009999999776 CM/S
```

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                              LAYER  5
                              --------

                        LATERAL DRAINAGE LAYER

   THICKNESS                                 =      6.00 INCHES
   POROSITY                                  =      0.4170 VOL/VOL
   FIELD CAPACITY                            =      0.0450 VOL/VOL
   WILTING POINT                             =      0.0200 VOL/VOL
   INITIAL SOIL WATER CONTENT                =      0.0450 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY          =      1.000000000000 CM/S
   SLOPE                                     =      2.00 PERCENT
   DRAINAGE LENGTH                           =    295.0 FEET

                              LAYER  6
                              --------

                          BARRIER SOIL LINER

   THICKNESS                                 =      6.00 INCHES
   POROSITY                                  =      0.0220 VOL/VOL
   FIELD CAPACITY                            =      0.0210 VOL/VOL
   WILTING POINT                             =      0.0200 VOL/VOL
   INITIAL SOIL WATER CONTENT                =      0.0210 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY          =      0.000000010000 CM/S

                        GENERAL SIMULATION DATA
                        -----------------------

   SCS RUNOFF CURVE NUMBER                   =      87.21
   TOTAL AREA OF COVER                       =   43560. SQ FT
   EVAPORATIVE ZONE DEPTH                    =      36.00 INCHES
   UPPER LIMIT VEG. STORAGE                  =      15.0200 INCHES
   INITIAL VEG. STORAGE                      =       3.0372 INCHES
   INITIAL SNOW WATER CONTENT                =       0.0000 INCHES
   INITIAL TOTAL WATER STORAGE IN
     SOIL AND WASTE LAYERS                   =       4.1450 INCHES

             SOIL WATER CONTENT INITIALIZED BY USER.

                         CLIMATOLOGICAL DATA
                         -------------------

   USER SPECIFIED RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
   SOLAR RADIATION FOR HANFORD SITE, WASHINGTON STATE.

   MAXIMUM LEAF AREA INDEX                      = 1.60
   START OF GROWING SEASON (JULIAN DATE)        =  113
   END OF GROWING SEASON (JULIAN DATE)          =  288

           NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------

   29.30       36.30       45.10       53.10       61.50       69.30
   76.40       74.30       65.20       53.00       39.80       32.70
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                         MONTHLY TOTALS FOR YEAR 1979
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                           JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                           ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)      0.54    0.17    0.54    0.52    0.10    0.00
                             0.09    0.38    0.20    0.67    1.36    0.99

 RUNOFF (INCHES)            0.000   0.000   0.000   0.000   0.000   0.000
                            0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION         0.774   0.564   0.206   0.455   0.542   0.027
     (INCHES)               0.090   0.277   0.303   0.158   0.359   0.518

 LATERAL DRAINAGE FROM     0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  5 (INCHES)       0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

 PERCOLATION FROM          0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  6 (INCHES)       0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                          ANNUAL TOTALS FOR YEAR 1979
-------------------------------------------------------------------------------

                                     (INCHES)      (CU. FT.)     PERCENT
                                     --------      ---------     -------
   PRECIPITATION                       5.56          20183.      100.00

   RUNOFF                              0.000             0.        0.00

   EVAPOTRANSPIRATION                  4.273         15512.       76.86

   LATERAL DRAINAGE FROM LAYER  5      0.0000            0.        0.00

   PERCOLATION FROM LAYER  6           0.0001            0.        0.00

   CHANGE IN WATER STORAGE             1.287          4670.       23.14

   SOIL WATER AT START OF YEAR         4.14          15046.

   SOIL WATER AT END OF YEAR           5.43          19717.

   SNOW WATER AT START OF YEAR         0.00              0.

   SNOW WATER AT END OF YEAR           0.00              0.

   ANNUAL WATER BUDGET BALANCE         0.00              0.        0.00

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                         MONTHLY TOTALS FOR YEAR 1980
-------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------

 PRECIPITATION (INCHES)     1.32     1.30     0.30     0.86     1.41     0.96
                            0.00     0.02     0.85     0.33     0.44     1.89

 RUNOFF (INCHES)            0.000    0.000    0.000    0.000    0.000    0.000
                            0.000    0.000    0.000    0.000    0.000    0.000

 EVAPOTRANSPIRATION         0.485    1.158    1.882    0.593    1.668    2.041
      (INCHES)              0.303    0.020    0.384    0.379    0.287    0.314

 LATERAL DRAINAGE FROM      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   LAYER  5 (INCHES)        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

 PERCOLATION FROM           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   LAYER  6 (INCHES)        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1980
-------------------------------------------------------------------------------

                                          (INCHES)     (CU. FT.)     PERCENT
                                          --------     ---------     -------
   PRECIPITATION                            9.68         35138.      100.00

   RUNOFF                                   0.001            3.        0.01

   EVAPOTRANSPIRATION                       9.514        34534.       98.28

   LATERAL DRAINAGE FROM LAYER  5           0.0000           0.        0.00

   PERCOLATION FROM LAYER  6                0.0001           0.        0.00

   CHANGE IN WATER STORAGE                  0.166          601.        1.71

   SOIL WATER AT START OF YEAR              5.43         19717.

   SOIL WATER AT END OF YEAR                5.60         20318.

   SNOW WATER AT START OF YEAR              0.00             0.

   SNOW WATER AT END OF YEAR                0.00             0.

   ANNUAL WATER BUDGET BALANCE              0.00             0.        0.00

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                     MONTHLY TOTALS FOR YEAR 1981
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                             JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                             ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)       0.56    0.60    0.70    0.02    0.99    0.43
                              0.19    0.03    0.60    0.39    1.08    1.45

 RUNOFF (INCHES)              0.000   0.000   0.000   0.000   0.000   0.000
                              0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION           0.663   1.429   1.050   0.389   0.350   1.569
      (INCHES)                0.186   0.030   0.114   0.357   0.513   0.542

 LATERAL DRAINAGE FROM        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  5 (INCHES)          0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

 PERCOLATION FROM             0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  6 (INCHES)          0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                      ANNUAL TOTALS FOR YEAR 1981
-------------------------------------------------------------------------------

                                      (INCHES)     (CU. FT.)     PERCENT
                                      --------     ---------     -------
  PRECIPITATION                         7.04         25555.      100.00

  RUNOFF                                0.000            0.        0.00

  EVAPOTRANSPIRATION                    7.193        26111.      102.17

  LATERAL DRAINAGE FROM LAYER  5        0.0000           0.        0.00

  PERCOLATION FROM LAYER  6             0.0001           0.        0.00

  CHANGE IN WATER STORAGE              -0.153         -556.       -2.18

  SOIL WATER AT START OF YEAR           5.60         20318.

  SOIL WATER AT END OF YEAR             5.44         19762.

  SNOW WATER AT START OF YEAR           0.00             0.

  SNOW WATER AT END OF YEAR             0.00             0.

  ANNUAL WATER BUDGET BALANCE           0.00             0.        0.00

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                          MONTHLY TOTALS FOR YEAR 1982
-----------------------------------------------------------------------------

                            JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                            ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)      0.33    0.57    0.30    0.75    0.28    0.75
                             0.22    0.20    0.55    1.33    0.91    1.79

 RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                             0.000   0.000   0.000   0.008   0.000   0.000

 EVAPOTRANSPIRATION          0.657   1.105   0.949   0.592   0.702   0.504
     (INCHES)                0.683   0.200   0.300   0.397   0.982   0.544

 LATERAL DRAINAGE FROM       0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  5 (INCHES)         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

 PERCOLATION FROM            0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  6 (INCHES)         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-----------------------------------------------------------------------------
                          ANNUAL TOTALS FOR YEAR 1982
-----------------------------------------------------------------------------

                                       (INCHES)      (CU. FT.)     PERCENT
                                       --------      ---------     -------
   PRECIPITATION                         7.98          28967.       100.00

   RUNOFF                                0.008            28.         0.09

   EVAPOTRANSPIRATION                    7.615         27643.        95.43

   LATERAL DRAINAGE FROM LAYER  5        0.0000            0.         0.00

   PERCOLATION FROM LAYER  6             0.0001            0.         0.00

   CHANGE IN WATER STORAGE               0.357          1297.         4.48

   SOIL WATER AT START OF YEAR           5.44          19762.

   SOIL WATER AT END OF YEAR             5.80          21059.

   SNOW WATER AT START OF YEAR           0.00              0.

   SNOW WATER AT END OF YEAR             0.00              0.

   ANNUAL WATER BUDGET BALANCE           0.00              0.         0.00

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                       MONTHLY TOTALS FOR YEAR 1983
------------------------------------------------------------------------------

                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)      1.44    1.36    1.00    0.42    0.52    0.68
                            0.31    0.12    0.46    0.52    2.12    2.12

RUNOFF (INCHES)            0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

EVAPOTRANSPIRATION         0.574   0.960   2.199   0.830   0.655   1.913
     (INCHES)              0.946   0.121   0.460   0.159   0.627   0.446

LATERAL DRAINAGE FROM     0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  5 (INCHES)       0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

PERCOLATION FROM          0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  6 (INCHES)       0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

------------------------------------------------------------------------------
                        ANNUAL TOTALS FOR YEAR 1983
------------------------------------------------------------------------------

                                       (INCHES)    (CU. FT.)    PERCENT
                                       --------    ---------    -------
  PRECIPITATION                         11.07        40184.     100.00

  RUNOFF                                 0.000           0.       0.00

  EVAPOTRANSPIRATION                     9.891       35906.      89.35

  LATERAL DRAINAGE FROM LAYER  5         0.0000          0.       0.00

  PERCOLATION FROM LAYER  6              0.0001          0.       0.00

  CHANGE IN WATER STORAGE                1.179        4278.      10.65

  SOIL WATER AT START OF YEAR            5.80        21059.

  SOIL WATER AT END OF YEAR              6.98        25337.

  SNOW WATER AT START OF YEAR            0.00            0.

  SNOW WATER AT END OF YEAR              0.00            0.

  ANNUAL WATER BUDGET BALANCE            0.00            0.       0.00

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                        MONTHLY TOTALS FOR YEAR 1984
-------------------------------------------------------------------------------

                            JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                            -------  -------  -------  -------  -------  -------

PRECIPITATION (INCHES)       0.23     0.94     1.01     0.60     0.55     0.99
                             0.06     0.00     0.42     0.07     1.83     0.57

RUNOFF (INCHES)              0.000    0.000    0.000    0.000    0.000    0.000
                             0.000    0.000    0.000    0.000    0.000    0.000

EVAPOTRANSPIRATION           0.446    1.282    2.024    0.515    0.742    2.307
     (INCHES)                0.592    0.000    0.225    0.263    0.466    0.581

LATERAL DRAINAGE FROM        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  5 (INCHES)          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

PERCOLATION FROM             0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  6 (INCHES)          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
                        ANNUAL TOTALS FOR YEAR 1984
-------------------------------------------------------------------------------

                                       (INCHES)      (CU. FT.)     PERCENT
                                       --------      ---------     -------

  PRECIPITATION                          7.27          26390.      100.00

  RUNOFF                                 0.000             0.        0.00

  EVAPOTRANSPIRATION                     9.442         34276.      129.88

  LATERAL DRAINAGE FROM LAYER  5         0.0000            0.        0.00

  PERCOLATION FROM LAYER  6              0.0001            0.        0.00

  CHANGE IN WATER STORAGE               -2.173         -7886.      -29.88

  SOIL WATER AT START OF YEAR            6.98          25337.

  SOIL WATER AT END OF YEAR              4.81          17450.

  SNOW WATER AT START OF YEAR            0.00              0.

  SNOW WATER AT END OF YEAR              0.00              0.

  ANNUAL WATER BUDGET BALANCE            0.00              0.        0.00

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                        MONTHLY TOTALS FOR YEAR 1985
-------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------

PRECIPITATION (INCHES)    0.34     0.82     0.36     0.01     0.12     0.15
                          0.12     0.01     0.63     0.46     1.24     0.84

RUNOFF (INCHES)           0.000    0.000    0.000    0.000    0.000    0.000
                          0.000    0.000    0.000    0.000    0.000    0.000

EVAPOTRANSPIRATION        0.656    1.176    0.971    0.037    0.144    0.171
     (INCHES)             0.031    0.099    0.356    0.266    0.276    0.615

LATERAL DRAINAGE FROM     0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  5 (INCHES)       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

PERCOLATION FROM          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  6 (INCHES)       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
                        ANNUAL TOTALS FOR YEAR 1985
-------------------------------------------------------------------------------

                                       (INCHES)      (CU. FT.)     PERCENT
                                       --------      ---------     -------
  PRECIPITATION                          5.10          18513.      100.00

  RUNOFF                                 0.000             0.        0.00

  EVAPOTRANSPIRATION                     4.798         17415.       94.07

  LATERAL DRAINAGE FROM LAYER  5         0.0000            0.        0.00

  PERCOLATION FROM LAYER  6              0.0001            0.        0.00

  CHANGE IN WATER STORAGE                0.302          1098.        5.93

  SOIL WATER AT START OF YEAR            4.81          17450.

  SOIL WATER AT END OF YEAR              5.11          18548.

  SNOW WATER AT START OF YEAR            0.00              0.

  SNOW WATER AT END OF YEAR              0.00              0.

  ANNUAL WATER BUDGET BALANCE            0.00              0.        0.00

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                         MONTHLY TOTALS FOR YEAR 1986
-------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------

PRECIPITATION (INCHES)     1.76     1.37     0.76     0.00     0.30     0.00
                           0.21     0.02     0.96     0.29     0.65     0.77

RUNOFF (INCHES)            0.000    0.000    0.000    0.000    0.000    0.000
                           0.000    0.000    0.000    0.000    0.000    0.000

EVAPOTRANSPIRATION         0.534    1.357    1.798    0.362    0.362    0.415
    (INCHES)               1.229    0.020    0.353    0.263    0.230    0.270

LATERAL DRAINAGE FROM      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  5 (INCHES)        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

PERCOLATION FROM           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  6 (INCHES)        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
                          ANNUAL TOTALS FOR YEAR 1986
-------------------------------------------------------------------------------
                                      (INCHES)     (CU. FT.)     PERCENT
                                      --------     ---------     -------
  PRECIPITATION                         7.09         25737.       100.00

  RUNOFF                                0.000            0.         0.00

  EVAPOTRANSPIRATION                    7.193        26110.       101.45

  LATERAL DRAINAGE FROM LAYER  5        0.0000           0.         0.00

  PERCOLATION FROM LAYER  6             0.0001           0.         0.00

  CHANGE IN WATER STORAGE              -0.103         -374.        -1.45

  SOIL WATER AT START OF YEAR           5.11         18548.

  SOIL WATER AT END OF YEAR             5.01         18175.

  SNOW WATER AT START OF YEAR           0.00             0.

  SNOW WATER AT END OF YEAR             0.00             0.

  ANNUAL WATER BUDGET BALANCE           0.00             0.         0.00

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MONTHLY TOTALS FOR YEAR 1987

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION (INCHES)	0.80 0.50	0.19 0.07	1.05 0.01	0.14 0.00	0.17 0.40	0.11 1.63
RUNOFF (INCHES)	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000
EVAPOTRANSPIRATION (INCHES)	0.479 0.500	0.952 0.070	0.643 0.010	0.386 0.000	0.577 0.222	0.978 0.432
LATERAL DRAINAGE FROM LAYER 5 (INCHES)	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000
PERCOLATION FROM LAYER 6 (INCHES)	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000

ANNUAL TOTALS FOR YEAR 1987

	(INCHES)	(CU. FT.)	PERCENT
PRECIPITATION	5.07	18404.	100.00
RUNOFF	0.000	0.	0.00
EVAPOTRANSPIRATION	5.249	19054.	103.53
LATERAL DRAINAGE FROM LAYER 5	0.0000	0.	0.00
PERCOLATION FROM LAYER 6	0.0001	0.	0.00
CHANGE IN WATER STORAGE	-0.179	-650.	-3.53
SOIL WATER AT START OF YEAR	5.01	18175.	
SOIL WATER AT END OF YEAR	4.83	17525.	
SNOW WATER AT START OF YEAR	0.00	0.	
SNOW WATER AT END OF YEAR	0.00	0.	
ANNUAL WATER BUDGET BALANCE	0.00	0.	0.00

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                        MONTHLY TOTALS FOR YEAR 1988
-------------------------------------------------------------------------------

                              JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                              ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)        0.48    0.00    0.39    1.12    0.33    0.11
                               0.13    0.00    0.39    0.01    0.82    0.40

 RUNOFF (INCHES)               0.000   0.000   0.000   0.000   0.000   0.000
                               0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION            0.796   0.664   0.538   0.506   0.580   0.722
      (INCHES)                 0.130   0.000   0.173   0.196   0.284   0.274

 LATERAL DRAINAGE FROM         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  5 (INCHES)           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

 PERCOLATION FROM              0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  6 (INCHES)           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1988
-------------------------------------------------------------------------------
                                         (INCHES)      (CU. FT.)     PERCENT
                                         --------      ---------     -------
   PRECIPITATION                           4.18          15173.      100.00

   RUNOFF                                  0.000             0.        0.00

   EVAPOTRANSPIRATION                      4.863         17652.      116.34

   LATERAL DRAINAGE FROM LAYER  5          0.0000            0.        0.00

   PERCOLATION FROM LAYER  6               0.0001            0.        0.00

   CHANGE IN WATER STORAGE                -0.683         -2479.      -16.34

   SOIL WATER AT START OF YEAR             4.83          17525.

   SOIL WATER AT END OF YEAR               4.14          15046.

   SNOW WATER AT START OF YEAR             0.00              0.

   SNOW WATER AT END OF YEAR               0.00              0.

   ANNUAL WATER BUDGET BALANCE             0.00              0.        0.00

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      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1979 THROUGH 1988
-------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------
   PRECIPITATION
   -------------
     TOTALS                 0.78     0.73     0.64     0.44     0.48     0.42
                            0.18     0.09     0.51     0.41     1.09     1.24

     STD. DEVIATIONS        0.54     0.51     0.30     0.40     0.42     0.40
                            0.14     0.12     0.28     0.39     0.57     0.60

   RUNOFF
   ------
     TOTALS                0.000    0.000    0.000    0.000    0.000    0.000
                           0.000    0.000    0.000    0.001    0.000    0.000

     STD. DEVIATIONS       0.000    0.000    0.000    0.000    0.000    0.000
                           0.000    0.000    0.000    0.002    0.000    0.000

   EVAPOTRANSPIRATION
   ------------------
     TOTALS                0.606    1.065    1.226    0.466    0.632    1.065
                           0.469    0.084    0.268    0.244    0.425    0.454

     STD. DEVIATIONS       0.123    0.283    0.697    0.205    0.408    0.831
                           0.398    0.093    0.137    0.121    0.237    0.128

   LATERAL DRAINAGE FROM LAYER  5
   ------------------------------
     TOTALS               0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

     STD. DEVIATIONS      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   PERCOLATION FROM LAYER  6
   -------------------------
     TOTALS               0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

     STD. DEVIATIONS      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1979 THROUGH 1988

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	7.00	(2.164)	25425.	100.00
RUNOFF	0.001	(0.002)	3.	0.01
EVAPOTRANSPIRATION	7.003	(2.135)	25421.	99.99
LATERAL DRAINAGE FROM LAYER 5	0.0000	(0.0000)	0.	0.00
PERCOLATION FROM LAYER 6	0.0001	(0.0000)	0.	0.00
CHANGE IN WATER STORAGE	0.000	(0.974)	0.	0.00

PEAK DAILY VALUES FOR YEARS 1979 THROUGH 1988

	(INCHES)	(CU. FT.)
PRECIPITATION	0.93	3375.9
RUNOFF	0.008	27.5
LATERAL DRAINAGE FROM LAYER 5	0.0000	0.0
PERCOLATION FROM LAYER 6	0.0000	0.0
HEAD ON LAYER 6	0.0	
SNOW WATER	0.76	2743.4
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.1685	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0649	

```
              FINAL WATER STORAGE AT END OF YEAR 1988
     ----------------------------------------------------------------
                 LAYER        (INCHES)         (VOL/VOL)
                 -----        --------         ---------
                   1            1.95            0.0977
                   2            1.35            0.0677
                   3            0.29            0.0476
                   4            0.16            0.0259
                   5            0.27            0.0450
                   6            0.13            0.0210
                SNOW WATER      0.00
```

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APPENDIX C-3

MODIFIED RCRA SUBTITLE D BARRIER DESIGN PRELIMINARY PERFORMANCE ASSESSMENT FOR STEADY-STATE CONDITIONS (HELP VERSION 2.0 RESULTS)

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APPENDIX C-3

MODIFIED RCRA SUBTITLE D BARRIER DESIGN PRELIMINARY PERFORMANCE ASSESSMENT FOR STEADY-STATE CONDITIONS (HELP VERSION 2.0 RESULTS)

```
                              LAYER  1
                              --------

                     VERTICAL PERCOLATION LAYER

THICKNESS                         =       8.00 INCHES
POROSITY                          =       0.4734 VOL/VOL
FIELD CAPACITY                    =       0.2381 VOL/VOL
WILTING POINT                     =       0.0627 VOL/VOL
INITIAL SOIL WATER CONTENT        =       0.1356 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY  =       0.000989999971 CM/S

                              LAYER  2
                              --------

                     VERTICAL PERCOLATION LAYER

THICKNESS                         =      16.00 INCHES
POROSITY                          =       0.5140 VOL/VOL
FIELD CAPACITY                    =       0.2585 VOL/VOL
WILTING POINT                     =       0.0681 VOL/VOL
INITIAL SOIL WATER CONTENT        =       0.0742 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY  =       0.000989999971 CM/S

                              LAYER  3
                              --------

                     VERTICAL PERCOLATION LAYER

THICKNESS                         =      12.00 INCHES
POROSITY                          =       0.3470 VOL/VOL
FIELD CAPACITY                    =       0.2109 VOL/VOL
WILTING POINT                     =       0.0681 VOL/VOL
INITIAL SOIL WATER CONTENT        =       0.0681 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY  =       0.000001600000 CM/S
```

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                          GENERAL SIMULATION DATA
                          -----------------------

SCS RUNOFF CURVE NUMBER                =       87.21
TOTAL AREA OF COVER                    =    43560.  SQ FT
EVAPORATIVE ZONE DEPTH                 =       36.00 INCHES
UPPER LIMIT VEG. STORAGE               =       16.1752 INCHES
INITIAL VEG. STORAGE                   =        3.0892 INCHES
INITIAL SNOW WATER CONTENT             =        0.0000 INCHES
INITIAL TOTAL WATER STORAGE IN
  SOIL AND WASTE LAYERS                =        3.0892 INCHES

              SOIL WATER CONTENT INITIALIZED BY USER.


                           CLIMATOLOGICAL DATA
                           -------------------

USER SPECIFIED RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
SOLAR RADIATION FOR HANFORD SITE, WASHINGTON STATE.


MAXIMUM LEAF AREA INDEX                   = 1.60
START OF GROWING SEASON (JULIAN DATE)     =  113
END OF GROWING SEASON (JULIAN DATE)       =  288


       NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

 JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
 -------     -------     -------     -------     -------     -------

  29.30       36.30       45.10       53.10       61.50       69.30
  76.40       74.30       65.20       53.00       39.80       32.70
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                         MONTHLY TOTALS FOR YEAR 1979
-------------------------------------------------------------------------------

                            JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                            ------- ------- ------- ------- ------- -------

  PRECIPITATION (INCHES)     0.54    0.17    0.54    0.52    0.10    0.00
                             0.09    0.38    0.20    0.67    1.36    0.99

  RUNOFF (INCHES)            0.000   0.000   0.000   0.000   0.000   0.000
                             0.000   0.000   0.000   0.000   0.000   0.000

  EVAPOTRANSPIRATION         0.774   0.580   0.209   0.468   0.510   0.010
       (INCHES)              0.090   0.276   0.304   0.159   0.362   0.518

  PERCOLATION FROM           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
    LAYER  3 (INCHES)        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                         ANNUAL TOTALS FOR YEAR 1979
-------------------------------------------------------------------------------

                                          (INCHES)   (CU. FT.)    PERCENT
                                          --------   ---------    -------
    PRECIPITATION                           5.56       20183.     100.00

    RUNOFF                                  0.000          0.       0.00

    EVAPOTRANSPIRATION                      4.260      15463.      76.61

    PERCOLATION FROM LAYER  3               0.0000         0.       0.00

    CHANGE IN WATER STORAGE                 1.300       4720.      23.39

    SOIL WATER AT START OF YEAR             3.09       11214.

    SOIL WATER AT END OF YEAR               4.39       15934.

    SNOW WATER AT START OF YEAR             0.00           0.

    SNOW WATER AT END OF YEAR               0.00           0.

    ANNUAL WATER BUDGET BALANCE             0.00           0.       0.00

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                           MONTHLY TOTALS FOR YEAR 1980
---------------------------------------------------------------------------

                           JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                           ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)      1.32    1.30    0.30    0.86    1.41    0.96
                            0.00    0.02    0.85    0.33    0.44    1.89

RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                            0.000   0.000   0.000   0.000   0.000   0.000

EVAPOTRANSPIRATION          0.485   1.159   1.894   0.678   1.678   2.003
     (INCHES)               0.233   0.020   0.382   0.383   0.291   0.314

PERCOLATION FROM            0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  3 (INCHES)         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

---------------------------------------------------------------------------
                           ANNUAL TOTALS FOR YEAR 1980
---------------------------------------------------------------------------

                                    (INCHES)      (CU. FT.)     PERCENT
                                    --------      ---------     -------

  PRECIPITATION                       9.68          35138.      100.00

  RUNOFF                              0.001             3.        0.01

  EVAPOTRANSPIRATION                  9.520         34559.       98.35

  PERCOLATION FROM LAYER  3           0.0000            0.        0.00

  CHANGE IN WATER STORAGE             0.159           576.        1.64

  SOIL WATER AT START OF YEAR         4.39          15934.

  SOIL WATER AT END OF YEAR           4.55          16510.

  SNOW WATER AT START OF YEAR         0.00              0.

  SNOW WATER AT END OF YEAR           0.00              0.

  ANNUAL WATER BUDGET BALANCE         0.00              0.        0.00

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                         MONTHLY TOTALS FOR YEAR 1981
-------------------------------------------------------------------------------

                            JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                            ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)      0.56    0.60    0.70    0.02    0.99    0.43
                             0.19    0.03    0.60    0.39    1.08    1.45

 RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                             0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION          0.665   1.433   1.066   0.452   0.406   1.426
     (INCHES)                0.182   0.030   0.113   0.358   0.516   0.543

 PERCOLATION FROM            0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  3 (INCHES)         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                          ANNUAL TOTALS FOR YEAR 1981
-------------------------------------------------------------------------------

                                       (INCHES)     (CU. FT.)     PERCENT
                                       --------     ---------     -------

   PRECIPITATION                        7.04          25555.      100.00

   RUNOFF                               0.000             0.        0.00

   EVAPOTRANSPIRATION                   7.191         26103.      102.15

   PERCOLATION FROM LAYER  3            0.0000            0.        0.00

   CHANGE IN WATER STORAGE             -0.151          -548.       -2.15

   SOIL WATER AT START OF YEAR          4.55          16510.

   SOIL WATER AT END OF YEAR            4.40          15962.

   SNOW WATER AT START OF YEAR          0.00              0.

   SNOW WATER AT END OF YEAR            0.00              0.

   ANNUAL WATER BUDGET BALANCE          0.00              0.        0.00

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                    MONTHLY TOTALS FOR YEAR 1982
------------------------------------------------------------------------------

                        JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                        ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)   0.33    0.57    0.30    0.75    0.28    0.75
                          0.22    0.20    0.55    1.33    0.91    1.79

 RUNOFF (INCHES)          0.000   0.000   0.000   0.000   0.000   0.000
                          0.000   0.000   0.000   0.008   0.000   0.000

 EVAPOTRANSPIRATION       0.660   1.109   1.032   0.607   0.676   0.408
      (INCHES)            0.697   0.199   0.300   0.400   0.988   0.547

 PERCOLATION FROM         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  3 (INCHES)      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

------------------------------------------------------------------------------
                     ANNUAL TOTALS FOR YEAR 1982
------------------------------------------------------------------------------

                                       (INCHES)   (CU. FT.)    PERCENT
                                       --------   ---------    -------
   PRECIPITATION                         7.98       28967.     100.00

   RUNOFF                                0.008         28.       0.09

   EVAPOTRANSPIRATION                    7.623      27671.      95.52

   PERCOLATION FROM LAYER  3             0.0000         0.       0.00

   CHANGE IN WATER STORAGE               0.350       1269.       4.38

   SOIL WATER AT START OF YEAR           4.40       15962.

   SOIL WATER AT END OF YEAR             4.75       17231.

   SNOW WATER AT START OF YEAR           0.00           0.

   SNOW WATER AT END OF YEAR             0.00           0.

   ANNUAL WATER BUDGET BALANCE           0.00           0.       0.00

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                       MONTHLY TOTALS FOR YEAR 1983
-------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------

PRECIPITATION (INCHES)     1.44     1.36     1.00     0.42     0.52     0.68
                           0.31     0.12     0.46     0.52     2.12     2.12

RUNOFF (INCHES)            0.000    0.000    0.000    0.000    0.000    0.000
                           0.000    0.000    0.000    0.000    0.000    0.000

EVAPOTRANSPIRATION         0.577    0.965    2.210    0.848    0.720    1.989
     (INCHES)              0.758    0.121    0.460    0.161    0.578    0.445

PERCOLATION FROM           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  LAYER  3 (INCHES)        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
                       ANNUAL TOTALS FOR YEAR 1983
-------------------------------------------------------------------------------

                                      (INCHES)      (CU. FT.)     PERCENT
                                      --------      ---------     -------
  PRECIPITATION                        11.07          40184.      100.00

  RUNOFF                                0.000            0.         0.00

  EVAPOTRANSPIRATION                    9.832         35690.       88.82

  PERCOLATION FROM LAYER  3             0.0001           0.         0.00

  CHANGE IN WATER STORAGE               1.238          4493.       11.18

  SOIL WATER AT START OF YEAR           4.75          17231.

  SOIL WATER AT END OF YEAR             5.98          21724.

  SNOW WATER AT START OF YEAR           0.00             0.

  SNOW WATER AT END OF YEAR             0.00             0.

  ANNUAL WATER BUDGET BALANCE           0.00             0.         0.00

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                           MONTHLY TOTALS FOR YEAR 1984
-----------------------------------------------------------------------------

                             JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                             ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)       0.23    0.94    1.01    0.60    0.55    0.99
                              0.06    0.00    0.42    0.07    1.83    0.57

 RUNOFF (INCHES)              0.000   0.000   0.000   0.000   0.000   0.000
                              0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION           0.444   1.276   2.100   0.539   0.753   2.115
      (INCHES)                0.729   0.000   0.230   0.260   0.468   0.577

 PERCOLATION FROM             0.0000  0.0000  0.0000  0.0000  0.0002  0.0003
   LAYER  3 (INCHES)          0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-----------------------------------------------------------------------------
                            ANNUAL TOTALS FOR YEAR 1984
-----------------------------------------------------------------------------

                                         (INCHES)     (CU. FT.)    PERCENT
                                         --------     ---------    -------
   PRECIPITATION                           7.27         26390.     100.00

   RUNOFF                                  0.000            0.       0.00

   EVAPOTRANSPIRATION                      9.490        34449.     130.54

   PERCOLATION FROM LAYER  3               0.0005           2.       0.01

   CHANGE IN WATER STORAGE                -2.221        -8061.     -30.55

   SOIL WATER AT START OF YEAR             5.98         21724.

   SOIL WATER AT END OF YEAR               3.76         13663.

   SNOW WATER AT START OF YEAR             0.00             0.

   SNOW WATER AT END OF YEAR               0.00             0.

   ANNUAL WATER BUDGET BALANCE             0.00             0.       0.00
```

MONTHLY TOTALS FOR YEAR 1983

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION (INCHES)	1.44 0.31	1.36 0.12	1.00 0.46	0.42 0.52	0.52 2.12	0.68 2.12
RUNOFF (INCHES)	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000
EVAPOTRANSPIRATION (INCHES)	0.577 0.758	0.965 0.121	2.210 0.460	0.848 0.161	0.720 0.578	1.989 0.445
PERCOLATION FROM LAYER 3 (INCHES)	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000

ANNUAL TOTALS FOR YEAR 1983

	(INCHES)	(CU. FT.)	PERCENT
PRECIPITATION	11.07	40184.	100.00
RUNOFF	0.000	0.	0.00
EVAPOTRANSPIRATION	9.832	35690.	88.82
PERCOLATION FROM LAYER 3	0.0001	0.	0.00
CHANGE IN WATER STORAGE	1.238	4493.	11.18
SOIL WATER AT START OF YEAR	4.75	17231.	
SOIL WATER AT END OF YEAR	5.98	21724.	
SNOW WATER AT START OF YEAR	0.00	0.	
SNOW WATER AT END OF YEAR	0.00	0.	
ANNUAL WATER BUDGET BALANCE	0.00	0.	0.00

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                          MONTHLY TOTALS FOR YEAR 1986
-------------------------------------------------------------------------------

                               JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                               ------- ------- ------- ------- ------- -------

  PRECIPITATION (INCHES)         1.76    1.37    0.76    0.00    0.30    0.00
                                 0.21    0.02    0.96    0.29    0.65    0.77

  RUNOFF (INCHES)                0.000   0.000   0.000   0.000   0.000   0.000
                                 0.000   0.000   0.000   0.000   0.000   0.000

  EVAPOTRANSPIRATION             0.533   1.350   1.805   0.452   0.364   0.406
        (INCHES)                 1.136   0.020   0.365   0.267   0.233   0.271

  PERCOLATION FROM               0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
    LAYER  3 (INCHES)            0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                          ANNUAL TOTALS FOR YEAR 1986
-------------------------------------------------------------------------------

                                          (INCHES)    (CU. FT.)    PERCENT
                                          --------    ---------    -------

    PRECIPITATION                           7.09        25737.     100.00

    RUNOFF                                  0.000           0.       0.00

    EVAPOTRANSPIRATION                      7.201       26140.     101.57

    PERCOLATION FROM LAYER  3               0.0000          0.       0.00

    CHANGE IN WATER STORAGE                -0.111        -403.      -1.57

    SOIL WATER AT START OF YEAR             4.05        14712.

    SOIL WATER AT END OF YEAR               3.94        14309.

    SNOW WATER AT START OF YEAR             0.00            0.

    SNOW WATER AT END OF YEAR               0.00            0.

    ANNUAL WATER BUDGET BALANCE             0.00            0.       0.00

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                  MONTHLY TOTALS FOR YEAR 1985
-----------------------------------------------------------------------

                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)     0.34    0.82    0.36    0.01    0.12    0.15
                           0.12    0.01    0.63    0.46    1.24    0.84

RUNOFF (INCHES)            0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

EVAPOTRANSPIRATION         0.652   1.169   1.033   0.010   0.142   0.150
      (INCHES)             0.031   0.099   0.362   0.273   0.278   0.612

PERCOLATION FROM           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  3 (INCHES)        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-----------------------------------------------------------------------
                   ANNUAL TOTALS FOR YEAR 1985
-----------------------------------------------------------------------

                                    (INCHES)    (CU. FT.)   PERCENT
                                    --------    ---------   -------

  PRECIPITATION                       5.10        18513.    100.00

  RUNOFF                              0.000           0.      0.00

  EVAPOTRANSPIRATION                  4.811       17464.     94.33

  PERCOLATION FROM LAYER  3           0.0000          0.      0.00

  CHANGE IN WATER STORAGE             0.289        1049.      5.67

  SOIL WATER AT START OF YEAR         3.76        13663.

  SOIL WATER AT END OF YEAR           4.05        14712.

  SNOW WATER AT START OF YEAR         0.00            0.

  SNOW WATER AT END OF YEAR           0.00            0.

  ANNUAL WATER BUDGET BALANCE         0.00            0.      0.00

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                          MONTHLY TOTALS FOR YEAR 1988
-------------------------------------------------------------------------------

                           JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                           ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)     0.48    0.00    0.39    1.12    0.33    0.11
                            0.13    0.00    0.39    0.01    0.82    0.40

 RUNOFF (INCHES)            0.000   0.000   0.000   0.000   0.000   0.000
                            0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION         0.776   0.655   0.550   0.529   0.590   0.711
     (INCHES)               0.130   0.000   0.177   0.200   0.287   0.276

 PERCOLATION FROM           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  3 (INCHES)        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------------
                           ANNUAL TOTALS FOR YEAR 1988
-------------------------------------------------------------------------------

                                        (INCHES)     (CU. FT.)    PERCENT
                                        --------     ---------    -------
   PRECIPITATION                          4.18        15173.      100.00

   RUNOFF                                 0.000           0.        0.00

   EVAPOTRANSPIRATION                     4.880       17713.      116.74

   PERCOLATION FROM LAYER  3              0.0000          0.        0.00

   CHANGE IN WATER STORAGE               -0.700       -2540.      -16.74

   SOIL WATER AT START OF YEAR            3.79        13752.

   SOIL WATER AT END OF YEAR              3.09        11212.

   SNOW WATER AT START OF YEAR            0.00            0.

   SNOW WATER AT END OF YEAR              0.00            0.

   ANNUAL WATER BUDGET BALANCE            0.00            0.        0.00

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                      MONTHLY TOTALS FOR YEAR 1987
-------------------------------------------------------------------------

                        JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                        ------- ------- ------- ------- ------- -------

 PRECIPITATION (INCHES)   0.80    0.19    1.05    0.14    0.17    0.11
                          0.50    0.07    0.01    0.00    0.40    1.63

 RUNOFF (INCHES)          0.000   0.000   0.000   0.000   0.000   0.000
                          0.000   0.000   0.000   0.000   0.000   0.000

 EVAPOTRANSPIRATION       0.274   1.012   0.697   0.406   0.597   1.007
      (INCHES)            0.500   0.070   0.010   0.000   0.226   0.423

 PERCOLATION FROM         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
   LAYER  3 (INCHES)      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

-------------------------------------------------------------------------
                       ANNUAL TOTALS FOR YEAR 1987
-------------------------------------------------------------------------

                                      (INCHES)    (CU. FT.)   PERCENT
                                      --------    ---------   -------
   PRECIPITATION                        5.07        18404.    100.00

   RUNOFF                               0.000           0.      0.00

   EVAPOTRANSPIRATION                   5.223       18961.    103.03

   PERCOLATION FROM LAYER  3            0.0000          0.      0.00

   CHANGE IN WATER STORAGE             -0.153        -557.     -3.03

   SOIL WATER AT START OF YEAR          3.94        14309.

   SOIL WATER AT END OF YEAR            3.79        13752.

   SNOW WATER AT START OF YEAR          0.00            0.

   SNOW WATER AT END OF YEAR            0.00            0.

   ANNUAL WATER BUDGET BALANCE          0.00            0.      0.00

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1979 THROUGH 1988

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	7.00	(2.164)	25425.	100.00
RUNOFF	0.001	(0.002)	3.	0.01
EVAPOTRANSPIRATION	7.003	(2.134)	25421.	99.99
PERCOLATION FROM LAYER 3	0.0001	(0.0002)	0.	0.00
CHANGE IN WATER STORAGE	0.000	(0.996)	0.	0.00

PEAK DAILY VALUES FOR YEARS 1979 THROUGH 1988

	(INCHES)	(CU. FT.)
PRECIPITATION	0.93	3375.9
RUNOFF	0.008	27.5
PERCOLATION FROM LAYER 3	0.0000	0.0
SNOW WATER	0.76	2743.4
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.1698	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0667	

```
         AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1979 THROUGH 1988
-------------------------------------------------------------------------------

                      JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                      -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS               0.78     0.73     0.64     0.44     0.48     0.42
                        0.18     0.09     0.51     0.41     1.09     1.24

   STD. DEVIATIONS      0.54     0.51     0.30     0.40     0.42     0.40
                        0.14     0.12     0.28     0.39     0.57     0.60

 RUNOFF
 ------
   TOTALS               0.000    0.000    0.000    0.000    0.000    0.000
                        0.000    0.000    0.000    0.001    0.000    0.000

   STD. DEVIATIONS      0.000    0.000    0.000    0.000    0.000    0.000
                        0.000    0.000    0.000    0.002    0.000    0.000

 EVAPOTRANSPIRATION
 ------------------
   TOTALS               0.584    1.071    1.259    0.499    0.644    1.023
                        0.449    0.083    0.270    0.246    0.423    0.453

   STD. DEVIATIONS      0.156    0.279    0.697    0.216    0.408    0.809
                        0.370    0.093    0.138    0.122    0.233    0.127

 PERCOLATION FROM LAYER  3
 -------------------------
   TOTALS               0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS      0.0000   0.0000   0.0000   0.0000   0.0001   0.0001
                        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
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FINAL WATER STORAGE AT END OF YEAR 1988

LAYER	(INCHES)	(VOL/VOL)
1	1.09	0.1356
2	1.19	0.0742
3	0.82	0.0681
SNOW WATER	0.00	

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APPENDIX C-4

CALIBRATION OF HELP VERSION 2.0 AND PERFORMANCE ASSESSMENT OF THREE INFILTRATION BARRIER DESIGNS FOR HANFORD SITE REMEDIATION

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ABSTRACT

The U.S. Environmental Protection Agency's HELP model was used to evaluate water balances of three alternative covers for buried waste at the semi-arid Hanford Site. The evaluation was made to assess the effects of restrictive assumptions within the HELP model on simulations of arid sites. The HELP model assumes that only gravitational forces act upon pore water movement. However, the cover designs utilize the concept of a capillary barrier to minimize meteoric water infiltration into the waste. The evaluation was performed by accomplishing two objectives. The first objective was to calibrate the HELP model to Hanford Site lysimeter data. The second objective was to compare results from the calibrated HELP model with results from the UNSAT-H model for equivalent barrier performance simulations.

This report presents results of the calibration exercise and cover simulations. The calibration results suggest that the HELP model may adequately account for near-surface capillarity at semi-arid sites by considering the combined effects of evaporation and transpiration if: (a) the vegetative option in the model is used and (b) the evaporative depth is known beforehand. However, estimating the evaporative depth at the Hanford Site is difficult because it is not temporally static and may be specific to soil type and profile layering.

Simulations were performed for three precipitation scenarios: (a) ambient, (b) two times (2x) ambient, and (c) design storm. The results of the barrier simulations indicate that for the ambient and design storm precipitation conditions, the barriers will perform as designed and will return nearly 100% of the precipitation to the atmosphere through evaporation and transpiration. For the 2x ambient precipitation conditions, two of the three cover designs are projected to provide only marginal protection from deep infiltration into the stored waste.

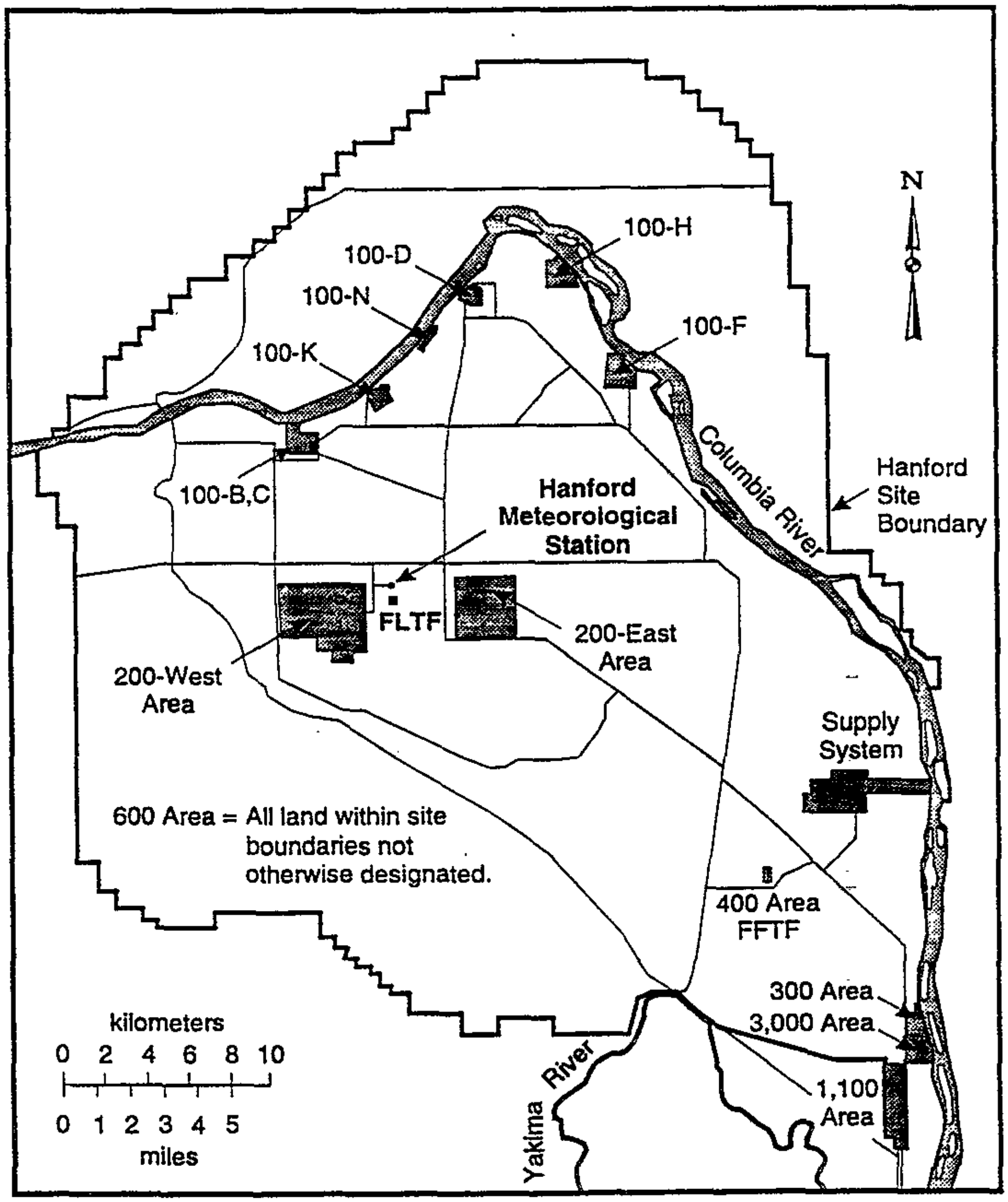

Figure 1. Hanford site, showing locations of numerically designated areas.

Calibration of HELP Version 2.0 and Performance Assessment of Three Infiltration Barrier Designs for Hanford Site Remediation

1. INTRODUCTION

The U.S. Department of Energy's Hanford Site in south-central Washington State has been used for national defense programs and nuclear reactor research activities since the mid-1940s. As a result of these activities, radioactive and hazardous waste is present at the Hanford Site in a variety of locations. These locations include subsurface tank farms, solid waste burial grounds, and contaminated burial grounds. Geographic locations within the Hanford Site are numerically designated as the 100, 200, 300, 400, 600 and 1100 areas (Figure 1).

In 1993, the Westinghouse Hanford Company (WHC) evaluated alternative concepts for covers engineered to minimize risks from hazardous and radioactive wastes stored at the 200 Area of the Hanford Site. The evaluation included categorization of alternative designs with respect to the types of waste to which they could be applied to comply with regulations.

The engineering objectives of the covers are to minimize the potential of four scenarios: (a) penetration of biota into contaminated materials, (b) direct human exposure to the contaminated areas, (c) atmospheric transport of radioactive and/or toxic particulates and gases, and (d) deep infiltration of precipitation.

A key measure of an engineered barrier's effectiveness in meeting objective (d) is its ability to intercept, temporarily store and return moisture to the atmosphere by evapotranspiration. To assess each barrier's effectiveness, WHC numerically simulated the effect of each design on the subsurface water balance. These analyses were made using the Hydrologic Evaluation of Landfill Performance (HELP Version 2.0) simulation model developed for the U.S. Environmental Protection Agency (Schroeder et al., 1989).

WHC contracted with EG&G Idaho, Inc. to review WHC's water-balance analysis of barrier performance by (a) calibrating the HELP model to Hanford site lysimeter data, (b) simulating the performance of the alternative barrier designs using both the HELP and UNSAT-H (Fayer and Jones, 1990) models, and (c) analyzing and documenting the results. These tasks were accomplished by meeting the objectives discussed in Section 2.

2. PURPOSE AND OBJECTIVES

The main purpose of this study was to determine if the HELP model provides adequate water balance analysis at the semi-arid Hanford Site for evaluating alternative barrier designs. This purpose was achieved by accomplishing two objectives which are briefly described below. A more in-depth discussion of the methods used are presented in Sections 4 and 5 of this report.

The first objective was to calibrate the HELP Version 2.0 model using data from four weighing lysimeters located within the Hanford Site Field Lysimeter Test Facility (FLTF). The FLTF is a unique research facility designed specifically to test the performance of capillary barriers for the semi-arid conditions at the Hanford Site. The FLTF consists of 24 lysimeters filled with a variety of soil/sediment configurations.

The second objective of the study was to numerically simulate fluid flow for three infiltration barrier designs using the HELP and UNSAT-H models. Equivalent parameters were used in both models whenever

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K_T(h)\frac{\partial h}{\partial z} + K_L(h) + q_{vT}\right] - S(z,t)\ , \qquad (1)$$

where

z = depth
$S(z,t)$ = evapotranspiration sink term
q_{vt} = thermal vapor flux density
K_T = total hydraulic conductivity; $K_T=K_L+K_{vh}$
K_L = liquid conductivity
K_{vh} = isothermal vapor conductivity
$C(h)$ = slope of soil moisture curve; $\partial\theta/\partial h$.

The governing equations are solved using an iterative finite difference approximation with a Crank-Nicholson method for the time derivative. The finite difference technique replaces the partial derivatives with a quotient of two finite differences. The end result of using finite differences is that the partial differential equation is approximated by a series of algebraic equations which are solved simultaneously.

To solve Richard's equation, UNSAT-H requires parameterization of the moisture characteristic (C(h)) and hydraulic conductivity curves (K_L(h)). UNSAT-H contains four options for describing these soil hydraulic properties: polynomials, Haverkamp functions, Brooks-Corey functions, and van Genutchen functions.

UNSAT-H permits the user to select several boundary conditions. The lower boundary condition can be a unit gradient, constant head, specified flux, or zero flux. The upper boundary condition can be either a flux or a constant head. When the flux option is selected, the upper boundary condition is a function of meteorologic conditions and alternates between a flux and a constant head. Initially, during periods of infiltration or evaporation, the boundary is a flux. However, if the value at the surface node becomes less than a minimum suction head (saturated conditions) during infiltration, or if the surface node exceeds a maximum value (unnaturally dry conditions) during evaporation, the upper boundary becomes a constant head until conditions revert to normal. If the surface node becomes less than a minimum, the minimum value can either be calculated internally from relative humidity or specified by the user.

Within UNSAT-H, evaporation is calculated either by an energy balance at the soil surface when the heat transfer option is selected or by the potential evapotranspiration (PET) concept. If heat transfer is not simulated or if the PET option is selected, PET is partitioned into potential transpiration (PT) and evaporation by one of two methods. The first method uses the leaf area index (LAI) to partition evaporation and transpiration by the equation

$$PT = PET[-0.21 + 0.70\,(LAI)^{1/2}]\ , \qquad (2)$$

where PET is the measured radiation and is not the PET calculated using the Penman method (Ritchie, 1972). In the second method, PET (net radiation) is partitioned into transpiration and evaporation using an empirical method posed by Hinds (1975) using data on cheatgrass growth.

The UNSAT-H model does not directly calculate runoff. However, if the flux of meteoric water into the surface exceeds the infiltration capacity, the excess water is assumed to be lost to runoff.

possible. Performing equivalent simulations with both models provided a benchmarking test to evaluate how well the HELP model compares to a code that has been previously calibrated at the Hanford site.

A general description of the HELP and UNSAT-H models are presented in Section 3. Next, previous evaluations of the HELP models's performance is presented in Section 4. The methods used to calibrate the HELP model to the FLTF data and the calibration results are presented in Section 5. A discussion of barrier simulations and the results in Section 6. Finally, the calibration and barrier simulation results, and general study conclusions are discussed in Section 7.

3. MODEL DESCRIPTIONS

Two numerical models, UNSAT-H and HELP, were used to simulate the performance of three barriers designed to minimize infiltration of precipitation into waste materials. The two models represent two different approaches in groundwater modeling. The UNSAT-H model takes a very general approach that maximizes flexibility; the HELP model makes is very specific assumptions that are more restrictive.

The UNSAT-H model numerically solves the general partial differential equation (PDE) governing unsaturated fluid flow in porous media. Because no significant limiting assumptions are used in formulating this equation, the model is applicable to all unsaturated conditions.

The HELP model uses a mass balance approach to partition flow into water-balance components. The model assumes that only gravitational forces act on pore water. This assumption effectively reduces the governing equation for unsaturated flow from a 2nd-order PDE to a 1st-order PDE. This assumption also reduces the computational effort required to solve the problem and makes the model more computationally efficient. An in-depth description of the general features and theoretical background for each model is presented in the three sections that follow.

3.1 UNSAT-H Model

3.1.1 General Description

The UNSAT-H model code is designed to simulate the dynamics of water movement through the vadose zone as a function of meteorologic conditions and soil hydraulic properties. UNSAT-H Version 2.0 is an enhanced version of UNSAT-H 1.0. Version 1.0 simulates the processes of infiltration, redistribution, drainage, and evapotranspiration and uses the potential evapotranspiration (PET) concept. Version 2.0 additionally includes the options to calculate soil heat transfer coupled with water flow, surface-energy balance, and actual evaporation.

The model is written in FORTRAN 77 and consists of three main programs: (1) DATAINH, a preprocessor, (2) UNSAT-H, the flow simulator, and (3) DATAOUT, a post-processor. For simple problems the model runs efficiently on a personal computer. However, for cases with complex stratigraphy, the model requires a scientific workstation or larger computer. The model was verified and benchmark tested by Baca and Magnuson (1990), and has successfully been applied to simulate moisture movement at several semi-arid locations (Fayer et al., 1992; Baca et al., 1992; and Martian and Magnuson, 1994).

3.1.2 Theoretical Background

The PDE for flow in unsaturated porous media is Richards' equation (Richards, 1931). The UNSAT-H model solves an extended, one-dimensional form of Richards' equation, that includes both liquid- and vapor-phase water movement. To model soil heat transfer, the model solves the advection diffusion equation. The extended form of Richards' equation, as implemented in the model is

G = psychrometric constant, 0.68

A = slope of saturation vapor pressure curve computed from

$$A = \frac{5304}{T^2} e^{(21.255 - 5304/T)}, \tag{5}$$

where

T = the mean daily temperature.

If a LAI is specified, the PET is partitioned into PT and ET by using the LAI the equation

$$PT = PETe^{-0.4LAI}. \tag{6}$$

The daily PT is first applied to any free water on the surface. PT demand in excess of surface water is first extracted through soil evaporation and any further demand is extracted through transpiration. Soil evaporation occurs in two stages. Stage 1 assumes evaporation is controlled by atmospheric demand. However, when the evaporation amount exceeds an upper limit determined from the evaporation coefficient for the soil type, stage two evaporation occurs and the soil's unsaturated conductivity controls the evaporation. The sum of the evaporation and transpiration is then distributed throughout a static evaporative zone depth using a function in which the weighting factors decrease with depth.

Infiltration through the drainage layers is computed by Darcy's law for unsaturated conditions. The hydraulic gradient is assumed to be a downward unit gradient. This assumption neglects capillarity and assumes that only gravitational forces act on the pore water. The downward flux is then equivalent to the unsaturated hydraulic conductivity of the soil, which is assumed to be a linear function of soil moisture and can be expressed as

$$q = K\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{3 + (2/\lambda)}, \tag{7}$$

where

q = rate of downward flux

θ = soil water content

θ_r = residual soil water content

θ_s = porosity

λ = pore size index.

Infiltration through the barrier (i.e., low permeability) layer is assumed to occur under saturated conditions and proceeds by Darcy's law where the pressure gradient is determined from the water accumulated over the barrier.

The amount and timing of percolation through each layer is calculated by applying the mass-balance equation over each segment, with the amount of storage evaluated at the midpoint of each time step. This method is analogous to the Crank-Nicholson finite difference scheme used to numerically solve Richard's equation in UNSAT-H.

Finally, the amount of lateral drainage that occurs is estimated by an approximated solution of the mass-balance equation for lateral drainage. The approximated solution assumes steady-state conditions and a unit gradient in the direction of drainage. The lateral drainage equation is

3.2 HELP Model

3.2.1 General Description

The Hydrologic Evaluation of Landfill Performance (HELP) Model Version 1.0 was developed to assist hazardous waste landfill designers and regulators evaluate the hydrologic performance of proposed landfill designs. The model was specifically designed to rapidly and economically assess landfill designs without an in-depth knowledge of unsaturated soil hydraulic parameters or computational techniques. To meet these objectives, HELP contains a broad meteorologic and soil type data base and operates interactively with the user. In Version 2.0, the capabilities were enhanced by the addition of a synthetic weather generator (Richardson and Wright, 1984) and a vegetative growth model (Arnold et al., 1986).

The code is written in FORTRAN 77 and consists of two modules: (1) HELPI, an interactive input program and (2) HELPO, the execution and output program. The program is designed to run efficiently on an IBM or compatible personal computer.

3.2.2 Theoretical Background

HELP is a quasi-two-dimensional, deterministic water budget model that maintains a continuous water balance between surface runoff, evapotranspiration, vertical drainage, and lateral subsurface drainage. Each component of the water balance is computed as follows:

- Surface runoff is computed using the Soil Conservation Service (SCS) method
- Evapotranspiration is computed using the PET concept
- Percolation is computed using Darcy's law modified for unsaturated conditions
- Lateral drainage is computed using a mass balance equation.

In the SCS method, infiltration rates have been empirically found for different soil types and levels of vegetation. The amount of runoff is computed by the equation

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}, \qquad (3)$$

where

Q = runoff
P = precipitation
S = retention parameter.

The retention parameter is a non-linear function of soil moisture and vegetative cover density. This function is described by a series of curves developed by the SCS. The method attempts to encompass all processes involved in infiltration and redistribution (i.e., surface storage due to roughness, raindrop effects, soil surface compaction, and any number of other factors that may affect runoff).

The evaporation calculated by HELP is a portion of the PET that is determined by the Penman method, as developed by Ritchie (1972) from

$$PET = \frac{1.28AH}{(A + G)\,25.4}, \qquad (4)$$

where

H = net solar radiation

4. PREVIOUS EVALUATIONS

The ability of HELP to accurately simulate arid and semi-arid vadose zone processes has been investigated by several researchers with conflicting results. This section summarizes their previous work and conclusions regarding the application of the HELP model for arid sites.

4.1 Thompson and Tyler

Thompson and Tyler (1984) compared the results of HELP Version 1.0 and UNSAT1D (an early predecessor of UNSAT-H) in simulating fluid flow in covered fly ash landfills. The models were applied to a landfill profile consisting of bare topsoil underlain by compacted clay and fly ash waste. The simulations were performed for three locations: (1) a humid site at Cincinnati, Ohio, (2) a semi-humid site at Brownsville, Texas, and (3) a semi-arid site at Phoenix, Arizona. To ensure consistency of input data used in the two models, the same climatological, initial conditions, and material hydraulic properties for each site were used to the extent practical.

The results of the simulations reflected the different solution algorithms used by each model. For semi-humid and arid conditions, UNSAT1D predicted an upward flux through the clay layer while HELP predicted a downward or zero flux. UNSAT1D also predicted more evaporation for all cases. In addition, over the entire simulation period, HELP predicted an increase in storage for all sites while UNSAT1D predicted an increase in storage only for the humid site. HELP also predicted more runoff for all three sites. This result was thought by the authors to be more representative of actual conditions because HELP uses the SCS's empirical method while UNSAT1D simply assumes that runoff is equivalent to any precipitation in excess of the soil's infiltration capacity. The two models showed good agreement for predicted infiltration and final water storage only for the humid site.

4.2 Nichols

Nichols (1991) compared the results of HELP Version 2.0 and UNSAT-H Version 2.0 in simulating the performance of a two-layer infiltration barrier designed to minimize deep infiltration at the Hanford Site. The landfill barrier was modeled as a silt-loam top layer with grass underlain by a fine sand capillary break. Water movement in the soil profile was modeled for a 10-year period using daily meteorologic data recorded at the Hanford Site. As in the Thompson and Tyler study, input parameters were chosen to achieve a comparable representation of the physical system by both models. However, a data-entry error was subsequently identified in the precipitation totals, resulting in the application of 2.13 cm more water in the HELP simulation than in the UNSAT-H simulation. Another difference between input data for the two models was the length of the growing season. The growing season used in the HELP model was specified to be 50-days longer than that specified in the UNSAT-H model.

The results from both models indicated that very little deep infiltration would occur through the infiltration barrier. UNSAT-H predicted no infiltration while HELP predicted that approximately 0.2% of the precipitation total precipitation would infiltrate through the barrier. Other differences between the two simulations were that HELP predicted a higher percentage of precipitation would be returned to the atmosphere than was predicted by UNSAT-H. HELP also predicted no change in storage while UNSAT-H predicted a slight increase in storage over the period simulated.

4.3 Stevens and Coons

Stevens and Coons (1994) applied HELP Version 2.05 to simulate long-term infiltration from a proposed landfill in southern New Mexico. The infiltration rate predicted by the model was compared to estimates of infiltration based on predictions from chloride mass-balance studies and laboratory evaluations of core samples from the site. The model was used to simulate moisture movement in the landfill during 8[illegible] years of operation and approximately 4,500 years after closure. Default hydraulic parameters for fine loamy

$$K_s \cos^2\alpha \frac{\partial}{\partial x}\left(y\frac{\partial h}{\partial x}\right) + R - K_B\left(1+\frac{y}{T}\right) = 0, \tag{8}$$

where

x = horizontal distance from drain
y = saturated thickness in lateral drainage layer
α = inclination angle of lateral drain
h = elevation of phreatic surface
R = vertical drainage rate into saturated portion of lateral drainage layer
K_s = saturated hydraulic conductivity in lateral drainage layer
K_B = saturated hydraulic conductivity in barrier soil
T = thickness of barrier soil layer.

The abstract appearance of this equation warrants an explanation. The first term represents the lateral flow amount; the second term represents drainage from above into the lateral drainage layer; the third term represents infiltration into the barrier layer.

3.3 Discussion of Differences

The previous two sections illustrate the different approaches used by the two models in approximating the physics of infiltration and redistribution. UNSAT-H uses a very general approach that can be applied over a wide range of conditions. HELP uses several assumptions that may or may not be appropriate for specific applications.

The most significant of these assumptions is a unit gradient for vertical infiltration. This assumes that only gravitational forces affect pore water below the arbitrarily defined evaporative zone depth. Although HELP does not directly consider capillary forces, the effect of capillarity is indirectly accounted for by applying continuity to evapotranspiration and pore water above the evaporative zone depth. For humid conditions, the unit gradient assumption is appropriate. However, for semi-arid conditions, the arbitrary and static evaporative zone depth could either over- or under-estimate deep infiltration into the vadose zone. Under-estimating the evaporative zone depth could result in over-estimation of infiltration below the root zone by not allowing deeper pore water to return to the surface. Over-estimating the evaporative zone depth, particularly during the rainy season when the evaporative zone depth may become relatively shallow, could under-estimate deep infiltration.

5. HELP CALIBRATION

Model calibration is a trial-and-error process of adjusting input data until computed data match field observations. The Field Lysimeter Test Facility (FLTF) was specifically constructed to test the performance of capillary barriers. The measurements collected at the FLTF provide a readily available source of data to calibrate numerical models of potential barrier designs at the Hanford Site.

Moisture content, drainage, and storage data gathered in the four weighing lysimeters from January 1, 1988 to December 31, 1992 were used to calibrate HELP Version 2.05 to the Hanford Site. The main focus of the calibration was to estimate the depth of the evapotranspiration zone in the subject lysimeters. A description of the weighing lysimeters is presented in Section 5.1. The calibration method and results are given in Sections 5.2 and 5.3, respectively.

5.1 Weighing Lysimeter Descriptions

Covers with a capillary barrier have been proposed to isolate low-level radioactive waste at the Hanford Site. The FLTF was designed and constructed to test this concept. Four weighing lysimeters were chosen to calibrate HELP Version 2.0 because the weighing capability of the lysimeters provided an additional calibration parameter (i.e., storage). The four weighing lysimeters represent vegetated and bare surfaces for ambient and augmented precipitation. Each weighing lysimeter measures 1.5 m square and 1.7 m deep and is filled with 1.5 m of soil over 0.2 m of #20 - #30 sand, as illustrated in Figure 2.

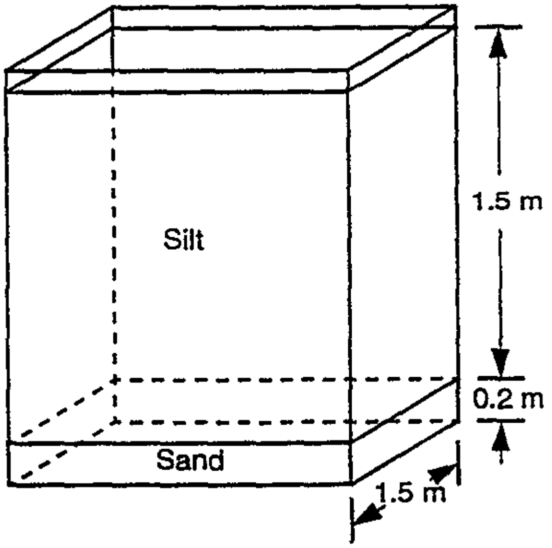

Figure 2. Weighing lysimeter configuration

Two of the four weighing lysimeters received augmented precipitation which was 2 times the ambient precipitation during the first three years of operation (November 1987 - October 1990) and 3 times the ambient during October 1990 through the present (Gee et al.,1993). Table 1 lists the four weighing lysimeters and their respective precipitation treatments and surface conditions.

sand and refuse provided in HELP were used with model-generated precipitation and evaporation data to simulate landfill performance.

The chloride mass balance method assumes that the principle source of chloride in the soil water is from precipitation. At equilibrium, the rate of chloride mass entering the soil from precipitation will equal the rate of chloride mass leaving the soil through deep infiltration, and the recharge rate can be calculated by the equation

$$R = (Cl_p / Cl_{sw}) \times P , \qquad (9)$$

where

R = recharge rate
Cl_p = chloride concentration in precipitation
Cl_{sw} = chloride concentration in soil water
P = average annual precipitation.

To estimate recharge rates from core samples taken from the site, the van Genuchten relations (van Genuchten, 1980) were fit to moisture retention and unsaturated hydraulic conductivity curves obtained from laboratory analysis of the core sections. The unsaturated hydraulic conductivity at the in-situ moisture content was then used to calculate the darcy velocity, assuming a downward unit gradient.

Their HELP simulation predicted infiltration would reach a maximum of 0.0084 in/yr after 1,200 years and equilibrate at 0.0027 in/yr after 4,200 years. The recharge estimate from the chloride mass balance method was 0.0077 in/yr and 0.0072 in/yr for two locations. The geometric mean of laboratory estimates of recharge was 0.0062 in/yr.

4.4 Conclusions of Previous Evaluations

In summary, the study by Thompson and Tyler concluded that HELP and UNSAT1D yield similar fluid-flow results only under humid conditions, and the assumption on which HELP is based (namely the downward unit gradient) appears to limit its applicability at arid sites. Nichols concluded that HELP is "conservative" in the sense it over-predicts deep infiltration. However, the differences in simulated water balance between HELP and UNSAT-H were relatively small compared to the differences encountered by Thompson and Tyler. The results from Nichols should be viewed with caution because of the data entry error and the appreciably different growing seasons specified for the two simulations.

The study by Stevens and Coons concluded that HELP predicted reasonable deep infiltration rates at a semi-arid site because the results compared well to estimates from chloride mass balance and laboratory evaluation of core samples. Their results should also be viewed with caution because the laboratory estimates of recharge used the same unit gradient assumption. The estimates of recharge based on the chloride mass balance were determined from the average chloride concentration. If the peak and lowest values were used, the recharges estimate would be 10 times smaller or 3 times larger, respectively.

Finally, graphical comparisons between the measured and simulated data were used to qualitatively judge how well the simulation results represented the lysimeter data. Plots were made of the measured data superimposed over the simulation results, and the agreement was visually evaluated.

5.2.2 Calibration Parameters and Methods

The HELP input parameters that were adjusted in the calibration process were: (1) porosity, (2) field capacity, (3) wilting point, (4) saturated hydraulic conductivity, (5) LAI, and (6) evaporative depth. A description of each parameter as it is defined within the HELP model, and the effect of increasing the parameter on the amount of water retained within the simulated lysimeter profile (storage) is discussed below.

- Porosity is the soil water content at saturation. The effect of increasing porosity is to increase the amount of lysimeter storage because the unsaturated hydraulic conductivity at any given moisture content is reduced (see Equation 7 in Section 3.2.2). This reduces the rate at which water may evaporate or drain out of the bottom of the profile.
- Field capacity is the soil water content after a prolonged period of drainage and is defined as the moisture content at 1/3-bars. The effect of increasing this parameter is to increase the vegetated lysimeter storage and decrease bare lysimeter storage. The decrease in bare lysimeter storage was probably due to the fact that moisture content is higher at any given tension and the unsaturated hydraulic conductivity (see Equation 7 in Section 3.2.2) is also higher. Initial storage after an infiltration event is higher, however the water evaporates and drains faster which results in a lower average storage. This trend was not seen in the vegetated simulations because transpiration is not limited by the soil's unsaturated hydraulic conductivity.
- Wilting point is the lowest soil water content that can be achieved through plant transpiration and is defined as the moisture content at 15-bars. The effect of increasing the value of this parameter was to increase lysimeter storage because more water is retained at all tensions. However, the unsaturated hydraulic conductivity does not increase because the wilting point increases proportionally to the moisture content (see equation 7 in Section 3.2.2).
- The evaporative depth is the maximum depth at which water may return to the surface as a result of evaporation and transpiration. Increasing the evaporative depth decreases the amount of water in storage by allowing more evapotranspiration.
- The leaf area index (LAI) is used to represent the amount of vegetation at the surface and is used to partition evaporation and transpiration. Increasing the LAI decreases storage because a larger LAI results in a larger ratio of transpiration to evaporation, and the transpiration rate is not limited by the unsaturated soil's hydraulic conductivity.

Initial estimates for the values of these parameters in the calibration simulations were those of the original barrier simulations by WHC (DOE, 1993). The uncompacted McGee Ranch Silt specified in the WHC simulations is identical to the fill used in the weighing lysimeters. The initial hydraulic parameters for the barrier silt are presented in Table 2. Parameter values for the lysimeter sand were those of the HELP default soil type 1 (coarse sand). Initial estimates of moisture content correspond to the lysimeter storage at the beginning of the calibration period. Each parameter was varied to obtain a best fit to the observed water storage while minimizing drainage. After improvement trends were identified, all of the parameters were adjusted to obtain the best overall agreement with the lysimeter observations.

Table 1. Weighing lysimeter precipitation treatments and surface conditions.

Lysimeter	Precipitation Treatment	Surface Condition
W01-1	Ambient	Vegetation
W02-2	Ambient	Bare
W03-3	2x and 3x	Vegetation
W04-4	2x and 3x	Bare

5.2 Calibration Procedure

5.2.1 Evaluation Criteria

The measured values of lysimeter storage and drainage were used to evaluate how well the HELP model approximated the lysimeter observations. Because no drainage was observed from any of the lysimeters during the calibration period, the result of using drainage as a calibration parameter was to minimize drainage in all simulations.

Evaluating the match between simulated and measured storage required both quantitative and qualitative criteria. Two quantitative indicators were chosen to measure the agreement between field data and simulation results. The first indicator was the root mean square (RMS) error; the second was the correlation coefficient.

The RMS error provides a good estimation of the average error throughout the two data sets and is defined by the equation

$$RMS = \frac{\sqrt{\left(\sum_{i=1}^{k} (s_i - f_i)^2\right)}}{k}, \tag{10}$$

where

f_i = field data point
s_i = simulation data point
k = number of comparison points.

The correlation coefficient measures the degree to which there is a linear correlation between corresponding field data and simulation results. It provides an estimate of how well the trends between the data sets agree (i.e., the shape of the data curve). The correlation coefficient is defined by the quantity

$$r = \frac{k\sum_{i=1}^{k} s_i f_i - \sum_{i=1}^{k} s_i \sum_{i=1}^{k} f_i}{\sqrt{\left[k\sum_{i=1}^{k} s_i^2 - \left(\sum_{i=1}^{k} s_i\right)^2\right]\left[k\sum_{i=1}^{k} f_i^2 - \left(\sum_{i=1}^{k} f_i\right)^2\right]}}. \tag{11}$$

A perfectly linear relationship between data sets would result in a correlation coefficient of 1. At the other end of the scale, a correlation coefficient of 0 would indicate that the data sets are completely independent.

5.3 Calibration Results

The simulations using the initial hydraulic parameters from WHC showed poor agreement with lysimeter storage and drainage results. Simulated drainage was as high as 18% of the precipitation totals and RMS storage errors approached 30% for the irrigated lysimeters. The correlation coefficients for these initial, uncalibrated simulations varied from a maximum value of 0.925 for the vegetated lysimeter with ambient precipitation to 0.798 for the bare lysimeter with augmented precipitation. The high correlation coefficient and RMS values indicate the uncalibrated results matched the seasonal variations in storage better than the base line storage amounts in these simulations.

Overall, the initial simulations over-predicted drainage and under-predicted evapotranspiration. Results of these uncalibrated simulations are presented in Figure 4 (two-layer representation) and Figure 5 (four layer representation). The uncalibrated results from the four-layer representation illustrate that evaporation from the bare lysimeters was under-predicted by a larger degree than was evapotranspiration for simulations of vegetated conditions. The augmented precipitation condition resulted in even more departure between simulated and measured storage values. The calibration effort greatly improved the agreement between measured and simulated storage. The RMS errors were reduced to approximately 10% and drainage was reduced to approximately 1% of total precipitation for the vegetated lysimeters. The resulting hydraulic parameters that provided the best agreement between measured and simulated lysimeter storage for the McGee Ranch silt are in Table 3.

Table 3. Silt hydraulic parameters for calibrated HELP model.

Parameter	Recommended Value
Porosity (cm^3/cm^3)	0.514
Field Capacity (cm^3/cm^3)	0.200
Wilting Point (cm^3/cm^3)	0.060
Saturated Conductivity (cm/s)	0.0001
Evaporative Depth (in)	> 59.06
Leaf Area Index	1.60

It is important to note that the values for the hydraulic parameters in Table 3. do not represent the actual values for the silt. However, they provide the best agreement with observed lysimeter conditions when used within the HELP model. This is primarily due to the fact that the HELP model may not be adequately modeling the physics in a shallow capillary barrier.

Table 2. Initial hydraulic parameters for silt.

Parameter	Initial Value
Porosity (cm^3/cm^3)	0.514
Field Capacity (cm^3/cm^3)	0.258
Wilting Point (cm^3/cm^3)	0.068
Saturated Conductivity (cm/s)	0.001
Evaporative Depth (in)	36.0
Leaf Area Index	1.60

The calibration methods discussed above was applied to three representations of the weighing lysimeter soil profile. The three profiles are described below and are illustrated in Figure 3.

- *Two layers consisting of McGee Ranch Silt and coarse sand:* This is the simplest representation of the weighing lysimeter's two soil types and is how HELP was intended to represent a two-layer cover system.
- *Six layers consisting of five identical silts and a coarse sand:* This representation was evaluated because HELP assumes a uniform moisture content in each layer when solving for the water balance. The multi-layered representation of the silt allows portrayal of different moisture contents as a function of depth.
- *Four layers consisting of silt, coarse sand, barrier membrane, and barrier soil:* This representation was used to depict a zero flux bottom boundary condition because no drainage was observed from the lysimeters during the calibration period.

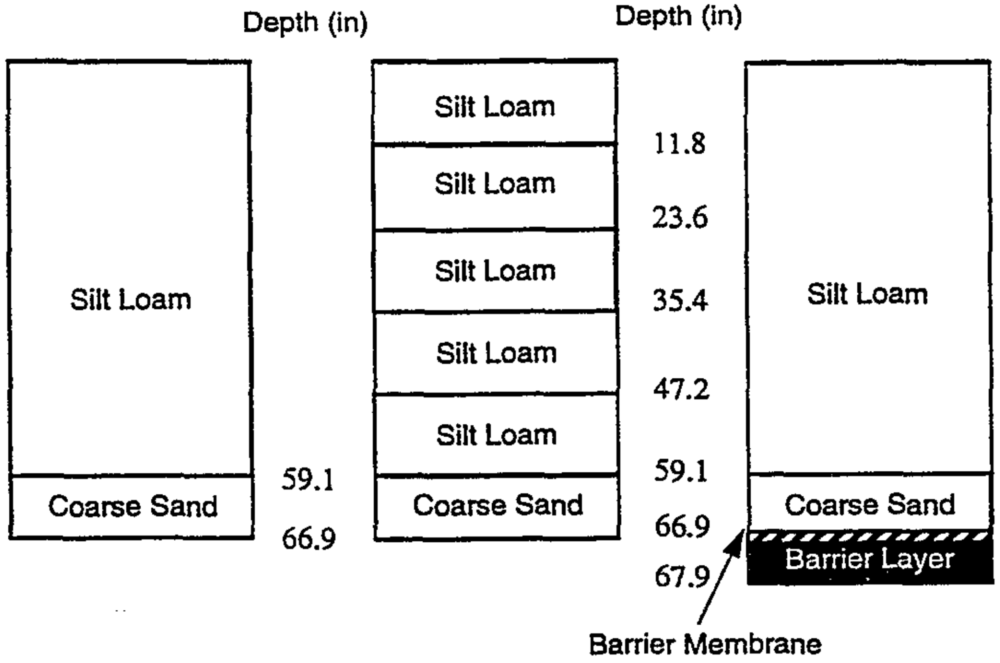

Figure 3. Weighing lysimeter representations used in HELP simulations.

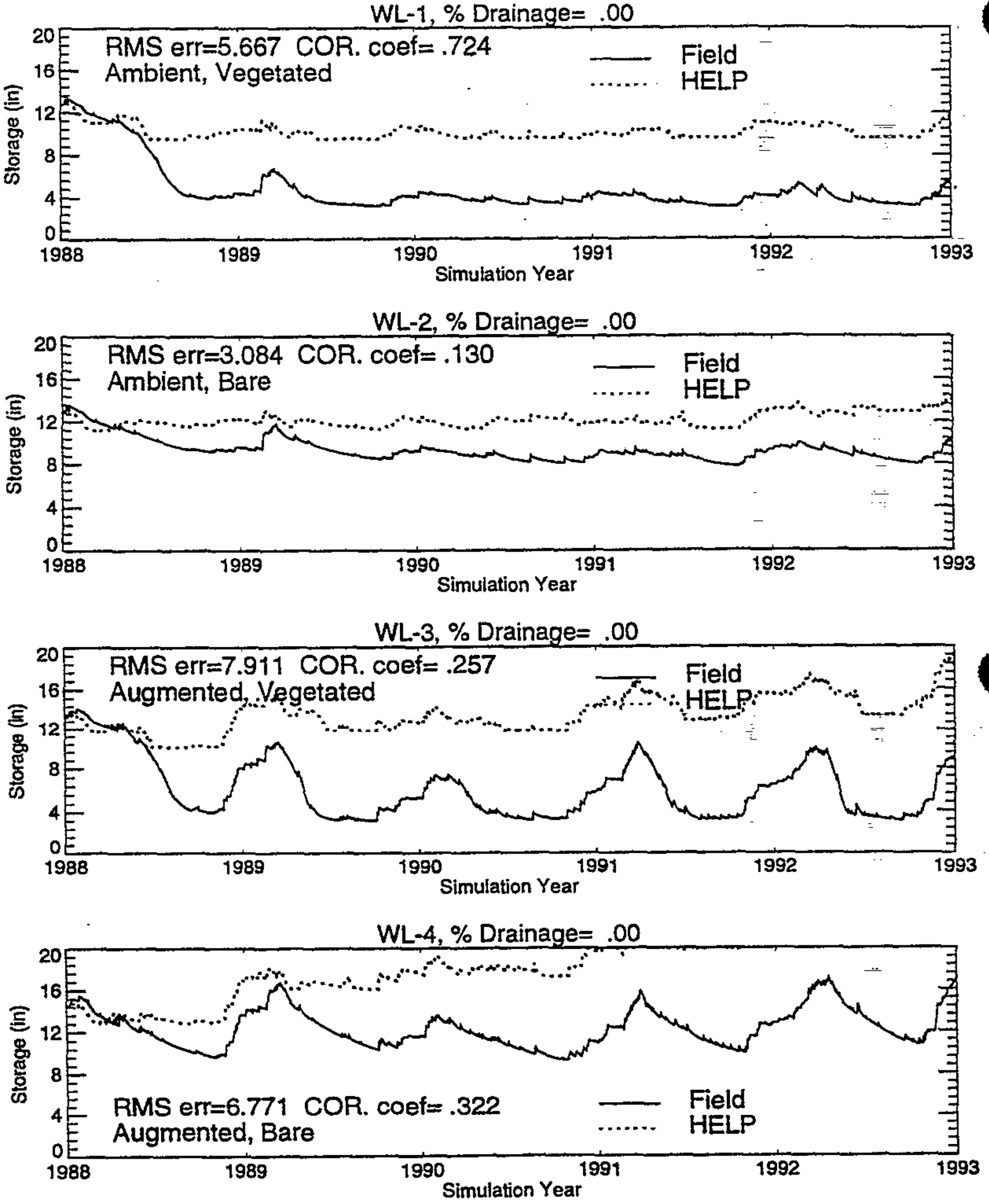

Figure 5. Simulation results of storage for the uncalibrated four-layer lysimeter representation.

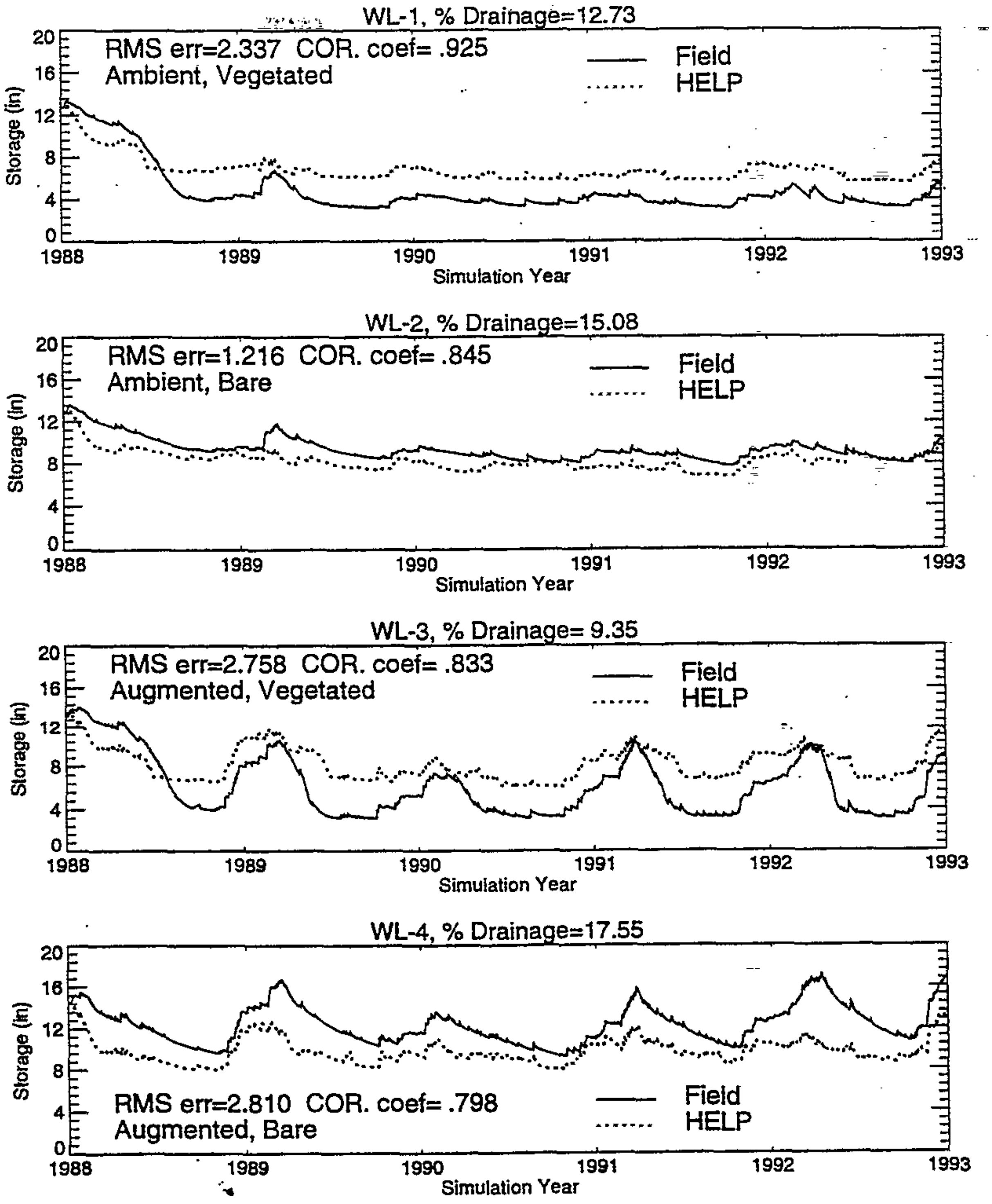

Figure 4. Simulation results of storage for the uncalibrated two-layer lysimeter representation.

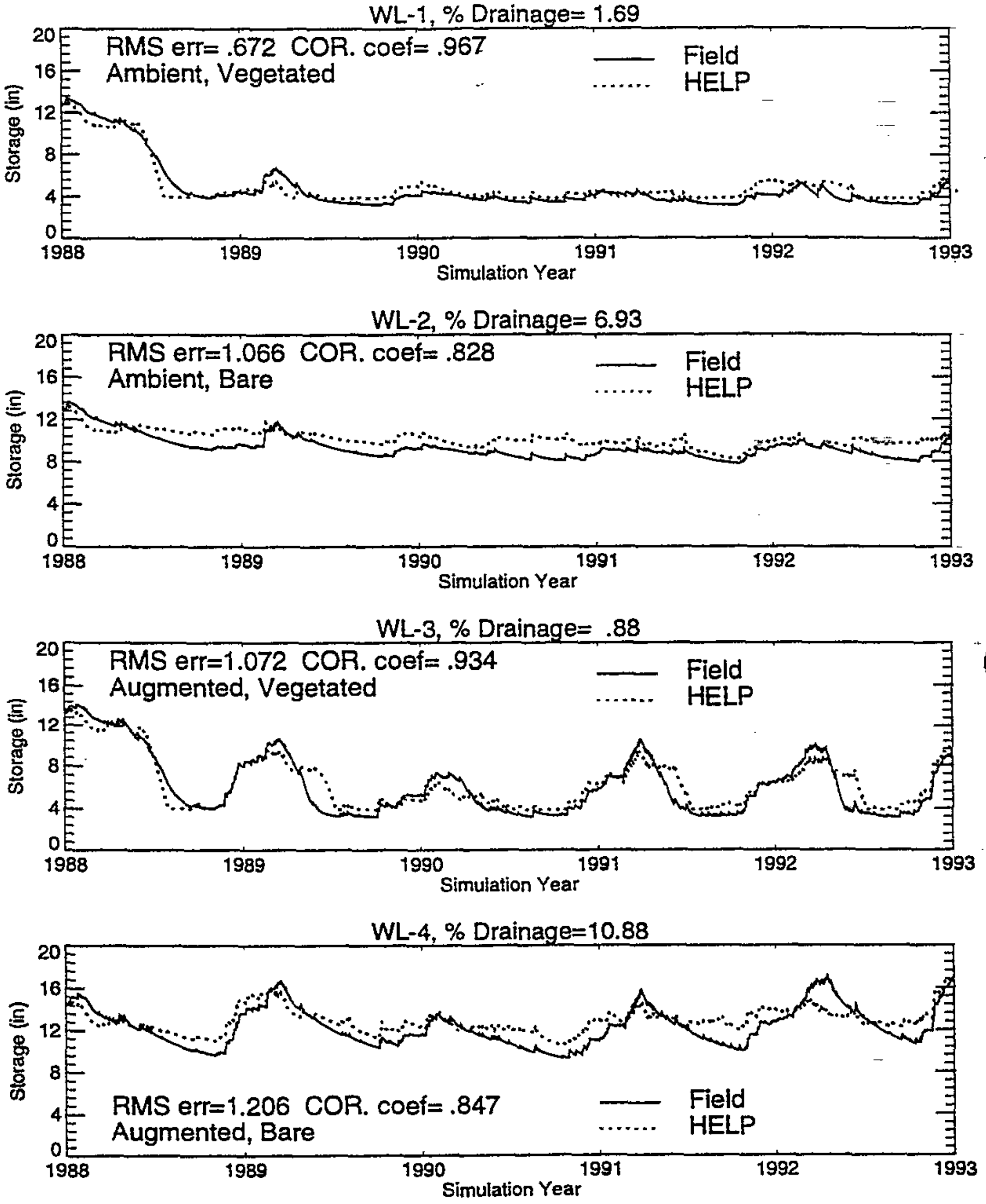

Figure 6. Simulation storage results using best-fit parameters for the two-layer lysimeter representation.

A quantitative comparison of measured and simulated lysimeter storage using the calibrated final parameters discussed above is provided in Table 4. Dividing the silt profile into several layers to permit different moisture contents with depth did not significantly change the simulation results. Nearly identical storage and drainage results were obtained with two-layer and six-layer representations which could be seen in identical RMS error and correlation coefficients between the two- and six-layer representations. These six-layer results were not included in the figures or in Table 4. Plots comparing measured and simulated lysimeter storage for the two-layer and four-layer representations are illustrated in Figures 6 and 7, respectively.

Table 4. Quantitative evaluation of HELP simulation results using calibrated parameter values.

Two-Layer Representation			
Lysimeter	Root Mean Square Error	Correlation Coefficient	Drainage (%)
WO1-1	0.674	0.967	1.75
WO2-2	1.048	0.830	6.99
W03-3	1.071	0.934	0.91
W04-4	1.193	0.847	10.9
Four-Layer Representation			
WO1-1	0.987	0.963	0
WO2-2	2.473	0.425	0
W03-3	1.385	0.930	0
W04-4	5.728	0.383	0

5.4 Discussion of Calibration Results

Overall results of the calibration exercise indicate that HELP under-predicts evapotranspiration and over-predicts drainage in the weighing lysimeters, as can be seen in Figure 7. These tendencies were more evident in the bare-surface lysimeters than in the vegetated surface lysimeters, as indicated in the larger RMS and lower correlation coefficients for the bare lysimeter simulations. These results suggest that HELP Version 2.05 inadequately models the physics of a shallow capillary barrier. The departure of simulated from the observed storage is primarily due to the unit gradient assumption implied within the model's solution algorithm, as well as the assumption of a static evaporative depth.

The results of the simulations of vegetated surfaces suggest that the model may adequately simulate the combined effects of evaporation and transpiration at a semi-arid location in a non-capillary barrier application if the evaporative depth is known beforehand and the location experiences a temporally constant evaporative depth. However, the partitioning between evaporation and transpiration, and the evaporation algorithm may not correctly portray conditions at the Hanford Site. This is evident in the simulated performance of the vegetated and bare lysimeters. The simulations of the vegetated lysimeters predicted evaporation and drainage near the measured values. However, the simulations of the bare surfaced lysimeters significantly over-predicted drainage and under-predicted evaporation.

The average evaporative-zone depth appears to be more than the 59-in. depth of the lysimeter's silt layer. However, the assumption of a static evaporative depth may not be appropriate for Hanford Site conditions. The dynamic nature of soil processes in northern arid climates results in relatively shallow winter and early spring evaporative depths, and relatively deep late summer and early fall evaporative depths. Assuming an average depth tends to smooth out the observed extremes in storage. Hence, this assumption may limit the application of HELP at northern arid sites because seasonal variations in climatic tend to be very severe.

Finally, it should be noted that these conclusions were drawn from a seemingly unfair evaluation of the HELP model. The model was calibrated to experimental data collected from a capillary barrier designed to hold moisture near the surface. This is because the capillary forces within finer textured soil are much larger than gravitational or capillary forces in the coarser material below. However, the solution algorithm within the HELP model assumes that only gravitational forces are present.

5.5 HELP Sensitivity

Sensitivities to the key input parameters discussed in Section 5.2.2 were identified throughout the calibration process, as well as through a separate parametric sensitivity analysis. During the formal sensitivity analysis, the input parameters that provided the "best" fit to the measured lysimeter storage were used as the base case. These parameters were individually increased and decreased by 20%, and the resulting change in predicted storage was evaluated through their effect on the RMS error and the correlation coefficient. The sensitivity ranking of each parameter for each lysimeter is presented in Table 5.

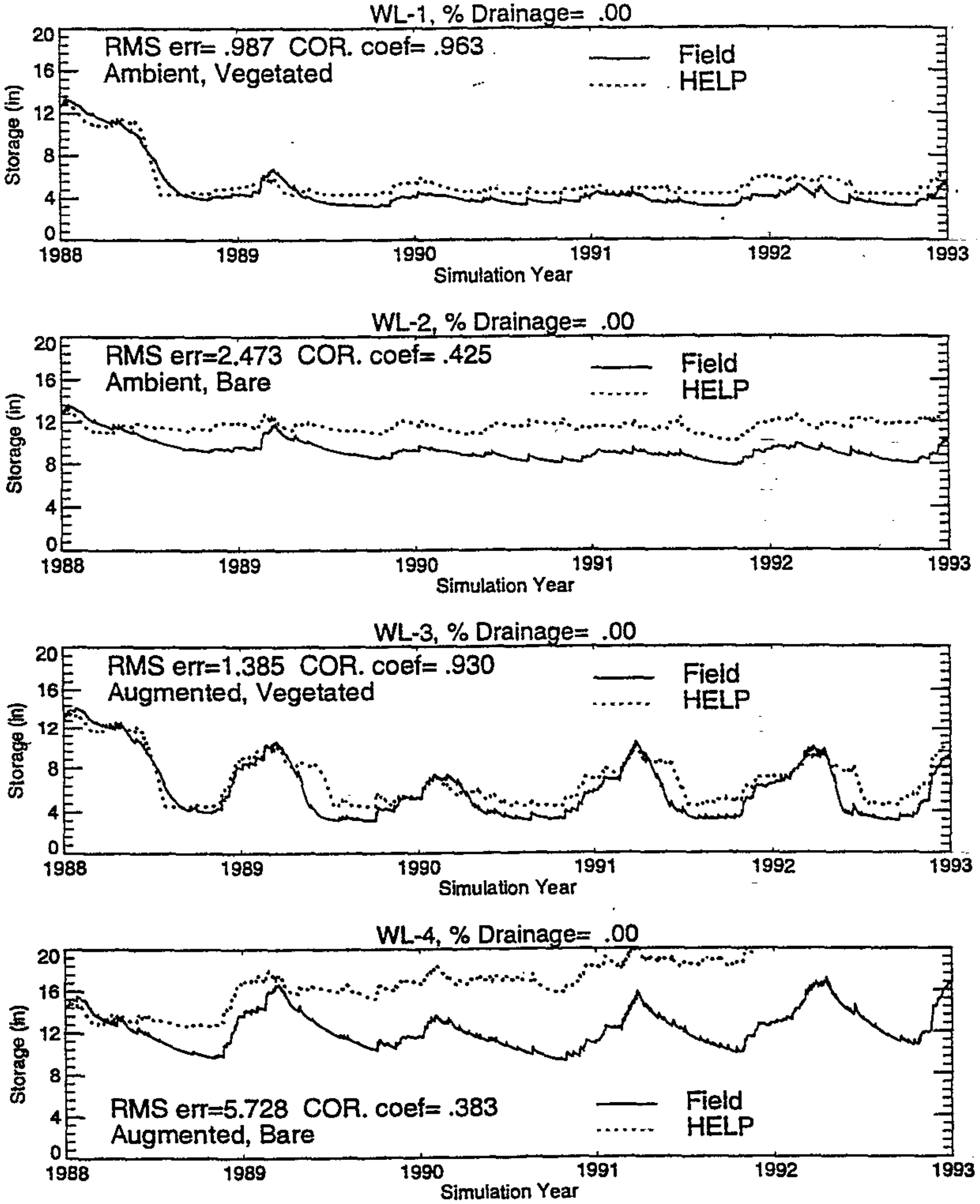

Figure 7. Simulation storage results using best-fit parameters for the four-layer lysimeter representation.

6. BARRIER SIMULATIONS

6.1 Barrier Descriptions

Three alternative cover designs were developed for isolating low-level and hazardous waste in the Hanford Site's 200 areas. These designs were engineered to minimize infiltration of meteoric water below the covers by utilizing the concept of a capillary barrier. A capillary barrier relies on the concept of a capillary break that occurs when a fine-textured soil (i.e., silt) overlies a coarser textured soil (i.e., sand or gravel). The effect of surface tension (i.e., capillarity) is larger in the small pores of the fine textured soil than in the large pores of a coarser soil. These capillary forces in the fine textured soil tend to be larger than the gravitational forces and infiltrated water is retained in the fine soil until it is removed by evaporation or plant uptake. However, the fine textured soil must remain unsaturated for a capillary barrier to perform effectively. The calibrated HELP and UNSAT-H model were used to simulate the water-balance performance of the infiltration barriers for ambient, and 2 times ambient precipitation conditions. Additionally, the HELP code was used to simulate design storm conditions to determine a maximum runoff.

The three infiltration barriers evaluated are described below in order of decreasing overall performance and level of protection provided.

- *Hanford Barrier*: This cover is 15-ft. thick and provides the highest level of containment and hydrologic protection of the three infiltration barriers. This barrier was designed for use at sites containing transuranic wastes, and has a minimum life expectancy of 1,000 years.
- *RCRA Subtitle C cover*: This is 5.7 ft. thick and was designed for use at sites containing hazardous and low-level radioactive waste. It was designed for a minimum life expectancy of 500 years.
- *RCRA Subtitle D cover*: This 3 ft. thick and was designed for use at sites containing non-hazardous solid wastes. It has a design life 100 years.

The three barriers are illustrated in Figure 8, and a description of barrier structure is presented in Sections 6.1.1 through 6.1.3.

6.1.1 Hanford Barrier Design

The Hanford barrier consists of nine layers. A detailed description of each layer starting with the uppermost layer and proceeding downward follows:

- Layer 1 is a 40-in. silt and pea gravel mix. The functions of this layer are threefold. The first function is to support the growth of vegetation and thereby promote evapotranspiration. The second function is to prevent wind and water erosion by the addition of the pea gravel. The third function is to temporarily intercept and store moisture for later removal by evapotranspiration.
- Layer 2 is a 40-in. thick silt layer designed to function as layer 1, except that erosion protection is not needed.
- Layer 3 is a geotextile filter fabric designed to prevent the mixing of topsoil and sand during construction.
- Layer 4 is a 6-in. thick sand filter layer designed to act as a capillary break and prevent migration of silt into the underlying gravel (layer 5).
- Layer 5 is a 12-in. thick gravel filter also designed to act as a capillary break and to prevent migration of sand into the underlying crushed basalt (layer 6).
- Layer 6 is a 60-in. thick crushed basalt bio-intrusion layer designed to isolate the covered wastes from contact with plant roots and burrowing animals.

Table 5. Parameter sensitivity ranking for each lysimeter.

	Sensitivity Ranking for each Lysimeter (1 is the most Sensitive parameter)			
Parameter	W01-1	W02-2	W03-3	W04-4
Porosity	3	1	3	1
Field Capacity	2	3	2	3
Wilting Point	5	2	4	2
Saturated Conductivity (cm/s)	6	4	6	4
Evaporative Depth (in)	1	5	1	5
Leaf Area Index	4	NA	5	NA

The most prominent sensitivity trend identified during the calibration effort was the different response to changes in evaporative depth between the vegetated and bare lysimeters. Evaporative depth was the most sensitive parameter in the vegetated lysimeter simulations (W01-1 and W03-3) and was the least sensitive parameter in the bare-surface lysimeter simulations (W02-2 and W04-4).

This trend can be partially explained by the method HELP uses to determine evaporation amounts. As discussed in Section 3.2.2, evaporation occurs in two stages. Stage one assumes evaporation is controlled by atmospheric demand while stage two assumes the unsaturated conductivity of the soil controls the rate of evaporation. Because the Hanford Site has an arid climate, stage two evaporation occurs during much of the growing season and the evaporation rate is primarily controlled by the soils hydraulic conductivity and not the evaporative zone depth. However, if plants are included in the simulations, the transpiration rate is not restricted by the soil's hydraulic conductivity and substantially more evapotranspiration occurs. Consequently, evaporative depth is the most sensitive parameter in the vegetated simulations and the least sensitive parameter in the bare surface simulations.

- Layer 5 is a 6-in. thick gravel layer designed to function in a manner analogous to layer 7 of the Hanford barrier.
- Layers 6 and 7 are 6- and 4-in. thick asphalt layers designed to function in a manner analogous to layers 8 and 9 of the Hanford barrier.

6.1.3 RCRA Subtitle D Cover Design

The RCRA Subtitle D barrier was designed for use at solid-waste sites that do not contain hazardous or radioactive wastes and does not include the filter sand and gravel layers used by the Hanford and Subtitle C barrier designs. Instead, it relies on the coarse nature of the grading backfill to provide the capillary break. The design can be described as consisting of:

- Layer 1 is a 8-in. thick silt and pea-gravel mix designed to function similar to the Hanford barrier layer 1.
- Layer 2 is a 16-in. thick silt layer designed to function in a manner analogous to layer 2 of the Hanford barrier.
- Layer 3 is a 12-in. thick compacted silt designed to function in a manner similar to layer 2 of the RCRA Subtitle C barrier.

6.2 Precipitation Treatments

Water balance simulations for each barrier design were conducted for three precipitation scenarios: (a) ambient precipitation, (b) 2x ambient precipitation, and (c) design storm conditions. The ambient precipitation scenarios used daily precipitation data collected at the Hanford Meteorologic Station for the time simulated. The 2x ambient precipitation scenario was realized by doubling the precipitation that was recorded each day rather than by doubling the number of days during which precipitation occurred. This was done to maintain better agreement with the other meteorologic records used in the simulations (e.g., solar radiation and dew point). The 2x ambient and scenario was simulated to evaluate the effects of climatic changes which result in dramatically more precipitation. The design storm scenario was simulated to determine the maximum runoff which may occur during the barriers' life-span.

A different design storm intensity was used to evaluate the performance of each barrier. The simulation of the Hanford barrier used a 1,000-year, 24-hour storm scenario. The RCRA Subtitle C barrier simulation used a 500-year, 24-hour storm scenario, and the RCRA Subtitle D barrier simulation used a 100-year, 24-hour storm. The 1,000-year, 24-hour storm was projected to deliver 2.68 in. of precipitation. The 500-year, 24-hour storm was projected to produce 2.47 in. of precipitation, and the 100-year, 24-hour storm was projected to generate 1.99 in. of precipitation (Stone et al., 1983). These precipitation values were applied on the day following the largest simulated precipitation event when soil moisture content was at a maximum (December 31, 1983). This date was chosen by WHC to result in the largest simulated runoff during the modeling period.

6.3 Application of UNSAT-H

To solve Richard's equation, UNSAT-H must be supplied with soil hydraulic parameters, a computational grid, initial conditions, and boundary conditions. Each of these components is discussed in the following sections.

6.3.1 Barrier Hydraulic Parameters

The hydraulic parameters specified in the UNSAT-H simulations represent three basic soil properties: (a) the moisture characteristic curve, (b) the hydraulic conductivity curve, and (c) saturated

- Layer 7 is a 12-in. thick gravel layer designed to facilitate lateral drainage and prevent head build-up over the underlying asphalt (layers 8 and 9).
- Layers 8 and 9 are 6- and 4- in. thick asphalt layers designed to act as a hydraulic barrier, thereby minimizing infiltration into the underlying materials.

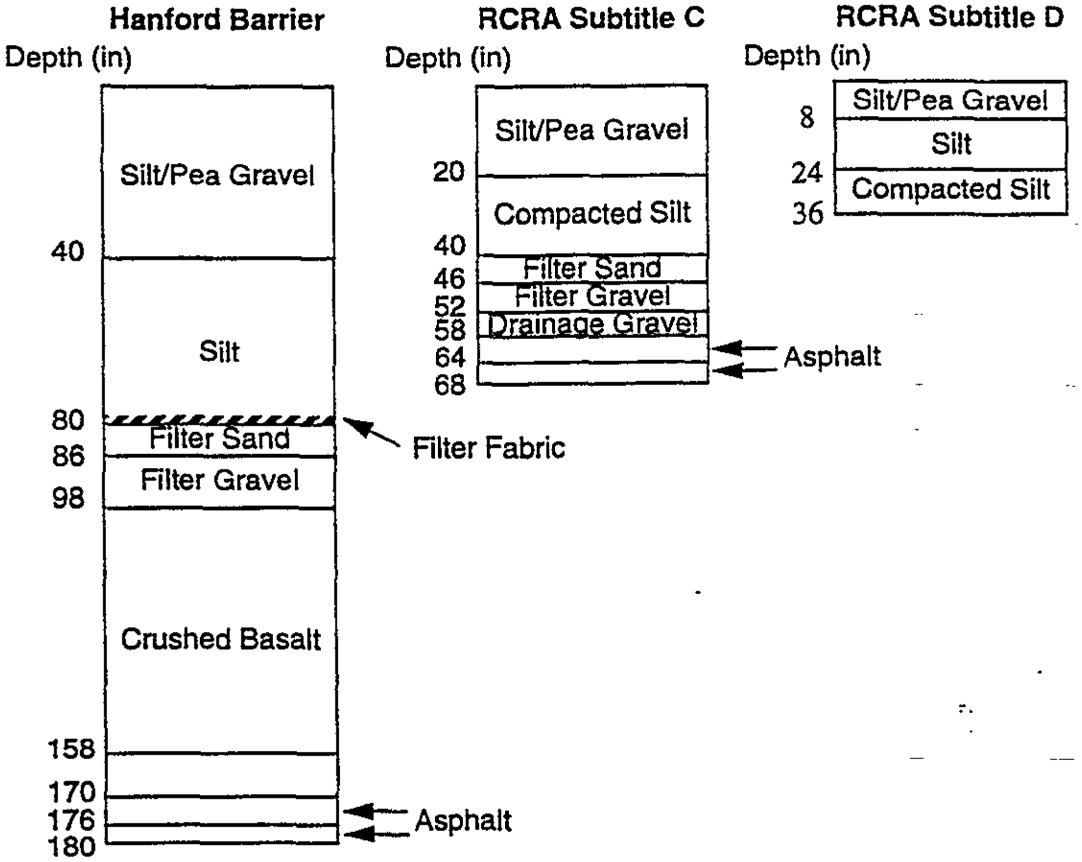

Figure 8. Barrier layers.

6.1.2 RCRA Subtitle C Cover Design

The RCRA Subtitle C barrier is an economical version of the Hanford barrier that does not include the bio-intrusion layer. The conceptual model used to represent the barrier consists of seven layers and is described as follows:

- Layer 1 is a 20-in. thick silt and pea-gravel mix designed to function in a manner analogous to layer 1 of the Hanford barrier.
- Layer 2 is a 20-in. thick compacted silt layer designed to function in a manner analogous to layer 2 of the Hanford barrier. It is compacted to retard moisture migration through the lower part of the cover.
- Layer 3 is a 6-in. thick sand filter designed to function in a manner analogous to layer 4 of the Hanford barrier.
- Layer 4 is a 6-in. thick gravel filter designed to function in a manner analogous to layer 5 of the Hanford barrier.

relative humidity measurement methods. The resulting tension versus moisture content data were then simultaneously fit to the van Genuchten equations. The work performed by Gee et al. did not include estimation of hydraulic parameter values for very dry conditions. Therefore, the residual moisture content resulting from the curve fitting was predicted to be unrealistically low. However, because moisture conditions for the simulations never approached the values represented by the driest portion of the soil moisture curves, the unrealistic residual moisture content did not affect the simulation results. The resulting hydraulic parameters are presented in Table 7.

Table 7. UNSAT-H McGee Ranch Silt hydraulic parameters.

Parameter	Value
K_s (cm/sec)	9.9×10^{-4}
θ_s (cm^3/cm^3)	0.496
θ_r(cm^3/cm^3)	0.0049
α (1/cm)	0.0163
n	1.3716

Because the hydraulic parameters for silt have the largest impact on barrier performance, the fitted silt parameters were validated by simulating weighing lysimeters W02-2 and W04-4 during the period form January 1, 1988 through December 31, 1992. For both the lysimeter simulations, and the barrier simulations the pore interaction term (*l*) in Equation 13 was set to zero, as proposed by Fayer et al. (1992). In Fayer's analysis, UNSAT-H was used to model eight lysimeters at the Hanford Site's FLTF and the match between lysimeter observations and the UNSAT-H simulations were greatly improved by setting *l* to zero. The effect of setting *l* to zero was to increase the unsaturated hydraulic conductivity for dry conditions, thereby reducing summer storage while not significantly changing winter storage. The PET was also set to zero and the precipitation amounts were modified to account for melting and freezing. An in-depth description of this procedure is presented in Section 6.3.4.1

The results showed very good agreement between simulated and observed values for both lysimeters. The agreement is illustrated below in Figure 9. RMS errors of 0.39 and 0.701, and correlation coefficients of 0.96 and 0.94 were obtained for lysimeters W02-2 and W04-4, respectively.

hydraulic conductivity. The van Genuchten equations were used to represent these constitutive relationships. The equation for the characteristic curve is

$$\theta = \theta_r + (\theta_s - \theta_r)\,[1 + (\alpha h)^n]^{1-\frac{1}{n}} \qquad (12)$$

where

h = suction head
θ = volumetric moisture content
θ_r = residual moisture content
θ_s = porosity
n = curve fitting parameter
α = inverse air-entry potential.

The equation for the hydraulic conductivity curve is

$$K(h) = K_s \frac{\{1 - (\alpha h)^{n-1}\,[1 + (\alpha h)^n]^{1-1/n}\}^2}{[1 + (\alpha h)^n]^{l(1-1/n)}} \qquad (13)$$

where

$K(h)$ = unsaturated hydraulic conductivity
K_s = saturated hydraulic conductivity
l = pore interaction term.

Seven soil types were identified in the three barrier simulations. The seven soil types and sources of the hydraulic parameters are listed below in Table 6. A discussion of each soil type follows the table.

Table 6. Sources of hydraulic parameter values for UNSAT-H barrier simulations.

Soil Type	Source of Hydraulic Parameters
McGee Ranch Silt	Gee et al., 1989
Compacted Silt	UFA data and calculated from Silt
Silt/Pea Gravel Mix	Calculated from Silt
Filter Sand	UNSAT-H modeling in Fayer et al., (1992)
Filter Gravel	UNSAT-H modeling in Fayer et al., (1992)
Drainage Gravel/Crushed Basalt	Estimated by author and DOE-RL-93-33
Loamy Sand	Carsel and Parrish, 1988

6.3.1.1. McGee Ranch Silt.

Gee et al. (1989) packed 16 soil samples representative of the McGee Ranch silt to a density of 1.37 g/cm^3. The saturated hydraulic conductivity of the samples was determined using a falling head method. The water retention characteristics were obtained using hanging columns, pressure plates, and

$$\rho_p = \frac{\rho_{buc}}{1-\theta_s} \qquad (15)$$

where

ρ_{buc} = uncompacted bulk density
θ_s = uncompacted porosity.

Third, the UNGRA computer program (van Genuchten, 1988) was used to curve fit the UFA unsaturated conductivity data. The resultant hydraulic parameter estimates are presented in Table 8.

Table 8. UNSAT-H hydraulic parameters for compacted silt.

Parameter	Value
K_s (cm/sec)	5.236×10^{-4}
θ_s (cm^3/cm^3)	0.454
θ_r(cm^3/cm^3)	0.1114
α (1/cm)	0.0077
n	1.783

6.3.1.3. Silt/Pea Gravel Mix.

Hydraulic parameters for the silt/pea gravel mix were estimated from the silt parameters. The porosity and residual moisture content were reduced 8% to reflect the reduction in void volume due to the pea gravel addition. Bubbling pressure and saturated hydraulic conductivity were not significantly changed because flow would occur principally in the silt matrix. The reduced porosity and residual moisture content are 0.457 and 0.0045, respectively.

6.3.1.4. Filter Sand.

The hydraulic parameters for the filter sand were taken from Fayer et al. (1992).The moisture characteristic curve for sand was derived from combined data for two sands. The particle diameters were 0.5 to 1.0 mm and 0.25 to 0.5 mm. These sizes are comparable to the particle size distributions specified in DOE-RL-93-33 (i.e., D_{15} = 0.15-0.5 mm, D_{50} = 0.375-1.2 mm, and D_{85} = 0.7-2.5 mm). The hydraulic properties for the barrier filter sand are given in Table 9.

Table 9. UNSAT-H hydraulic properties for filter sand.

Parameter	Value
K_s (cm/sec)	0.109
θ_s (cm^3/cm^3)	0.445
θ_r(cm^3/cm^3)	0.010
α (1/cm)	0.0726
n	2.8

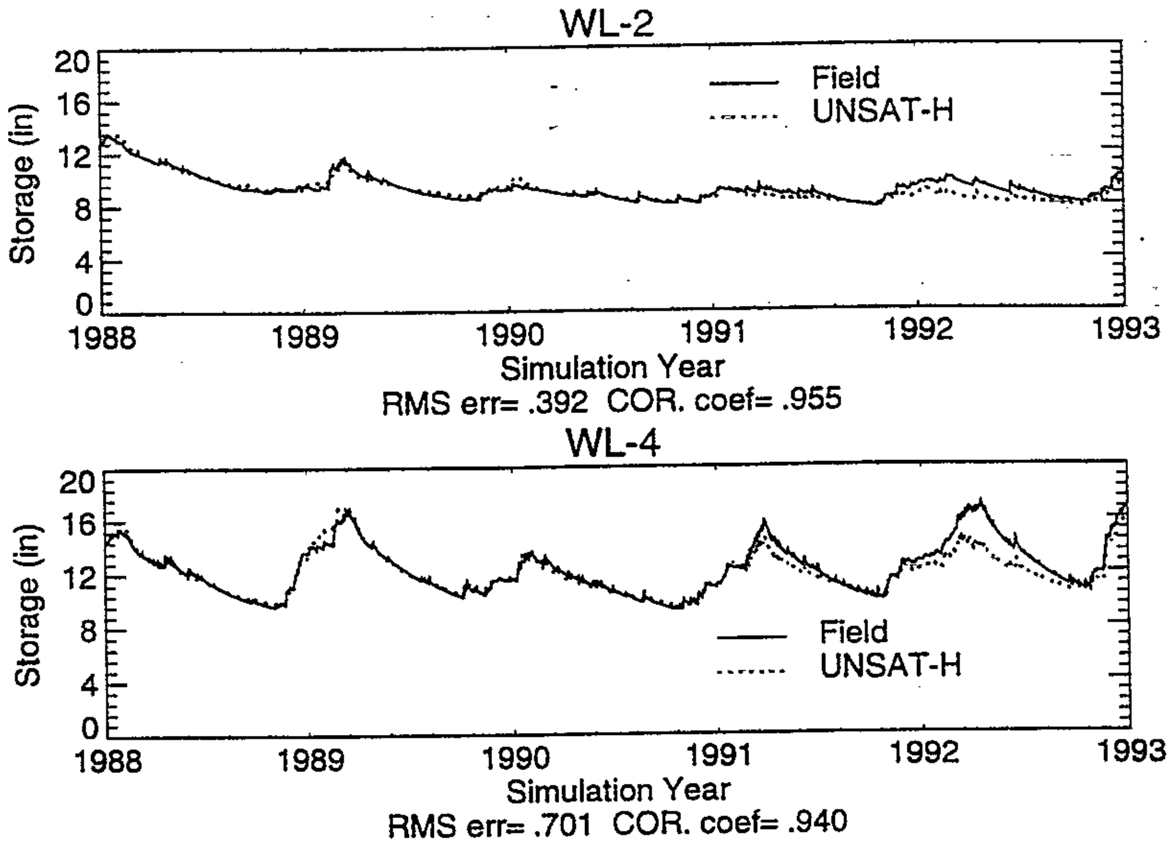

Figure 9. Validation results for McGee Ranch silt.

6.3.1.2. Compacted Silt.

The compacted silt properties were determined from unsaturated hydraulic conductivities of the compacted silt and from the compacted silt properties. The unsaturated conductivities were obtained from WHC and were determined using the Unsaturated Flow Apparatus (UFA) method (Conca and Wright, 1990). This method uses an open-flow centrifuge to achieve hydraulic steady state and Darcy's Law to calculate the unsaturated conductivity.

The compacted silt hydraulic parameters were then determined in three steps. First, the inverse air-entry potential (α) in Equation 13 was calculated from the uncompacted silt air entry potential, and from an empirical relation by Campbell (1985). The relation is

$$\psi_e = \psi_{es} (\rho_{bc}/\rho_{buc})^{0.67b} \qquad (14)$$

where

ψ_{es} = uncompacted silt air-entry potential
ρ_{bc} = compacted bulk density
ρ_{buc} = uncompacted bulk density
b = $-2\psi_{es} + 0.2\sigma_g$ in which σ_g is the particle size geometric standard deviation.

Second, the porosity was determined by calculating the particle density (ρ_p) from the relation gradient lower boundary condition more appropriate. The soil underlying the surface of the Hanford Site's 200 area was specified as a loamy sand. Proxy hydraulic parameters for this soil were selected by WHC as being the most representative of the Hanford Site soils for purposes of barrier design evaluation. The hydraulic parameters for this soil were taken from Carsel and Parrish (1998), and are listed in Table 12.

Table 12. UNSAT-H hydraulic properties for the representative Hanford Site soil.

Parameter	Value
K_s (cm/sec)	4.05×10^{-3}
θ_s (cm^3/cm^3)	0.410
θ_r(cm^3/cm^3)	0.057
α (1/cm)	0.124
n	2.000

6.3.2 Computational Grid

The model domain for each of the three barrier simulations was a one-dimensional vertical column. Computational grids were assigned to the three barrier profiles using exponentially decreasing and increasing spacing, moving respectively towards and away from soil type boundaries. Exponential spacing at material interfaces and profile boundaries results in the placement of more nodes in areas where they were needed (i.e., in areas at the surface where high gradients are caused by evaporation or infiltration and where high-gradients are caused by interfaces of different material types). The end result was to reduce pressure gradients across adjacent nodes and provide a more accurate solution. The simulation profiles are presented in Figure 10.

Two transition layers were included between the compacted silt and loamy sand in the RCRA Subtitle D computational grid. The transition layers were necessary to smooth out numerical instabilities resulting from the very different hydraulic properties of the two soils. Transitional layers were not necessary in the Hanford and RCRA Subtitle C simulations because these profiles included a fine filter sand below the final silt layer which behaved analogous to the transitional layers. The hydraulic parameters for the two transition layers were linearly interpolated between the compacted silt and loamy sand soils.

6.3.1.5. Filter Gravel.

Hydraulic parameters for the filter gravel hydraulic parameters were also taken from Fayer et al. (1992). A capillary pore model was used to calculate moisture contents for different tensions up to 0.27-cm. For tensions exceeding 0.27 cm, moisture contents were estimated.

Assumption of a 1-in. pore diameter for the capillary model resulted in simulation particle diameters that were near the center of the size distribution specified for the Hanford and Subtitle C barrier gravels (i.e., D_{15} = 1.5-2.0 mm, D_{50} = 15.0-20.0 mm, and D_{85} ≥37.5 mm for the Subtitle C barrier). The hydraulic properties of the filter gravel are given in Table 10.

Table 10. UNSAT-H hydraulic properties for filter gravel.

Parameter	Value
K_s (cm/sec)	0.350
θ_s (cm^3/cm^3)	0.419
θ_r(cm^3/cm^3)	0.005
α (1/cm)	4.93
n	2.19

Although the values of these parameters appear to be similar to those of a very coarse sand, they are believed to adequately represent the filter gravel well because of possible settling or infilling of the sand immediately above the gravel.

6.3.1.6. Drainage Gravel/Crushed Basalt.

The saturated hydraulic conductivity for the drainage gravel was specified in DOE/RL-93-33 to be 1 cm/sec. Because no experimental data are available for porous media similar to the drainage gravel and crushed basalt, the author relied on his experience to estimate the hydraulic properties. The values were assigned to permit rapid drainage of the gravel/crushed basalt. The assigned values for the parameters are given in Table 11.

Table 11. UNSAT-H hydraulic properties for drainage gravel/crushed basalt.

Parameter	Value
K_s (cm/sec)	1.0
θ_s (cm^3/cm^3)	0.400
θ_r(cm^3/cm^3)	0.005
α (1/cm)	10.0
n	3.0

6.3.1.7. Loamy Sand.

Because of the shallow depth of the RCRA Subtitle D cover, it was necessary to also simulate the soil beneath the cover. Including the soil beneath the cover in the conceptual model results in making a unit long, and tensions in the gravel and sand layers were low, the unit gradient boundary condition was a good choice for the Hanford and Subtitle C barriers. To ensure that the unit gradient boundary condition was appropriate for the Subtitle D barrier, the simulation profile was extended to include an additional layer. The additional layer was a loamy sand that extended 2 m beneath the barrier. The upper boundary condition was a function of meteorologic conditions that alternated between a flux or constant head, as discussed in Section 3.1.2.

6.3.4.1. Meteorologic Data

The UNSAT-H model requires daily records of meteorologic data to compute the upper boundary condition when the flux option is selected. The required parameters are maximum and minimum air temperature, dewpoint temperature, solar radiation, average wind speed, average cloud cover, and daily precipitation. With exception of dewpoint temperature, these meteorologic data were obtained from the Hanford Meteorology Station. Average dewpoint temperatures were calculated from the average relative humidity using an empirical relation from Linsley et al. (1982), described by

$$f = 100\left(\frac{112 - 0.1T + T_d}{112 + 0.9T}\right)^8, \tag{16}$$

where

f = relative humidity

T = the temperature in degrees celsius

T_d = the dewpoint temperature in degrees celsius.

Because the daily precipitation records collected at the Hanford Meteorology Station include all forms of precipitation, the precipitation amounts were modified during the winter months to account for snow accumulation and melting. This was accomplished by (a) calculating the average temperature as the midpoint between the minimum and maximum daily temperatures for each day, (b) accumulating as snow fall any precipitation that occurred on days in which the average temperature was at or below 32° F, and (c) calculating snowmelt by the degree-day method (Mockus, 1972) from the equation

$$M = CD, \tag{17}$$

where

M = snowmelt (in)

C = a with value 0.06

D = the number of degree-days.

A degree-day is a day with an average temperature that is 1° F above 32° F. In other words, the number of degree-days is the difference between the average temperature and 32° F. Use of the degree-day method results in the concentration of precipitation during freezing periods into a short duration at the end of the freezing period.

When the ground surface is covered with snow, the snow prevents most evaporation from occurring by insulating the ground from wind and solar radiation. As the ground freezes, the effective porosity and hydraulic conductivity are reduced by any remaining moisture freezing in the soil pores. Additionally, most vegetation becomes dormant during the winter months, thus reducing transpiration. To accurately simulate these processes, the PET was set to zero during a short period each winter. The criteria for selecting the start of the winter period was the beginning of the first extended period in which the average temperature fell below freezing. Conversely, the criterion for selecting the last day of the winter period was the day preceding

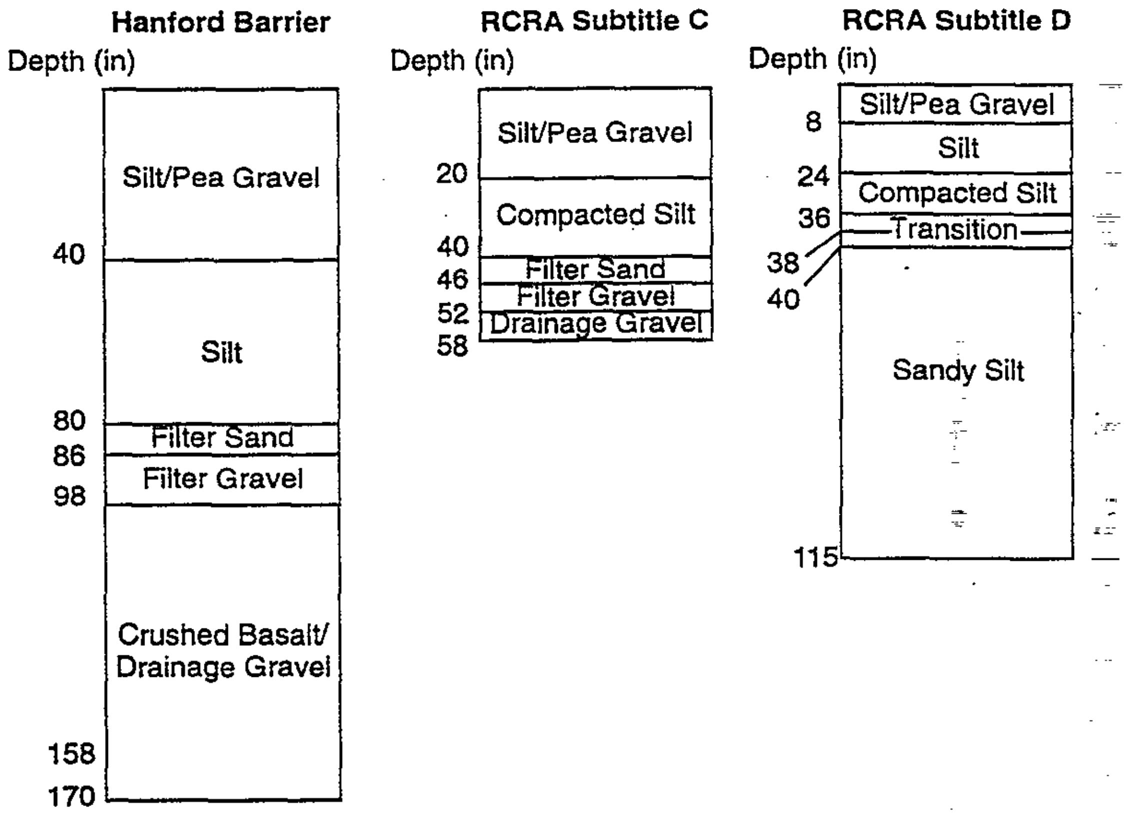

Figure 10. UNSAT-H simulation profiles.

The computational grids for each barrier were evaluated for numerical stability by performing three checks. First, the number of nodes in each profile was increased by 50%, and simulated tensions were compared before and after the grid refinement. Next, the numerical solutions from each simulation were inspected for oscillations. Finally, the convergence criterion was specified to ensure that the mass balance error was relatively small compared to the total storage and precipitation.

6.3.3 Initial Conditions

Near-surface movement of moisture is dynamic because the driving forces of precipitation and evaporation are continually changing. Estimation of initial conditions must consider this dynamic nature. The method used in this study was to begin with uniform, low tensions (i.e., the initial moisture content was higher than the final moisture content). The simulation period was then rerun repetitively until a quasi-steady-state condition was achieved. To verify a quasi-steady-state condition was reached, two criteria were evaluated. The first criterion was that the difference between initial and ending tension was less than 2%. The second criterion was that drainage did not monotonically decrease during the simulation period (i.e., the wet initial conditions were no longer influencing drainage).

6.3.4 Boundary Conditions

The lower boundary condition for each simulation was specified as a unit gradient for all three barriers (i.e., water movement across the bottom boundary of the model domain is influenced only by gravity). The distance from the lowermost silt layer to the bottom boundary was 2.25 m for the Hanford barrier and 0.45 m for the Subtitle C barrier. Because the distance to the bottom boundary was relatively

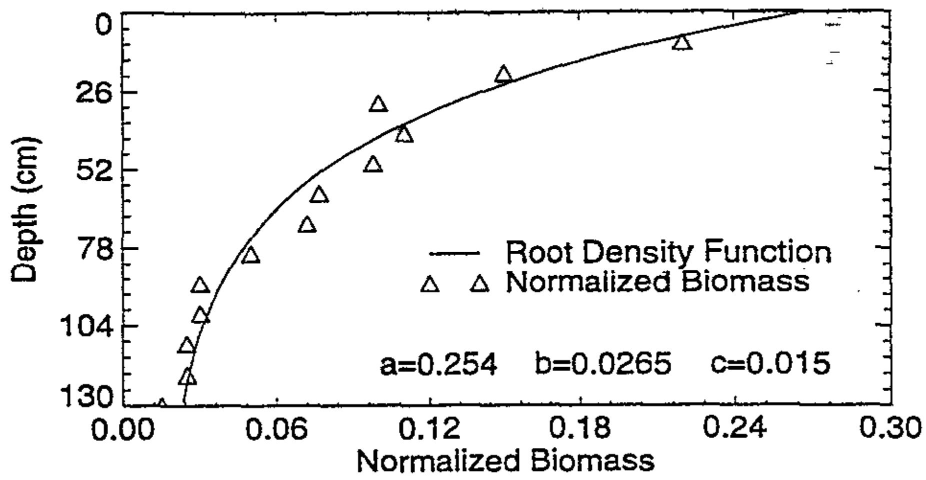

Figure 11. Fitted root density function.

Because the bluebunch wheatgrass is a perennial species, the rooting depth was assumed to be constant at the maximum depth (130 cm) throughout the growing season.

Other transpiration parameters required by UNSAT-H are the soil tensions at the wilting point, at the point where transpiration begins to slow, and at the point where the plants cease to transpire because of anaerobic conditions. The wilting point was assumed to occur at 15 bars. The tension at which transpiration slows was assumed to occur when the unsaturated hydraulic conductivity decreased four orders of magnitude from the saturated hydraulic conductivity.

Finally, UNSAT-H also requires the fraction of the surface covered by plants, the above-surface biomass, the parametrization of partitioning between evaporation and transpiration, and the growing season. The fractional plant coverage was assigned at 15%. The plant shoot biomass was assigned a value of 220 g/ m^2. These estimates were based on personal conversations with Mike Fayer of Pacific Northwest Laboratories. Because no reliable LAI data were available for bunchgrass, the UNSAT-H option for partitioning based on cheatgrass data was used. The growing season was specified to commence on day 68 and end on day 243. These dates provided an equivalent growing season length for the UNSAT-H and HELP simulations. However, when the evaporation/transpiration partitioning option for cheatgrass was selected, the occurrence of the growing season start date is constrained after day 273 or before day 91, and the end date is constrained between day 151 and day 243. It is important to note that this is only the potential growing season. If moisture contents drop below the wilting point, the plants will cease transpiring and simulate a dormant period until moisture contents rise above the wilting point.

Appendix A contains the UNSAT-H input decks used in the ambient precipitation simulations for the Hanford, RCRA Subtitle C, and RCRA Subtitle D barriers.

6.3.5 UNSAT-H Simulation Results

A summary of average annual water balance totals for the 10-year simulation period is presented in Table 14. These results indicate that nearly 100% of total precipitation will leave the soil through evapotranspiration for all scenarios except the 2x ambient for the Subtitle D barrier. Drainage out of the simulated Subtitle D cover, for the 2x ambient precipitation condition, accounted for 2% of the total precipitation.

the first period in which the average temperature was above freezing. Table 13 presents the last and first days of the winter period for each calendar year of the simulation.

Table 13. Winter period, by calendar year.

Year	Last Day	First Day
1979	36	313
1980	35	319
1981	42	347
1982	42	316
1983	38	334
1984	36	327
1985	41	314
1986	51	313
1987	25	347
1988	37	336

6.3.4.2. Parameterization of Transpiration

Because the barriers were designed to maximize evapotranspiration, it was necessary to address the effects of plant transpiration in analyzing barrier performance.

UNSAT-H requires several parameters to estimate the effect of plant transpiration on the soil water balance. Because no data were available on the species of vegetation that may populate the barrier surface, values for these parameters were estimated. The parameters chosen and the basis for choosing these parameters are discussed in the following paragraph.

Several parameters related to plant roots are required by UNSAT-H. These are the rooting depth, the root density function, and the day on which roots are assumed to reach various depths. The rooting depth and the root depth function were derived from data provided in Fayer and Jones (1990). Root mass as a function of depth was provided for indigenous bluebunch wheatgrass at the Hanford Site. The maximum root depth was assigned a value of 130 cm. This was the lower depth of the 10-cm interval in which root mass was less than 2% of the total root mass. The rooting density function is an exponential curve in which constants are chosen to match the normalized root mass with depth. The root density function is

$$RLD = Ae^{-Bz} + C, \tag{18}$$

where

RLD = root length density
A = root density at surface
B = exponential fitting parameter
C = constant root density at depth.

The root mass data from Fayer and Jones were normalized and fit to the root density function using a non-linear least-squares method with weighting inverse to depth (i.e., the data points near the surface were weighted more than deeper data points). The normalized data and fitted curve are illustrated in Figure 11.

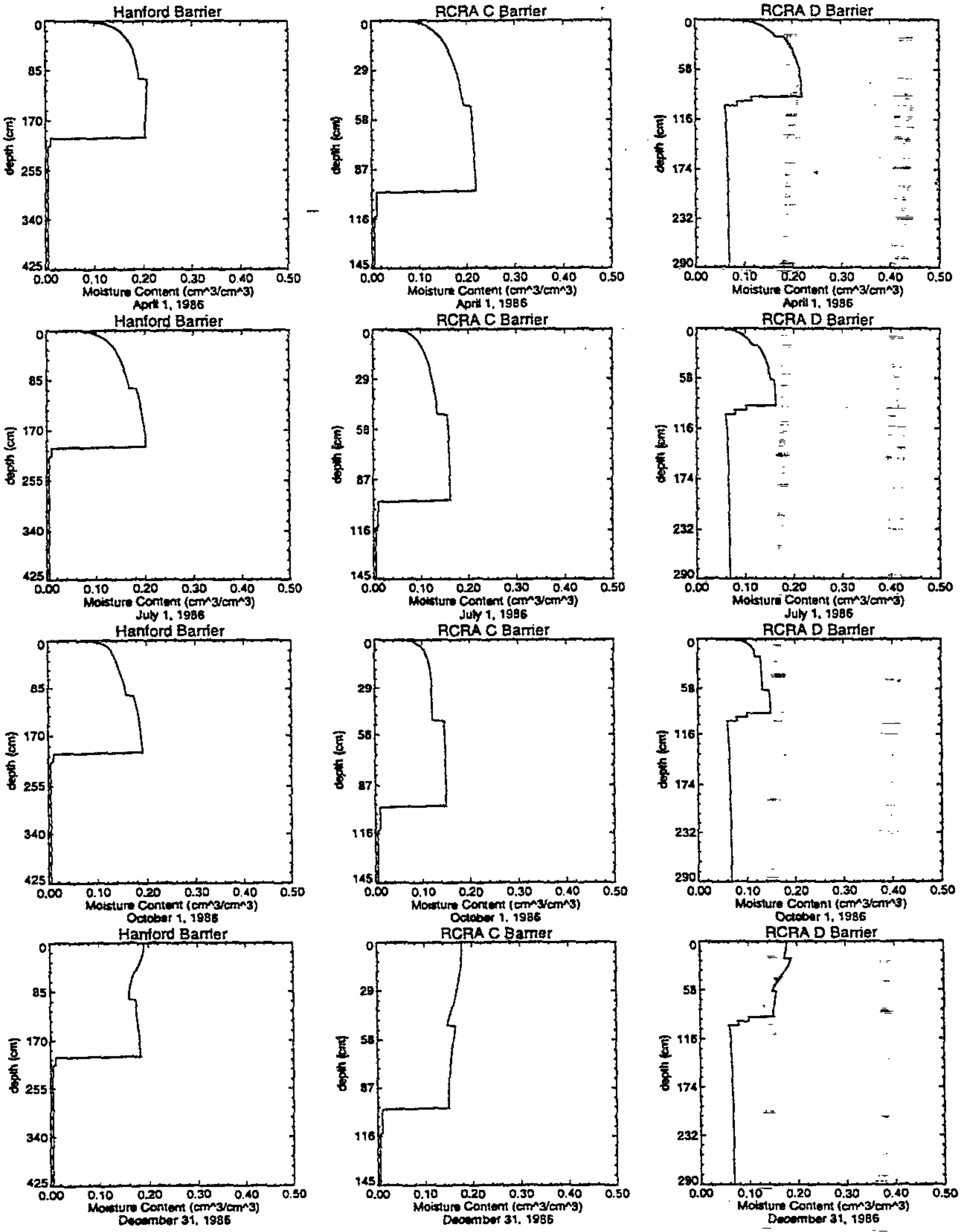

Figure 12. Hanford, RCRA C, and RCRA D ambient precipitation moisture content profiles.

Table 14. Average annual water balance totals from the UNSAT-H simulations.

Precipitation Treatment	Precipitation (in)	Runoff (in)	Evaporation (in)	Transpiration (in)	Drainage (in)
Hanford Barrier					
Ambient	6.99	0.0	6.84	0.157	0.0
Double	13.98	0.0	13.79	0.212	0.0
Subtitle C Barrier					
Ambient	6.99	0.0	6.33	0.668	0.0
Double	13.98	0.0	13.14	1.017	0.0
Subtitle D Barrier					
Ambient	6.99	0.0	6.33	0.670	0.002
Double	13.98	0.0	12.97	0.751	0.269

The UNSAT-H results also illustrate the dramatic effect that the capillary barrier materials have on soil moisture contents. Moisture contents in the sands and gravels are remained very low and nearly constant throughout the modeling period while the moisture contents in the overlying silts varied from 10 to 40%. The low static moisture contents in the sand and gravel represent the residual moisture content and do not indicate significant amounts of water is moving out of the overlying silts. The results also indicate the RCRA Subtitle C and D barriers outperformed the Hanford barrier in returning more moisture to the surface through transpiration. The UNSAT-H simulations predicted RCRA subtitle C transpiration would be almost 5x more than that of the Hanford barrier. The difference is most likely due to the fact that the relatively shallow storage layers in the subtitle C and D barriers retain more water closer to the plant roots.

To illustrate the soil moisture dynamics occurring in the barrier profiles, moisture content and soil tension profiles are illustrated in Figures 12 through 15. The profiles represent a spring, summer, fall, and winter time plane for each barrier and precipitation treatment for a representative year of the simulation period. The year 1986 is illustrated because the total precipitation that occurred during this year was close to the average precipitation over the entire simulation period.

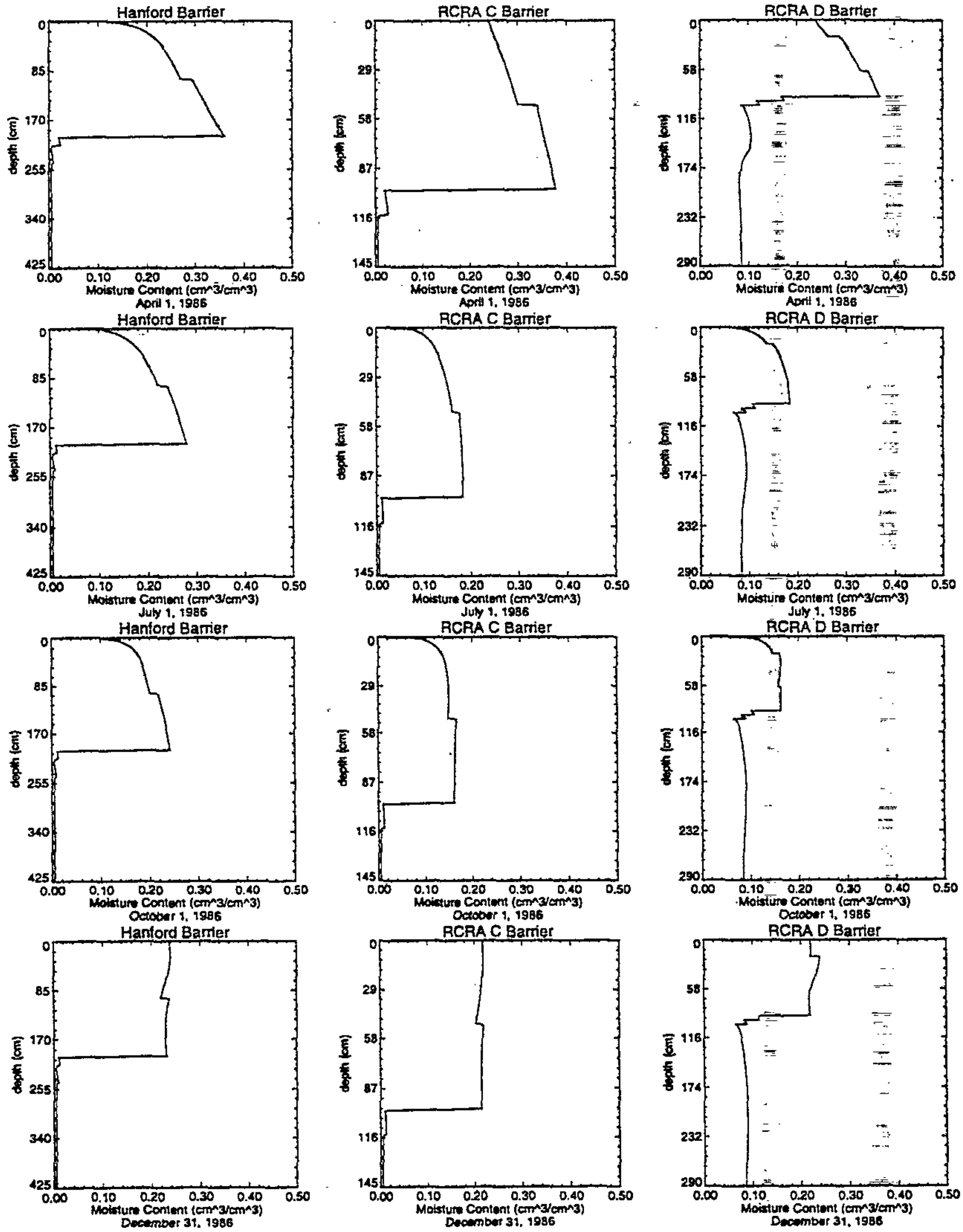

Figure 14. Hanford, RCRA C, and RCRA D 2x ambient moisture content profiles.

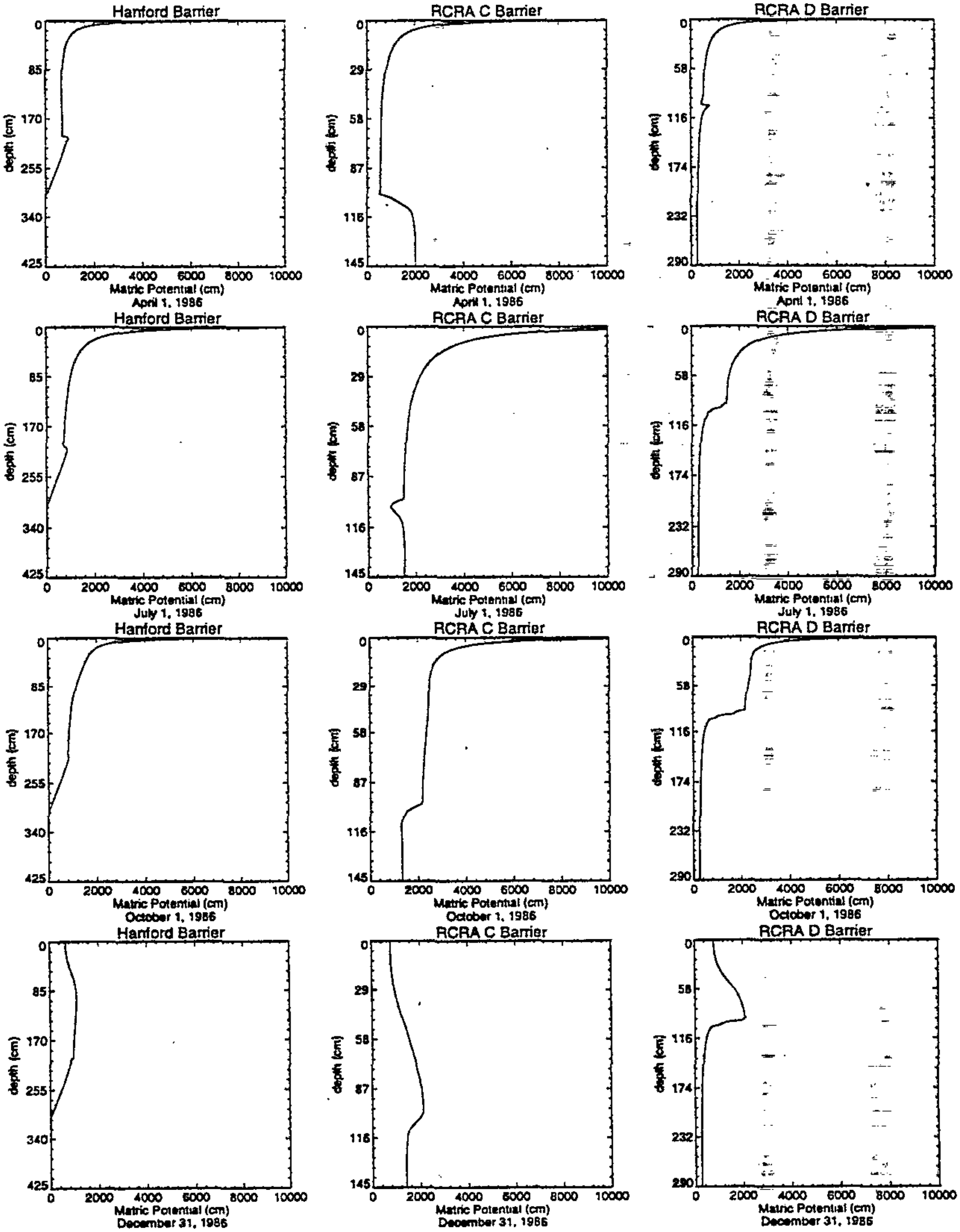

Figure 13. Hanford, RCRA C, and RCRA D ambient precipitation matric potential profiles.

6.4 Application of HELP

The HELP model requires three general types of input data: soil hydraulic properties, cover design specifications, and climatological records. Each data type is discussed in the following sections.

6.4.1 Soil Hydraulic Data

Eight material types were identified for the HELP barrier simulations. The material types and the source of the hydraulic parameters are presented in Table 15. Each soil type and source of the hydraulic parameters is discussed in the sections following the table.

Table 15. Sources of hydraulic parameters used in HELP barrier simulations.

Soil Type	Source of Hydraulic Parameters
Silt	Weighing Lysimeter Calibration
Compacted Silt	Calculated from Silt
Silt/Pea Gravel Mix	Calculated from Silt
Filter Sand	HELP Default Textural Type 3
Filter Gravel	HELP Default Textural Type 1
Drainage Gravel/Crushed Basalt	HELP Default Textural Type 1 and DOE-RL-93-33
Asphalt	DOE-RL-93-33
Loamy Sand	Carsel and Parish, 1988

6.4.1.1. Silt.

Hydraulic properties for the uncompacted silt were obtained by calibration to the FLTF weighing lysimeters, as discussed in Section 5 and is presented in Table 3.

6.4.1.2. Compacted Silt.

The compacted silt hydraulic parameters were derived from the calibrated silt parameters by applying the compaction algorithm from the HELP user's guide (Shroeder et al., 1989). The hydraulic parameters were adjusted as follow: (a) the saturated hydraulic conductivity was reduced by a factor of 20, (b) the porosity was reduced by 25%, and (c) the field capacity was reduced by 25% of the difference between the uncompacted silt field capacity and the wilting point. The resulting parameters are presented in Table 16.

Table 16. HELP hydraulic parameters for compacted silt.

Parameter	Value
Porosity (cm^3/cm^3)	0.385
Field Capacity (cm^3/cm^3)	0.165
Wilting Point (cm^3/cm^3)	0.060
Saturated Conductivity (cm/s)	5.00×10^{-6}

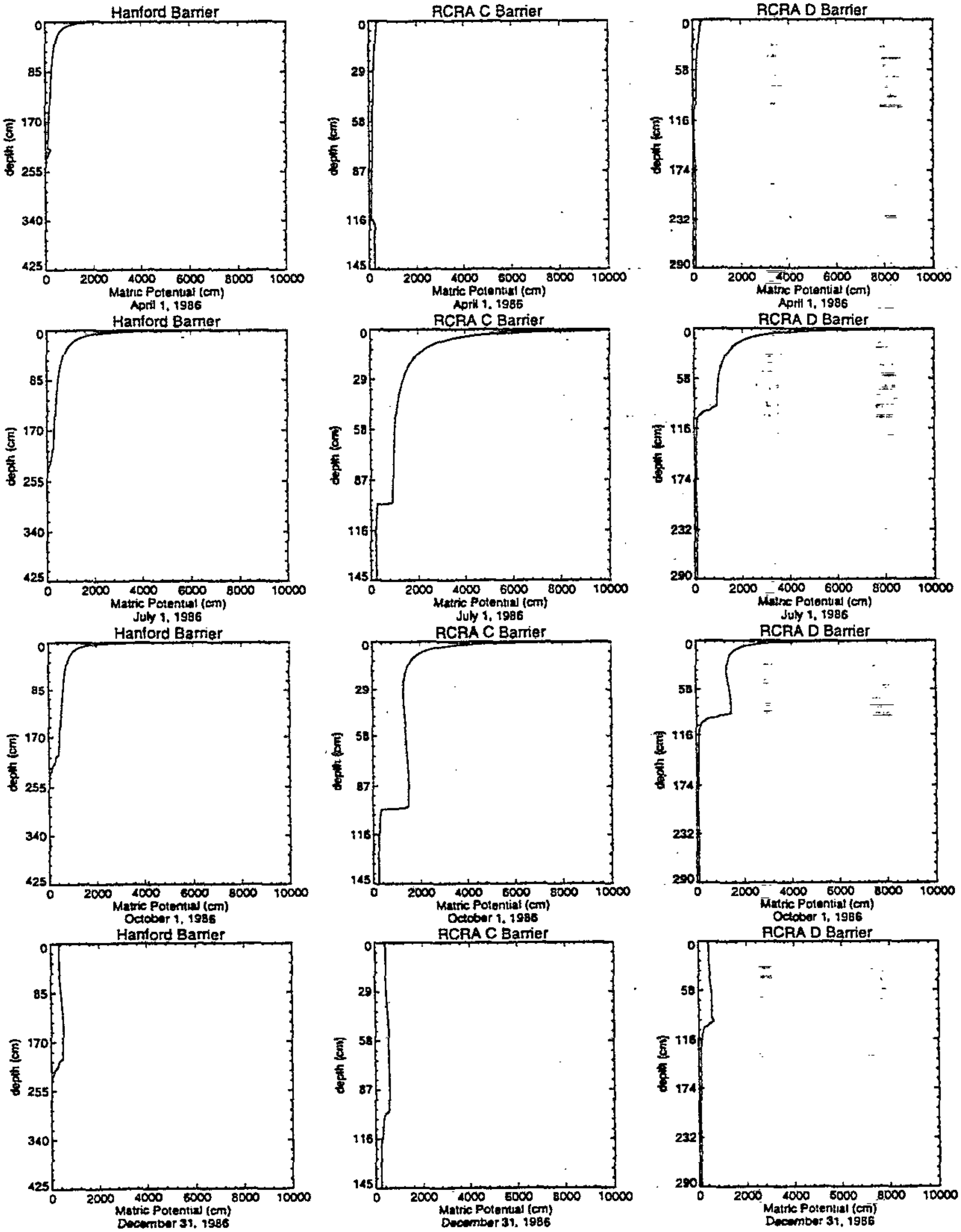

Figure 15. Hanford, RCRA C, and RCRA D 2x ambient matric potential profiles.

Table 19. HELP hydraulic parameters for asphalt.

Parameter	Value
Porosity (cm^3/cm^3)	0.022
Field Capacity (cm^3/cm^3)	0.021
Wilting Point (cm^3/cm^3)	0.020
Saturated Conductivity (cm/s)	1×10^{-8}

Initial conditions for each soil type were obtained by rerunning each simulation with moisture contents from the previous simulation until a quasi-steady-state condition was reached. The quasi-steady-state condition was defined to occur when moisture contents between the simulation start and end differed by less than 1%.

6.4.1.8. Loamy Sand.

To make the UNSAT-H and HELP simulations equivalent, the soil underlying the RCRA Subtitle D barrier was also included in the Subtitle D simulation profile. The source of the loamy sand hydraulic parameters was the same as for the UNSAT-H simulations. However, the wilting point and field capacity moisture contents were calculated from the van Genuchten parameters listed in Section 6.3.1.7 at 15 and 1/3 bars tension, respectively. These parameters are given in Table 20.

Table 20. HELP hydraulic properties for the representative Hanford Site soil.

Parameter	Value
Porosity (cm^3/cm^3)	0.410
Field Capacity (cm^3/cm^3)	0.065
Wilting Point (cm^3/cm^3)	0.057
Saturated Conductivity (cm/s)	4.05×10^{-3}

6.4.2 Barrier Design Data

The hydraulic properties discussed in the previous sections were applied to the barrier profiles as illustrated in Figure 16.

6.4.1.3. Silt/Pea Gravel Mix.

Hydraulic properties for the silt/pea gravel mix were derived from the uncompacted silt. The porosity, field capacity, and wilting point were reduced by 8% to reflect the reduced void volume occupied by the pea gravel. The porosity, field capacity, and wilting point were reduced to 0.474, 0.1824, and 0.0553 cm^3/cm^3, respectively.

6.4.1.4. Filter Sand.

The sand filter layer was simulated as the HELP default textural type 3 soil (fine sand). The hydraulic properties for this default soil are listed in Table 17.

Table 17. HELP hydraulic parameters for filter sand.

Parameter	Value
Porosity (cm^3/cm^3)	0.457
Field Capacity (cm^3/cm^3)	0.083
Wilting Point (cm^3/cm^3)	0.033
Saturated Conductivity (cm/s)	0.0031

6.4.1.5. Filter Gravel.

The filter gravel hydraulic properties were also taken from the HELP default soils. The soil type was specified as HELP default soil 1 (coarse sand). The hydraulic properties are given Table 18.

Table 18. HELP hydraulic parameters for filter gravel.

Parameter	Value
Porosity (cm^3/cm^3)	0.417
Field Capacity (cm^3/cm^3)	0.045
Wilting Point (cm^3/cm^3)	0.020
Saturated Conductivity (cm/s)	0.01

6.4.1.6. Drainage Gravel/Crushed Basalt.

Hydraulic parameters specified for the drainage gravel and crushed basalt were identical except that the crushed basalt was specified as a vertical infiltration layer and the drainage gravel was specified as a lateral drainage layer. Their hydraulic properties, except for saturated hydraulic conductivities were taken from the HELP default soil type 1. The saturated hydraulic conductivities were increased to 1.0 cm/sec, as specified in DOE-RL-93-33.

6.4.1.7. Asphalt.

The asphalt was modeled as a low conductivity layer. Its hydraulic properties were taken from DOE-RL-93-33. These asphalt hydraulic properties are given in Table 19.

potential gradients were larger in the ambient simulations due to dryer conditions at the soil surface. Although soil surface was also dryer in the RCRA Subtitle D ambient simulations, the evaporative zone depth increased significantly for the 2x precipitation scenario. This was primarily due the fact that more water was available deeper in the profile. Figures 12 and 14 illustrate there is an increase in the Subtitle D loamy sand moisture content for the 2x ambient precipitation conditions over the ambient conditions while the Hanford and Subtitle C profiles illustrate there is no increase in sand and gravel moisture content. From a barrier performance standpoint, these results indicate the sand and gravel materials provide a more effective capillary break and due not allow the evaporative zone depth to extend beyond the lowest silt layer.

The runoff number was specified as 87.2, which was the same value used in the DOE-RL-93-33 simulations. The LAI was 1.6 and was obtained from the HELP calibration exercise. This value corresponds to a point midway between a poor and medium grass as indicated by the HELP User's Guide.

6.4.3 Climate Data

Precipitation data used in the HELP simulations were identical to the those used for the UNSAT-H simulations. The precipitation values were not adjusted to account for freezing and melting because HELP makes this adjustment internally. In addition to entering precipitation data, the normal mean monthly temperatures were included in the simulation. HELP uses these temperatures to condition the stochastically generated solar radiation values.

Appendix B contains the HELP soil and design (DATA10) input decks used in the Hanford, RCRA Subtitle C, and RCRA Subtitle D ambient precipitation simulations.

6.4.4 HELP Simulation Results

Results from the HELP ambient and 2x ambient precipitation simulations are presented in Table 22. These results indicate that the three barriers will perform as designed; that is, they will intercept and return > 99% of the ambient precipitation to the atmosphere. The small amount of vertical drainage that is predicted to occur out of the Hanford and RCRA Subtitle C barriers probably is an artifact of the assumed saturated conditions and unit gradient in the barrier layers. The total hydraulic gradient through a barrier layer is calculated in HELP as

$$\frac{dh}{dl} = \frac{TH + TS}{TS}, \qquad (19)$$

where

h = total head

l = vertical distance

TH = total head on barrier layer

TS = barrier layer thickness.

Equation 19 illustrates even if no water is ponded over the barrier layer, a unit gradient is still imposed on the saturated barrier layer. To maintain mass balance in the simulation profile, the small amount of water that does infiltrate down to the barrier layer is routed through the barrier layer instead of to lateral drainage.

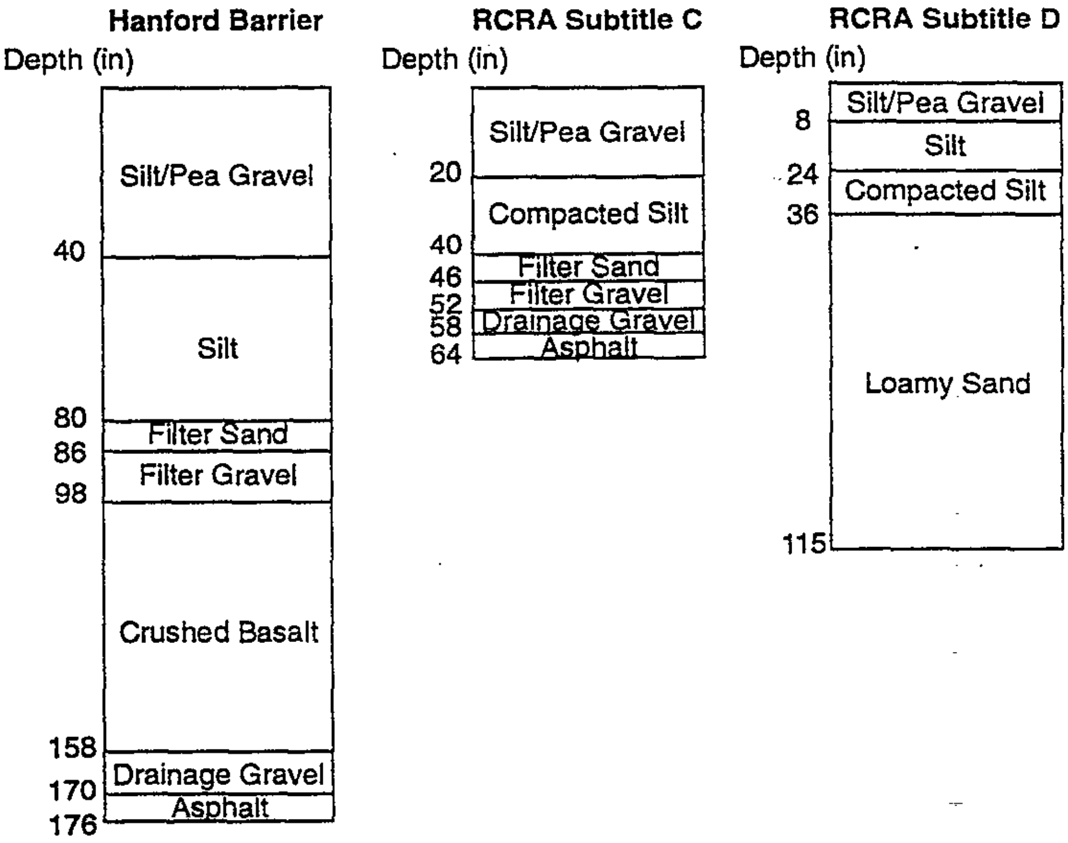

Figure 16. Barrier profiles for the HELP simulations.

The evaporative depths for the HELP simulations were determined from the results of the UNSAT-H simulations. The depth of the lowest point where water was seen to move upwards was averaged over the entire simulation period for the ambient and 2x precipitation scenarios for each barrier. The evaporative zone depths for the two scenarios is presented in Table 21.

Table 21. HELP simulation evaporative zone depths.

Barrier	Evaporative Zone Depth (in)	
	Ambient Precipitation	2x Ambient Precipitation
Hanford	69.2	65.3
RCRA Subtitle C	32.0	29.9
RCRA Subtitle D	29.2	47.5

The Hanford and RCRA Subtitle C simulations indicated the 2x ambient precipitation evaporative zone depth would decrease slightly decrease from the ambient precipitation depth. This is because the matric included in the HELP simulations to make the UNSAT-H and HELP simulations equivalent. This additional layer permitted more storage capacity in the Subtitle D simulations than in the Subtitle C simulations.

The results of the Subtitle D 2x precipitation simulations illustrate that HELP will not always be conservative in predicting drainage (i.e., over-estimate drainage) when compared to a more physically based model. This HELP simulation indicated that less drainage would occur than was indicated by the equivalent UNSAT-H simulation. The UNSAT-H simulation indicated that approximately 2% of the total precipitation would drain from the profile, while the equivalent HELP simulation indicated that less than half of this amount would drain from the profile.

The most likely reason HELP can under-predict deep infiltration at an arid site is related to the assumption of a static evaporative zone. As discussed in Section 5.4, many arid and semi-arid climates have a rainy season. During that time, the evaporative zone depth can be greatly reduced. It is at these times when most deep infiltration can occur. This dynamic nature of the Hanford Site evaporative zone depth, as predicted by the UNSAT-H simulations, is illustrated in Figure 17. The lowest depths from which moisture was observed to move upwards for representative dry, average, and wet year, is plotted in the figure for each barrier. The dry, average and wet years correspond to 1988, 1981, and 1983, respectively. Figure 19 also illustrates that the Hanford Site evaporative zone depths can change with seasonal and long-term precipitation trends, as well as with differences in soil layering.

Table 22. Average annual water balance totals from HELP ambient and 2x ambient precipitation simulations.

Precipitation Treatment	Precipitation (in)	Runoff (in)	Evaporation (in)	Lateral Drainage (in)	Drainage (in)
Hanford Barrier					
Ambient	6.99	0.001	6.99	0.0	0.0004
Double	13.98	0.180	13.80	0.0	0.0004
Subtitle C Barrier					
Ambient	6.99	0.001	6.99	0.0	0.0001
Double	13.98	0.233	12.22	1.41	0.118
Subtitle D Barrier					
Ambient	6.99	0.001	6.99	NA	0.0009
Double	13.98	0.210	13.66	NA	0.1131

Significant lateral and/or vertical drainage was simulated to occur in the RCRA Subtitle C and D barriers under the 2x ambient precipitation scenario. Lateral drainage accounted for 10% and vertical drainage accounted for 1% of the average annual precipitation in the Subtitle C simulation. In the Subtitle D simulation, vertical drainage also accounted for 1% of the precipitation.

The design storm analysis showed no significant increase in percolation or lateral drainage in the three barrier designs. In each design storm analysis, only the runoff amounts increased significantly. This is due to the fact that the design storm precipitation was applied after the largest infiltration event, when soil moisture was at its highest levels. Much of the additional water applied at this time contributed to runoff because the infiltration capacity of the soil and the storage capacity of the vegetation was already exceeded. The peak daily runoff values for each barrier as a result of the design storm is presented in Table 23.

Table 23. Design storm runoff for each barrier simulation.

Barrier	Runoff (in.)
Hanford	0.846
RCRA Subtitle C	0.910
RCRA Subtitle D	0.600

6.5 Discussion of Results

Barrier performance results from the HELP and UNSAT-H models were similar for all simulations, except the RCRA Subtitle C and D 2x precipitation scenarios. UNSAT-H indicated that significant drainage would occur only for the Subtitle D barrier design for 2x precipitation conditions. HELP also predicted that significant lateral flow (i.e., drainage in the UNSAT-H simulations) would occur for the Subtitle C barrier design, for 2x precipitation conditions.

The reason that the Subtitle D barrier was indicated by HELP to outperform the Subtitle C barrier was the inclusion of an additional 2 m of soil underlying the Subtitle D barrier. The additional soil was

7. CONCLUSIONS

The results of this study indicate that the three engineered barriers designed to minimize deep percolation will perform as expected. The simulations indicate that the three barriers will intercept, store, and return nearly 100% of total precipitation under ambient and design storm conditions. However, if precipitation is increased to 2x ambient, both the RCRA Subtitle C and D barriers will approach saturation. Under these conditions, the RCRA Subtitle C and D barriers will approach their design performance limits, and any additional water applied will result in significant drainage. The RCRA Subtitle D barrier drained nearly 2% of the precipitation under these conditions.

The HELP Model Version 2.05 may successfully account for near-surface capillarity at an arid site only if the depth of the evaporative zone is known beforehand. However, its assumption of a static evaporative zone depth may preclude its use at northern arid sites because the evaporative zone depth is rarely constant. The HELP Code can either under-estimate or over-estimate deep infiltration at the Hanford Site. The evaporative zone depth is the most ill-defined hydraulic parameter at the Hanford Site, and is the most sensitive input in the HELP model when plant transpiration is included in the simulations. Before HELP can be applied with confidence at the Hanford Site, a better estimate of an average evaporative zone depth is needed. An easily obtained estimate may not be feasible because, if an evaporative depth is determined for a particular soil and soil profile as was done for the weighing lysimeter; it may be appropriate only to that particular application. Furthermore, the Hanford Site's evaporative zone depth may vary significantly with seasonal weather patterns.

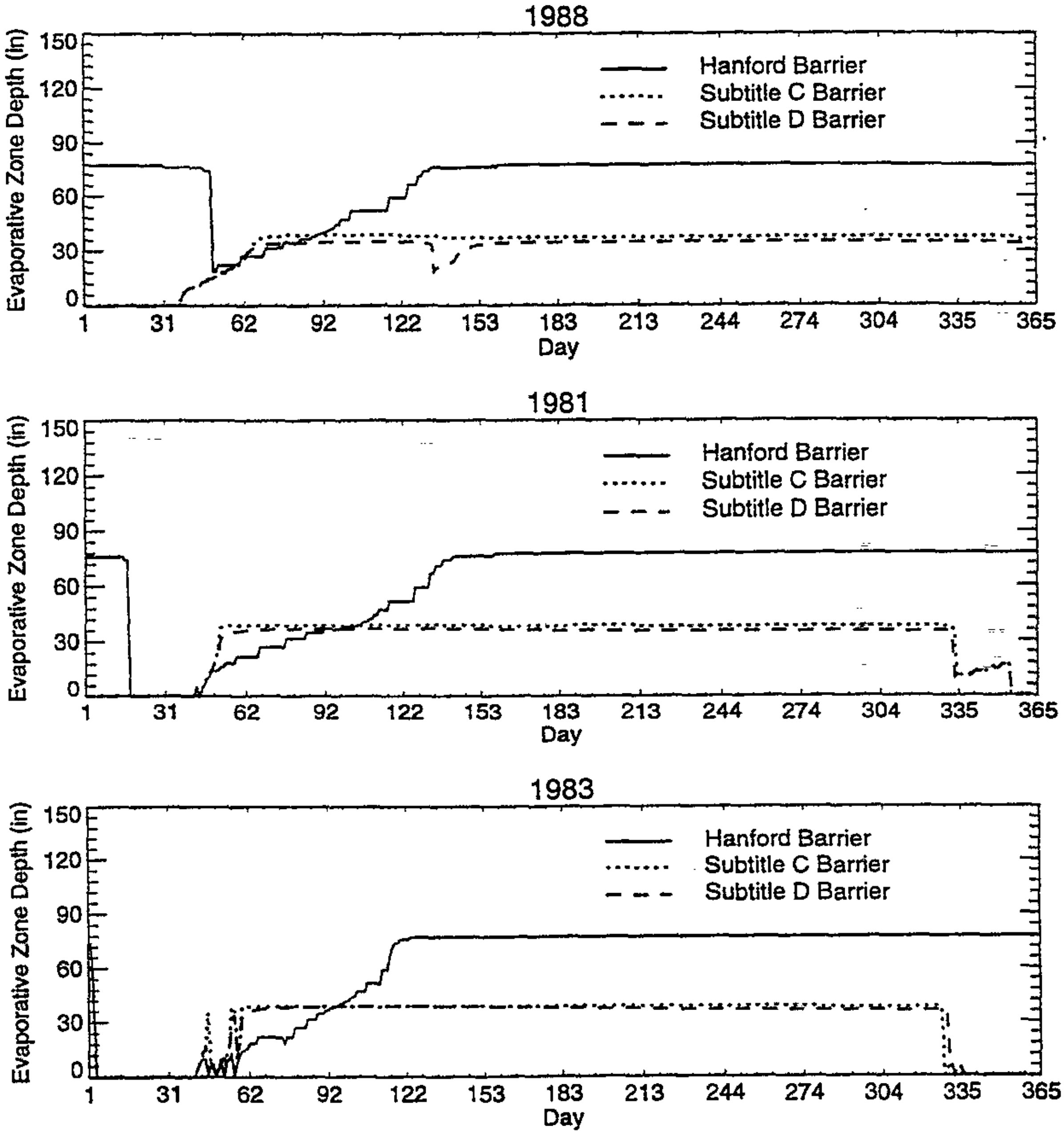

Figure 17. Evaporative zone depths from UNSAT-H barrier simulations.

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Appendix A
UNSAT-H Input Data Decks

This appendix contains the Hanford, Subtitle C, and Subtitle D input data decks for the ambient precipitation simulations. It includes the ISNOW parameter set to 1 for the modification which sets the potential evapotranspiration to zero during a short period each winter. Details of this modification is discussed in Section 6.3.4.1. The meteorological data set for the input decks are not included for brevity.

A.1 Hanford Barrier Input Deck

```
HANFORD SITE BARRIER FEASIBILITY STUDY: tru barrier, 6 layers
 1    1    1    1    0    1    1            IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
 0   365  365   1    1    0         1.0    NPRINT,DAYEND,NDAYS,NYEARS,IRAIN,ICONVH,OUTTIM
 1    2    0    1    1                     NSURPE,NFHOUR,ITOPBC,ET_OPT,ICLOUD
 4    3    1    0    5    5                KOPT,KEST,IVAPOR,SH_OPT,INMAX,INHMAX
 0.000E+00 5.00E+04    50.0       5.0E+1   HIRRI,HDRY,HTOP,DHMAX
 1.000E-04    1.00    1.E-04      24.0     DMAXBA,DELMAX,DELMIN,STOPHR
 0.66       283.00       .24       0.0     TORT,TSOIL,VAPDIF,QHTOP
 -1.E-4     283.00    10.00E+00     0.0    TGRAD,TSMEAN,TSAMP,QHLEAK
 0.5        2.00      1.000E-03   5.0E-1   1         WTF,RFACT,RAINIF,DHFACT,isnow
    6    79                                MATN,NPT
   1     .0000   1     .3462   1     .7356   1    1.1737
   1    1.6665   1    2.2210   1    2.8448   1    3.5465
   1    4.3360   1    5.2242   1    6.2234   1    7.3474
   1    8.6120   1   10.0347   1   11.6351   1   13.4357
   1   15.4613   1   17.7401   1   20.3038   1   23.1879
   1   26.4326   1   30.0828   1   34.1893   1   38.8091
   1   44.0064   1   49.8534   1   61.6346   1   75.6538
   1   85.0000   1   91.2308   1   95.3846   1   98.1538
   2  100.0000   2  101.8462   2  104.6154   2  108.7692
   2  115.0000   2  124.3462   2  138.3654   2  161.6346
   2  175.6538   2  185.0000   2  191.2308   2  195.3846
   2  198.1538   3  200.0000   3  201.8462   3  204.6154
   3  210.3846   3  213.1538   4  215.0000   4  216.8462
   4  219.6154   4  223.7692   4  236.2308   4  240.3846
   4  243.1538   5  245.0000   5  246.8462   5  249.6154
   5  253.7692   5  260.0000   5  269.3462   5  283.3654
   5  304.3942   5  335.6058   5  356.6346   5  370.6538
   5  380.0000   5  386.2308   5  390.3846   5  393.1538
   6  395.0000   6  396.8462   6  399.6154   6  403.7692
   6  410.0000   6  419.3462   6  425.0000
 Soil Number 1 McGee Ranch Silt/Pea Gravel
     .4570    .00450    0.0163    1.3700
 Soil Number 1 McGee Ranch Silt/Pea Gravel
   2.0000    3.5640    0.0163    1.3700     .0000
 Soil Number 2 McGee Ranch Silt
     .4960    .00490    0.0163    1.3700
 Soil Number 2 McGee Ranch Silt
   2.0000    3.5640    0.0163    1.3700     .0000
 Soil Number 3 Fayer's lysimter sand
     .4450    .01000    0.0726    2.8000
 Soil Number 3 Fayer's lysimter sand
   2.0000    394.00    0.0726    2.8000     .5000
 Soil Number 4 gravel filter, Fayer's lysimeter gravel
     .4190    0.0050    4.9300    2.1900
 Soil Number 4 gravel filter, Fayer's lysimeter gravel
   2.0000    1260.0    4.9300    2.1900     .5000
 Soil Number 5 Crushed Basalt, my estimation
     .4000    .00500    10.000    3.0000
 Soil Number 5 Crushed Basalt, my estimation
   2.0000    3600.0    10.000    3.0000     .5000
 Soil Number 6 Lateral Drainage, my estimation
     .4000    .00500    10.000    3.0000
 Soil Number 6 Lateral Drainage, my estimation
   2.0000    3600.0    10.000    3.0000     .5000
    0     (TOSS.OUT file for day  3.65000E+02)           NDAY (UNSAT-H V2.01)
   1.03471E+03    1.03453E+03    1.03471E+03    1.03540E+03    Head Values
   1.03681E+03    1.03919E+03    1.04288E+03    1.04834E+03
```

Appendix A
UNSAT-H Input Data Decks

```
     .4540     .11140     0.0077     1.7830
  Soil Number 2 Compacted McGee Ranch Silt
    2.0000    1.8850     0.0077     1.7830      .0000
  Soil Number 3 Fayer's lysimter sand
     .4450     .01000     0.0726     2.8000
  Soil Number 3 Fayer's lysimter sand
    2.0000    394.00     0.0726     2.8000      .5000
  Soil Number 4 gravel filter, Fayer's lysimeter gravel
     .4190     0.0050     4.9300     2.1900
  Soil Number 4 gravel filter, Fayer's lysimeter gravel
    2.0000    1260.0     4.9300     2.1900      .5000
  Soil Number 5 Lateral Drainage, my estimation
     .4000     .00500     10.000     3.0000
  Soil Number 5 Lateral Drainage, my estimation
    2.0000    3600.0     10.000     3.0000      .5000
    0     (TOSS.OUT file for day  3.65000E+02)                 NDAY (UNSAT-H V2.01)
   1.19951E+03    1.19943E+03    1.19945E+03    1.19970E+03    Head Values
   1.20023E+03    1.20114E+03    1.20258E+03    1.20472E+03
   1.20779E+03    1.21210E+03    1.21805E+03    1.22619E+03
   1.23722E+03    1.25214E+03    1.27228E+03    1.29955E+03
   1.33668E+03    1.38772E+03    1.45891E+03    1.56021E+03
   1.70814E+03    1.93087E+03    2.27440E+03    2.78958E+03
   3.40977E+03    3.86154E+03    4.02214E+03    4.02953E+03
   4.01375E+03    3.99791E+03    3.98554E+03    3.97661E+03
   3.96911E+03    3.95991E+03    3.94596E+03    3.92482E+03
   3.89302E+03    3.84624E+03    3.78096E+03    3.69292E+03
   3.65689E+03    3.64024E+03    3.63244E+03    3.62871E+03
   3.62687E+03    3.60751E+03    3.58862E+03    3.56162E+03
   3.52449E+03    3.44122E+03    3.42596E+03    3.41944E+03
   3.41667E+03    3.41400E+03    3.41032E+03    3.40551E+03
   3.39636E+03    3.39510E+03    3.39477E+03    3.39477E+03
   3.39477E+03    3.39476E+03    3.39477E+03    3.39477E+03
   3.39477E+03    3.39477E+03
    0     1     1     2    68   243
        .25        .03        .15
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1   365   365   365   365
  365   365   365   365   365   365   365   365   365   365
  365   365   365   365   365   365
  15313.00      571.48       36.08
  15313.00      866.07       75.73
  15313.00       49.18        7.51
  15313.00        1.00         .10
  15313.00         .33         .06
    220.00         .85
 0.3000     223.0      15.0       988.0
```

A.3 RCRA Subtitle D Input Deck

```
HANFORD SITE BARRIER FEASIBILITY STUDY: subtitle D barrier, 6 layers
 1     1     1     1     0     1     1                 IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
 0    365   365    1     1     0           1.0         NPRINT,DAYEND,NDAYS,NYEARS,IRAIN,ICONVH,OUTTIM
 1     2     0     1     1                             NSURPE,NFHOUR,ITOPBC,ET_OPT,ICLOUD
 4     3     1     0     5     5                       KOPT,KEST,IVAPOR,SH_OPT,INMAX,INHMAX
 0.000E+00  5.00E+04    50.0         5.0E+1            HIRRI,HDRY,HTOP,DHMAX
 1.000E-04    1.00     1.E-04        24.0              DMAXBA,DELMAX,DELMIN,STOPHR
 0.66        283.00       .24         0.0              TORT,TSOIL,VAPDIF,QHTOP
 -1.E-4      283.00    10.00E+00       0.0             TGRAD,TSMEAN,TSAMP,QHLEAK
 0.5          2.00     1.000E-03    5.0E-1    1          WTF,RFACT,RAINIF,DHFACT,isnow
    6   135                                            MATN,NPT
   1      .0000    1      .0458    1      .1053    1      .1826
   1      .2832    1      .4139    1      .5839    1      .8048
   1     1.0920    1     1.4654    1     1.9508    1     2.5818
   1     3.4021    1     4.4685    1     5.8549    1     7.6571
   1    10.0000    1    12.3429    1    14.1451    1    15.5315
   1    16.5979    1    17.4182    1    18.0492    1    18.5346
   1    18.9080    1    19.1952    1    19.4161    1    19.5861
   1    19.7168    1    19.8174    1    19.8947    1    19.9542
   2    20.0000    2    20.4693    2    21.0793    2    21.8724
```

```
  1.05619E+03   1.06724E+03   1.08263E+03   1.10391E+03
  1.13329E+03   1.17394E+03   1.23051E+03   1.30990E+03
  1.42221E+03   1.58085E+03   1.79708E+03   2.05546E+03
  2.27718E+03   2.37856E+03   2.37490E+03   2.32193E+03
  2.25037E+03   2.17042E+03   2.02219E+03   1.87454E+03
  1.79242E+03   1.74385E+03   1.71394E+03   1.69501E+03
  1.68283E+03   1.67098E+03   1.65383E+03   1.62945E+03
  1.59566E+03   1.55067E+03   1.49430E+03   1.42474E+03
  1.39478E+03   1.37912E+03   1.37047E+03   1.36547E+03
  1.36247E+03   1.35362E+03   1.23499E+03   1.08572E+03
  8.96017E+02   8.49598E+02   8.26580E+02   8.03575E+02
  7.70146E+02   7.22347E+02   5.94747E+02   5.57039E+02
  5.33270E+02   5.17683E+02   5.01726E+02   4.77793E+02
  4.41896E+02   3.88056E+02   3.07314E+02   1.86262E+02
  4.97095E+00   4.48654E+00   4.31661E+00   4.20113E+00
  4.17682E+00   4.13833E+00   4.11051E+00   4.10014E+00
  4.09281E+00   4.08168E+00   4.07279E+00   4.06140E+00
  4.01965E+00   3.98400E+00   3.96010E+00
   0    1    1    2   68  243
      .25       .03       .15
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1  365  365
 365  365  365  365  365  365  365  365  365  365
 365  365  365  365  365  365  365  365  365  365
 365  365  365  365  365  365  365  365  365  365
 365  365  365  365  365  365  365  365  365
 15313.00    571.48     36.08
 15313.00    571.48     36.08
 15313.00     49.18      7.51
 15313.00      1.00       .10
 15313.00       .33       .06
 15313.00       .33       .06
   220.00       .85
0.3000     223.0      15.0       988.0
```

A.2 RCRA Subtitle C Input Deck

```
HANFORD SITE BARRIER FEASIBILITY STUDY: subtitle C barrier, 5 layers
 1     1     1     1     0     1     1           IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
 0    365   365    1     1     0        1.0      NPRINT,DAYEND,NDAYS,NYEARS,IRAIN,ICONVH,OUTTIM
 1     2     0     1     1                       NSURPE,NFHOUR,ITOPBC,ET_OPT,ICLOUD
 4     3     1     0     5     5                 KOPT,KEST,IVAPOR,SH_OPT,INMAX,INHMAX
 0.000E+00  5.00E+04   50.0       5.0E+1         HIRRI,HDRY,HTOP,DHMAX
 1.000E-04   1.00     1.E-04      24.0           DMAXBA,DELMAX,DELMIN,STOPHR
 0.66       283.00      .24        0.0           TORT,TSOIL,VAPDIF,QHTOP
 -1.E-4     283.00    10.00E+00    0.0           TGRAD,TSMEAN,TSAMP,QHLEAK
 0.5        2.00      1.000E-03   5.0E-1   1          WTF,RFACT,RAINIF,DHFACT,isnow
    5   66                                       MATN,NPT
   1     .0000    1     .1731    1      .3678   1      .5868
   1     .8333    1    1.1105    1     1.4224   1     1.7733
   1    2.1680    1    2.6121    1     3.1117   1     3.6737
   1    4.3060    1    5.0173    1     5.8176   1     6.7178
   1    7.7307    1    8.8701    1    10.1519   1    11.5940
   1   13.2163    1   15.0414    1    17.0946   1    19.4046
   1   22.0032    1   24.9267    1    30.8173   1    37.8269
   1   42.5000    1   45.6154    1    47.6923   1    49.0769
   2   50.0000    2   50.9231    2    52.3077   2    54.3846
   2   57.5000    2   62.1731    2    69.1827   2    80.8173
   2   87.8269    2   92.5000    2    95.6154   2    97.6923
   2   99.0769    3  100.0000    3   100.9231   3   102.3077
   3  104.3846    3  110.6154    3   112.6923   3   114.0769
   4  115.0000    4  115.9231    4   117.3077   4   119.3846
   4  125.6154    4  127.6923    4   129.0769   5   130.0000
   5  130.9231    5  132.3077    5   134.3846   5   137.5000
   5  142.1731    5  145.0000
  Soil Number 1 McGee Ranch Silt/Pea Gravel
      .4570     .00450     0.0163     1.3700
  Soil Number 1 McGee Ranch Silt/Pea Gravel
     2.0000     3.5640     0.0163     1.3700      .0000
  Soil Number 2 Compacted McGee Ranch Silt
```

```
  2.32378E+03    2.21582E+03    2.09029E+03    1.95042E+03
  1.80263E+03    1.65544E+03    1.54480E+03    1.47736E+03
  1.43337E+03    1.40333E+03    1.38217E+03    1.36693E+03
  1.33830E+03    1.33123E+03    1.32211E+03    1.31041E+03
  1.29533E+03    1.27612E+03    1.25169E+03    1.22093E+03
  1.18272E+03    1.13600E+03    1.08037E+03    1.01644E+03
  9.46324E+02    8.73674E+02    8.02758E+02    7.37042E+02
  6.78299E+02    6.26706E+02    5.81301E+02    5.40579E+02
  5.03068E+02    4.67695E+02    4.34311E+02    4.02810E+02
  3.73413E+02    3.46364E+02    3.21653E+02    2.99384E+02
  2.79988E+02    2.64284E+02    2.56855E+02
   0    1    1    2   68  243
       .25       .03      .15
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1  365  365  365
 365  365  365  365  365
 15313.00     571.48      36.08
 15313.00     571.48      36.08
 15313.00     866.07      75.73
 15313.00     135.16      12.07
 15313.00      69.68       6.38
 15313.00      45.34       4.27
   220.00        .85
0.3000     223.0     15.0      988.0
```

```
  2   22.9034   2   24.2436   2   25.9860   2   28.2511
  2   31.1957   2   35.0236   2   40.0000   2   44.9764
  2   48.8043   2   51.7489   2   54.0140   2   55.7564
  2   57.0966   2   58.1276   2   58.9207   2   59.5307
  3   60.0000   3   60.2018   3   60.4642   3   60.8052
  3   61.2486   3   61.8250   3   62.5743   3   63.5484
  3   64.8148   3   66.4610   3   68.6011   3   71.3832
  3   75.0000   3   78.6168   3   81.3989   3   83.5390
  3   85.1852   3   86.4516   3   87.4257   3   88.1750
  3   88.7514   3   89.1948   3   89.5358   3   89.7982
  4   90.0000   4   90.1422   4   90.3270   4   90.5673
  4   90.8797   4   91.2858   4   91.8137   4   92.5000
  4   93.1863   4   93.7142   4   94.1203   4   94.4327
  4   94.6730   4   94.8578   5   95.0000   5   95.1422
  5   95.3270   5   95.5673   5   95.8797   5   96.2858
  5   96.8137   5   97.5000   5   98.1863   5   98.7142
  5   99.1203   5   99.4327   5   99.6730   5   99.8578
  6  100.0000   6  100.0218   6  100.0501   6  100.0868
  6  100.1347   6  100.1968   6  100.2776   6  100.3827
  6  100.5192   6  100.6968   6  100.9276   6  101.2276
  6  101.6176   6  102.1247   6  102.7839   6  103.6408
  6  104.7548   6  106.2031   6  108.0857   6  110.5332
  6  113.7150   6  117.8512   6  123.2283   6  130.2186
  6  139.3060   6  151.1195   6  166.4771   6  186.4420
  6  212.3964   6  246.1371   6  290.0000
Soil Number 1 McGee Ranch Silt/Pea Gravel
    .4570    .00450    0.0163    1.3700
Soil Number 1 McGee Ranch Silt/Pea Gravel
  2.0000    3.5640    0.0163    1.3700      .0000
Soil Number 2 McGee Ranch Silt
    .4960    .00490    0.0163    1.3700
Soil Number 2 McGee Ranch Silt
  2.0000    3.5640    0.0163    1.3700      .0000
Soil Number 3 Compacted McGee Ranch Silt
    .4540     .1114     .0077    1.7830
Soil Number 3 Compacted McGee Ranch Silt
  2.0000    1.8850     .0077    1.7830      .0000
Soil Number 4 Interpolated soil layer 1
    .4393     .0933     .0465    1.8553
Soil Number 4 Interpolated soil layer 1
  2.0000    6.1200     .0465    1.8553      .1667
Soil Number 5 Interpolated soil layer 2
    .4247     .0751     .0852    1.9277
Soil Number 5 Interpolated soil layer 2
  2.0000   10.3550     .0852    1.9277      .3334
Soil Number 6 Loamy sand
    .4100     .0570     .1240    2.0000
Soil Number 6 Loamy sand
  2.0000   14.5900     .1240    2.0000      .5000
   0    (TOSS.OUT file for day  3.65000E+02)              NDAY (UNSAT-H V2.01)
  1.64994E+03   1.65054E+03   1.65028E+03   1.65019E+03   Head Values
  1.65012E+03   1.65002E+03   1.64989E+03   1.64976E+03
  1.64963E+03   1.64954E+03   1.64953E+03   1.64973E+03
  1.65034E+03   1.65171E+03   1.65449E+03   1.65980E+03
  1.66961E+03   1.68279E+03   1.69528E+03   1.70631E+03
  1.71567E+03   1.72340E+03   1.72965E+03   1.73466E+03
  1.73862E+03   1.74173E+03   1.74417E+03   1.74607E+03
  1.74754E+03   1.74869E+03   1.74957E+03   1.75025E+03
  1.75078E+03   1.75628E+03   1.76368E+03   1.77375E+03
  1.78760E+03   1.80692E+03   1.83435E+03   1.87407E+03
  1.93297E+03   2.02257E+03   2.16226E+03   2.32619E+03
  2.46355E+03   2.57120E+03   2.65208E+03   2.71144E+03
  2.75459E+03   2.78594E+03   2.80879E+03   2.82556E+03
  2.83902E+03   2.84524E+03   2.85329E+03   2.86370E+03
  2.87712E+03   2.89436E+03   2.91640E+03   2.94434E+03
  2.97931E+03   3.02217E+03   3.07288E+03   3.12945E+03
  3.18631E+03   3.22552E+03   3.24531E+03   3.25519E+03
  3.25996E+03   3.26210E+03   3.26288E+03   3.26298E+03
  3.26277E+03   3.26244E+03   3.26209E+03   3.26177E+03
  3.25933E+03   3.22424E+03   3.17867E+03   3.12053E+03
  3.04836E+03   2.96204E+03   2.86342E+03   2.75662E+03
  2.67033E+03   2.61534E+03   2.57869E+03   2.55344E+03
  2.53560E+03   2.52276E+03   2.48707E+03   2.41374E+03
```

Appendix B
HELP Input Data Decks

This appendix contains the Hanford, Subtitle C, and Subtitle D soil and design data (DATA10) input decks for the ambient precipitation simulations.

B.1 Hanford Barrier Input Deck

```
2Hanford Barrier
Calibrated Silt Parameters
7/13/94
  7     1.000000   87.210000       4
   40.00      40.00       6.00      12.00      60.00      12.00       5
    6.00       0.00       0.00       0.00       0.00       0.00       6
  0.4734     0.5140     0.4570     0.4170     0.4170     0.4170       7
  0.0220     0.0000     0.0000     0.0000     0.0000     0.0000       8
  0.1842     0.2000     0.0830     0.0450     0.0450     0.0450       9
  0.0210     0.0000     0.0000     0.0000     0.0000     0.0000      10
  0.0553     0.0600     0.0330     0.0200     0.0200     0.0200      11
  0.0200     0.0000     0.0000     0.0000     0.0000     0.0000      12
    0.000100000000      0.000100000000      0.003100000000      0.010000000000 13
    1.000000000000      1.000000000000      0.000000010000      0.000000000000 14
    0.000000000000      0.000000000000      0.000000000000      0.000000000000 15
  0.0669     0.0575     0.0507     0.0270     0.0232     0.0450      16
  0.0220     0.0000     0.0000     0.0000     0.0000     0.0000      17
     43560.      18
   1    1    1    1    1    2    3    0    0    0    0    0    19
    0.00       0.00       0.00       0.00       0.00       2.00      20
    0.00       0.00       0.00       0.00       0.00       0.00      21
     0.0        0.0        0.0        0.0        0.0      295.0      22
     0.0        0.0        0.0        0.0        0.0        0.0      23
 1.00000000  1.00000000  1.00000000  1.00000000  1.00000000  1.00000000     24
 1.00000000  1.00000000  1.00000000  1.00000000  1.00000000  1.00000000     25
   0.0000      26
  8  0  0
```

B.2 RCRA Subtitle C Input Deck

```
RCRA C Barrier
Calibrated Silt Parameters
7/13/94
  6     1.000000   87.210000       4
   20.00      20.00       6.00       6.00       6.00       6.00       5
    0.00       0.00       0.00       0.00       0.00       0.00       6
  0.4734     0.3855     0.4570     0.4170     0.4170     0.0220       7
  0.0000     0.0000     0.0000     0.0000     0.0000     0.0000       8
  0.1842     0.1650     0.0830     0.0450     0.0450     0.0210       9
  0.0000     0.0000     0.0000     0.0000     0.0000     0.0000      10
  0.0553     0.0600     0.0330     0.0200     0.0200     0.0200      11
  0.0000     0.0000     0.0000     0.0000     0.0000     0.0000      12
    0.000100000000      0.000005000000      0.003100000000      0.010000000000 13
    1.000000000000      0.000000010000      0.000000000000      0.000000000000 14
    0.000000000000      0.000000000000      0.000000000000      0.000000000000 15
  0.0782     0.0596     0.0515     0.0269     0.0450     0.0220      16
  0.0000     0.0000     0.0000     0.0000     0.0000     0.0000      17
     43560.      18
   1    1    1    1    2    3    0    0    0    0    0    0    19
    0.00       0.00       0.00       0.00       2.00       0.00      20
    0.00       0.00       0.00       0.00       0.00       0.00      21
     0.0        0.0        0.0        0.0      295.0        0.0      22
     0.0        0.0        0.0        0.0        0.0        0.0      23
 1.00000000  1.00000000  1.00000000  1.00000000  1.00000000  1.00000000     24
 1.00000000  1.00000000  1.00000000  1.00000000  1.00000000  1.00000000     25
   0.0000      26
  8  0  0
```

Appendix B
HELP Input Data Decks

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B.3 RCRA Subtitle D Input Deck

```
CRA D Barrier
Calibrated Silt Parameters
7/13/94
  4     1.000000    87.210000       4
     8.00     16.00     12.00     79.00      0.00      0.00       5
     0.00      0.00      0.00      0.00      0.00      0.00       6
   0.4734    0.5140    0.3855    0.4100    0.0000    0.0000       7
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000       8
   0.1842    0.2000    0.1650    0.0654    0.0000    0.0000       9
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000      10
   0.0553    0.0600    0.0600    0.0570    0.0000    0.0000      11
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000      12
     0.000100000000      0.000100000000      0.000005000000      0.004050000000 13
     0.000000000000      0.000000000000      0.000000000000      0.000000000000 14
     0.000000000000      0.000000000000      0.000000000000      0.000000000000 15
   0.1073    0.0601    0.0601    0.2494    0.0000    0.0000      16
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000      17
      43560.     18
   1    1    1    1    0    0    0    0    0    0    0    0      19
     0.00      0.00      0.00      0.00      0.00      0.00      20
     0.00      0.00      0.00      0.00      0.00      0.00      21
      0.0       0.0       0.0       0.0       0.0       0.0      22
      0.0       0.0       0.0       0.0       0.0       0.0      23
 1.00000000  1.00000000  1.00000000  1.00000000  1.00000000  1.00000000      24
 1.00000000  1.00000000  1.00000000  1.00000000  1.00000000  1.00000000      25
    0.0000     26
 8  0  0
```

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APPENDIX D

SAMPLE CALCULATIONS OF WIND AND WATER EROSION FOR ENGINEERED SURFACE BARRIERS

The equation can be considered to be solved by successive modifications to I. The I factor is the potential annual wind erosion in tons per acre per year for a given soil on an isolated, level, smooth, unsheltered, wide, and bare field with a noncrusted surface for which the climatic factor is 100%.

The I factor is dependent on soil texture and the percentage of dry aggregates over 0.84 mm in size (i.e., coarser than 20 mesh). McGee Ranch soils normally exhibit a crusted surface and no less than 3% dry aggregates coarser than 20 mesh. The indicated I value in Table D-1 for these conditions is 36.7. It is expected that the topsoil layer will form a crusted surface relatively soon after construction, in response to rain and snowfall events during the winter of the first year. If necessary, formation of a crusted surface may be accelerated by direct application of water. Adjustment of the I factor for knoll configuration as indicated in Curve b of Figure D-1 for a 2% surface slope yields an I value of about 40. If the surface slope of the barrier is increased by just 1%, the I factor increases to 48.

The ridge roughness factor (K) primarily applies to soil surfaces that are exposed to recurring agricultural practices (e.g., plowing, planting, disking, and harrowing). Ridges are created on the soil surface at planting time. For surface barriers, a ridge height of 1 to 2 in. may exist during the first year after construction. However, soil ridges will not be restored in subsequent years by periodic tillage. Therefore, a ridge height value of zero is assumed beyond the first year. For this condition, the indicated K value in Figure D-2 is 1 (the worst case).

The distribution of climatic factor (C) values across Washington State is indicated in Figure D-3. Appropriate C values for the Hanford Site are in the range of 60 to 70.

The unsheltered field length (L) will vary with individual barrier applications. For this analysis, a value of 152 m (500 ft) is assumed. Unbroken slope lengths much larger than 152 m (500 ft) are likely to require special provisions for wind erosion control.

The vegetative factor (V) is the most difficult parameter in the WEQ to characterize. During the first year after cover construction, before a mature stand of cover vegetation has been produced, the soil surface will be protected from wind erosion by spreading and crimping 1,816 kg (4,000 lb) of straw per acre on/into the soil surface. For subsequent years, the amount of plant production must be estimated. The USDA Soil Conservation Service has performed a number of evaluations of range site conditions for varying soil and precipitation conditions. Average annual rainfall for the Hanford Site is in the 15 to 17 cm (6 to 7 in.) range. Using data from similar climate and land-use areas, the total annual production of air-dry weight per acre for cover vegetation of mixed wheatgrasses is predicted to range from a minimum of 90 kg (200 lb) in unfavorable years to 227 kg (500 lb) in favorable years (USDA 1981), yielding a median value for V of 159 kg (350 lb) of air-dry material. Based on data for crested wheatgrass in Table D-2, the flat small-grain equivalent quantity is roughly 499 kg (1,100 lb) per acre.

With the given information I equals 40, K equals 0.6 for the first year and then 1.0 for the life of the barrier, C equals 60 to 70, L equals 152 m (500 ft), and V equals 1,816 kg (4,000 lb) per acre for the first year and then 499 kg (1,100 lb) per acre for subsequent years; the value of E in the WEQ is determined by interpolation of Soil Conservation Service wind erosion charts for these values. Sample wind erosion charts are provided as Table D-3. Wind erosion for the first year is estimated to be essentially zero, attributable primarily to the projected effectiveness of the straw mulch treatment. In subsequent years, wind erosion is predicted to average between 1.4 tons per acre per year (for C equals 60) and 1.8 tons per acre per year (for C equals 70). The straw mulch will

1.0 INTRODUCTION

The Hanford Barrier, Modified RCRA Subtitle C Barrier, and Modified RCRA Subtitle D Barrier designs employ a common top layer design treatment consisting of silt loam topsoil material containing a 15 wt.% admixture of pea gravel, constructed with a slope angle of 2%, planted with a mixture of perennial grasses. A primary objective in designing surface barriers is to anticipate and minimize the destructive effects of wind and water erosion. The pea gravel admixture, the low-slope angle, and the cover vegetation are all design provisions to mitigate erosion.

Estimates of the long-term effects of erosion are provided in this appendix, using computational methods developed originally for agricultural applications. Because the three barriers share a similar top surface design, they are computationally equivalent with respect to estimating erosion rates.

The computational methods employed help evaluate soil loss potential from surfaces comprised of fine-textured soils such as McGee Ranch silt loam. However, the effectiveness of the pea gravel admix treatment cannot be readily assessed using these same methods. The utility of admixing pea gravel into the topsoil layer has been demonstrated directly by wind tunnel testing (Ligotke and Klopfer 1990). The presence of the pea gravel admix component is excluded from consideration in the following estimates. Consequently, these estimates should be viewed as "worst-case" projections, rather than expected actual values.

Because it is a site-specific variable, the effect of slope length on erosion is not considered in detail in the following calculations. For purposes of preparing the estimates that appear in this appendix, a slope length of 152 m (500 ft) is assumed to be representative of the upper limit on the unsheltered slope length dimension that would be necessary for barrier applications at the Hanford Site, given the types and sizes of waste sites present.

2.0 SAMPLE CALCULATIONS OF POTENTIAL WIND EROSION

The wind erosion equation (WEQ) was developed by the U.S. Department of Agriculture (USDA), Agricultural Research Service. It has been modified for use in Washington State by the U.S. Soil Conservation Service (USDA 1987). The equation is used to evaluate potential wind erosion of soil surfaces in the following manner:

$$E = f(IKCLV)$$

where

E = the estimated average annual soil loss in tons per acre per year due to wind erosion
f = an indication that the equation includes functional relationships that are not straight-line mathematical functions
I = soil erodibility factor
K = ridge roughness factor
C = climatic factor
L = unsheltered distance
V = vegetative factor.

The K factor is used to differentiate the erodibility potential of various soil types under conditions where rainfall, topography, cover, and management are invariant. Using the nomograph in Figure D-5, the proposed topsoil (McGee Ranch silt loam) has a K value of about 0.64.

The USLE combines the effects of cover length and steepness into a single topographic factor, LS. From Figure D-6, LS for a 2% slope angle and 152-m (500-ft) slope length is about 0.32. (For a 3% slope angle and 152-m (500-ft) slope length, LS is about 0.45.)

The cover/management factor addresses the effects of vegetation and other agricultural (as opposed to engineering) erosion-control practices. On freshly covered surfaces without any vegetation or erosion-reducing vegetative controls (such as mulch), the C factor usually has a value of about 1. Application of straw mulch is highly effective in reducing the C factor component of the USLE during the initial period before perennial vegetation becomes established, particularly if the mulch is punched or tacked in place (Israelsen et al. 1980). For the purpose of developing these estimates, it is assumed that approximately 2 tons per acre of straw mulch would be spread and crimped into the soil surface in conjunction with seeding barrier surfaces. Based on this assumption, the expected C value for the first year would be about 0.10. For subsequent years, C values can be estimated from Table D-3. It is envisioned that a 60 to 80% grass cover will be attained over the cover area within a 3- to 5-year period after cover construction, corresponding to a range of C values of 0.01 to 0.04 (use C equals 0.025).

The supporting practices factor P takes into account some agricultural practices other than vegetation effects (e.g., contouring, terracing and contour strip cropping) and also includes the beneficial effects of engineering treatments such as compaction, soil blending, and stabilization with additives. For this analysis, no credit is taken for any ongoing support practices that would be performed after the cover is constructed and planted (use P equals 1).

For the first year, E is estimated to be:

$$E = (12)(0.64)(0.32)(0.10)(1) = 0.25 \text{ tons per acre per year.}$$

For subsequent years, E is estimated to be:

$$E = (12)(0.64)(0.32)(0.025)(1) = 0.06 \text{ tons per acre per year.}$$

Comparing these estimates with the previous calculations for wind erosion potential, it can be seen that water erosion potential for barrier surfaces at the Hanford Site is relatively low compared to potential wind erosion. The sum of projected soil loss rates (i.e., wind and water erosion) for the first year after construction is less than 1 ton per acre per year. Expected wind and water erosion rates for subsequent years (1.5 to 1.9 tons per acre per year) are consistent with EPA's target value (2.0 tons per acre per year). Increasing the surface slope to 3% would tend to increase water erosion potential slightly (i.e., from about 0.06 to 0.08 tons per acre per year). However, the beneficial effect of the lower slope angle on wind erosion is the primary rationale for maintaining the surface slope at 2%.

continue to assist in reducing wind erosion for 2 to 3 years after placement, depending on actual weather conditions experienced during that time span.

For a 3% slope angle and the same 152-m (500-ft) slope length, for which I equals 48, and K, C, and V defined as above, predicted wind erosion would average between about 2 tons per acre per year (for C equals 60) and 2.75 tons per acre per year (for C equals 70).

The soil loss projections represent average annual estimates and are highly dependent upon characterization of the vegetative factor. In years when cover vegetation yield is above average, the erosion rate will be significantly reduced. Until the vegetative cover is established, erosion rates may exceed the estimated range. After vegetation has been established, erosion rates should coincide more closely with the predicted range. Increasing vegetative growth to optimal production (227 kg [500 lb] air-dry weight per acre) would decrease predicted soil losses to zero.

3.0 SAMPLE CALCULATIONS OF POTENTIAL WATER EROSION

The potential for erosion of the barrier surface as a result of precipitation events is evaluated below using the USDA's universal soil loss equation (USLE) (Ecology 1987):

$$A = RKLSCP$$

where,

A = average soil loss in tons per acre
R = rainfall and runoff erosivity factor
K = soil erodibility factor
LS = slope-length factor
C = cover/management factor
P = erosion control practice factor.

The following topsoil properties and cover design information are used to evaluate A:

- Topsoil type: sandy silt
- Organic matter: <0.5%
- Estimated percent sand (coarser than 0.1 mm): 18%
- Estimated percent silt and sand finer than 0.1 mm: 77%
- Estimated percent clay: 5%
- Cover slope: 3%
- Slope length: 70.6 m (231.5 ft)
- Cover vegetation: (first year) 2 tons of straw mulch crimped into the soil surface; (subsequent years) 60 to 80% ground cover consisting of mixed perennial grasses.

The R factor in the USLE is a rainfall erosion index value that accounts for site meteorological conditions. In Figure D-4, R values of less than 20 are shown for most of eastern Washington, including the Columbia Basin and the Hanford Site. More detailed information provided in Figure 5-2 in Israelsen et al. (1980) indicates that appropriate R values for the Hanford Site are in the range of 9 to 12 (use R equals 12).

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4.0 PROJECTED SOIL LOSSES OVER BARRIER DESIGN LIFE

The projected thickness of soil that may be lost to wind and water erosion over a barrier's design life can be estimated from the annual loss rate projections (developed in Sections 1.0 and 2.0 above) and the in-place bulk density of the topsoil. The estimates developed below are for topsoil material consisting of McGee Ranch silt loam without pea gravel admixture. A representative value for in-place bulk density for this material is 1.38 g/cc (86.3 lb/ft^3). With the 15 wt% pea gravel admixture in the topsoil surface layer, actual losses should be significantly below these projections.

1.9 tons/acre/yr = 3,800 lb (1,725 kg)/acre/yr
3,800 lb (1,725 kg)/acre/yr x 1 acre/43,560 ft^2 (4,051 m^2) = 0.0872 lb (0.34 kg)/ft^2/yr
0.0872 lb (0.34 kg)/ft^2/yr / 86.3 lb (39 kg)/ft^3 = 0.00101 ft (0.00030805 m)/yr
0.00101 ft (0.00030805 m)/yr x 12 in. (30 cm)/ft = 0.0121 in. (0.030734 cm)/yr

For the Hanford Barrier (design life of 1,000 yr):

0.0121 in. (0.030734 cm)/yr x 1,000 yr = 12.1 in.(30.7 cm)/1,000 yr

For the Modified RCRA Subtitle C Barrier (design life of 500 yr):

0.0121 in. (0.030734 cm)/yr x 500 yr = 6 in. (15 cm)/500 yr

For the Modified RCRA Subtitle D Barrier (design life of 100 yr):

0.0121 in. (0.030734 cm)/yr x 500 yr = 1.2 in.(3.048 cm)/100 yr

Figure D-2. Soil Ridge Roughness Factor K from Actual Soil Ridge Roughness (EPA 1979).

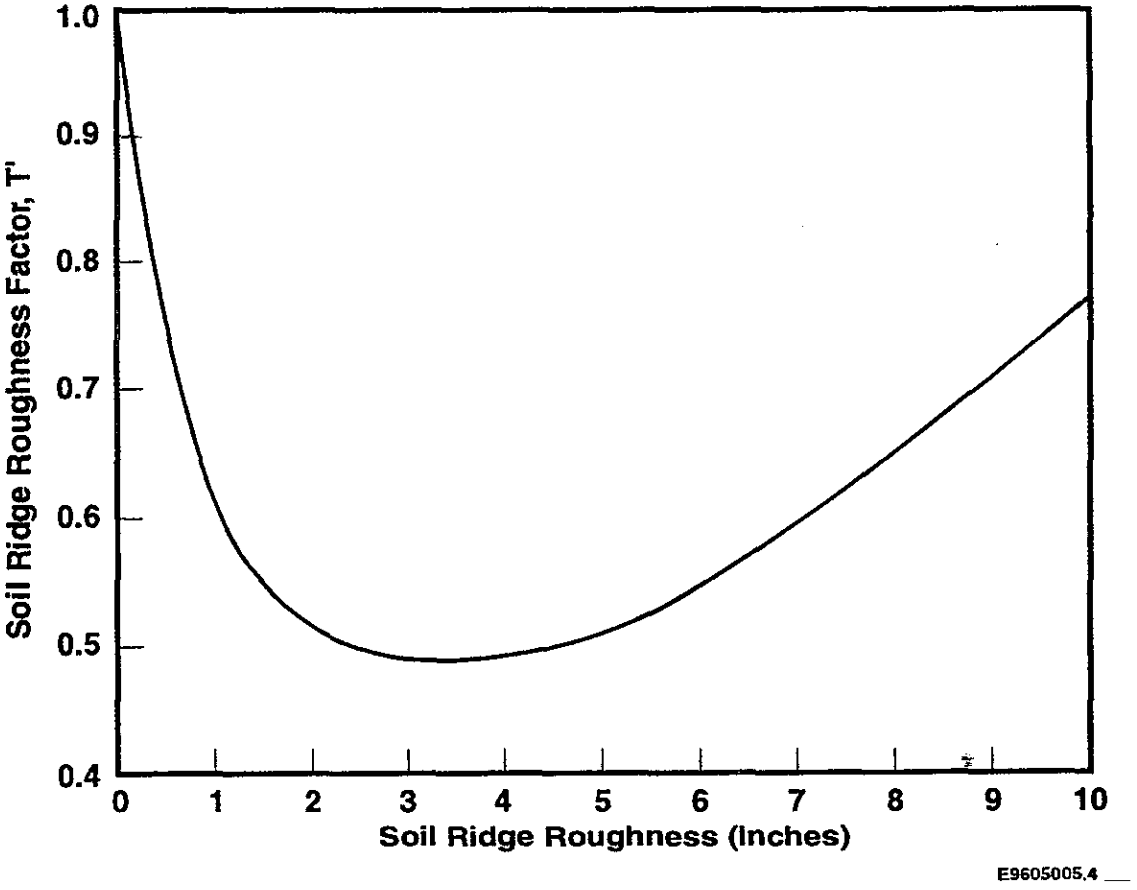
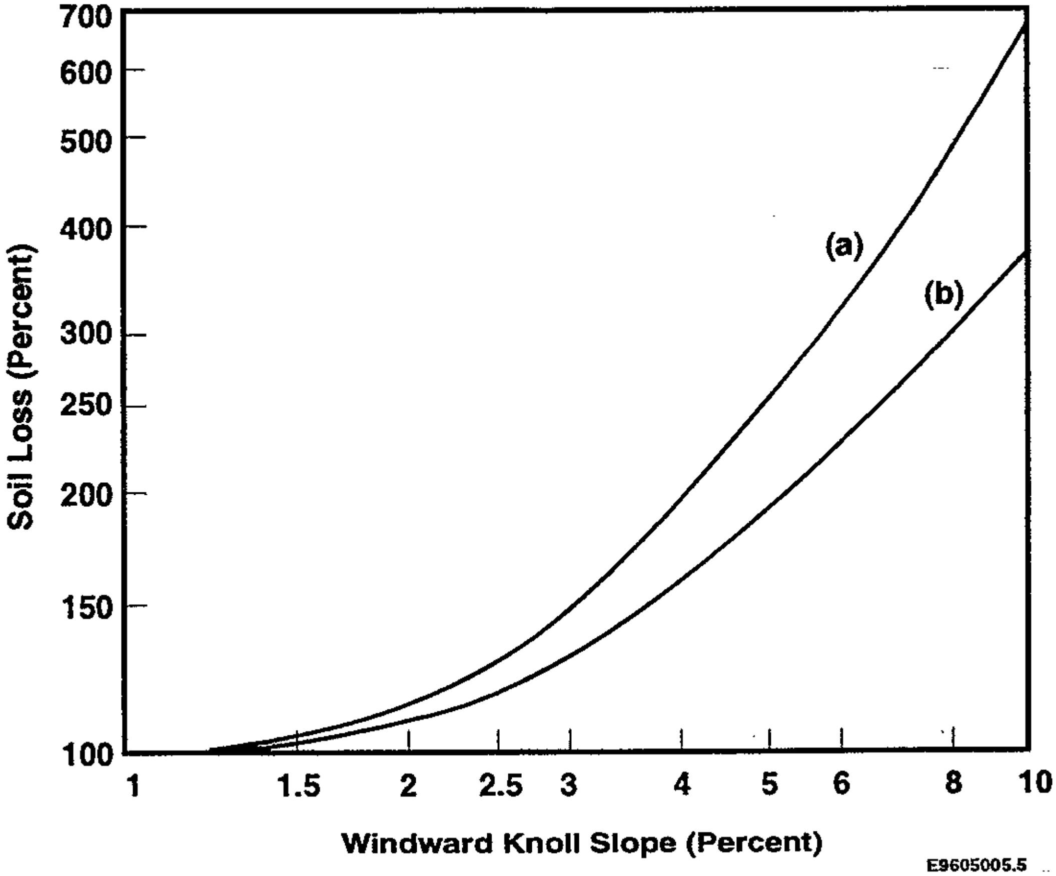
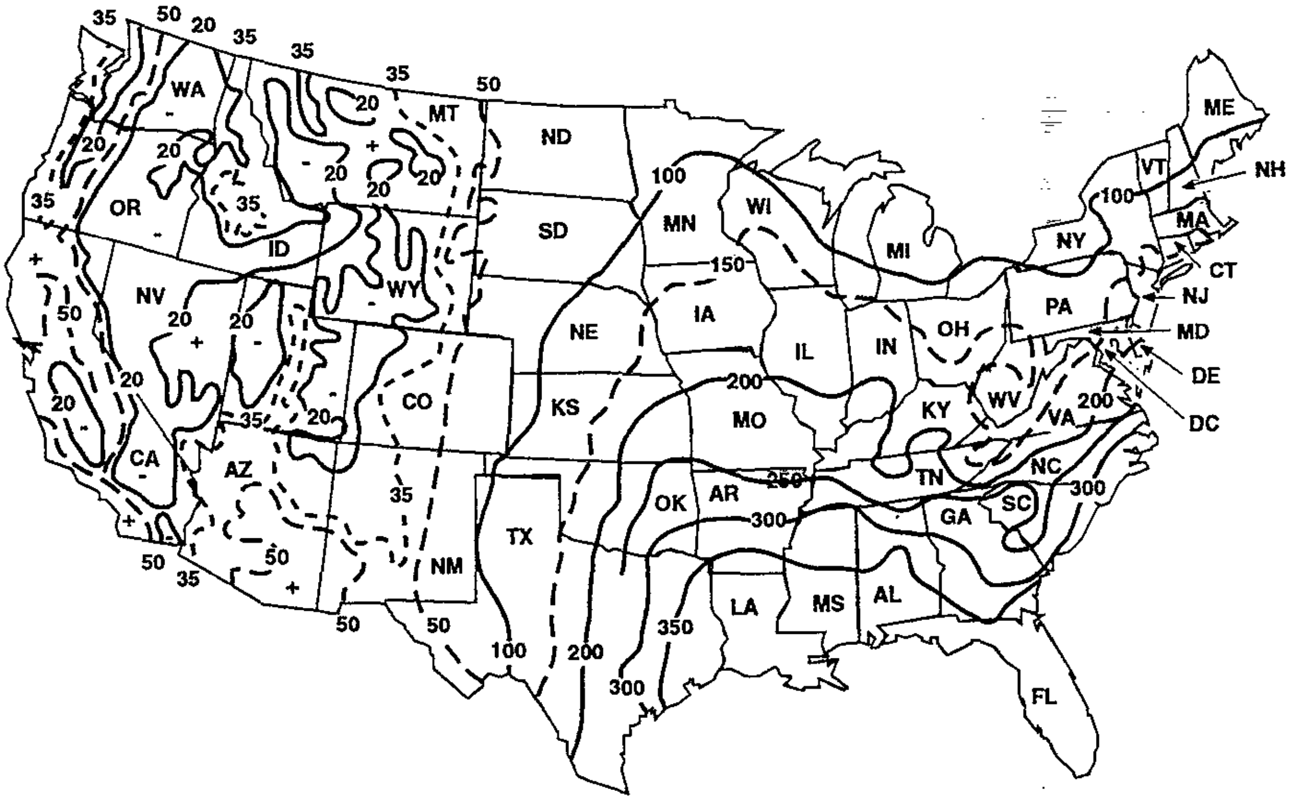


Figure D-1. Knoll Adjustment (a) from Top of Knoll and (b) from Upper Third of Slope (EPA 1979).



E9605005.5

Figure D-4. Average Annual Values of Rainfall-Erosivity Factor R (EPA 1979).



E9605005.1

Figure D-3. Annual Wind Erosion Climatic 'C' Factor in Percent (USDA 1987).

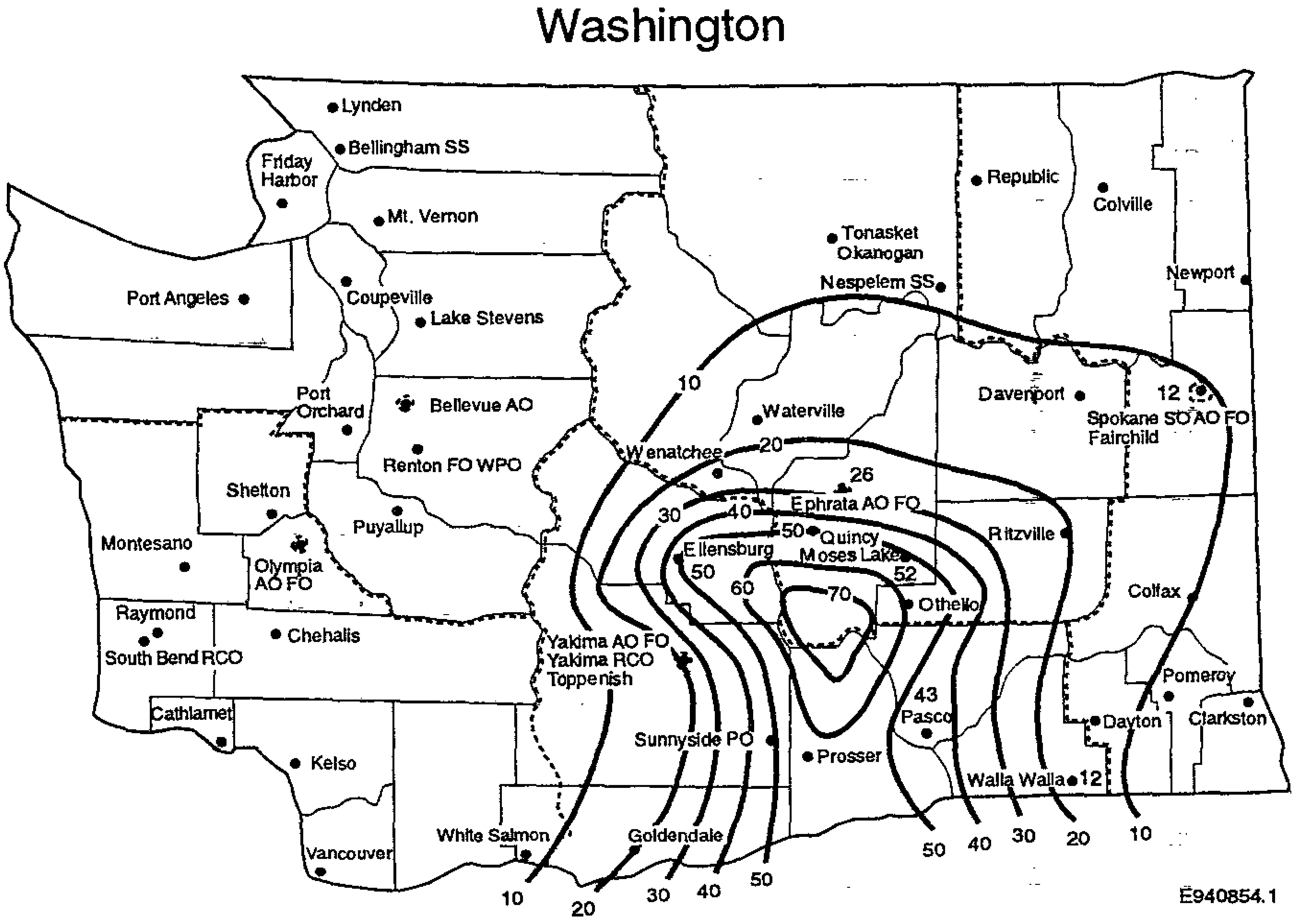
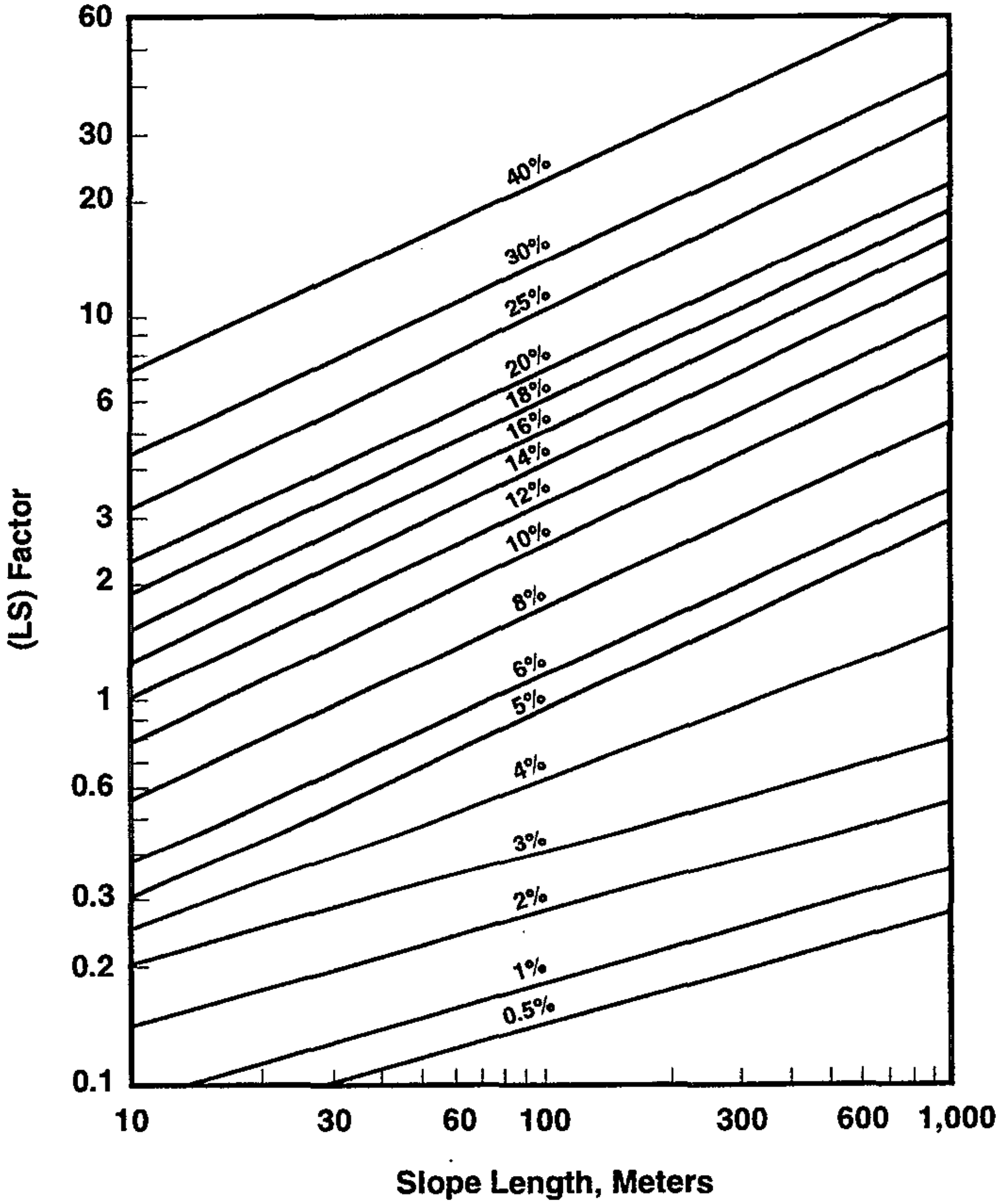
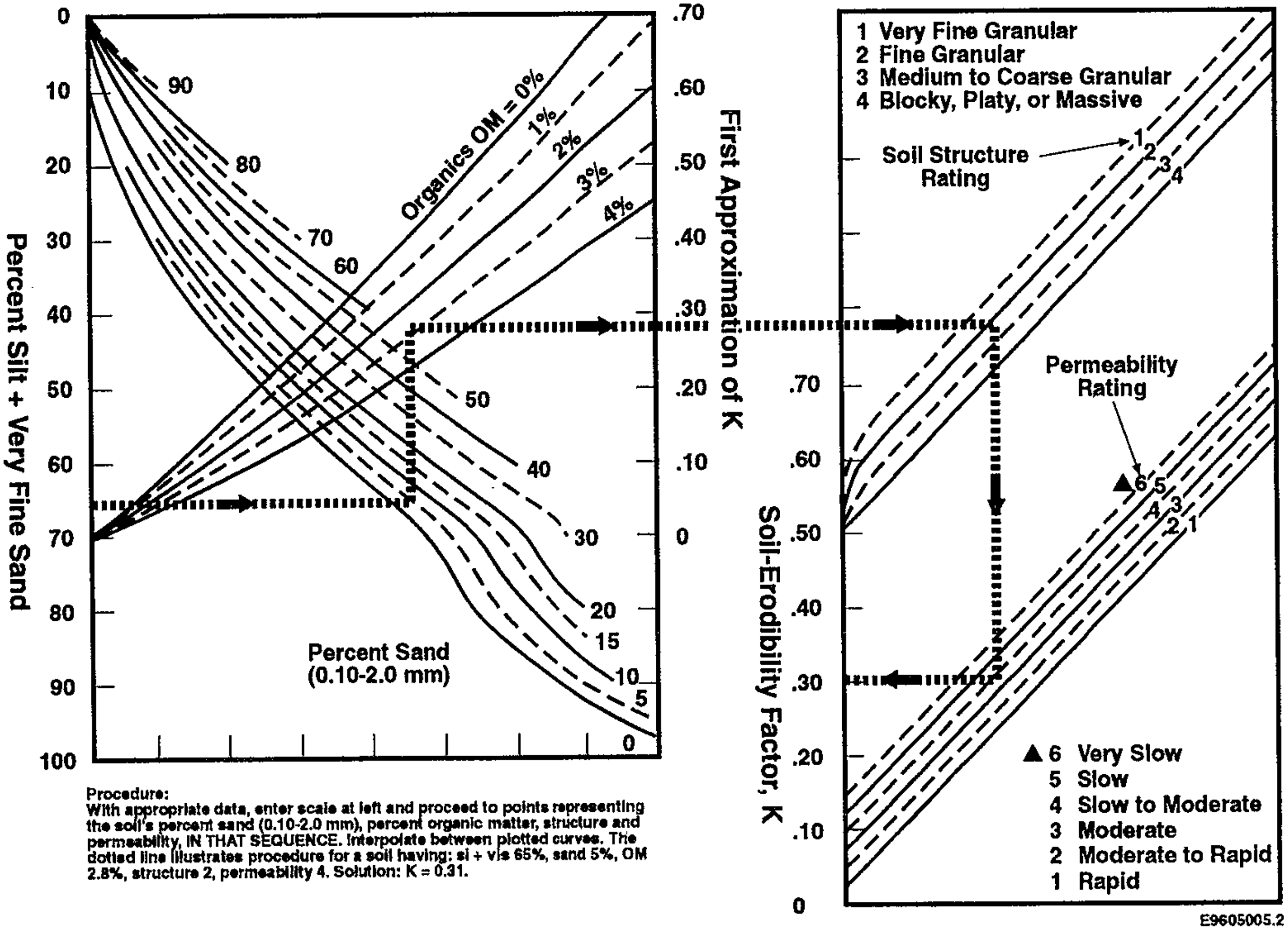


Figure D-6. Length-Slope Factor (LS) for Different Slopes (Ecology 1987).



E9605005.3



Procedure:
With appropriate data, enter scale at left and proceed to points representing the soil's percent sand (0.10-2.0 mm), percent organic matter, structure and permeability, IN THAT SEQUENCE. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si + vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

Figure D-5. Nomograph for Determining Soil Erodibility Factor K for U.S. Mainland (EPA 1979).

Table D-2. Guide for Converting Range Vegetation to an Equivalent Quantity of Flat, Small-Grain Residue (USDA 1987).

Grass plants	Pounds per acre of range vegetation										
	50	100	200	300	400	500	600	700	800	900	1,000
Buffalograss[a], burrograss, and inland saltgrass	320	720	1,630	2,630							
Big bluestem[a]	45	110	280	480	705	950	1,215	1,495	1,785	2,090	2,410
Western wheatgrass[a], creeping wildrye, and sideoats grama	155	245	775	1,240	1,740	2,260	2,795	3,345			
Little bluestem[a]	45	110	285	495	735	995	1,280	1,580	1,900	2,230	2,575
Blue grama[a], threadleaf sedge, and perennial three-awn	110	235	490	760	1,040	1,325	1,610	1,905			
Galleta and tobosa	150	300	800	1,200	1,700	2,600					
Bottlebrush squirreltail, needle-and-thread[a], and Thurber's needlegrass	70	150	300	600	800	1,200					
Alkali sacaton	60	150	400	800	1,400	2,200	2,800	3,600			
Bluebunch wheatgrass	50	120	300	550	850	1,150	1,500	1,900	2,300	2,600	3,000
Idaho fescue	100	200	400	900	1,500	2,300					
Indian ricegrass	100	175	300	600	900	1,400					
Crested wheatgrass	130	300	600	900	1,300	1,800	2,400	3,100	4,000		
Cheatgrass	100	200	300	600	800	1,000	1,200	2,000	2,500	3,000	

NOTE: Other grass species equivalents were estimated by comparing the growth characteristics with the tested species.

[a] Lyles and Allison (1980).

Table D-1. Soil-Wind Erodibility Index I (Israelsen et al. 1980).

Percent of dry soil not passing a 20 mesh screen	0	1%	2%	3%	4%	5%	6%	7%	8%	9%
(Units)	Noncrusted soil surface (tons/acre)									
0	-	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	-	-	-	-	-	-	-	-	-
	Fully crusted soil surface (tons/acre)									
0	-	51.7	41.7	36.7	32.5	30.0	28.3	26.7	25.0	23.3
10	22.3	21.8	21.3	20.8	20.2	19.5	18.8	18.2	17.7	17.0
20	16.3	15.8	15.3	15.0	14.7	14.3	13.8	13.5	13.2	12.7
30	12.3	12.0	11.8	11.5	11.2	10.8	10.5	10.3	10.0	9.7
40	9.3	9.0	8.7	8.5	8.3	8.0	7.8	7.5	7.2	6.8
50	6.3	6.0	5.5	5.2	4.8	4.5	4.2	4.0	3.8	3.7
60	3.5	3.3	3.2	3.0	2.8	2.7	2.7	2.5	2.3	2.2
70	2.0	1.8	1.7	1.3	1.2	1.0	0.7	0.5	0.5	0.3
80	0.3	-	-	-	-	-	-	-	-	-

Table D-4. Values of C for Idle Land (Ecology 1987).

Grass cover 95-100%	C
As grass	0.003
As weeds	0.01
Ground cover 80%	
As grass	0.01
As weeds	0.04
Ground cover 60%	
As grass	0.04
As weeds	0.09
No ground cover	1.00

Table D-3. Sample Wind Erosion Charts.

(E)* Soil Loss from Wind Erosion (Tons Per Acre Per Year)

January, 1981
C = 60
I = 38

Surface - K = 1.0

(V)** - Flat Small Grain Residue (Pounds per Acre)

Unsheltered Distance (ft)	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
10000	22.8	18.9	13.7	8.9	4.6	1.7	0.6						
8000	22.8	18.9	13.7	8.9	4.6	1.7	0.6						
6000	22.6	18.8	13.6	8.8	4.6	1.7	0.6						
4000	21.4	17.7	12.8	8.2	4.2	1.5	0.6						
3000	20.4	16.9	12.1	7.7	3.9	1.4	0.5						
2000	18.6	15.4	10.9	6.9	3.5	1.2							
1000	14.9	12.2	8.5	5.2	2.6	0.8							
800	14.0	11.4	7.9	4.8	2.3	0.7							
600	12.4	10.1	6.9	4.1	2.0	0.4							
400	10.1	8.1	5.5	3.2	1.5	0.3							
300	8.5	6.8	4.5	2.6	1.2	0.2							
200	5.6	4.4	2.9	1.6	0.6								
150	4.2	3.2	2.0	1.1	0.4								
100	3.0	2.3	1.4	0.7									
80	2.2	1.6	1.0	0.5									
60	1.5	1.1	0.6										
50	1.1	0.8	0.4										
40	0.8	0.5											
30	0.6	0.3											
20													
10													

(E)* Soil Loss from Wind Erosion (Tons Per Acre Per Year)

January, 1981
C = 70
I = 48

Surface - K = 1.0

(V)** - Flat Small Grain Residue (Pounds per Acre)

Unsheltered Distance (ft)	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
10000	33.6	28.3	21.2	14.4	8.0	3.3	1.4	0.5					
8000	33.6	28.3	21.2	14.4	8.0	3.3	1.4	0.5					
6000	33.6	28.3	21.2	14.4	8.0	3.3	1.4	0.5					
4000	32.2	27.1	20.2	13.6	7.5	3.1	1.3	0.4					
3000	31.1	26.2	19.4	13.0	7.1	2.9	1.2	0.4					
2000	29.2	24.5	18.1	12.1	6.5	2.6	1.0						
1000	24.5	20.5	14.9	9.7	5.1	1.9	0.7						
800	23.0	19.1	13.8	9.0	4.7	1.7	0.6						
600	20.8	17.3	12.4	7.9	4.1	1.5	0.5						
400	18.1	14.9	10.6	6.6	3.3	1.2							
300	15.7	12.9	9.0	5.6	2.7	0.9							
200	12.6	10.3	7.1	4.2	2.0	0.4							
150	10.0	8.1	5.5	3.2	1.5	0.3							
100	7.6	6.0	4.0	2.2	0.9								
80	5.8	4.6	3.0	1.6	0.6								
60	4.0	3.2	2.0	1.0	0.4								
50	3.3	2.5	1.6	0.7									
40	2.5	1.9	1.1	0.5									
30	1.6	1.2	0.7										
20	0.9	0.5											
10													

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APPENDIX E

COST ESTIMATES

fill will be needed (corresponding to 60,435 loose m^3 [79,000 loose yd^3], assuming 20% swell). The material will be sourced from Pit 30, situated between 200 West Area and 200 East Area, opposite the 609-A fire station. Moisture conditioning (i.e., addition and control) will be performed at Pit 30 before transportation to the construction site. The one-way haul will be approximately 6.4 km (4 mi). Grading fill and existing site soils will be densified by making several passes over the site with a vibratory compactor to create a suitable subbase for barrier construction.

Place Asphalt Base Course: The base course material will be >80% minus 5/8-in. material conforming to WSDOT M41-10, 9-03.9(3). The material will be provided by a local commercial supplier. Cover construction will require hauling and placing approximately 4,852 metric tons (5,350 tons) of material (corresponding to approximately 2,524 m^3 [3,300 yd^3]). These quantities were determined based on placing 10 cm (4 in.) of material over an area of (530+48)(415+48) ft^2 and a dry unit weight of 54 kg/m^3 (120 lb/ft^3). A track dozer will spread and grade the material. A vibratory compactor will densify the base course material as it is placed. The base course layer will be constructed on a 2% slope.

Place Asphalt: The asphalt layer will be placed by a qualified contractor (possibly different from the one performing other construction activities). The asphalt will be a double-tar asphaltic concrete mix with a spray-applied top coat of a proprietary liquid styrene-butadiene asphaltic material. The asphalt layer will be 15 cm (6 in.) thick and will be placed over an area of (530+48)(415+48) ft^2 = 267,600 ft^2 (24,870 m^2) = 29,700 yd^2 (2,483 m^2). The asphalt layer will be constructed on a 2% slope.

Place Gravel Drainage Layer: The specification for the gravel drainage material is a saturated hydraulic conductivity value of 1 cm/s. Material will be sourced from Pit 30 between 200 West Area and 200 East Area. Run-of-pit material will be screened to specification at the pit. The one-way haul will be approximately 6.4 km (4 mi). Construction of the gravel drainage layer will require hauling and placing approximately 14,784 metric tons (16,300 tons) of material (corresponding to approximately 7,803 m^3 [10,200 yd^3]). These quantities were determined based on placing 30 cm (12 in.) of material over an area of (530+56)(415+56) ft^2; a material density of 0.065 m^2 (0.70 ft^2) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 53.5 kg/m^3 (117.9 lb/ft^3). A motor grader will be used to spread and grade material. A vibratory compactor also will support construction of this layer.

Place Coarse, Fractured Basalt Layer, and Side Slopes: The coarse basalt layer and the perimeter side slope will be built up by placing basalt above the drainage gravel layer described in the previous task. The side slopes of the barrier will be constructed at 2H:1V. There will be a 4.5-m (15-ft)-wide perimeter access road bed for service vehicles at the crown. The maximum thickness of basalt, 3.9 m + 5 cm (13 ft + 2 in.), will be beneath the access road. The coarse basalt layer will be a uniform 1.5 m (5 ft) thick. At the margin, the basalt layer will taper up to the crown on a slope of 3H:1V. The basalt will be minus 20- to 30-cm (8- to 12-in.) material that is free of fines (similar to the coarse, fractured material specified for the biointrusion barrier layer). The material will be sourced from an existing quarry immediately east of State Highway 24 on the east end of Umtanum Ridge, overlooking the Vernita Bridge. The one-way haul will be approximately 27 km (17 mi). It is estimated that barrier construction will require hauling and placing approximately 116,096 metric tons (128,000 tons) of material (corresponding to approximately 57,375 m^3 [75,000 yd^3]). These quantities were determined using a material density of 0.021 m^3 (0.75 ft^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 57.4 kg/m^3 (126.4 lb/ft^3).

1.0 INTRODUCTION

Appendix E presents cost estimates for each of the three proposed barrier designs (Hanford Barrier, Modified RCRA Subtitle C Barrier, and Modified RCRA Subtitle D Barrier). The estimates were developed for an actual 5-acre waste site in the 200-BP-1 Operable Unit (216-B-43 to 216-B-50 cribs): refer to Section 2.0 and Table E-1 for the Hanford Barrier; Section 3.0 and Table E-2 for the Modified RCRA Subtitle C Barrier; and Section 4.0 and Table E-3 for the Modified RCRA Subtitle D Barrier.

2.0 HANFORD BARRIER COST ESTIMATE

2.1 ENGINEERING

Definitive Design: Definitive design will be performed by a consulting civil engineer. Definitive design activities will include preparation of plan and section drawings, specifications, and quality control plans for construction; materials testing to support preparation of specifications; stability and performance analysis calculations; and preparation of procurement documents. Costs for this task (including OH&P) are estimated as 5% of construction costs.

Construction Management, Engineering and Inspection: This task covers bid evaluations, control and review of vendor submittals, engineering support during construction (including survey support), design change control, inspection planning, constructibility reviews, and production of as-built drawings. This task includes costs for QC overview and sampling and testing exclusive of SDRI test (see following task). Costs for this task (including OH&P) are estimated as 10% of construction costs.

Sealed Double-Ring Infiltrometer (SDRI) Test on Asphalt Layer: Costs are included in the estimate for performing two SDRI tests on the asphalt layer: after construction of the layer and before construction of any superimposed layers, to obtain a direct measurement of the hydraulic conductivity of the layer as built. The tests will be performed by a consulting geotechnical engineering subcontractor. The task will include equipment, labor, per diem and travel expenses related to construction, installation, and monitoring, followed by disassembly of the testing apparatus. Equipment costs are limited to expendable portions of the apparatus. Costs for this task (including OH&P) are estimated at $9,000 per test, or a total of $18,000.

2.2 IMPROVEMENTS TO LAND

Site Grading, Compaction, and Placement of Grading Fill: Construction will be performed by a qualified contractor. Cost is based on a site-surface measuring approximately 126 m (415 ft) (E-W) by 161 m (530 ft) (N-S). The area is assumed to be devoid of vegetation (no clearing and grubbing will be necessary). The existing site surface is slightly irregular and slopes at approximately 1.5% to the north. A planar surface is desirable before placement of the barrier layers, to facilitate survey control and QC of material placement and layer thicknesses. Consistent with ALARA principles, balanced cuts and fills will not be used to create a uniform site surface. Surface grading will be done exclusively with fill. It is estimated that approximately 50,413 bank m^3 (65,900 bank yd^3) of grading

4.5 lineal m [15 lineal ft]); a material density of 0.02 m^3 (0.75 ft^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 57.3 kg/m^3 (126.4 lb/ft^3). A motor grader and a vibratory compactor will be used to spread, grade, and compact the material.

3.0 MODIFIED RCRA SUBTITLE C BARRIER COST ESTIMATE

3.1 ENGINEERING

Definitive Design: Definitive design will be performed by a consulting civil engineer. Definitive design activities will include preparation of plan and section drawings, specifications, and quality control plans for construction; materials testing to support preparation of specifications; stability and performance analysis calculations; and preparation of procurement documents. Costs for this task (including OH&P) are estimated as 5% of construction costs.

Construction Management, Engineering and Inspection: This task covers bid evaluations, control and review of vendor submittals, engineering support during construction (including survey support), design change control, inspection planning, constructibility reviews, and production of as-built drawings. This task includes costs for QC overview, and sampling and testing exclusive of SDRI test (see following task). Costs for this task (including OH&P) are estimated as 10% of construction costs.

Sealed Double-Ring Infiltrometer (SDRI) Test on Asphalt Layer: Costs are included in the estimate for performing two SDRI tests on the asphalt layer: after construction of the layer and before construction of any superimposed layers, to obtain a direct measurement of the hydraulic conductivity of the layer as built. The tests will be performed by a consulting geotechnical engineering subcontractor. The task will include equipment, labor, per diem and travel expenses related to construction, installation, and monitoring, followed by disassembly of the testing apparatus. Equipment costs are limited to expendable portions of the apparatus. Costs for this task (including OH&P) are estimated at $18,000.

3.2 IMPROVEMENTS TO LAND

Site Grading, Compaction and Placement of Grading Fill: Construction will be performed by a qualified contractor. The site surface measures approximately 126 m (415 ft) (E-W) by 161 m (530 ft) (N-S). The area is devoid of vegetation (no clearing and grubbing will be necessary). The existing site surface is slightly irregular and slopes at approximately 1.5% to the north. A planar surface is desirable before placement of the barrier layers, to facilitate survey control and QC of material placement and layer thicknesses. Consistent with ALARA principles, balanced cuts and fills will not be used to create a uniform site surface. Surface grading will be done exclusively with fill. It is estimated that approximately 43,299 bank m^3 (56,600 bank yd^3) of grading fill will be needed (corresponding to 51,943 loose m^3 [67,900 loose yd^3], assuming 20% swell). The material will be sourced from Pit 30, situated between 200 West and 200 East, opposite the 609-A fire station. Moisture conditioning (i.e., addition and control) will be performed at Pit 30 before transportation to the construction site. The one-way haul will be approximately 6.4 km (4 mi). Grading fill and existing site soils will be densified by making several passes over the site with a vibratory compactor to create a suitable subbase for barrier construction.

Place Gravel and Sand Filter Layers: The two filter layers will prevent entry and accumulation of fines in the lateral drainage layer. Filter gravel will be sourced from Pit 30. Run-of-pit material will be screened to specification at the pit. Construction of the gravel filter layer will require hauling and placing approximately 10,249 metric tons (11,300 tons) of material (corresponding to approximately 5,431 m^3 [7,100 yd^3]). These quantities were determined based on placing 30 cm (12 in.) of material over an area of (530-30)(415-30) ft^2; a material density of 0.02 m^3 (0.70 ft^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 53.5 kg/m^3 (117.9 lb/ft^3). A motor grader will spread and grade the material over the majority of the work area. A vibratory compactor will be needed to support construction of this layer.

Filter sand also will be sourced from Pit 30. This material will be another size fraction product from the same size separation plant providing the gravel filter material. Construction of the sand filter layer will require hauling and placing approximately 5,079 metric tons (5,600 tons) of material (corresponding to approximately 2,754 m^3 [3,600 yd^3]). These quantities were determined based on placing 15 cm (6 in.) of material over an area of (530-30)(415-30) ft^2; a material density of 0.02 m (0.70 ft^3) solids per ft^3 volume and a specific gravity of 2.65, corresponding to 52.5 kg/m^3 (115.8 lb/ft^3). A motor grader will spread and grade the material. A vibratory compactor will support placement of this layer. When completed, the two filter layers will slope down at 2% over the central part of the cover area and will slope up at 3:1 around the perimeter.

A nonwoven, needle-punched, polypropylene geotextile will be placed over the top of the sand filter layer as a construction aid. The area to be covered is 17,902 m^2 (192,500 ft^2).

Place Lower Silt Layer: Silt loam soil will be sourced from the McGee Ranch site, which represents a 27-km (17-mi) one-way haul. The layer will be 101 cm (40 in.) thick. Construction will require hauling and placing approximately 20,861 metric tons (23,000 tons) of material (corresponding to 15,070 m^3 [19,700 yd^3]). Quantities were computed based on the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3) (assumes 20% swell), and placement at bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3). The layer will be constructed in three lifts, using a motor grader or a small dozer to spread material. A water tanker truck and a farm tractor with disk will be needed to support construction of the layer.

Place Upper Silt Layer With Pea Gravel Admix: The silt soil will be sourced from the McGee Ranch site. However, the material will first be transported to an admix plant (assumed to be sited at Pit 30). Pea gravel will be mechanically mixed with the silt to produce a product that is 85% silt and 15% pea gravel by weight. Construction will require hauling and placing approximately 23,944 metric tons (26,400 tons) of material (corresponding to 16,600 m^3 [21,700 yd^3]). These quantities were determined based on placing material to a depth of 101 cm (40 in.) and the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3) (assumes 20% swell), and placement to a unit weight of 41 kg/m^3 (90 lb/ft^3), similar to the original bank density. A motor grader or a small dozer will be used to spread the material. Minimal compaction of this material is needed (i.e., wheel or track loads of placement equipment will provide sufficient compaction; no additional compaction equipment will be required).

Place Road Base Aggregate on Perimeter Access Road: The road base material will be minus 3.8 cm (1.5 in.) of material provided by a local commercial supplier. Construction will require hauling and placing approximately 1,541 metric tons (1,700 tons) of material (corresponding to approximately 765 m^3 [1,000 yd^3]). These quantities were determined based on placing 15 cm (6 in.) of material over an area of (415)(530) - (415-30)(530-30) = 27,450 ft^2 (2,552 m^2) (i.e., a road width of

The sand filter layer material also will be sourced from Pit 30. This material will be a separate product from the size separation plant providing the gravel filter material. As described previously, construction of the sand filter layer will require hauling and placing approximately 4,896 metric tons (6,400 tons) of material (corresponding to approximately 3,136 m^3 [4,100 yd^3]). These quantities were determined based on placing 15 cm (6 in.) of material over an area of (530)(415) ft^2; a material density of 0.02 m^3 (0.70 ft^3) solids per ft^3 volume and a specific gravity of 2.65, corresponding to 52.5 kg/m^3 (115.8 lb/ft^3). A motor grader will spread and grade the material. A vibratory compactor will be needed to support placement of this layer. When completed, the surface of the sand filter layer will slope down at 2% over the central part of the cover area and will slope up at 2:1 around the perimeter.

Placement of Compacted Silt: The silt soil will be sourced from the McGee Ranch site, which represents a 27-km (17-mi) one-way haul. Construction will require hauling, placing and compacting approximately (22,900-1,400) = 21,500 tons (19,500 metric tons) of material (corresponding to 13,600-800 = 12,800 yd^3 [9,792 m^3]). These quantities were determined based on placing and compacting material to a depth of 50 cm (20 in.) over an area of (530)(415) ft^2, less the volume occupied by fill and filter layers in the perimeter area sloped at 2:1 and the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3, assumes 20% swell), and compacted unit weight of 56 kg/m^3 (125 lb/ft^3). The layer will be constructed in three lifts, using a motor grader or a small dozer to spread material and a static compactor (such as a sheep's foot roller) to densify the material. Moisture conditioning will be performed at Pit 30. A water tanker truck and a farm tractor with disk will be needed to support placement of this layer.

Placement of Silt/Pea Gravel Admix: The silt soil will be sourced from the McGee Ranch site. However, the material will first be transported to an admix plant (assumed to be sited at Pit 30). Pea gravel will be mechanically mixed with the silt to produce a product that is 85% silt and 15% pea gravel by weight. Construction will require hauling and placing approximately (22,900-700) = 22,200 tons (20,135 metric tons) of material (corresponding to 13,600-450 = 13,150 yd^3 [10,059 m^3]). These quantities were determined based on placing and compacting material to a depth of 50 cm (20 in.) over an area of (530)(415) ft^2, less the volume occupied by fill and filter layers in the perimeter area sloped at 2:1 and the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3, assumes 20% swell), and compacted unit weight of 56 kg/m^3 (125 lb/ft^3). A motor grader or a small dozer will be used to spread the material. Minimal compaction of this material is needed (i.e., wheel loads of placement equipment will provide sufficient compaction; no additional compaction equipment will be required).

Placement of Coarse, Fractured Basalt Surfacing Material on Perimeter Berm: The fractured basalt will be minus 30-cm (12-in.) material sourced from the existing quarry immediately east of State Highway 24 on the east end of Umtanum Ridge, overlooking Vernita Bridge. The one-way haul will be approximately 27 km (17 mi). Construction will require hauling and placing approximately 3,083 metric tons (3,400 tons) of material (corresponding to approximately 1,530 m^3 [2,000 yd^3]). These quantities were determined based on placing 30 cm (12 in.) of material around a perimeter of 2(530+415) + 8(27)/2 = 1,998 lineal ft (609 lineal m) over a width of 27 lineal ft (8 lineal m); a material density of 0.75 ft^3 (0.021 m^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 57.3 kg/m^3 (126.4 lb/ft^3). A track dozer will be used to spread and grade the material. Compacting equipment will not be required. When completed, the perimeter berm will slope down at 3H:1V to meet surrounding grade.

Placement of Base Course for Asphalt Layer: The base course material will be >80% minus 5/8-in. material conforming to WSDOT M41-10, 9-03.9(3). The material will be provided by a local commercial supplier. Barrier construction will require hauling and placing approximately 3,990 metric tons (4,400 tons) of material (corresponding to approximately 2,065 m^3 [2,700 yd^3]). These quantities were determined based on placing 10 cm (4 in.) of material over an area of (530)(415) ft^2, and a dry unit weight of 54 kg/m^3 (120 lb/ft^3). A track dozer will spread and grade the material. A vibratory compactor will be needed to densify the base course material as it is placed. The base course layer will be placed on a uniform 2% slope.

Placement of Asphalt: The asphalt layer will be placed by a qualified contractor (possibly different from the one performing other construction activities). The asphalt will be a polymer-modified asphaltic concrete material with a spray-applied styrene-butadiene top coat. The asphalt layer will be 15 cm (6 in.) thick (nominally), and will be placed over an area of (530)(415) ft^2 = 220,000 ft^2 (20,460 m^2) = 24,500 yd^2 (2,048 m^2). The asphalt layer will be placed on a uniform 2% slope.

Placement of Gravel Drainage Layer: The specification for the gravel drainage material is a saturated hydraulic conductivity value of 1 cm/s. Material will be sourced from the Pit 30 site between 200 West and 200 East. Run-of-pit material will be screened to specification at the pit. The one-way haul will be approximately 6.4 km (4 mi). Construction of the gravel filter layer will require hauling and placing approximately 5,895 metric tons (6,500 tons) of material (corresponding to approximately 3,136 m^3 [4,100 yd^3]). These quantities were determined based on placing 15 cm (6 in.) of material over an area of (530)(415) ft^2; a material density of 0.02 m^3 (0.70 ft^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 53.5 kg/m^3 (117.9 lb/ft^3). A motor grader will be used to spread and grade the material. A vibratory compactor also will support construction of this layer.

Placement of Side-Slope Fill and Fill to Support Graded Filter Layers: The perimeter side slope will be built up by placing and compacting fill along the west, north, and east sides of the covered area. The perimeter fill will be placed with a 3H:1V slope and will be approximately 1.2 m + 20 cm (4 ft + 8 in.) thick. Mixed sand and gravel (pit run material from Pit 30) will be used as fill material. Approximately 3,366 m^3 (4,400 yd^3) of fill will be needed for side slope construction. Additional fill (of the same type and source) will be placed to facilitate termination of the graded filter layers around the perimeter of the covered area. The graded filter layers will be angled up to intersect the surface at a slope of 2H:1V. The additional fill requirement beneath the filter layers is 765 m^3 (1,000 yd^3). A track dozer will be used to spread and grade the material. A vibratory compactor will be needed to support construction of this layer.

Placement of Gravel and Sand Filter Layers: Two 15-cm (6-in.) filter layers will be placed above the lateral drainage layer to prevent entry and accumulation of fines in the lateral drainage layer. The gravel filter material will be sourced from Pit 30. Run-of-pit material will be screened to specification at the pit. Construction of the gravel filter layer will require hauling and placing approximately 5,895 metric tons (6,500 tons) of material (corresponding to approximately 3,136 m^3 [4,100 yd^3]). These quantities were determined based on placing 15 cm (6 in.) of material over an area of (530)(415) ft^2; a material density of 0.02 m^3 (0.70 ft^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 53.5 kg/m^3 (117.9 lb/ft^3). A motor grader will spread and grade the material over the majority of the work area. A vibratory compactor will be needed to support construction of this layer.

Placement of Uncompacted (Middle) Silt Layer: The silt soil will be sourced from the McGee Ranch site. The middle silt layer will be 40 cm (16 in.) thick. Construction will require hauling and placing approximately 11,518 metric tons (12,700 tons) of material (corresponding to 8,338 m^3 [10,900 yd^3]). Quantities were computed based on the area and layer thickness and the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3, assumes 20% swell), and placement at bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3). The layer will be constructed in three lifts, using a motor grader or a small dozer to spread material. A water tanker truck and a farm tractor with disk will be needed to support construction.

Placement of Upper Silt Layer With Pea Gravel Admix: The silt loam soil will be sourced from the McGee Ranch site. However, the material will first be transported to an admix plant (assumed to be sited at Pit 30). Pea gravel will be mechanically mixed with the silt to produce a product that is 85% silt and 15% pea gravel by weight. Construction will require hauling and placing approximately 5,986 metric tons (6,600 tons) of material (corresponding to 4,131 m^3 [5,400 yd^3]). These quantities were determined based on placing material to a depth of 20 cm (8 in.), the area defined previously, and the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3, assumes 20% swell), and placement to a unit weight of 40 kg/m^3 (90 lb/ft^3), similar to the original bank density. A motor grader or a small dozer will be used to spread the material. Minimal compaction of this material is needed (i.e., wheel or track loads of placement equipment will provide sufficient compaction; no additional compaction equipment will be needed).

Placement of Coarse, Fractured Basalt Surfacing Material on Perimeter Berm: The fractured basalt will be minus 30-cm (12-in.) material sourced from the existing quarry overlooking Vernita Bridge. The one-way haul will be approximately 27 km (17 mi). Construction will require hauling and placing approximately 3,083 metric tons (3,400 tons) of material (corresponding to approximately 1,530 m^3 [2,000 yd^3]). These quantities were determined based on placing 30 cm (12 in.) of material around a perimeter of 2(530 + 415) + 8(27)/2 = 1,998 lineal ft (609 lineal m) over a width of 27 lineal ft (8 lineal m); a material density of 0.75 ft^3 (0.22 m^3) solids per ft^3 volume and a specific gravity of 2.70, corresponding to 126.4 lb/ft^3 (57.3 kg/m^3). A track dozer will be used to spread and grade the material. Compacting equipment will not be needed.

4.0 MODIFIED RCRA SUBTITLE D BARRIER COST ESTIMATE

4.1 ENGINEERING

Definitive Design: Definitive design will be performed by a consulting civil engineer. Definitive design activities will include preparation of plan and section drawings, specifications, and quality control plans for construction; materials testing to support preparation of specifications; stability and performance analysis calculations; and preparation of procurement documents. Costs for this task (including OH&P) are estimated as 5% of construction costs.

Construction Management, Engineering and Inspection: This task covers bid evaluations, control and review of vendor submittals, engineering support during construction (including survey support), design change control, inspection planning, constructibility reviews, and production of as-built drawings. This task includes costs for QC overview and sampling and testing exclusive of SDRI test (see following task). Costs for this task (including OH&P) are estimated as 10% of construction costs.

4.2 IMPROVEMENTS TO LAND

Site Grading, Compaction and Placement of Grading Fill: Construction will be performed by a qualified subcontractor. Cost is based on a site surface measuring approximately 126 m (415 ft) (E-W) by 161 m (530 ft) (N-S). The area is devoid of vegetation (no clearing and grubbing will be necessary). The existing site surface is slightly irregular and slopes at approximately 1.5% to the north. The RCRA Subtitle D cover design does not include provisions for internal lateral drainage. However, grading to create a planar surface will be performed before placement of the barrier layers to facilitate survey control and QC of material placement and layer thicknesses. Consistent with ALARA principles, balanced cuts and fills will not be used to create a uniform site surface. Surface grading will be done exclusively with fill. It is estimated that approximately 43,299 bank m^3 (56,600 bank yd^3) of grading fill will be needed (corresponding to 51,943 loose m^3 [67,900 loose yd^3], assuming 20% swell). The material will be sourced from Pit 30, situated between 200 West and 200 East, opposite the 609-A fire station. Moisture conditioning (i.e., addition and control) will be performed at Pit 30 before transportation to the construction site. The one-way haul will be approximately 6.4 km (4 mi). Grading fill and existing site soils will be densified by making several passes with a vibratory compactor to create a suitable subbase for barrier construction.

Placement of Compacted (Lower) Silt Layer: The silt loam soil will be sourced from the McGee Ranch site, which represents a 27-km (17-mi) one-way haul. Construction will require hauling, placing, and compacting approximately 6,196 m^3 (8,100 yd^3) or 12,425 metric tons (13,700 tons) of material. These quantities were determined based on placing and compacting material to a depth of 30 cm (12 in.) over an area of (530)(415) ft^2 and the following dry unit weights: bank unit weight of 39.2 kg/m^3 (86.5 lb/ft^3), loose unit weight loaded on haul trucks of 32.7 kg/m^3 (72.1 lb/ft^3, assumes 20% swell), and compacted unit weight of 56 kg/m^3 (125 lb/ft^3). The layer will be constructed in two lifts, using a motor grader or a small dozer to spread material and a static compactor (such as a sheep's foot roller) to densify the material. Moisture conditioning will be performed at the borrow site to the maximum practical extent. However, a water tanker truck and a farm tractor with disk will be needed to support construction.

Table E-1. Hanford Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 2 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Placement of Gravel Drainage Layer					
- Load trucks with screened run-of-pit gravel.	76,245				
- Haul and dump gravel at site, assume 12 km (8 mi) round trip.	31,416				
- Spread and level gravel with dozer/grader, 30-cm (12-in.) layer.	10,199				
- Compact gravel with vibratory roller, 2 passes.	2,639				
- Sales Tax @ 7.8%	5,171				
- OH&P (on markups only)	775				
Subtotal	126,446	17,702	144,148	21,622	165,770
Crushed Basalt Layer/Side Slopes					
- Load, haul and spread 20 to 30-cm (8 to 12-in.) crushed basalt. Existing quarry is 27 km (17 mi) from site.	1,902,905				
- Sales Tax @ 7.8%	46,800				
- OH&P (on markups only)	7,020				
Subtotal	1,956,725	273,942	2,230,667	334,600	2,565,267
Gravel and Sand Filter Layers					
- Load trucks with screened run-of-pit gravel.	53,073				
- Haul and dump gravel at site, assume 12 km (8 mi) round trip.	21,868				
- Spread and level gravel with dozer/grader, 15-cm (6-in.) layer.	7,115				
- Compact gravel with vibratory roller, 2 passes.	1,852				
- Load trucks with screened sand.	42,021				
- Haul and dump sand at site, assume 12 km (8 mi) round trip.	11,088				
- Spread and level sand with dozer/grader, 15-cm (6-in.) layer.	3,613				
- Compact sand with vibratory roller, 2 passes.	932				
- Place geotextile fabric, cost assumes polypropylene mesh, stapled, 184 g/m^2 (6.5 oz/yd^2).	44,281				
- Sales Tax @ 7.8%	9,035				
- OH&P (on markups only)	1,355				
Subtotal	196,234	27,473	223,707	33,556	257,263
Placement of Lower Silt Layer					
- Load, haul, and dump McGee Ranch silt, 58 km (36 mi) round trip.	151,562				
- Spread and Static Compact to 101-cm (40-in.) depth using dozer/grader and water truck for dust control.	103,981				
Subtotal	255,543	35,776	291,319	43,698	335,017

Table E-1. Hanford Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 1 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Definitive Design (Technical Services)					
Subtotal	250,000	0	250,000	37,500	287,500
Engineering/Inspection (Technical Services)					
Subtotal	500,000	0	500,000	75,000	575,000
SDRI Test on Asphalt Layer (Technical Services)					
Subtotal	18,000	0	18,000	2,700	20,700
TOTALS	768,000	0	768,000	115,200	883,200
Site Grading, Compaction & Fill					
- Load, haul, and dump soil from pit 30, 12 km (8 mi) round trip using five dump trucks at 9 m^3 (12 yd^3) each, and one 3 m^3 (4 yd^3) loader; 50,413 m^3 (65,900 yd^3) plus 20% swell = 60,435 m^3 (79,000 yd^3) to haul. Ten-man crew will average 624 m^3 (816 yd^3) per day for 97 days (20 week job).	359,312 79,040				
- Spread soil and level with dozer/grader.	20,441				
- Compact site with vibratory roller, 126 x 161 m (415 x 530 ft) area, 15-cm (6-in.) lifts, 2 passes.					
Subtotal	458,793	79,231	538,024	80,704	618,728
Placement of Base Course					
- Base course material 5/8" minus, delivered to site.	56,911				
- Spread gravel and level with dozer/grader, 10 cm (4 in.) deep.	3,307 1,288				
- Compact with vibratory roller, 2 passes.	3,860				
- Sales Tax at 7.8%	579				
- OH&P (on markups only)					
Subtotal	65,945	9,232	75,177	11,277	86,454
Placement of Asphalt					
- 15-cm (6-in.) polymer-modified asphalt. (Per Don @ A & B Asphalt)	457,380				
- Fluid applied asphalt top coat. (Per KEH estimate ER 3412 (W-263), dated 2-10-93). **NOTE**: High cost may be temporary due to current monopoly on product.	1,176,120				
Subtotal	1,633,500	228,690	1,862,190	279,329	2,141,519

Table E-2. Modified RCRA Subtitle C Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 1 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Definitive Design (Technical Services)					
Subtotal	121,000	0	121,000	18,150	139,150
Engineering/Inspection (Technical Services)					
Subtotal	242,000	0	242,000	36,300	278,300
SDRI Test on Asphalt Layer (Technical Services)					
Subtotal	18,000	0	18,000	2,700	20,700
TOTALS	381,000	0	381,000	57,150	438,150
Site Grading, Compaction and Fill					
- Load, haul, and dump soil from pit 30, 12-km (8-mi) round trip using 5 dump trucks at 9 m^3 (12 yd^3) each, and one 3 m^3 (4 yd^3) loader.	308,821 0				
- 43,299 m^3 (56,600 yd^3) plus 20% swell = 51,943 m^3 (67,900 yd^3) to haul. Ten-man crew will average 624 m^3 (816 yd^3) per day for 85 days (17-week job).	67,922 17,584				
- Spread soil and level with dozer/grader.					
- Compact site with vibratory roller, 126 x 161 m (415 x 530 ft) area 15-cm (6-in.) lifts, 2 passes.					
Subtotal	394,327	70,206	464,533	69,680	534,213
Placement of Base Course					
- Base course material, 5/8" minus, delivered to site.	46,805				
- Spread gravel and level with dozer/grader, 10 cm (4 in.) deep.	2,696				
- Compact with vibratory roller, 2 passes.	1,041				
- Sales Tax at 7.8%	3,174				
- OH&P (on markups only)	476				
Subtotal	54,192	7,587	61,779	9,267	71,046
Placement of Asphalt					
- 15-cm (6-in.) polymer-modified asphalt. (Per Don at A&B Asphalt.)	377,300				
- Fluid applied asphalt top coat. (Per KEH estimate ER 3412 [W-263], dated 2-10-93). **NOTE:** High cost may be temporary due to current monopoly on product.	970,200				
Subtotal	1,347,500	188,650	1,536,150	230,423	1,766,573

Table E-1. Hanford Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 3 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Placement of Silt/Pea Gravel Admix					
- Load, haul, and dump McGee Ranch silt at pit 30, 41 km (26 mi) round trip.	141,959				
- Mix above silt with 2,486 m^3 (3,250 yd^3) of local sourced pea gravel, load haul 6 km (4 mi), and dump.	146,324 21,705				
- Spread mix and level to depth of 101 cm (40 in.).	3,385				
- Sales Tax @ 7.8%	338				
- OH&P (on markups only)					
Subtotal	313,711	43,920	357,631	53,645	411,276
Base for Perimeter Access Road					
- Base course material, 3.8 cm (1.5 in.) minus, delivered to site.	18,084				
- Spread gravel and level with dozer/grader, 30 cm (6 in.) deep.	1,001 403				
- Compact with vibratory roller, 2 passes.	1,226				
- Sales Tax @ 7.8%	183				
- OH&P (on markups only)					
Subtotal	20,899	2,926	23,825	3,574	27,399
TOTALS	5,027,796	718,892	5,746,688	862,005	6,608,693
PROJECT TOTALS	5,795,796	718,892	6,514,688	977,205	7,491,893

Table E-2. Modified RCRA Subtitle C Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 3 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Placement of Compacted Silt					
- Load, haul, and dump McGee Ranch silt, 57 km (36 mi) round trip.	98,477				
- Spread and Static Compact to 50-cm (20-in.) depth in 3 lifts, using dozer/grader, roller and water truck.	69,411				
Subtotal	167,888	23,504	191,392	28,709	220,101
Placement of Silt/Pea Gravel Admix					
- Load, haul, and dump McGee Ranch silt at pit 30, 41 km (26 mi) round trip.	86,025				
- Mix above silt with 1,514 m³ (1,980 yd³) of local sourced pea gravel, load haul 6 km (4 mi), and dump.	88,673				
- Spread mix and level to depth of 50 cm (20 in.).	13,146				
- Sales Tax at 7.8%	2,051				
- OH&P (on markups only)	205				
Subtotal	190,100	26,614	216,714	32,507	249,221
Placement of Coarse, Fractured Basalt on Perimeter Berm					
- Load, haul, and spread 30-cm (12-in.) layer of 30-cm (12-in.) minus crushed basalt around perimeter berm. Existing quarry is 27 km (17 mi) from site.	50,744				
- Sales Tax at 7.8%	1,248				
- OH&P (on markups only)	187				
Subtotal	52,179	7,305	59,484	8,923	68,407
TOTALS	2,415,462	353,166	2,768,628	415,296	3,183,924
PROJECT TOTALS	2,796,462	353,166	3,149,628	472,446	3,622,074

Table E-2. Modified RCRA Subtitle C Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 2 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Placement of Gravel Drainage Layer					
- Load trucks with screened run-of-pit gravel.	30,648				
- Haul and dump gravel at site, assume 12 km (8 mi) round trip.	12,628				
- Spread and level gravel with dozer/grader, 15-cm (6-in.) layer.	4,114				
- Compact gravel with vibratory roller, 2 passes.	1,075				
- Sales Tax at 7.8%	2,078				
- OH&P (on markups only)	311				
Subtotal	50,854	7,120	57,974	8,696	66,670
Placement of Side-Slope Fill					
- Load, haul, and dump pit run sand and gravel mix from pit 30.	20,007				
- Spread material along west, north, and east sides of the covered area at 3 to 1 slope with dozer/grader.	8,810				
- Compact berm with vibratory roller, 15-cm (6-in.) lifts, 2 passes.	2,277				
Placement of Fill to Support Graded Filter Layer	4,548				
- Load, haul, and dump pit run sand and gravel mix from pit 30.	2,001				
- Spread material along perimeter of the covered area at 2 to 1 slope with dozer/grader.	518				
- Compact berm with vibratory roller, 15-cm (6-in.) lifts, 2 passes.					
Subtotal	38,161	5,343	43,504	6,526	50,030
Gravel and Sand Filter Layers					
- Load trucks with screened run-of-pit gravel.	30,648				
- Haul and dump gravel at site, assume 12 km (8 mi) round trip.	12,628				
- Spread and level gravel with dozer/grader, 15-cm (6-in.) layer.	4,114				
- Compact gravel with vibratory roller, 2 passes.	1,075				
- Load trucks with screened sand.	47,857				
- Haul and dump sand at site, assume 12 km (8 mi) round trip.	12,628				
- Spread and level sand with dozer/grader, 15-cm (6-in.) layer.	4,114				
- Compact sand with vibratory roller, 2 passes.	1,075				
- Sales Tax at 7.8%	5,324				
- OH&P (on markups only)	798				
Subtotal	120,261	16,837	137,098	20,565	157,663

Table E-3. Modified RCRA Subtitle D Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 2 of 2)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Placement of Silt/Pea Gravel Admix - Load, haul, and dump McGee Ranch silt at pit 30, 41 km (26 mi) round trip. 85% x 4,131 m³ (5,400 yd³) + 20% swell. - Mix above silt with 619 m³ (810 yd³) of local sourced pea gravel, load, haul 6 km (4 mi), and dump. 4,131 m³ (5,400 yd³) x 15% = 810. - Spread mix and level to depth of 20 cm (8 in.). - Sales Tax at 7.8% - OH&P (on markups only)	42,366 42,594 6,318 985 98				
Subtotal	92,363	12,931	105,294	15,794	121,088
Placement of Coarse, Fractured Basalt on Perimeter Berm - Load, haul, and spread 30-cm (12-in.) layer of 30 cm (12 in.) minus crushed basalt around perimeter berm. Existing quarry is 27 km (17 mi) from site. - Sales Tax at 7.8% - OH&P (on markups only)	50,744 1,248 187				
Subtotal	52,179	7,305	59,484	8,923	68,407
TOTALS	836,835	132,157	968,992	145,349	1,114,341
PROJECT TOTALS	896,835	132,157	1,028,992	154,349	1,183,341

Table E-3. Modified RCRA Subtitle D Barrier Conceptual Cost Estimate for a 5-Acre Site. (Page 1 of 2)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Definitive Design (Technical Services)					
Subtotal	20,000	0	20,000	3,000	23,000
Engineering/Inspection (Technical Services)					
Subtotal	40,000	0	40,000	6,000	46,000
TOTALS	60,000	0	60,000	9,000	69,000
Site Grading, Compaction, and Fill - Load, haul, and dump soil from pit 30, 12 km (8 mi) round trip using 5 dump trucks at 9 m^3 (12 yd^3) each, and one 3 m^3 (4 yd^3) loader. - 43,299 m^3 (56,600 yd^3) plus 20% swell = 51,943 m^3 (67,900 yd^3) to haul. Ten-man crew will average 624 m^3 (816 yd^3) per day for 85 days (17-week job). - Spread soil and level with dozer/grader. - Compact site with vibratory roller, 126 x 161 m (415 x 530 ft) area 15-cm (6-in.) lifts, 2 passes.	308,821 0 67,922 17,584				
Subtotal	394,327	70,206	464,533	69,680	534,213
Placement of Lower Silt Layer - Load, haul, and dump McGee Ranch silt, 57 km (36 mi) round trip. 62,347 m^3 (81,500 yd^3) + 20% swell. - Spread and compact to 30-cm (12-in.) depth in 2 lifts, using dozer/grader, roller, and water truck.	75,254 53,041				
Subtotal	128,295	17,961	146,256	21,938	168,194
Placement of Middle Silt Layer - Load, haul, and dump McGee Ranch silt, 57 km (36 mi) round trip. 8,338 m^3 (10,900 yd^3) + 20% swell. - Spread to depth of 40 cm (16 in.) with dozer/grader; use water, as necessary, for dust control.	100,642 69,029				
Subtotal	169,671	23,754	193,425	29,014	222,439

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