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

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FOCUSED FEASIBILITY STUDY OF ENGINEERED BARRIERS FOR WASTE MANAGEMENT UNITS IN THE 200 AREAS

EXECUTIVE SUMMARY

The 200 Areas of the U.S. Department of Energy Hanford Site are included on the National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) 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, ten Aggregate Area Management Studies (AAMS) were prepared for the 200 Areas in support of RI/FS activities. These AAMS reports summarize characterization information for 200 Area waste management units (WMUs). Additionally, the AAMS reports arrange WMUs into analogous groups and recommend a range of potential remedial technologies.

The AAMS 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 AAMS reports for an FFS is remediation with surface barriers. Based on that recommendation this FFS was undertaken.

As the result of conducting this FFS, a total of three conceptual barrier designs are proposed which meet all regulatory design requirements for IRM and LFI candidate WMUs. The three designs provide a range of cover options to minimize health and environmental risks associated with a site in the most cost-effective manner. A brief description of each design and its intended use is provided below.

- **Hanford Barrier.** This design is proposed for implementation at transuranic (TRU)-contaminated soil sites, sites with TRU or TRU mixed waste in nonretrievable configuration, and sites with Greater-Than-Class C Low-Level Waste (LLW) or mixed waste. 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 three proposed designs. This barrier includes a layer of coarse, fractured basalt that is intended to perform the primary biointrusion and human intrusion control functions.

- **Modified RCRA Subtitle C Barrier.** This barrier design is proposed for applications at sites containing hazardous waste, Category 3 LLW 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. This design also 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 design life of the Modified RCRA Subtitle C Barrier.

- **Modified RCRA Subtitle D Barrier.** This design is proposed for applications at nonradiological and nonhazardous solid waste sites, as well as Category 1 LLW sites where no hazardous waste constituents are present. 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 selected to conform to the minimum projected duration of active institutional control.

Design criteria for the three designs were determined by screening all potentially applicable regulatory statutes, regulatory guidance documents and recognized design standards. Those regulations or standards determined to be 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 three proposed barrier designs are described in Section 3.0. The designs were reviewed against the established design criteria to ensure conformance. In addition, the cover designs were evaluated against the nine U.S. Environmental Protection Agency evaluation criteria for selecting a preferred remediation alternative (Section 4.0).

A flow diagram is presented in Section 5.0 to summarize the proposed implementation logic for barrier selection for designated WMUs. 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 (Section 5.0).

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CONTENTS

CONTENTS (continued)

APPENDICES

CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (continued)

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) 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 (CERCLA) of 1980. Inclusion on the NPL initiates the Remedial Investigation (RI) and Feasibility Study (FS) process for characterizing the nature and extent of contamination, assessing risks to human health and the environment, and selecting remedial actions.

The *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) was developed and signed by representatives from the EPA, Washington State Department of Ecology (Ecology), and DOE in May 1989 to provide a framework for implementing and integrating cleanup activities (Ecology et al. 1991). The scope of the agreement covers all CERCLA past practice, Resource Conservation and Recovery Act (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* (DOE-RL 1992b) and established a milestone (major milestone M-27-00) to complete 10 *Aggregate Area Management Study (AAMS) Reports* (DOE-RL 1992a) in 1992.

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

This FFS evaluates conceptual remedial designs for covers or caps applicable to a range of high priority source waste management units (primarily units recommended for action under the interim remedial measure [IRM] or limited field investigation [LFI] paths) identified in the AAMS reports.

1.1 BACKGROUND

The following sections provide background information regarding (1) the location of the 200 Areas, (2) the *Hanford Site Past-Practice Strategy*, 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 including 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) (WHC 1991), including CERCLA and RCRA past-practice waste management units, 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 waste management units or spills. The Tri-Party Agreement describes the assignment of waste management units and unplanned release sites to specific operable units. Ecology et al. (1991) also defines the various types of waste sites.

1.1.2 Hanford Site Past-Practice Strategy

The *Hanford Site Past-Practice Strategy* was developed by Ecology, EPA, and DOE to streamline the existing RI/FS and RCRA Facility Investigation/Corrective Measures Study (RFI/CMS) processes at Hanford. Primary objectives were(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 Hanford. The past-practice strategy 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 in the strategy was to evaluate existing information through the AAMS process. Based on this information, recommendations were made in the AAMS reports (DOE-RL 1992a) regarding which Hanford Site Past-Practices path to pursue for individual past-practice waste management units, unplanned release sites, and groundwater contaminant plumes. The strategy established four types of remediation paths including expedited response action (ERA), IRM, 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** - Final remedy selection 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 for an entire operable unit or aggregate area.

The *Hanford Site Past-Practice Strategy* recognizes that the NPL does not require an RI/FS before cleanup begins.. The *Hanford Site Past-Practice Strategy* indicates that, for IRMs, a remedy might be obvious or, at most, an FFS might be needed to select a remedy. The FFSs are designed to 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), 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, 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 plant-wide scale. Environmental media of interest included air, biota, surface water, surface soil, and unsaturated subsurface soil.

The major objective of the AAMS program was to determine and recommend the appropriate *Hanford Site Past-Practice Strategy* path for performing cleanup actions for each waste management unit 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 *Hanford Site Past-Practice Strategy*. Section 7.0 of the AAMS reports (DOE-RL 1992a) identifies preliminary remedial alternatives. This was accomplished by first establishing preliminary remedial action objectives (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 (ARARs) or risk based levels that will allow industrial use of the area"***
> (DOE-RL 1992a).

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 waste management units 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 selected and considered applicable for 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, bio-mobilization, 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) reduction of the volatilization of volatile organic compounds (VOCs) and tritium to the atmosphere (refer to Section 7.4.2 of the source AAMS reports [DOE-RL 1992a]). Table 7-4 of DOE-RL (1992a) indicates that covers make up one of several alternatives that potentially have broad applicability to remediating various types of waste management units throughout the 200 Areas. Because of the potential broad application of covers at high priority sites, the 200 Area source AAMS reports recommended that an FFS be prepared that focuses on covers applicable to various waste type categories rather than on specific waste sites.

1.2 SCOPE AND OBJECTIVES

The scope of this FFS is to develop a limited number of preengineered cover design options for source IRMs and LFIs previously identified in the AAMS reports as candidates for remediation with surface barriers. The cover designs are to be developed in a manner that provides traceability to ARARs for recognized categories of waste and/or soil contamination. The applicable waste categories are defined in Section 1.4.

The cover alternatives described in this document are 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 in support of these designs. Therefore, implementation for IRMs is practical because lengthy studies will not generally be required before application. Long-term performance and maintenance objectives and design criteria were established based on an evaluation of ARARs and engineering criteria. The adequacy of existing cover designs was evaluated against the established criteria and modified accordingly.

This FFS provides generic conceptual cover designs for waste site applications rather than site-specific definitive designs. The generic conceptual designs provide descriptions of the layer sequence in section view through the cover but do not include construction details such as termination of the edges of the layers or sideslope configuration. Definitive design must take into account 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 proposed for remediation under the IRM path, the IRM process described in *Hanford Site Past-Practice Strategy* will be followed to formulate a conceptual model and perform a qualitative baseline risk assessment (QBRA) for the site. The QBRA includes a human health evaluation and a separate environmental evaluation. The specific methodology for QBRAs is provided in *Hanford Site Baseline Risk Assessment Methodology*, Appendix C (DOE-RL 1993a). The pathways typically evaluated in the QBRA include:

- Soil ingestion,
- Fugitive dust inhalation,

- Inhalation of volatile organic chemicals from soil (if present),
- Ingestion of water, and
- 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 qualitative risk assessment, 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. If a specific remedy is identified and that remedy is a cover, then this FFS will be used to assist in selecting the appropriate cover for the application, considering the type and concentration of waste present and the results of the QBRA.

The primary objective of this FFS report is to provide a limited number of preengineered cover options to support the IRM path. Decision logic for selecting the appropriate cover alternative is provided in Section 5.0.

A secondary objective of this FFS report is to provide recommendations for any additional studies that may be required to facilitate the near-term implementation of conceptual designs described in this report for specific IRM applications.

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 source IRM and LFI waste management units 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 waste management units and unplanned release sites (summarized by waste category) that have been identified in source AMMS reports (DOE-RL 1992a) as candidates for remediation with engineered surface barriers, following either the IRM or the LFI path.

2. **Preliminary Identification of ARARs.** A matrix of all potentially pertinent ARARs and other standards was developed for each waste category identified in Step 1.All potential ARARs and standards(including chemical-, location-, and action-specific requirements) were then screened.. Potential ARARs and standards 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 wastes were retained for further consideration as FFS conceptual design criteria. Potential ARARs that were considered applicable only to definitive design were identified for future application during the definitive design stage.

3. **Establishment of Conceptual Design Criteria.** Criteria were established based on the ARARs and "to be considered" (TBC) standards and requirements determined in Step 2 to be applicable to generic conceptual cover designs .

4. **Preliminary Selection 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 design criteria established in Step 3.

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

7. **Development of Conclusions and Recommendations.** A logic chart was prepared illustrating how information on cover designs supports implementation of the selected cover alternatives for IRMs identified for cover installation. Site-specific testing, including type and data needs, was recommended where required to support timely cover installation.

1.4 WASTE SITES AND WASTE CATEGORY DESIGNATION

Terminology used at the Hanford Site and other DOE facilities for radiological, hazardous, and other solid waste types is defined below.

- **Radioactive Waste.** Solid, liquid, or gaseous material that contains radionuclides regulated under the Atomic Energy Act of 1954 as amended, and (which is) of negligible economic value considering costs of recovery. Radioactive waste includes spent nuclear fuel, high-level waste (HLW), byproduct material, transuranic (TRU) waste, and low-level waste (LLW) (DOE 5820.2A).

- **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 (DOE 5820.2A).

- **HLW.** As defined in 10 CFR 60.2, HLW includes (1) spent nuclear fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted.

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

As indicated in DOE 5820.2A, Section 1, new and readily retrievable existing HLW is to be processed to a final immobilized form for permanent disposal in a federal deep geologic repository. HLW that is not readily retrievable is to be monitored in situ. For HLW (specifically single- and double-shell tank wastes) stored at the Hanford Site, DOE policies and requirements relating to disposal options are described in RLID 5820.2A, Section 1(3)(d).

- **Byproduct Material.** As defined in the Atomic Energy Act of 1954 as amended, byproduct material includes two distinct types of material. Section 11e(1) describes byproduct material as any radioactive material (other than special nuclear material) yielded in or made radioactive by exposure to radiation incident to the process of producing or utilizing special nuclear material. According to Section 11e(2), the tailings or waste produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content also are considered to be byproduct material. At the Hanford Site, byproduct material (including both 11e(1) and 11e(2) material) is handled and disposed of as LLW.

- **TRU Waste.** Currently, DOE defines TRU 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.

Before 1970, there was no requirement to segregate TRU waste from LLW, and a considerable volume of LLW with TRU radionuclides was disposed of in burial grounds at various DOE sites. In 1970, the Atomic Energy Commission (AEC) 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.

Newly generated, stored, and/or retrieved solid TRU waste, including TRU mixed waste, is to 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 of by alternative methods, which could include disposal at the Hanford Site. Onsite disposal would require concurrence of the EPA administrator (RLID 5820.2A).

Sites with buried TRU and suspect TRU are to be characterized to determine the types and quantities of radioactive and hazardous constituents present (if any). Characterization activities will include assessments of waste migration from the burial sites and potential environmental and health impacts. Applicable closure plans will be approved by EPA and Ecology.

- **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.

A classification scheme for commercial LLW was promulgated by the Nuclear Regulatory Commission (NRC) in 10 CFR 61.55. This scheme identified four LLW categories: Class A, Class B, Class C, and Greater-Than-Class C. Wastes are classified according to concentrations of listed long- and short-lived radionuclides and other unlisted radionuclides. DOE elected not to 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.

The Hanford Site system has three waste categories: Category 1 (analogous to NRC Classes A and B), Category 3 (analogous to Class C) and Greater-Than-Class C as originally defined by NRC. Category 1 and 3 wastes 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 wastes with multiple constituents.

- **Hazardous (RCRA Subtitle C) Waste.** Any solid, semi-solid, or gaseous waste which, due to its physical or chemical properties, is toxic, persistent, carcinogenic, or otherwise could pose a threat to human health and the environment if not managed and disposed of properly.

Hazardous wastes are regulated at the Federal level in accordance with RCRA Subtitle C; Washington State regulates "dangerous wastes" that are essentially identical to hazardous wastes in accordance with Chapter 70.105 of the Revised Code of Washington (RCW), the Hazardous Waste Management Act. Hazardous wastes are specifically listed or characterized under Title 40 of the Code of Federal Regulations (CFR), Part 261, and Parts 173-303-070 through 173-303-103 of the Washington Administrative Code (WAC).

- **Mixed Waste.** Waste containing both radioactive and hazardous waste constituents.

- **Solid (RCRA Subtitle D) Waste.** Any putrescible or non-putrescible solid, semi-solid, liquid, or sludge waste that is not hazardous or radioactive. Solid wastes include domestic, commercial, and industrial wastes and are regulated at the Federal level in accordance with RCRA Subtitle D and by Washington State in accordance with Chapter 70.95 RCW, the Solid Waste Management -- Recovery and Recycling Act.

Waste management units identified in the source AAMS reports (DOE-RL 1992a) 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 WIDS (WHC 1991). The designations are based on current inventory information and may not account for all contaminants present at all of the individual units. However, the information is believed to provide a reasonable representation of the waste types in the subject units.

As summarized in Table 1-1, the categories include TRU, LLW, hazardous waste, mixed hazardous and radiological waste, and nonhazardous/nonradioactive solid waste. Based on the data presented in Table 1-1, four waste categories are identified that encompass all sites recommended for IRM/LFI actions:(1) TRU, (2) LLW, (3) RCRA Subtitle C waste, and (4) RCRA Subtitle D waste. These four categories form the basis for establishing preliminary ARARs and design criteria in Section 2.0.

Figure 1-1. Hanford Site Map.

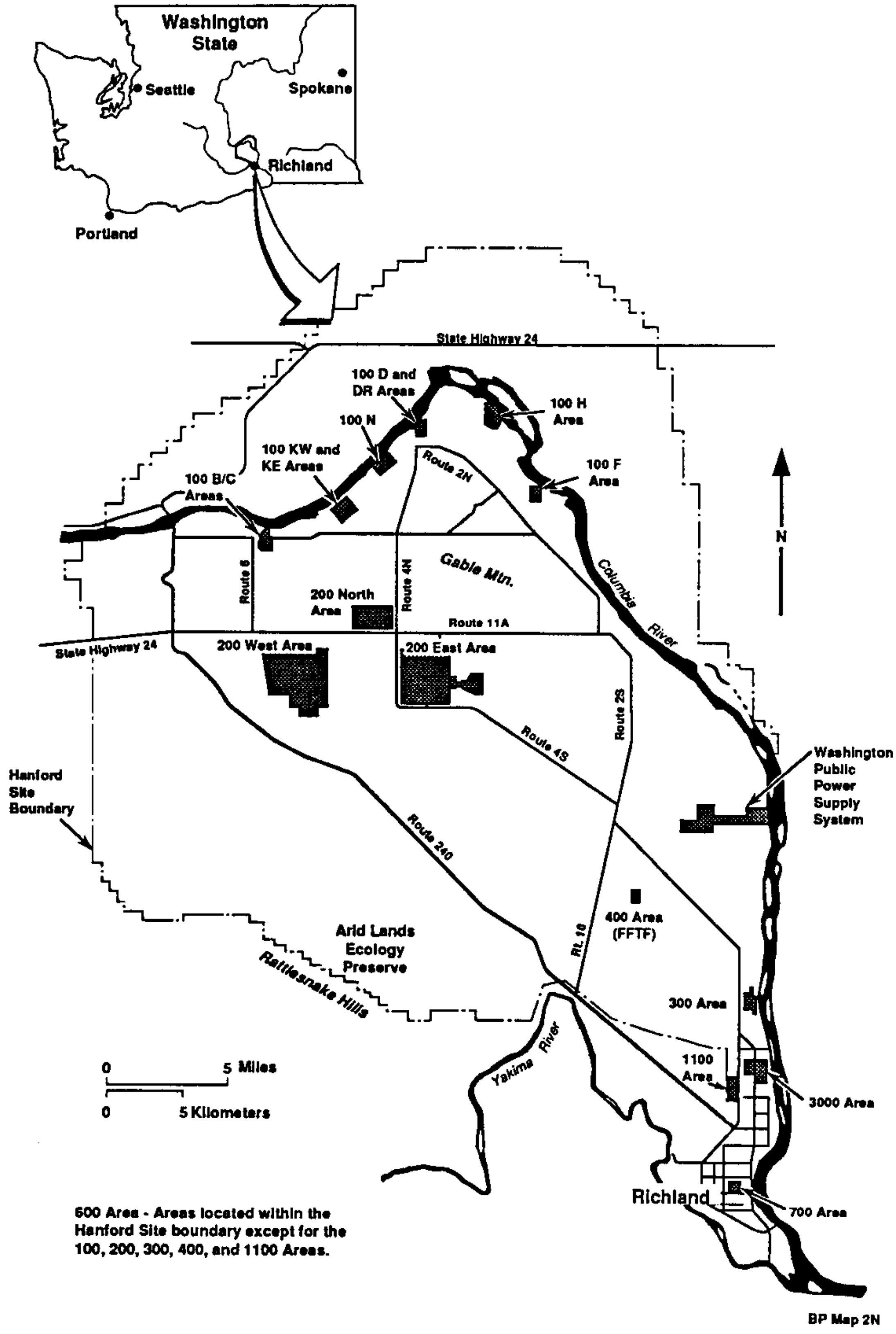

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Table 1-1. Waste Category Site Summary.

Waste category	No. of sites*
TRU and TRU/Mixed Waste	30
LLW and LL/Mixed Waste	239
Hazardous (RCRA C) Waste	8
Nonhazardous/Nonradiological (RCRA D) Waste	14
Total	291

TRU = Transuranic.
LLW = Low-Level Waste.
RCRA C = Resource Conservation and Recovery Act, Subtitle C.
RCRA D = Resource Conservation and Recovery Act, Subtitle D.

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2.0 DESIGN CRITERIA DEVELOPMENT

2.1 APPROACH TO DEVELOPING DESIGN CRITERIA

The design criteria for engineered multimedia covers for 200 Area waste sites were developed from two primary areas of consideration: (1) ARARs that are promulgated Federal and state statutes and regulations and related guidance and TBC materials derived from or based upon Federal and state requirements that could affect the design and performance of waste site covers; and (2) other engineering source documents pertinent to cover design and performance, based on engineering standard practices and experiences to date with Hanford Site covers.

Section 2.1.1 outlines the approach and process for evaluating and retaining potential ARARs and TBCs. Section 2.1.2 outlines the approach and process for evaluating other engineering factors affecting cover design. The potential ARARs considered in this FFS for cover design are summarized in Table 2-1. Section 2.2 describes potential ARARs and TBCs. Section 2.3 describes the engineering factors that pertain to cover design in this FFS. Further evaluation and screening of the potential ARARs, TBCs, and engineering considerations occurs in Section 2.4. Section 2.5 summarizes and presents the design criteria that pertain to the conceptual cover designs described in this FFS.

2.1.1 Regulatory Criteria (Potential ARARs and TBCs)

All potential ARARs were evaluated, including contaminant-, location-, and action-specific requirements. TBCs were also evaluated. Potential ARARs and TBCs 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 wastes in engineered units. Sections 2.1.1.1 and 2.1.1.2 describe the rationale for retaining ARARs and TBCs for further consideration.

2.1.1.1 Potential 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. Potential ARARs are typically grouped into contaminant-specific, location-specific, and action-specific categories. Potential ARARs in each of these categories were evaluated for their relevance to the development of cover designs in this FFS.

Contaminant-specific potential 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 selection of remediation alternatives by setting objectives that the alternatives must meet to reduce health and environmental risk. In this manner, contaminant-specific potential ARARs may provide broad, performance-based criteria that covers must achieve to be useful for remediating releases of chemical and radiological constituents to the environment. However, preliminary evaluation of these ARARs determined they provide only generic remediation objectives, and not design or performance criteria that would apply to the actual design of covers for this FFS. Therefore, contaminant-specific potential ARARs were not retained as cover design criteria.

Contaminant-specific potential ARARs may be reviewed during consideration of cover alternatives for particular waste management units or unplanned releases to determine if environmental contaminants will be confined to acceptable levels, or to further refine a selected cover design. It is anticipated that any refinements required because of contaminant-specific ARARs will not require significant modification of the generic conceptual cover designs. These potential ARARs are itemized and evaluated on a preliminary basis in Section 6.2 and Table 6-1 of the source AAMS reports (DOE-RL 1992a).

Although several location-specific potential 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 proscribe the types of environmental locations in which certain types of wastes may be disposed, they do not dictate cover design criteria or performance requirements. Consequently, the cover designs described in this FFS do not include standards based on potential location-specific ARARs. Potential location-specific ARARs may need to be considered on a site-by-site basis when final decisions are made about the ability to implement alternative waste remediation methods at particular waste management unit and unplanned release locations. These potential ARARs are itemized and evaluated on a preliminary basis in Section 6.3 and Table 6-2 of the source AAMS reports (DOE-RL 1992a). This evaluation indicates that, although location-specific ARARs may affect the use of covers, they are not expected to significantly impact cover designs.

Potential action-specific ARARs generally describe design and performance considerations that must be accounted for when implementing remedial alternatives. A significant number of potential ARARs of this type were found to apply to cover design. Potential action-specific ARARs constitute the majority of the regulatory criteria that were determined to be applicable to the cover designs in this FFS.

The retained ARARs are summarized in Table 2-1 and are 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 potential ARARs have been organized by the types of waste categories to which they are pertinent for IRM actions: TRU, LLW, hazardous (dangerous) waste (regulated in accordance with RCRA Subtitle C and equivalent state authorities), and solid waste (regulated in accordance with RCRA Subtitle D and equivalent state authorities). Citations to the Federal and state regulations are provided. In general, 10 CFR includes regulations promulgated by the U.S. Nuclear Regulatory Commission (NRC) and/or DOE. The 40 CFR regulations are promulgated by EPA. Washington State regulations promulgated by Ecology and Washington State Department of Health are adopted under WAC.

Once the preliminary evaluation was completed, the retained ARARs were reviewed further to determine if they established design criteria or performance requirements for covers. Source ARARs of design criteria provide explicit, physical, or quantitative attributes that covers must conform to. In general, design criteria are not dependent upon parameters or circumstances unique to a particular site location, configuration, topography, or other variables. Examples include potential ARARs setting the thickness of a final cover, minimum side slope angles, or the type of material that must be used to construct a cover. Potential ARARs that provide engineered design criteria are identified with a "Yes" in the third column of Table 2-1.

Sources of performance requirements include any other potential ARARs that do not identify physical limits or constraints or quantitative criteria. In general, performance requirements address particular environmental or waste management unit circumstances that a cover must be designed to control when implemented. Examples include potential ARARs for minimizing the effects of subsidence, diverting run-on, preventing erosion from run-off, and revegetation. In addition, performance requirements include any criteria for which the regulatory requirements (1) allow implementation of an alternative, equivalent design feature that does not have an explicit physical or quantitative specification; or (2) include a performance requirement along with a specific design criterion. Two examples are (1) allowing the use of intruder barriers in lieu of a fixed minimum cover thickness, and (2) requiring minimization of infiltration and erosion coupled with permeability and thickness limits. Potential ARARs that provide performance requirements are designated with a "Yes" in the fourth column of Table 2-1.

2.1.1.2 Potential TBCs. Myriad other Federal and state guidance, criteria, advisories, and similar materials are to be considered when performing CERCLA remediation work. Section 6.5 of DOE-RL (1992a) provides a preliminary review of potential TBCs that may affect remediation of the AAMS waste management units and unplanned releases.

Although many TBCs exist, only a few potential TBCs provide specific design standards or direction for covers. For the purposes of this FFS, DOE orders and other pertinent agency guidance were retained as potential TBCs if they established explicit design criteria and/or performance requirements for barriers, covers, landfill, or land disposal facilities, or containment of wastes in engineered units. Section 2.2.5 describes in detail the TBCs retained for further consideration.

2.1.2 Other Criteria

Considerable design codes, specifications, and guidance materials exist for the construction industry. A separate evaluation was undertaken to identify other sources of technical guidance that would be applicable to the design or construction of surface barriers. 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 applicable to covers. These sources are identified, along with the ARARs and TBCs, as design criteria for covers. The materials reviewed include engineering and construction specifications, computer codes for evaluating hydrologic performance of surface barriers (the Hydrologic Evaluation of Landfill Performance (HELP) Model and Battelle Pacific Northwest Laboratory's UNSAT-H Code (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 reference materials to be considered as sources of design criteria is provided in Section 2.3.

2.2 REGULATORY REQUIREMENTS

The potential ARARs and TBCs that were retained for consideration in developing the cover design criteria are described in detail in sections that follow.

2.2.1 Transuranic Waste

The EPA has promulgated regulations pertaining to disposal and management of TRU wastes. These regulations include requirements affecting design and performance of covers for TRU waste disposal sites. The EPA, Ecology, and Washington State Department of Health have promulgated regulations controlling air emissions of radionuclides and limiting public exposure to airborne radionuclides. These regulations may affect design and performance of covers for TRU disposal sites. Sources of pertinent requirements and criteria have been identified as potential ARARs and are described in the following sections.

2.2.1.1 40 CFR Part 191--EPA Radiation Protection Standards for Managing and Disposing of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes.

191.13 Containment requirements.

(a) Disposal systems for spent nuclear fuel or high-level or TRU radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal systems shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 of this regulation.

(2) Have a likelihood of less than one chance in 1,000 of exceeding 10 times the quantities calculated according to Table 1 of this regulation.

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

191.14 Assurance requirements.

(a) Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active institutional controls for more than 100 years after disposal.

(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their locations.

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

191.15 Individual protection requirements.

Disposal systems for spent nuclear fuel or high-level or TRU radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 mrem to the whole body or 75 mrem to any critical organ.

191.16 Groundwater protection requirements.

(a) Disposal systems for spent nuclear fuel or high-level or TRU radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of groundwater to exceed:

(1) 5 pCi/L of ^{226}Ra and ^{228}Ra

(2) 15 pCi/L of alpha-emitting radionuclides (including ^{226}Ra and ^{228}Ra but excluding radon).

2.2.1.2 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 which 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. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

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.

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 which 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 wastes after disposal.

61.52 Land disposal facility operation and disposal site closure.

(a)(2). Wastes designated as Class C must be disposed of so that the top of the waste is a minimum of 5 m 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.

2.2.1.3 40 CFR Part 61--EPA Regulations on Standards of Performance for New Stationary Sources.

61.192 Standard.

No source at a DOE facility shall emit more than 20 pCi/m^2-s of ^{222}Rn as an average for the entire source, into the air.

2.2.1.4 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, as low as reasonably achievable (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.

2.2.1.5 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 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 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 potential ARARs for LLW sites. Many of the following regulations from 10 CFR 61 also were identified in Section 2.2.1.2 as potential ARARs for TRU waste sites.

2.2.2.1 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 which 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. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

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.

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 which 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 wastes after disposal.

61.52 Land disposal facility operation and disposal site closure.

(a)(2) Wastes designated as Class C must be disposed of so that the top of the waste is a minimum of 5 m 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.

2.2.2.2 40 CFR Part 61--EPA Regulations on Standards of Performance for New Stationary Sources.

61.192 Standard.

No source at a DOE facility shall emit more than 20 $pCi/m^2 \cdot s$ of ^{222}Rn as an average for the entire source, into the air.

2.2.2.3 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, as low as reasonably achievable (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.

2.2.2.4 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.

2.2.3 RCRA Federal/State Hazardous Wastes (Subtitle C)

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

2.2.3.1 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 Post-Closure; 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, post-closure escape of dangerous waste, dangerous constituents, leachate, contaminated run-off, 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 post-closure 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 run-off from eroding or otherwise damaging the (final) cover.

40 CFR 264 and 265 Subpart N -- Landfills; 40 CFR 264.310/265.310 Closure and post-closure 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 run-off from eroding or otherwise damaging the (final) cover.

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

WAC 173-303-610 Closure and post-closure.

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

(a)(i and ii) [Refer to 40 CFR 264.111(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)].

2.2.3.3 Chapter 173-460 WAC--New Sources of Toxic Air Pollutants.

WAC 173-460-060--Control technology requirements.

Except as provided for in WAC 173-460-040, a person shall not establish, operate, or cause to be established or operated any new toxic air pollutant source which is likely to increase toxic air pollutant (TAP) emissions without installing and operating best available control technology for toxics (T-BACT).

2.2.4 RCRA Federal/State Solid Wastes (Subtitle D)

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

2.2.4.1 40 CFR Part 241--Guidelines for the Land Disposal of Solid Wastes.

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 [USCS] or U.S. Department of Agriculture [USDA] Classification System).

(b) Surface grades and side slopes needed to promote maximum run-off, 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.

2.2.4.2 40 CFR Part 258--EPA Criteria for Municipal Solid Waste Landfills.

40 CFR 258.60 Closure criteria.

(a) Owners or operators of all municipal solid waste landfill units must install a final cover system that is designed to minimize infiltration and erosion. The final cover system must be designed and constructed to:

(1) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1 x 10^{-5} cm/s, whichever is less

(2) Minimize infiltration through the closed municipal solid waste landfill by the use of an infiltration layer that contains a minimum 45 cm (18 in.) of earthen material

(3) Minimize erosion of the final cover by the use of an erosion layer that contains a minimum 15 cm (6 in.) of earthen material that is capable of sustaining native plant growth.

2.2.4.3 Chapter 173-304 WAC--Minimum Functional Standards for Solid Waste Handling.

WAC 173-304-407 General closure and post-closure 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 post-closure 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 Landfilling standards.
(3) Minimum functional standards for design.

(a)(iv) Designing the landfill to collect the run-off of surface waters and other liquids resulting from a 24-hour, 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 provided that 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%.

(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.

2.2.4.4 Chapter 173-460 WAC--New Sources of Toxic Air Pollutants.

WAC 173-460-060--Control technology requirements.
Except as provided for in WAC 173-460-040, a person shall not establish, operate, or cause to be established or operated any new toxic air pollutant source that is likely to increase TAP emissions without installing and operating Toxics-Best Available Control Technology (T-BACT).

2.2.5 Other Materials To Be Considered

Other TBCs as design criteria include standards or codes that are not promulgated as law. The list of potential TBCs included DOE orders and EPA guidance documents.

2.2.5.1 DOE Orders.

DOE Order 5820.2A Radioactive Waste Management.

DOE Order 5820.2A describes various health, environmental, and design requirements that must be satisfied in the management of radioactive waste. Pertinent sections of DOE Order 5820.2A are detailed below:

(a) DOE LLW operations shall be managed to protect the health and safety of the public, preserve the environment of the waste management facilities, and ensure that no legacy requiring remedial action remains after operations have been terminated [DOE Order 5820.2A (III)(2)(a)].

(b) Ensure that external exposure to the waste and concentrations of radioactive material which may be released into surface water, groundwater, soil, plants and animals results in an effective dose equivalent that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR Part 61. Reasonable effort should be made to maintain releases of radioactivity in effluent to the general environment ALARA [DOE Order 5820.2A (III)(3)(a)(2)].

(c) Ensure that the committed effective dose equivalents received by individuals who inadvertently may intrude into the facility after the loss of active institutional control (100 years) will not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure [DOE Order 5820.2A (III)(3)(a)(3)].

(d) Engineered modifications (stabilization, packaging, burial depth, barriers) for specific waste types and for specific waste compositions (fission products, induced radioactivity, uranium, thorium, radium) for each disposal site shall be developed through the performance assessment model [DOE Order 5820.2A (III)(3)(i)(20].

(e) Design criteria shall be established prior to selection of new disposal facilities, new disposal sites, or both. These design criteria shall be based on analyses of physiographic, environmental, and hydrogeological data to assure that the policy and requirements of this order can be met. The criteria shall be also based on assessments of projected waste volumes, waste characteristics, and facility and disposal site performance [DOE Order 5820.2 (III)(3)(i) (8)(a)].

(f) Disposal units shall be designed consistent with disposal site hydrology, geology, and waste characteristics and in accordance with the National Environmental Policy Act process [DOE Order 5820.2A (III)(3)(i)(8)(b)].

DOE Order 6430.1A General Design Criteria.

DOE Order 6430.1A describes general design criteria for use in the acquisition and maintenance of DOE facilities. Relevant sections of DOE Order 6430.1A are listed below:

(a) 1324 Radioactive Solid Waste Facility 1324-2.2.1 Disposal. Radiation dose requirements are the same as those found in 40 CFR 191.15.

(b) 1324-6.4 Tertiary Confinement System.
The natural setting composes the tertiary confinement system. The tertiary confinement system shall function during normal operations, anticipated operations, occurrences, the Design Basis Accident, and the severe natural phenomena postulated for the facility site. In addition, the tertiary confinement system shall meet the following performance objectives.

(i) Following permanent closure, ongoing site maintenance shall not be needed.

(ii) In the absence of unplanned natural processes or human contact with a LLW facility, calculated contaminant levels in groundwater at the site boundary shall not exceed the maximum containment levels established in 40 CFR 141.

(iii) Institutional controls shall not be relied upon for more than 100 years following permanent closure.

DOE Order 5400.5 Radiation Protection of the Public and the Environment.

DOE Order 5400.5 establishes standards and requirements for operations with respect to protection of members of the public and the environment against undue risk from radiation. Pertinent sections of DOE Order 5400.5 are detailed below:

(a) To the extent required by 40 CFR Part 191, the exposure of members of the public to direct radiation or radioactive material released from DOE management and storage activities at a disposal facility for spent nuclear material or for high-level or TRU radioactive wastes that are not regulated by NRC shall not cause members of the public to receive, in a year, a dose equivalent greater than 25 mrem to the whole body or a committed dose equivalent greater than 75 mrem to any organ [DOE Order 5400.5 (II)(1)(c)].

(b) Field elements shall develop a program and shall require contractors to implement the ALARA Process for all DOE activities and facilities that cause public doses [DOE Order 5400.5 (II)(2)].

(c) The concept of ALARA requires judgement with respect to what is reasonably achievable. Factors that relate to societal, technological, economic, and other public policy considerations shall be evaluated to the extent practicable in making such judgements. Factors to be considered, at a minimum, shall include:

- The maximum dose to the members of the public
- The collective dose to the population
- Alternative processes, such as alternative treatments or discharge streams, operating methods, or controls
- Doses for each process alternative
- Costs for each of the technological alternatives
- Examination of the changes in cost among alternatives
- Changes in societal impact associated with process alternatives, e.g., differential doses from various pathways [DOE Order 5400.5 (II)(2)(a)].

2.2.5.2 Other Agency Guidance and TBCs.

Design and Construction of Covers for Solid Waste Landfills (EPA-600/2-79-165).

This report was prepared for EPA by the U.S. Army Corps of Engineers as a technical overview of engineering information for the design of landfill cover systems. The report addresses cover and layer functions, determination of material properties of cover materials, design procedures, and strategies involving layering of materials and specification of non-soil materials in design.

Covers for Uncontrolled Hazardous Waste Sites (EPA/540/2-85/002).

This EPA document is intended to serve as a technical handbook for designers of cover systems for uncontrolled hazardous waste sites. Comprehensive coverage is given to site characterization, construction materials, cover design, construction, and construction quality control.

Technical Guidance Document--Construction Quality Assurance for Hazardous Waste Land Disposal Facilities (EPA/530-SW-86-031).

This EPA document describes the elements of a construction quality assurance plan that should be addressed during the permit application procedure for hazardous waste land disposal facilities.

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

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

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

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

Seminar Publication--Design and Construction of RCRA/CERCLA Final Covers (EPA/625/4-91/025).

This EPA seminar publication provides an overview of design, construction and evaluation requirements for cover systems for RCRA/CERCLA waste management facilities. The publication discusses various aspects of design and construction of final covers for both hazardous and nonhazardous waste landfills.

2.3 OTHER DESIGN CONSIDERATIONS

A number of other engineering design materials and resources exist (i.e., design procedures, specifications, numerical performance assessment models and/or construction codes), which are not promulgated state or Federal statutes, but which have been applied in designing surface barriers, either in consulting civil engineering practice or by designers working at the Hanford Site. These resources relate to civil construction and engineering practice and pertain to covers for all waste categories. An alphabetical listing of these materials is provided below.

American Society for Testing and Materials (ASTM) standards. Reference source for standard test methods and specifications for classification and analysis of soil and rock.

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.

HELP Model (Schroeder et al. 1988). A numerical model used to evaluate the hydrologic performance of liner and cover systems.

Seepage, Drainage and Flow Nets (Cedergren 1989). This reference provides engineering criteria and procedures for design of graded filters.

Uniform Building Code. Provides design specifications for the construction of residential, commercial, and industrial structures to meet civil, electrical, mechanical, and fire codes.

Universal Soil Loss Estimation Procedure. This procedure provides an areal estimate of soil loss rate resulting from surface run-off of storm water.

UNSAT-H Model (Fayer and Jones 1990). Another numerical model developed to evaluate the hydrologic performance of multi-layer soil barrier systems. The UNSAT-H code was developed specifically for arid climate applications.

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

Wind Erosion Estimation Procedure. This procedure provides an areal estimate of soil loss rate resulting from wind erosion.

2.4 SCREENING OF ARARs, TBCs AND OTHER MATERIALS

Certain items that did not contribute to the development of conceptual cover design criteria were eliminated from the listings provided in Sections 2.2 and 2.3. This section discusses the eliminated items.

2.4.1 Final Evaluation of Potential ARARs and TBCs

The ARARs and TBCs listed in Section 2.2 were evaluated to determine which would provide specific requirements and criteria for the conceptual cover designs presented in this FFS. Only the ARARs and TBCs that identify standards that would pertain to, and could be accounted for at, the conceptual design stage were considered.

All potential ARARs that are sources of specific design criteria were determined to be pertinent. These include the potential ARARs identified in Table 2-1 with a "Yes" in the third column. In addition, any TBCs that provide design criteria have been included in design criteria development.

Other ARARs and TBCs are sources of performance requirements but not of specific design criteria. The performance requirements that were considered relevant are the ones that apply to all covers, regardless of the site-specific circumstances that may exist at individual waste sites.

Some potential ARARs and TBCs are sources of design criteria and/or performance requirements that cannot be evaluated without knowledge of specific conditions and circumstances at the individual waste sites. Consideration of design criteria and performance requirements that can be interpreted only in the context of site-specific information are deferred until definitive design and/or construction.

The potential ARARs that were determined not pertinent to the conceptual cover designs in this FFS are discussed below, with a brief rationale for excluding them.

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).**

The scope of definitive design will include the preparation of grading plans to control the effects of run-off 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 to be considered in developing grading plans. These issues cannot be addressed in generic conceptual designs.

WAC 173-303-610 (2)(a)(iii).

The issue of returning waste management units on the Hanford Site to the use and appearance of surrounding land areas to the degree possible given the nature of the previous dangerous waste activity will have to be addressed from a site-specific perspective. In some cases, the surrounding areas are occupied by other active or inactive waste management units that will be remediated separately. Issues relating to future use options for various portions of the Hanford Site are being considered by others.

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

Procedures for promoting vegetative growth and for maintaining the integrity of cover material after construction will be addressed as aspects of definitive design.

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

Waste management units in the 200 Areas rarely, if ever, received putrescible solid waste. Landfill gas control is not expected to be a consequential issue for definitive design of covers for most units. Neither is routine installation of passive vents proposed or advocated. However, there are several active and inactive solid waste landfill units on the Hanford Site. Landfill gas production and control is a potential design issue for disposal units that were formerly operated as landfills. The need for landfill gas control will be evaluated on a site-specific basis.

WAC 173-304-460 (3)(a)(iv).
A generic conceptual design cannot address collection of run-off of surface water resulting from a 24-hour, 25-year storm from the cover area. The areal extent, topography and vegetative condition of the cover will significantly affect the volume of run-off to be dealt with from the design storm. However, at the conceptual design stage, potential run-off from the design storm can be estimated on a per-acre basis.

WAC 173-460-060.
The potential exists for activities related to construction of covers at some sites to result in increased TAP emissions. Issues concerning TAP emissions will be evaluated on a site-specific basis. The need for installing and operating T-BACT will be assessed during definitive design and/or in preparation for construction activities.

40 CFR 61.192, WAC 173-480-040, WAC 173-480-50 (1), (2), and (3) and WAC 246-247-040.
The potential exists for activities related to cover construction to result in emissions of radionuclides to the air. Technologies and measures to control radionuclide emissions will be addressed during definitive design and/or in preparation for construction activities, as necessary.

Few of the TBCs listed in Section 2.2.5 were determined to be directly relevant, generally because they identify evaluation criteria for covers that cannot be considered in the absence of site-specific information, they reiterate requirements in state or Federal statutes that have already been cited as ARARs, or they are less restrictive than requirements in the state or Federal statutes. Two notable TBCs are *Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments* (EPA 1989) and *Solid Waste Landfill Design Manual* (Ecology 1987). The first document provides a discussion of EPA's minimum technology guidance (MTG) for covers for hazardous waste sites. The second document provides guidance regarding Ecology's minimum functional standards (MFS) design for covers for nonhazardous and nonradiological solid waste sites in Washington State.

2.4.2 Final Evaluation of Other Resource Materials

Other resource materials described in Section 2.3 were evaluated to identify any sources of design criteria or performance requirements that may apply to the conceptual cover designs presented in sections of this FFS that follow. The screening process is summarized in Table 2-2.

ASTM standards. Specifications for testing of soil and rock materials were eliminated as potential sources of criteria for conceptual cover 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 for evaluating the hydrologic performance of liner and cover systems. The HELP model is particularly useful for evaluating design alternatives at the conceptual level of detail. The cover designs proposed in later sections of this FFS were evaluated with this model. However, the model itself is not a source of design criteria or performance requirements.

Graded Filter Design Criteria (Cedergren 1989). Criteria for design of graded filter media apply to covers that require filter layer elements. The graded filter criteria also are published in various guidance documents, such as EPA (1989) and Ecology (1987), which were reviewed as TBCs.

Hanford Plant Standards. The standards require the bottom of foundations for permanent buildings at the Hanford Site to be placed at least 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 proposed Hanford Barrier and Modified RCRA Subtitle C Barrier designs.

UNSAT-H Model. This model was developed locally by Battelle PNL and has been calibrated for soil textures, vegetation patterns, and arid climate conditions present at the Hanford Site. The UNSAT-H Code was used to evaluate the cover designs proposed in this FFS. However, the code is not itself a source of design criteria or performance requirements.

Uniform Building Code. These design specifications do not provide specific guidance that can be applied to the design of cover systems.

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 requirements.

Washington Department of Transportation Standard Specifications for Road, Bridge, and Municipal Construction. The specifications do not provide specific guidance for conceptual design of surface barriers. However, as specifications, they are useful design tools for earth work construction projects similar to surface barriers.

2.5 CONCEPTUAL DESIGN CRITERIA

Three cover designs are proposed in this FFS for applications at IRM sites in the 200 Areas containing the four categories of waste identified previously. Table 2-3 shows the relationship between these waste categories and cover designs. The proposed covers include the Hanford Barrier, a Modified RCRA Subtitle C Barrier, and a Modified RCRA Subtitle D Barrier. Design criteria and performance requirements for each barrier are discussed in the following sections with traceability to the pertinent ARARs and TBCs.

2.5.1 Design Criteria for the Hanford Barrier

This cover is envisioned for applications at waste management units in the 200 Areas containing radionuclides with concentrations and activities corresponding to Greater-Than-Class C LLW, including mixed LLW and hazardous waste, and non-retrievable TRU waste disposal sites and TRU-contaminated soil sites. This cover could also be applicable to sites where risk assessments predict elevated long-term environmental risks resulting from the concentrations or mobility of radionuclides and/or hazardous constituents 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.

Regulations that apply or potentially apply to the design of the Hanford Barrier include ARARs and TBCs pertaining to the storage and disposal of TRU waste, LLW, and hazardous waste. Numerous ARARs and one TBC were determined to be applicable as sources of conceptual design criteria. Table 2-4 presents a summary of the design criteria for the Hanford Barrier derived from these sources. A discussion of the criteria as they relate to the individual ARARs is provided below.

40 CFR 191.13.

This design ARAR primarily limits the amount of moisture infiltration through the cover and the vadose zone to the groundwater table. It requires that there be no release of contaminants to the accessible environment in amounts that exceed specified risk levels listed in the appendix of the regulation. The design criterion suggested by this ARAR is to minimize moisture infiltration through the cover (Criterion 1, Table 2-4).

40 CFR 191.14.

This design ARAR precludes reliance on active institutional controls beyond 100 years following disposal. It requires that disposal sites be designated by permanent markers, records, and other passive institutional controls intended to preserve knowledge about the location, design, and contents of a disposal system. It stipulates that the disposal system design should use both engineered and natural materials to achieve optimal containment. In Appendix B of the regulation, EPA expresses the view that passive institutional controls are expected to be effective in limiting inadvertent human intrusion but cannot be relied on to rule out the possibility that inadvertent intrusion will occur. Exploratory drilling for resources is the most severe intrusion scenario envisioned by EPA. Three design criteria are suggested by this ARAR: (1) design a multi-layer cover of materials that are resistent to natural degradation processes, (2) design a durable cover that will require minimal maintenance during its design life, and (3) include appropriate design provisions for limiting inadvertent human intrusion (Criteria 2, 3 and 7, Table 2-4).

40 CFR 191.15, 10 CFR 61.41, WAC 173-480-040 and 246-247-040.

These four performance ARARs 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 the design of TRU waste disposal systems, 40 CFR 191.15 also requires the disposal site to be designed to provide a reasonable expectation that undisturbed performance of the disposal system will not cause these annual limits to be exceeded for at least 1,000 years after disposal. 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. To do so, the cover must be designed to minimize moisture infiltration, prevent plant and animal intrusion, and inadvertent human intrusion. The design criteria suggested by this ARAR are (1) minimize moisture infiltration through the cover, (2) design a cover with a functional life of 1,000 years, (3) prevent plants from accessing and mobilizing contamination, and (4) prevent burrowing animals from accessing and mobilizing contamination (Criteria 1, 4, 5, and 6, Table 2-4).

40 CFR 191.16.

This performance ARAR imposes an additional requirement limiting contamination of the groundwater for a period of 1,000 years to less than 5 pCi/L of radium and 15 pCi/L of alpha-emitting radionuclides (including radium). The design criterion that will satisfy this ARAR is to minimize moisture infiltration through the cover (Criterion 1, Table 2-4).

10 CFR 61.42 and 61.52(a)(2).

For waste management units containing radioactive waste that will not decay to levels that present an acceptable hazard to an intruder within 100 years, (i.e., Category 3 waste or greater), these design ARARs require the cover to be designed with provisions that will protect humans from coming into inadvertent contact with the waste at some future time assuming the loss of institutional control. The design criterion suggested by this ARAR is to include appropriate design provisions for limiting 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. Settlement issues are site-specific and will be addressed during definitive design. The design criteria suggested by this potential ARAR are (1) design a multi-layer cover of materials that are resistent to natural degradation processes and (2) design a durable cover that will require minimal maintenance during its design life (Criteria 2 and 3, Table 2-4).

10 CFR 61.51.

This performance ARAR requires the cover to be designed to (a) minimize water infiltration, control run-off and run-on of surface water, and otherwise minimize contact between water and waste after disposal, and (b) resist degradation by surface geologic processes (i.e., surface erosion) and biotic activity. The design criteria suggested by this ARAR are (1) minimize moisture infiltration through the cover, (2) design a multi-layer cover of materials that are resistent 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 2-4).

40 CFR 264.111 and WAC 173-303-610.

These two performance ARARs require that a disposal facility for hazardous wastes be closed in a manner that minimizes the need for further maintenance and controls and minimizes or eliminates releases of hazardous constituents to the environment. These requirements can best be met by developing a low-maintenance cover design that is highly effective in limiting moisture infiltration. The design criteria suggested by these ARARs are as follows: (1) minimize moisture infiltration through the cover, (2) design a multi-layer cover of materials that are resistent to natural degradation processes, and (3) design a durable cover that will require 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: (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 can best be met by an engineered cover system supplemented as necessary by subgrade improvement 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 that will require 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).

Two TBCs provided additional design criteria. The TBCs and their relevance are discussed below.

EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. This TBC 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 by this TBC is to design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (Criterion 10, Table 2-4).

Hanford Plant Standards. The standards require the bottom of foundations for permanent buildings at the Hanford Site to be placed at least 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).

2.5.2 Design Criteria for the Modified RCRA Subtitle C Barrier

The Modified RCRA Subtitle C Cover is envisioned for applications at 200 Area sites having hazardous waste constituents. In addition, the Modified RCRA Subtitle C Cover is designed to meet or exceed the regulatory requirements for applications at Category 1 and 3 LLW sites, as well as sites with mixed hazardous and low-level constituents. This section discusses applicable regulatory requirements for hazardous waste and LLW and traceability between the ARARs and the conceptual design criteria.

Two groups of ARARs were identified that determine criteria for covers for hazardous waste sites. Five other ARARs apply to design criteria for disposal of LLW. Table 2-5 summarizes the design criteria for the Modified RCRA Subtitle C Cover. The applicable regulatory sources are discussed below.

40 CFR 264.111 and WAC 173-303-610.
These two performance ARARs require that a disposal facility for hazardous wastes be closed in a manner that minimizes the need for further maintenance and controls and minimizes or eliminates releases of hazardous constituents to the environment. As in the case of the Hanford

Barrier, these requirements can best be met by developing a low-maintenance cover design that is highly effective in limiting moisture infiltration. The design criteria suggested by these ARARs are as follows: (1) minimize moisture infiltration through the cover, (2) design a multi-layer cover of materials that are resistent 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).

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 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 multi-layer cover of materials that are resistent to natural degradation processes, (3) design a durable cover that will require 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 2-5).

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

These three performance ARARs 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. To do so, the cover must be designed to prevent plants and animals from intruding into the waste zone and redistributing contaminants into the accessible environment. The design criteria suggested by this ARAR are (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.

This design ARAR requires the cover to be designed with provisions that will protect humans from coming into inadvertent contact with the waste at some future time after loss of institutional control. As indicated in 10 CFR 61.7(b)(4) and 61.55(a)(2), this ARAR is applicable to LLW sites with Category 3 activity. Category 3 LLW will not decay to levels that present an acceptable hazard to an intruder within 100 years. This ARAR does not apply to sites containing only Category 1 LLW or mixed Category 1 LLW and hazardous waste. The design criterion suggested by this ARAR is to ensure that the top of the waste is at least 5 m below final grade or include appropriate design provisions for limiting inadvertent human intrusion (Criterion 7, Table 2-5).

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. Settlement issues are site-specific and will be addressed during definitive design. The design criteria suggested by this potential ARAR are (1) design a multi-layer cover of materials that are resistent to natural degradation processes and (2) design a durable cover that will require minimal maintenance during its design life (Criteria 2 and 3, Table 2-5).

10 CFR 61.51.
This performance ARAR requires the cover to be designed to (a) minimize water infiltration, control run-off and run-on of surface water, and otherwise minimize contact between water and waste after disposal, and (b) resist degradation by surface geologic processes (i.e., surface erosion) and biotic activity. The design criteria suggested by this ARAR are: (1) minimize moisture infiltration through the cover, (2) design a multi-layer cover of materials that are resistent 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).
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 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. The design criteria suggested by this ARAR are: (1) design cover with a functional life of 500 years, and (2) ensure that the top of the waste is at least 5 m below final grade or include appropriate design provisions for limiting inadvertent human intrusion (Criteria 4 and 7, Table 2-5).

Two TBCs were considered applicable to the development of design criteria for the Modified RCRA C Barrier. The TBCs and their relevance are discussed below.

EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. This TBC 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 by this TBC 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 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).

2.5.3 Design Criteria for the Modified RCRA Subtitle D Barrier

The Modified RCRA Subtitle D Cover is primarily envisioned for applications at waste sites in the 200 Areas containing nonradiological and nonhazardous solid waste. This cover is also designed to be appropriate for LLW sites containing wastes with Category 1 activity (equivalent to NRC Class A and Class B LLW). The Modified RCRA Subtitle D Cover 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 within the 100-year institutional control period, the design includes no human intrusion control provisions.

Regulations applicable to the Modified RCRA Subtitle D Cover include those pertinent to the storage and disposal of RCRA nonhazardous solid waste and Washington State nondangerous solid waste, as well as regulations applicable to disposal of Category 1 LLW. Nine potential ARARs were found to be applicable to developing generic conceptual design criteria. Table 2-6 presents a summary of the design criteria for the RCRA Subtitle D cover based on these nine ARARs.

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

40 CFR 241.209-1.

This performance ARAR 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, and 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. Three design criteria are suggested by this ARAR: (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 6, Table 2-6).

40 CFR 241.209-2(a).

This performance ARAR requires that surface grades and side slopes be determined such that run-off will be controlled and erosion will be minimized. The design criterion suggested by this ARAR 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 run-off and minimize erosion of the cover surface (Criterion 5, Table 2-6).

40 CFR 258.60.

This design ARAR requires the final cover to have (a) permeability less than or equal to any natural subsoils present, or permeability no greater than 1 x 10^{-5} cm/s (whichever is less), (b) a specification for an infiltration layer containing a minimum of 45 cm (18 in.) of soil to minimize moisture infiltration through the cover, and (c) an erosion layer containing a minimum 15 cm (6 in.) of soil capable of sustaining perennial vegetation to minimize erosion of the cover surface. Four design criteria are suggested by this ARAR: (1) design a cover system that includes a minimum thickness of 45 cm (18 in.) of earthen materials that will minimize moisture infiltration through the cover, (2) design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will 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 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), (Criteria 4, 5, 6 and 7, Table 2-6).

WAC 173-304-407.

This performance ARAR 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. 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 run-off and minimize erosion of the cover surface, and (4) design a durable cover that will require minimal maintenance during its design life (Criteria 1, 2, 5, and 8, Table 2-6).

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. In consideration of the arid climate, this design ARAR 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 percent; and (c) have at least 15 cm (6 in.) of topsoil seeded with grass, other shallow-rooted vegetation, or other native vegetation. Five design criteria are suggested by this ARAR: (1) design a multi-layer 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 run-off 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 percent (Criteria 3, 5, 6, 7, and 9, Table 2-6).

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

These three performance ARARs 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 C Cover will be required to satisfy all performance goals for isolating waste from the accessible environment. To do so, plants and animals must be prevented from intruding into the waste zone and redistributing contaminants into the accessible environment. The design criteria suggested by this ARAR are (1) minimize moisture infiltration through the cover, and (2) design the cover to provide limited biointrusion control (Criteria 1 and 2, Table 2-6).

10 CFR 61.42.

This ARAR identifies design requirements that are specific to the LLW classification at a given site. In the case of NRC Class C LLW (or DOE Category 3 LLW), this ARAR would require a cover to be designed with provisions that would protect humans from coming into inadvertent contact with the waste at some future time after loss of institutional control. The Modified RCRA Subtitle D Barrier is proposed for LLW sites with activity levels that do not exceed Category 1 limits. Human intrusion controls are not required for sites containing only Category 1 LLW because this waste class consists of types and concentrations of radioisotopes that will decay during the 100-year institutional control period to an acceptably low hazard level. This ARAR sets the design life for the Modified RCRA Subtitle D Cover at 100 years (Criterion 10, Table 2-6).

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. As indicated in the previous discussions of the other cover options, settlement issues are site-specific and will be addressed during definitive design. The design criteria suggested by this potential ARAR are (1) design a multi-layer 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 run-off 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 will require minimal maintenance during its design life (Criteria 3, 5, 6 and 8, Table 2-6).

10 CFR 61.51.

This ARAR requires the cover to be designed to (a) minimize water infiltration, control run-off 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. The design criteria suggested by this ARAR are: (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 run-off 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 will require minimal maintenance during its design life (Criteria 1, 2, 5, 6 and 8, Table 2-6).

Table 2-1. Summary of Potential ARARs.

Waste type	Regulation	Design criteria	Performance requirements
TRU	40 CFR 191.13, .14, .15, .16	No	Yes
	10 CFR 61.41, .42, .44, 51(a)	No	Yes
	10 CFR 61.52(a)(2)	Yes	Yes
	40 CFR 61.192	No	Yes
	WAC 173-480-040, -050	No	Yes
	WAC 246-247-040	No	Yes
LLW	10 CFR 61.41, .42, .44	No	Yes
	10 CFR 61.51(a)	No	Yes
	10 CFR 61.52(a)(2)	Yes	Yes
	40 CFR 61.192	No	Yes
	WAC 173-480-040, -050	No	Yes
	WAC 246-247-040	No	Yes
RCRA C	40 CFR 264.111/265.111	No	Yes
	40 CFR 264.228/265.228(a)(2)(iii), 40 CFR	No	Yes
	264.228/265.228(b)(4)	No	Yes
	40 CFR 264.310/265.310(a)	No	Yes
	WAC 173-303-610(2)(a)	No	Yes
	WAC 173-303-650(6)(a)(ii)(C)(I)	No	Yes
	WAC 173-303-650(6)(a)(ii)(C)(II)-(IV)	No	Yes
	WAC 173-303-665(6)(a)(i)-(iv)	No	Yes
	WAC 173-303-665(6)(a)(v)	No	Yes
	WAC 173-460-060	No	Yes
RCRA D	40 CFR 241.209-1, .209-2	Yes	Yes
	40 CFR 258.60(a)	Yes	Yes
	WAC 173-304-407(3)	No	Yes
	WAC 173-304-460(3)(a)	Yes	No
	WAC 173-304-460(3)(e)	Yes	Yes
	WAC 173-460-060	No	Yes

Notes:

ARAR = applicable or relevant and appropriate requirement.
TRU = Transuranic.
LLW = Low-Level Waste.
RCRA C = Resource Conservation and Recovery Act, Subtitle C.
RCRA D = Resource Conservation and Recovery Act, Subtitle D.
CFR = Code of Federal Regulations.
WAC = Washington Administrative Code.

Table 2-2. Summary of Other Criteria Sources.

Resource	Design criteria	Performance requirements
ASTM - Soil and Aggregate Testing Specifications	N	N
HELP Model	N	N
Graded Filter Design Criteria	Y	N
Hanford Plant Standards Design Criteria	Y	N
UNSAT-H Code	N	N
Uniform Building Code	N	N
USDA Universal Soil Loss Estimation Procedure	N	N
USDA Wind Erosion Equation Estimation Procedure	N	N
Washington Department of Transportation Standard Specifications for Road, Bridge, and Municipal Construction	N	N

Notes:
ASTM = American Society of Testing and Materials.
USDA = U.S. Department of Agriculture.

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

Cover type	Waste site characterization
Hanford Barrier	TRU Waste and TRU Mixed Waste GTCC LLW and GTCC Mixed LLW
Modified RCRA Subtitle C Barrier	RCRA Subtitle C (Hazardous) Waste Category 3 LLW and Category 3 Mixed LLW Category 1 Mixed LLW
Modified RCRA Subtitle D Barrier	RCRA Subtitle D (Nonhazardous and Nonradiological) Waste Category 1 LLW

Notes:
GTCC = Greater Than Class C.
RCRA = Resource Conservation and Recovery Act.
TRU = Transuranic.

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

1.	Minimize moisture infiltration through the cover.
2.	Design a multi-layer cover of materials that are resistent to natural degradation processes.
3.	Design a durable cover that will require 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 are to be located at least 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 multi-layer cover of materials that are resistent to natural degradation processes.
3.	Design a durable cover that will require 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 below final grade or 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 are to be located at least 2 ft 6 in. below final grade.

Table 2-6. 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 multi-layer cover system with a combined thickness of at least 60 cm (24 in.).
4.	Design a cover system that includes a minimum thickness of 45 cm (18 in.) of earthen materials that will minimize moisture infiltration through the cover.
5.	Design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control run-off and minimize erosion of the cover surface.
6.	Design a cover system with a surface layer capable of sustaining grass, other shallow-rooted vegetation, or other native vegetation.
7.	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).
8.	Design a durable cover that will require minimal maintenance during its design life.
9.	Design a cover with surface slopes of no less than 2 %.
10.	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 applicable regulatory requirements for waste disposal summarized in Chapters 1.0 and 2.0, design needs for three distinct barrier designs for 200 Area waste management units have been established. The three barriers are listed below in order of overall performance and environmental protection.

- **Hanford Barrier.** This design is proposed for implementation at TRU-contaminated soil sites, sites with TRU or TRU-mixed waste in nonretrievable configuration, and sites with Greater-Than-Class C LLW or mixed LLW. 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 three proposed 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 design is proposed for applications at sites containing hazardous 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 for controlling 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.

- **Modified RCRA Subtitle D Barrier.** This design is proposed for applications at nonradiological and nonhazardous solid waste sites, as well as Category 1 LLW sites where no hazardous 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 to conform to the minimum projected duration of active institutional control.

The three barrier designs are discussed in 3.1, 3.2, and 3.3.

3.1 HANFORD BARRIER DESIGN

The description of this design is divided into two subsections. Section 3.1.1 provides background information on development of the Hanford Barrier. Section 3.1.2 gives a detailed description of the proposed 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 Wastes* (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 Hanford by several years.

The Hanford Barrier is the product of extensive research and engineering by the Hanford Barrier Development Team. Since 1987, numerous design concepts have been explored and evaluated in the process of 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 for providing 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 in this FFS, the Hanford Barrier has also been identified as the appropriate barrier option for sites with Greater-Than-Class C LLW and cognate mixed wastes.

Based on its level of development and because it conforms to the design criteria identified in Section 2.5.1, the existing Hanford Barrier design is proposed for remediating ER sites with wastes of these types. Figure 3-1 shows the Hanford Barrier in profile view.

3.1.2 Proposed Design

The Hanford Barrier is composed of ten layers with a combined thickness of 4.5 m (14.8 ft). The sections that follow describe in detail 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 percent (by weight) admixture of pea gravel. 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 100 cm (40 in.) of the same topsoil material without pea gravel. Layer 2 also will 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 topsoil layers are required to 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 HELP and UNSAT-H predict that virtually 100 percent 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 7 and 8 as infiltration barriers, and they can perform as contingency components of the overall cover system.

Moisture retention and evapotranspiration within Layer 1 and Layer 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., 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 proposed topsoil material for the Hanford Barrier will 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 percent. 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 HELP and UNSAT-H (Appendices C-1 and C-4). Both models tend to indicate that storm events with associated runoff will be infrequent (perhaps not more than one in ten 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 during periods 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 Layer 1 and Layer 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 of about 1.38 g/cc (86.3 lb/ft^3), which 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.

3.1.2.2 Layer 3 - Geotextile Filter Fabric. The geotextile filter fabric will be placed as a construction aid to prevent mixing of fine-textured soil from Layer 2 with filter sand from Layer 4 during construction activities. After construction is completed, the fabric will have no ongoing function. Therefore, long-term durability of the fabric is not an issue.

3.1.2.3 Graded Filter Components - Layer 4 (Sand Filter) and Layer 5 (Gravel Filter). Layer 4 and Layer 5 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 6) and/or the lateral drainage layer (layer 7). Nominal thicknesses of Layer 4 and Layer 5 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 Area 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 filter criteria are conservative for this design application because they were developed for applications in earth dams where elevated pore pressure conditions often are present.

3.1.2.4 Layer 6 - Coarse, Fractured Basalt. Layer 6 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 on the Hanford Site to be determined. Size limits will be controlled by screening material at the quarry site.

The function of Layer 6 is to control biointrusion and to present an obstacle to inadvertent human intrusion. The intent of biointrusion control is to isolate wastes 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 6 is designed to preclude moisture retention. The large voids within this layer are designed to ensure that there is negligible storage capability in Layer 6 for any moisture that does move completely through the topsoil component of the barrier (Layer 1 and Layer 2). Liquid moisture entering Layer 6 will drain into Layer 7. Long-term maintenance of extremely dry conditions within Layer 6 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 all burrowing animals that inhabit the Hanford Site, including large predators such as badgers.

The requirement to consider human intrusion in the design of the Hanford Barrier is traceable to 40 CFR 191. Appendix C of the regulation identifies inadvertent and intermittent intrusion by exploratory drilling as the most severe intrusion scenario to be addressed. The regulation states that it can be assumed that passive institutional controls or the intruder's own exploratory procedures would be adequate for the intruder to soon detect the incompatibility of the area with exploratory activities.

The coarse, fractured basalt in Layer 6 is designed to be an impediment to exploratory drilling. A subsurface layer consisting of loose fractured rock represents a particularly adverse drilling condition, typically because circulation cannot be maintained, cuttings cannot adequately 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. These adverse conditions should serve to alert intruders to abnormal conditions at covered waste sites.

3.1.2.5 Layer 7 - Lateral Drainage Layer. This layer will facilitate the removal of any moisture that moves through the topsoil component of the barrier (Layer 1 and Layer 2). This layer represents a contingency scheme for removing soil moisture in response to extreme climatic events such as the design storm. The lateral drainage layer will be sloped at 2 percent to move water to the edge of the cover where it will be collected and/or diverted in an appropriate manner. Layer 7 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 required 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 be required to have a D_{10} of 1 mm or greater. Layer 7 will be approximately 4.0 m (13 ft) below final grade, which ensures that the layer's performance will be unaffected by frost penetration. Performance simulations with HELP and UNSAT-H both indicate little (if any) lateral drainage will actually occur (Appendices C-1 and C-4).

3.1.2.6 Layer 8 - Asphalt Layer. This layer will function as a low-permeability barrier layer and as a redundant biointrusion barrier. Layer 8 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. Tests have shown that this material can achieve in-field hydraulic conductivity values as low as 10^{-8} cm/s (Dunning 1990). At the time of construction, hydraulic conductivity testing will be performed on the asphalt layer in situ to determine its actual in-field value. 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 top of

Layer 8 will be approximately 4.3 m (14 ft) below final grade, well below the design frost depth of 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 as low as 10^{-11} cm/s have been demonstrated in tests of modified asphalt coatings (Romine 1992).

3.1.2.7 Layer 9 - Asphalt Base Course. This layer will provide a stable base for construction of the overlying asphalt layer. The base course will conform to a standard WDOT specification (WDOT 1991).

3.1.2.8 Layer 10 - 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 percent as required for internal lateral drainage and surface run-off control. Grading the site before construction will facilitate accurate and controlled placement of soil lifts and layers. Grading fill will be placed in conformance to a standard WDOT specification for backfill material (WDOT 1991).

3.2 MODIFIED RCRA SUBTITLE C BARRIER DESIGN

The Modified RCRA Subtitle C Barrier is discussed in two sections. Section 3.2.1 provides background information on development of the design. Section 3.2.2 provides a detailed description of each layer in the proposed 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 the design of covers for hazardous waste sites. Section 2.2.5.2 summarizes the current agency guidance. For RCRA Subtitle C Covers, EPA has developed a set of basic design elements referred to as the "minimum technology guidance" (MTG) (EPA 1989). Although RCRA Subtitle C covers 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 proposed for applications at sites containing not only hazardous waste but also Category 3 LLW and 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 2-ft-thick compacted clay layer with an overlain geosynthetic membrane material. Neither of these materials 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 is required, 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, RCRA Subtitle C Covers had been designed for the following hazardous waste site applications at Hanford:

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

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 Proposed Design

The Modified RCRA Subtitle C cover is composed of eight layers with a combined thickness of 1.7 m (5.6 ft). Table 3-2 provides summary descriptions of each of the cover layers. 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 percent (by weight) pea gravel. Layer 1 will be placed in a relatively loose condition, approximately the same as the in-place bulk density value at the borrow site, 1.38 g/cc (86.3 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., Layer 1 and Layer 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). Limiting surface slopes to 2 percent will minimize susceptibility to wind erosion.

Compaction of Layer 2 during construction will decrease its saturated hydraulic conductivity by three to four orders of magnitude. Compaction will retard moisture migration through Layer 2. Moisture retention and evapotranspiration within Layer 1 and Layer 2 will be enhanced by formation of a capillary barrier at the base of Layer 2, as explained in Section 3.1.2.1. Numerical performance assessments using HELP and UNSAT-H predict that essentially 100 percent of average annual precipitation will be removed from the barrier by evapotranspiration (Appendices C-2 and C-4).

The combined thickness of Layer 1 and Layer 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, estimated efficiency of evapotranspiration from the topsoil component of the barrier would only be impacted 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.

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 6-in. thickness is sufficient to achieve the design filtration function, although a 12-in. layer may be somewhat easier to construct. This modification is proposed 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 (Layer 1 and Layer 2). This layer represents a contingency scheme for removing soil moisture in response to extreme climatic events such as the design storm. Layer 5 will be sloped at 2 percent 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 required 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 HELP and UNSAT-H 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. The asphaltic concrete will be coated with a spray-applied asphaltic material. The same asphalt layer 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 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 requirements in 10 CFR 61.42 and 61.52(2) for protecting individuals from inadvertent human intrusion apply to Class C (DOE Category 3) LLW specifically. According to the regulation, protection may take either of the following forms:

1. 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.

2. 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 constructed already have been covered with sufficient fill to satisfy requirement 1 or would meet requirement 1 with the additional 1.7 m (5.6 ft) of cover materials in the Modified RCRA Subtitle C Barrier. In other cases, additional grading fill (Layer 8) could be placed at the site as an aspect of barrier construction in lieu of designating a layer within the barrier as a human intrusion layer.

3.2.2.5 Layer 7 - Asphalt Base Course. This layer will provide a stable base for construction of the asphalt layer. The base course will conform to a standard WDOT specification (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 percent as required for internal lateral drainage and surface run-off control. Grading the site before construction will facilitate accurate and controlled placement of soil lifts and layers. Grading fill will be placed in conformance with a standard WDOT specification for backfill material (WDOT 1991).

3.3 MODIFIED RCRA SUBTITLE D BARRIER DESIGN

The Modified RCRA Subtitle D Barrier design is discussed in two subsections. Section 3.3.1 provides background information on development of the design. Section 3.3.2 gives a detailed description of the proposed design.

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

This design is intended for applications at nonradiological and nonhazardous solid waste sites, as well as Category 1 LLW sites where no hazardous 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 to conform to the minimum projected duration of active institutional control. Figure 3-3 shows the Modified RCRA Subtitle D Barrier in profile.

Regulatory guidance for designing RCRA Subtitle D covers is the most explicit of the categories considered in this study. Design requirements 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 1993b). The SWL cover was designed to meet the regulatory requirements 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 proposed Modified RCRA Subtitle D cover 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 percent pea gravel admixture. The second change was to increase the thickness of uncompacted topsoil (Layer 1 in the SWL design; the sum of Layer 1 and Layer 2 in the proposed 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 minimum functional standards design for covers over solid waste sites.

3.3.2 Proposed Design

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

3.3.2.1 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 percent (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 also will 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 Layer 1 and Layer 2, but placed in a relatively densified condition of approximately 1.76 g/cc (110 lb/ft^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 also must provide a suitable medium for establishing and maintaining 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.

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 proposed cover Modified RCRA Subtitle D cover design calls for the surface of Layer 1 to be constructed with a uniform 2 percent slope. This angle is steep enough to facilitate run-off 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.

3.4.2.2 Layer 4 - Grading Fill. As in the previous two designs, grading fill is to 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 percent as required for internal lateral drainage and surface run-off control. Grading the site before construction will facilitate accurate and controlled placement of soil lifts and layers. Grading fill will be placed in conformance to a standard WDOT specification for backfill material (WDOT 1991).

Figure 3-1. Hanford Barrier Profile.

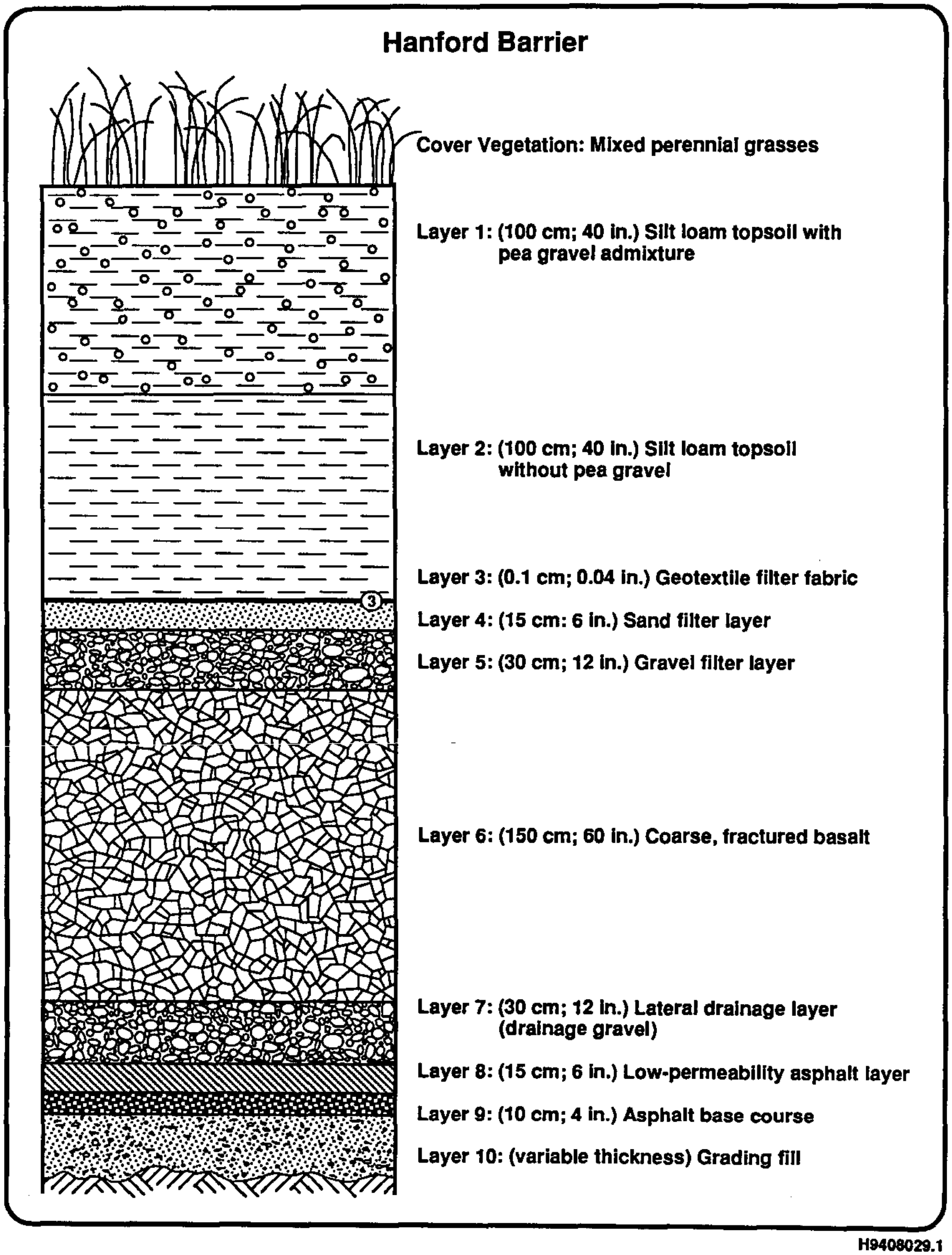
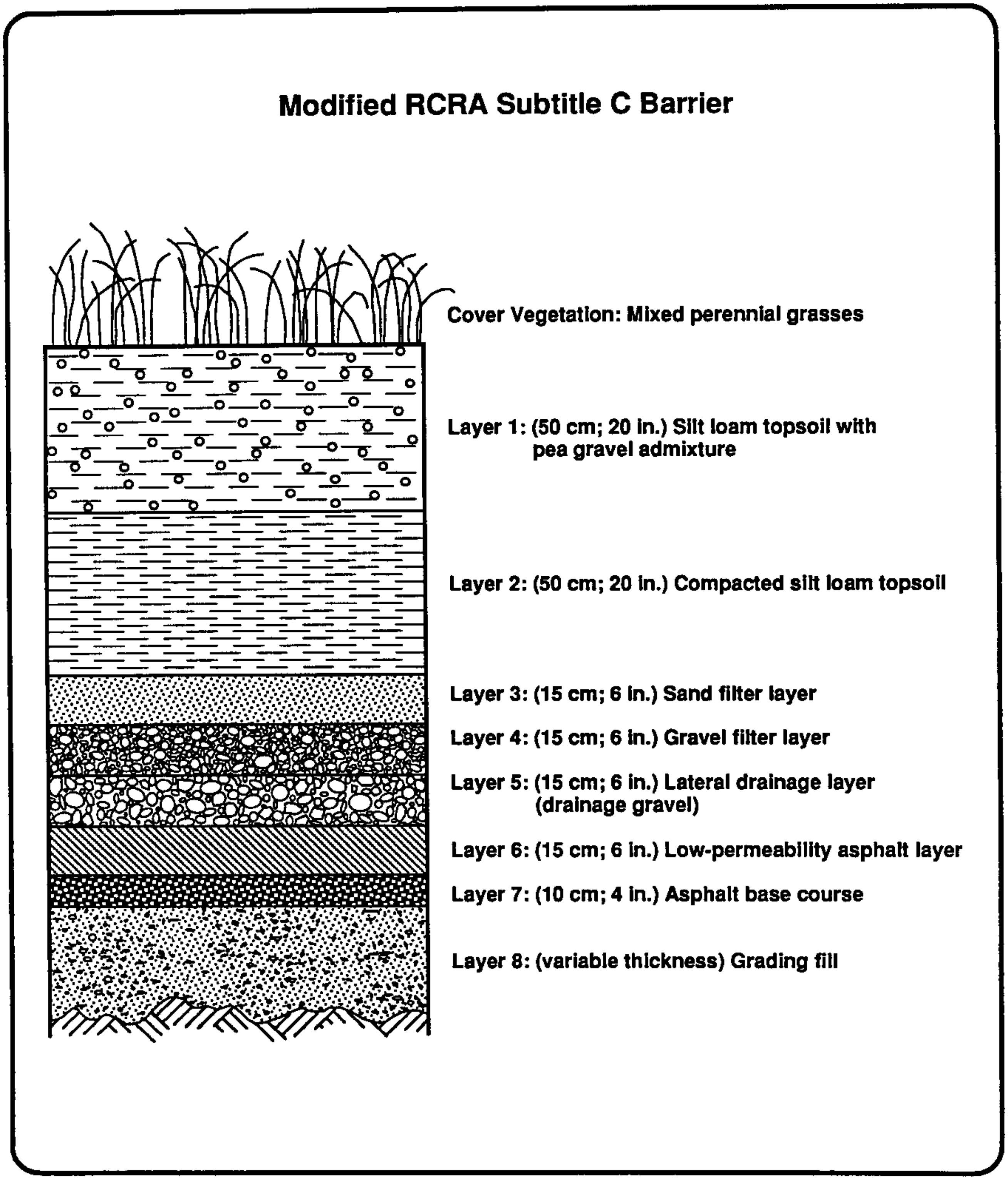
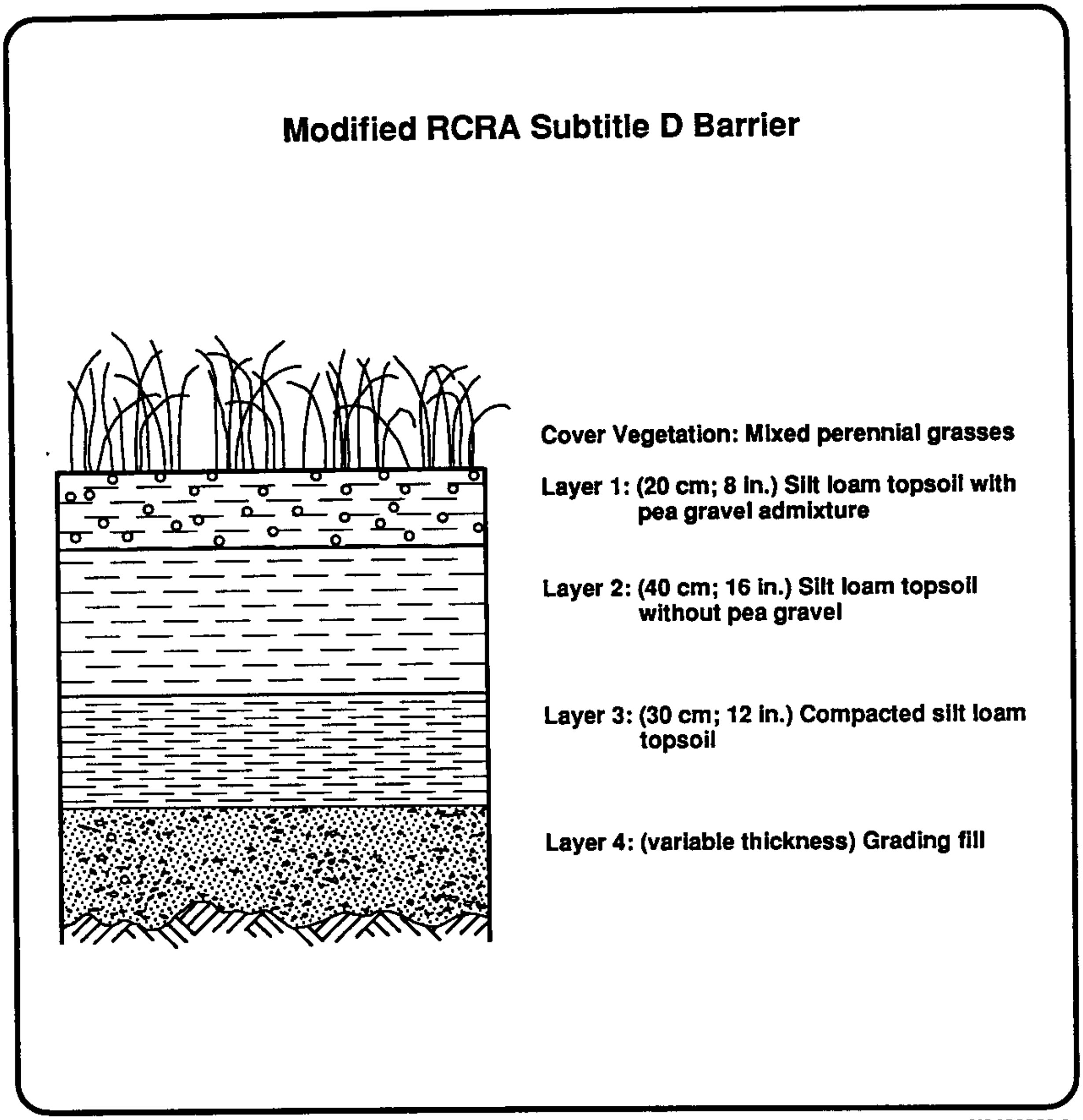


Figure 3-2. Modified RCRA Subtitle C Barrier Profile.



H9408029.2

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



H9408029.3

9513338.1710

Table 3-1. Summary of the Hanford Barrier Layers.

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 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	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 supplemental soil moisture storage capacity.
3	0.1 (0.04)	Geotextile fabric	Polypropylene fabric, non-woven, needle-punched, 35 mil nominal thickness, with a maximum apparent opening size of 120 mesh.	The fabric is a construction aid intended to prevent topsoil from being mixed with filter sand from Layer 4 during placement.
4	15 (6)	Sand filter	Clean, screened sand meeting the following particle size requirements: 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.
5	30 (25)	Gravel filter	Clean, screened aggregate meeting the following particle size requirements: D_{15}= 1.5 to 2.0 mm, D_{50}=15 to 20 mm, and D_{85}< 37.5 mm.	Same as Layer 4.
6	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 also will prevent plant and animal intrusion into the underlying layers.

Table 3-1. Summary of the Hanford Barrier Layers.

Layer No.[1]	Thickness cm (in.)	Layer description	Specifications	Function
7	30 (12)	Lateral drainage aggregate	Naturally occurring aggregate, minus 32 mm (1 1/4 in.) material, conforming to the grading requirements 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.
8	15 (6)	Asphaltic concrete with spray-applied asphalt coating	Asphaltic concrete, consisting of asphalt conforming to requirements of 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.
9	10 (4)	Asphalt base course	Crushed aggregate, minus 16 mm (5/8 in.) diameter material, conforming to the requirements of 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.
10	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.

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 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	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 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 size requirements: 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 size requirements: 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 requirements 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.

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 requirements of 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 the requirements of 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 the 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 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.

4.0 EVALUATION OF ENGINEERED SURFACE BARRIER DESIGNS

In this section, the three 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 selecting appropriate remedial actions, as described in Chapter 6 of *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). The purpose of the first evaluation is to provide verification of the technical adequacy of the three designs in terms of conformance of each design to its applicable ARARs. The second evaluation provides preliminary information to be used in evaluating surface barriers against other remedial alternatives.

4.1 CONFORMANCE TO DESIGN CRITERIA

This section reviews the three proposed cover designs (Hanford Barrier, Modified RCRA Subtitle C Cover, and Modified RCRA Subtitle D Cover) for conformance with the design criteria identified for each cover in Section 2.5. In Tables 4-1 through 4-3, 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 3-3.

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

4.2 ASSESSMENT AGAINST EPA EVALUATION CRITERIA

The EPA has developed nine criteria for comparing remedial alternatives to address the statutory, technical and policy considerations of CERCLA (EPA 1988). In a typical site-specific CERCLA FS, these criteria are applied to compare between specific remedial options, including barrier and non-barrier options. This FFS focuses exclusively on engineered surface barriers as generic remedial alternatives. This study does not provide a basis for comparing barrier and non-barrier alternatives for a specific waste site. Rather, the purpose of the following discussion is to document the evaluation of the three 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 selected 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 three criteria).

4.2.2 Compliance With ARARs

Section 2.2 presents a comprehensive evaluation of ARARs and TBCs as potential sources of design criteria for surface barriers. Conceptual design criteria for the Hanford Barrier, the Modified RCRA Subtitle C Barrier, and the Modified RCRA Subtitle D Barrier are developed in Sections 2.5.1, 2.5.2, and 2.5.3 respectively. The criteria, which are summarized in Tables 2-4, 2-5 and 2-6, reflect the regulatory guidance from the applicable ARARs and TBCs, as well as other appropriate non-regulatory sources.

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.

1. The only potential chemical-specific ARARs identified that apply 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 will need to be reconsidered at the definitive design phase.

2. No potential location-specific ARARs were identified as applicable to generic conceptual cover designs. Location-specific criteria such as those contained in DOE orders should be considered on a site-by-site basis during definitive design.

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

Each barrier design was assessed for compliance with potential applicable ARARs. All of the designs comply with the applicable ARARs as identified in Section 2.5. The designs all conform to their respective criteria.

The Hanford Barrier and the Modified RCRA Subtitle C Barrier are designed for application at sites containing hazardous waste. EPA's minimum technology guidance (MTG) applies to both designs. Following are the essential provisions of the guidance:

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

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

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

The MTG is not imposed as regulation. EPA recognizes that other design configurations (e.g., with fewer layers or optional layers) may be appropriate for site-specific applications. However, EPA requires that proposed alternative designs provide long-term performance that is equivalent to that implied in the MTG design as a minimum (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 proposed designs depart from the MTG in the following respects:

1. The surface slope and the slopes of internal layers are specified at 2 percent.

2. The thickness of the lateral drainage layer in the Modified RCRA Subtitle C Barrier is 15 cm (6 in.).

3. 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 of between 3 and 5 percent reflects EPA's intent to encourage run-off and to 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., run-off or standing water) are relatively rare at Hanford. Even in design storm simulations and analyses where precipitation is modeled at twice actual ambient values, relatively little run-off is generated. Estimates of potential losses of topsoil due to water erosion are small (see Appendix D, Section 3.0). For these reasons, water erosion of the barrier surface from stormwater run-off and ponding of surface water are not viewed as consequential issues at Hanford.

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 Figure D-3. Estimates of topsoil losses to wind erosion (Appendix D, Section 2.0) indicate that losses would be expected to exceed EPA's target value of 2.0 tons per acre per year for surface slopes of 3 percent. If slopes are limited to 2 percent, 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 percent rather than the 3 percent 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/sec (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 Minimum Functional Standards (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:

1. 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 percent but no more than 33 percent,

2. Barrier Layer: a minimum of 60 cm (24 in.) of soil with a maximum permeability of 10^{-5} cm/sec for arid regions within the state.

Ecology recognizes that other designs that meet or exceed the MFS specifications may be appropriate. The proposed 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 proposed 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 proposed design is considered to satisfy all functional equivalence requirements relative to the MFS design.

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 selected remedy.

In remedial investigations conducted thus far in the 200 Areas (DOE-RL 1993c), 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 remedial action objectives (RAO) were specified for the 200-BP-1 Operable Unit:

- Reduce the potential for intrusion and (direct) exposure to contaminants, and
- 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 proposed 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. 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 operate to 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 also is designed to present difficult drilling conditions to inadvertent human intruders engaged in exploratory drilling for mineral resources or water well development. Human intrusion controls designed into the Hanford Barrier are traceable to requirements for TRU waste sites and recommended performance assessment scenarios in 40 CFR 191.

The second control provision of the Hanford Barrier design is the 15-cm- (6-in.-) thick low-permeability asphalt layer. The asphalt layer is expected to 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. As previously indicated, the asphalt layer is expected to be highly effective in eliminating intrusion by plant roots, burrowing mammals, and insects. Regulatory requirements for human intrusion controls for Class C (i.e., DOE Category 3) LLW derive from 10 CFR 61. A barrier layer to human intrusion is only required by the regulation as part of the cover design in cases where the combined thickness of cover materials and earth fill placed directly over the waste is less than 5 m (16.4 ft). Aside from the issue of the utility of fill to satisfy the requirement, the asphalt layer in the Modified RCRA Subtitle C design is considered to provide sufficient control of inadvertent human intrusion to meet the intent of 10 CFR 61.

Although the asphalt layer is not serviceable as a deterrent to drilling intrusion, drilling is not singled out as the defining intrusion scenario in 10 CFR 61 (as it is in 40 CFR 191). Considering the differences in waste types addressed by the two regulations, drilling intrusion would represent a less consequential threat to human health in the case of 10 CFR 61 regulated wastes.

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. The Federal government is obligated to maintain active institutional control at the Hanford Site for at least 100 years. Therefore, reliance for control of inadvertent human intrusion will be placed on existing institutional controls (e.g., signage, fencing, surface markers). This approach is consistent with the intent of 10 CFR 61.7(b)(4) for disposal of Class A (DOE Category 1) LLW.

4.2.3.2 Moisture Infiltration Control. Numerical performance assessments of the three proposed barrier designs were made with HELP (Version 2.0) and UNSAT-H (Version 2.0). The HELP code is recommended by EPA for evaluating hydrologic performance of surface barrier designs. However, for arid site applications HELP has two significant limitations. HELP requires the assumption of a constant evaporative zone depth throughout the year. In actuality, evaporative depth can vary considerably during 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 most annual precipitation occurs. Secondly, moisture movement in the unsaturated state is calculated by algorithms in HELP that are computationally efficient but do not accurately represent unsaturated flow. As a result, HELP 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 all three of the barriers proposed in this FFS.

Water balance calculations are reported in Appendix C. Because of the importance of hydrologic performance in the context of the long-term effectiveness of each of the proposed designs, several different approaches were taken to prepare these calculations. The approaches were as follows.

1. HELP simulations were performed for each barrier using laboratory data for the fine-textured soil layers and default data for the layers of coarse-textured material. A conservative value of 36 in. (90 cm) was assigned as 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 C1, C2 and C3.

2. The three barriers were reevaluated using UNSAT-H. 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 code 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. Appendix C-4 reports and compares results of the UNSAT-H simulations with the "calibrated" HELP simulations.

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 7.00 in.

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

Barrier	Run-off	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	0.00	0.00

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

Barrier	Run-off	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

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

Barrier	Run-off	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.

The HELP code is not configured to provide separate reporting of evaporation and transpiration totals. The UNSAT-H 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 also was 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 provide an indication of the capabilities of the three designs to accommodate multi-year periods of above-average rainfall. The "twice ambient" simulations were performed using both UNSAT-H and the calibrated HELP code (see Appendix C-4).

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

Barrier	Run-off	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 Code, Calibrated (in Percent of Twice Ambient Annual Precipitation)

Barrier	Run-off	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, HELP predicts that a slight amount of run-off will be observed, whereas UNSAT-H predicts no run-off. 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 percent of "twice ambient" precipitation. Deep infiltration for the Modified RCRA Subtitle D Barrier is about 2 percent of "twice ambient" precipitation in the UNSAT-H simulation and about 1 percent according to HELP.

One additional group of simulations was conducted to assess run-off production from the design storm. The design storm analyses are reported in Appendix C-4, Table 23. Results of the analysis are summarized below.

Design Storm Analyses - HELP Code, Calibrated

Barrier	Return period and duration (yrs and hrs)	Design storm amount (in.) [A]	Run-off amount (in.)	Run-off (% storm amt.)
Hanford Barrier	1000 / 24	2.68	0.85	31.6
Mod. RCRA C Barrier	500 / 24	2.47	0.91	36.8
Mod. RCRA D Barrier	100 / 24	1.99	0.60	30.1

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

The design storm is the expected worst-case precipitation event to occur during the functional life of each barrier. Considering the Hanford Site's arid climate, the storm amounts themselves 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 two to five years. As indicated previously, run-off is less than 1 in. in each case, which is not particularly adverse in terms of erosion potential. These data also show indirectly that during even the largest storm events at the Hanford Site, the majority (60 percent or more) of precipitation will infiltrate.

4.2.3.3 Long-Term Durability. The Hanford Barrier is proposed for sites containing low-level radiological wastes (and corresponding mixed wastes) with the highest activity classification (Greater Than Class C) and the greatest persistence through time (TRU). This barrier is designed to offer the maximum available degree of environmental protection for the maximum performance period (1,000 years) of the three designs proposed in this FFS. The Hanford Barrier design uses natural soil and rock materials to the maximum practical extent. Natural materials provide a high degree of assurance of retained form and function for the full performance period (i.e., adequate resistance to chemical and physical weathering). Based on studies of natural analogs, materials specified for the low-permeability asphalt layer are expected to provide adequate durability. The asphalt layer and the lateral drainage layer are situated well below frost depth, which should eliminate deterioration due to freeze/thaw cycling and moisture accumulation (ice lenses) within the drainage layer. Materials of indeterminate durability have been avoided in the design.

The Modified RCRA Subtitle C Barrier has a design life of 500 years. This barrier is designed to isolate moderate activity (i.e., Category 3) LLW and mixed wastes for a sufficient period of time to accommodate radiological decay to activity levels that represent acceptable risks to human health and the environment as defined in 10 CFR 61. Like the Hanford Barrier, the Modified RCRA Subtitle C Barrier uses natural soil and rock materials to the maximum practical extent. The two barriers use the same asphalt low-permeability layer design, and the asphalt layer and the overlying drainage layer are both situated at sufficient depth below grade to ensure frost protection.

The design life of the modified RCRA Subtitle D barrier is 100 years. This barrier is designed to isolate low-activity (i.e., Category 1) LLW, and like the Subtitle C barrier, it is designed to isolate waste for a sufficient period of time to accommodate radiological decay to levels of activity that represent acceptable risks to human health and the environment as defined in 10 CFR 61. A significant difference between this barrier and the other two designs is that the performance period for the Subtitle D Barrier does not extend beyond the limit of active institutional control.

The topsoil components of the three barrier designs include a number of provisions for minimizing long-term degradation (erosion) of the topsoil surface by wind and water. Vegetation consisting of a mixture of native perennial grasses will be cultivated on the barrier surfaces. Pea gravel will be mixed into the uppermost layer of fine-textured soil. The topsoil layer will be constructed with excess thickness to ensure that the essential function of the layer (i.e., moisture infiltration control) will not be compromised by erosion during the design lives of the barriers.

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 proposed 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 function to control biointrusion as well as inadvertent intrusion by humans. Activity or toxicity of radionuclides gradually diminishes naturally over time due to radionuclide decay. Surface barriers provide for long-term containment and isolation of radiological contaminants from all exposure pathways while decay proceeds. However, surface barriers do not reduce contaminant mobility in the sense that either the contaminants or the host soil media are chemically or physically altered (as with technologies such as fixation and vitrification).

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 sub-criteria normally are considered under short-term effectiveness.

- **Risk to the community.** This issue addresses potential risks to the public resulting from implementation of the proposed 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 proposed remedial action, such as radiation exposure, and the reliability of proposed protective measures.

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

- **Time until remedial action objectives are achieved.** This consideration includes an estimate of the time required to complete the proposed remedial action and short-term health effects consequences (if any) associated with the timing of remedial activities.

Barrier construction activities at 200 Area waste sites generally will be performed on surfaces where radiological contamination is demonstrably below levels of worker health and safety concern. Most waste sites that were restricted areas at some time in the past because of surface contamination have undergone surface stabilization, which involves placing a blanket of a few to several feet of clean fill over the site. This practice eliminates direct exposure hazards 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. At any site scheduled to receive a surface barrier where unacceptable levels of surface contamination are still present, the surface will be stabilized with grading fill as an initial aspect of barrier construction. The risk of physically contacting subsurface waste or releasing contaminants into the air during barrier construction is considered low. Continuous 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 the activities themselves are managed and performed in a manner that maintains worker exposures as low as reasonably achievable.

The only significant exposure pathway to the offsite public is the air pathway. Barrier construction activities are not expected to generate contaminated particulate in rates or quantities that would be of any consequence to the offsite public. For example, the FS report prepared for the 200-BP-1 Operable Unit (DOE-RL 1994) concluded that the worst-case air release scenario (assuming surface exposure of all subsurface contamination within the operable unit) would not exceed 10^{-6} to any offsite community. Therefore, it is expected that baseline risk assessments for individual waste sites in the 200 Areas will consistently show that risk to the community is insignificant in absolute terms and in relation to worker risk.

Most or all waste sites in the 200 Areas that have been identified as candidates 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 required 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 three barrier designs proposed in this FFS would be expected to receive high ratings for constructibility.

- **Reliability.** The three proposed 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 likelihood of encountering significant technical problems, schedule delays, or cost overruns during construction is relatively low.

- **Ease of undertaking additional remedial actions.** 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.

  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 proposed as an interim action.

4.2.6.2 Administrative Feasibility. Administrative feasibility issues relate to requirements for coordinating with or between various agencies of government for concurrence, approvals, permits, or variance actions. A procedural framework has been negotiated between the DOE, EPA and Ecology for developing, prioritizing, implementing and monitoring environmental restoration and remediation activities on the Hanford Site (Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) (Ecology et al. 1992). Administrative feasibility 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 or permits.

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 40 million yards of suitable material. The McGee Ranch site has been reserved as a borrow site to support environmental restoration at the Hanford Site.

Parallel activities 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. These materials exist onsite in sufficient quantities, but specific borrow locations remain to be determined.

4.2.7 Cost

Comparative 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 200 East Area. The subject site is an area 126 m by 1,739 m (415 ft 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 proposed (DOE-RL 1993c).

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 would be equivalent for the three barrier designs. 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 4-4. For the subject 5-acre waste site (216-B-43 through 216-B-50 cribs), the table indicates that construction of a Hanford Barrier would involve approximately twice the capital cost of a Modified RCRA Subtitle C Barrier, and a RCRA C Barrier would involve approximately three times the capital cost of a Modified RCRA Subtitle D Barrier. These comparisons are offered as order-of-magnitude comparisons only. Cost comparisons for the three barriers will vary from one site to another, as a function of the size and shape of the covered area, the site topography (which will determine the nature and extent of site grading requirements), and costs relating to subgrade pretreatment to eliminate low-density fill and/or subsurface voids.

In the case of the three estimates in Appendix E, significant costs are identified for site grading, reflecting the irregular existing site surface over the eight cribs. Grading costs are similar between the three barriers in absolute terms. However, they vary widely as a percentage of total project cost. Another significant distortion 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.

4.2.8 State Acceptance

This criterion makes provision for resolution of State technical and administrative issues and concerns raised regarding the proposed barrier designs. This criterion will be addressed in the final draft of this FFS after the State has had the opportunity to review and comment on this draft.

4.2.9 Community Acceptance

This criterion provides for public input on proposed remedial action plans. Public comments regarding contents of this draft will be reviewed and evaluated by DOE, EPA and Ecology before comment incorporation in the final draft of this FFS.

Table 4-1. Conformance Assessment of Hanford Barrier to Design Criteria.

	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/sec) is specified for the lateral drainage layer to prevent buildup of hydraulic head within the layer. The low-permeability (approximately 10^{-8} cm/sec) 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 multi-layer 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.

	Design Criteria	Assessment of Conformance
3.	Design a durable cover that will require 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-yr, 24-hr storm has been evaluated (see Appendix C-4). Although the design storm delivers 2.68 in. of precipitation, run-off during the 24-hr period is less than 1 in. (i.e., run-off 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.

	Design Criteria	Assessment of Conformance
7.	Include appropriate design provisions for limiting inadvertent human intrusion.	Guidance in 40 CFR 191 identifies drilling as the most potentially adverse human intrusion scenario for TRU 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 ofmechanized 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/sec. 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 conform to standard filter criteria.
11.	For frost protection, locate the lateral drainage layer and the low-permeability asphalt layer at least 2 ft 6 in. below final grade.	The top of the lateral drainage layer will be situated approximately 13 ft 2 in. (3.95 m) below final grade.

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

	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/sec) is specified for the lateral drainage layer to prevent significant hydraulic head buildup within the layer. The low-permeability (approximately 10^{-8} cm/sec) 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 multi-layer 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. With the exception of 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.

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

	Design Criteria	Assessment of Conformance
3.	Design a durable cover that will require 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.
4.	Design a cover 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-yr, 24-hr storm has been evaluated (see Appendix C-4). Although the design storm delivers 2.47 in. of precipitation, run-off during the 24-hr period is less than 1 in. (i.e., run-off 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.

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

	Design Criteria	Assessment of Conformance
7.	Ensure that the top of the waste zone is at least 5 m below final grade or include appropriate design provisions for limiting inadvertent human intrusion.	Guidance in 10 CFR 61 identifies human habitation of the site surface as 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 requirement. At other sites, the requirement 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.
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/sec. 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 2 ft 6 in. below final grade.	The top of the lateral drainage layer will be situated approximately 4 ft 4 in. (1.3 m) below final grade.

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

	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 the addition of 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 wastes that attract vectors. Modified RCRA Subtitle 2D Barrier does not address human intrusion. The 100-year design life corresponds to the minimum limit of active institutional control.
3.	Design a multi-layer 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 4-3. Conformance Assessment of Modified RCRA Subtitle D Barrier to Design Criteria.

4.	Design a cover system that includes a minimum thickness of 45 cm (18 in.) of earthen materials that will minimize moisture infiltration through the cover.	The Modified RCRA Subtitle D Barrier facilitates moisture retention in the topsoil layers (Layers 1, 2 and 3) for removal by evaporation and plant transpiration. The capillary barrier interface at the base of the topsoil layers will restrict drainage and increase moisture storage capacity above the interface. The combined thickness of Layers 1, 2 and 3 is 90 cm (36 in.).
5.	Design a cover system that includes a surface layer of earthen materials with a minimum thickness of 15 cm (6 in.) that will control run-off 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.).
6.	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 for establishing and maintaining cover vegetation of perennial grass species.
7.	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/sec (whichever is less).	The compacted topsoil in Layer 3 is expected to have a saturated hydraulic conductivity value on the order of 10^{-6} cm/sec. This value is less than the permeabilities of native subsoils in the 200 Areas.

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

8.	Design a durable cover that will require 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.
9.	Design a cover with surface slopes of no less than 2 %.	The surface slope is specified in the design at 2%.
10.	Design a cover with a functional life of 100 years.	The thickness of topsoil in the Modified RCRA Subtitle D Barrier is sufficient to 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-yr, 24-hr storm has been evaluated (see Appendix C-4). Although the design storm delivers 1.99 in. of precipitation, run-off during the 24-hr period is less than 1 in. (i.e., run-off is not excessive, and the design storm is unlikely to cause severe erosion of the cover surface).

Table 4-4. 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
SRDI Test on Asphalt Layer (Technical Services)	58,075	58,075	0
ENGINEERING TOTALS	920,575	475,525	69,000
IMPROVEMENTS TO LAND			
Site Grading, Compaction, & 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	7,529,268	3,659,449	1,183,341

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 COVER FEASIBILITY - CONCLUSIONS

The results of the detailed assessments in Chapter 4.0, in which each of the three proposed surface barrier designs was assessed against its design criteria and the EPA evaluation criteria, demonstrate that the barrier designs will constitute acceptable remedies for application at candidate IRM and LFI sites. Following are the three proposed designs.

- **Hanford Barrier.** Designed to provide 1,000-year isolation of waste sites containing TRU contaminants, mixed TRU and hazardous contaminants, and Greater Than Class C LLW and mixed waste.
- **Modified RCRA Subtitle C Barrier.** Designed to provide 500-year isolation of waste sites with hazardous waste, Category 3 LLW, Category 3 LL mixed waste, and Category 1 LL mixed waste.
- **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, the barriers are readily constructible, are viewed as reliable remedial measures, and do not appear to be constrained by administrative issues or the availability of materials. Sample engineering and construction costs are presented in Section 4.2.7 and Appendix E.

5.2 DEFINITIVE DESIGN REQUIREMENTS

The three surface barrier designs in this FFS report have been developed as generic conceptual designs. The design process has accounted for all applicable requirements and criteria with the exception of site-specific items. Site-specific requirements and criteria will be considered during the 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 drainage requirements, 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 requirements.

- Availability of construction materials.

- Specification of suitable cover vegetation.

Additional research and engineering activities are ongoing to refine barrier materials and specifications. These activities include work associated with the Hanford Barrier Development Program and the field demonstration tests described in Section 5.3.1 associated with the cover remedy selected for units within the 200-BP-1 Operable Unit. Refinements will be incorporated into definitive cover designs as they become available.

5.3 RECOMMENDATIONS FOR FURTHER WORK

The following subsections highlight several design issues recommended as priority topics for further barrier development work.

5.3.1 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 focus on (1) developing and performing a defensible accelerated aging test procedure to measure asphalt properties over 1,000 years, and (2) supplementing and validating laboratory aging data by comparisons to asphalt artifacts from archaeological sites. The scope of work proposed by Freeman and Romine has been initiated.

5.3.2 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 mils thick. During construction of the Hanford Barrier prototype at 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 requirements. Therefore, it may be appropriate either to identify an appropriate substitute for the fluid-applied asphalt coating or to eliminate it altogether.

5.3.3 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 hazardous, 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 baseline 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 wastes physically but not hydrologically.

This concept was not considered further for several reasons. First, there is no provision in the ARARs for surface barriers that provide no hydrologic protection. Second, no sites in the 200 Areas have been evaluated to date by the Environmental Restoration Program that conform to this case (i.e., sites with no mobile constituents such as ^{99}Tc and U in the waste inventory). Third, there was a lack of consensus regarding the essential design attributes of such a barrier.

The biointrusion barrier has not been eliminated as a remedial option concept. However, it is apparent that implementation issues need to be dispositioned before a workable design can be proposed. As an example, regulatory approval of a biointrusion barrier would require waivers to several key ARARs. Therefore, additional work on the biointrusion barrier has been deferred until a candidate waste site is identified that provides an appropriate test case for the concept.

5.3.4 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 covers. This omission reflects the view that there is relatively little an engineer can do to design a barrier to minimize or eliminate its vulnerability to large, uneven settlement. To deal effectively with this issue, the engineering focus must be redirected from the barrier to the subgrade.

A second FFS is proposed 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 the three proposed surface barriers on sites with undisturbed subgrade. Estimates will be prepared for a range of barrier sizes (i.e., 100- , 500- , and 1,000-ft^2 areas), and separate estimates will be prepared for sites in 200 East Area (where the shallow subgrade generally consists of coarse alluvium) and 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.

5.3.5 Barrier Materials Data Base

The information that has been collected in Appendix B of this FFS could serve as the basis for a spreadsheet or data base for accumulating and correlating data on material quantity and scheduling requirements for barrier construction. Such a data base would be useful in budgeting and planning for tracking material quantity requirements, 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. Figure 5-1 represents the proposed logic for barrier selection 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 TRU constituents or TRU mixed waste in concentrations in excess of 100 nCi/g?

2. Does the WMU contain LLW or LL mixed waste with Greater-Than-Class C (GTCC) activity, i.e, does waste activity exceed Category 3 limits?

3. Does the WMU contain LLW or LL mixed waste with Category 3 (C3) activity?

4. Does the WMU contain only hazardous (dangerous) waste?

5. Does the WMU contain LLW with Category 1 (C1) activity?

6. Does the WMU contain LL mixed waste with Category 1 (C1) activity?

7. Only nonradiological, nonhazardous solid waste is present.

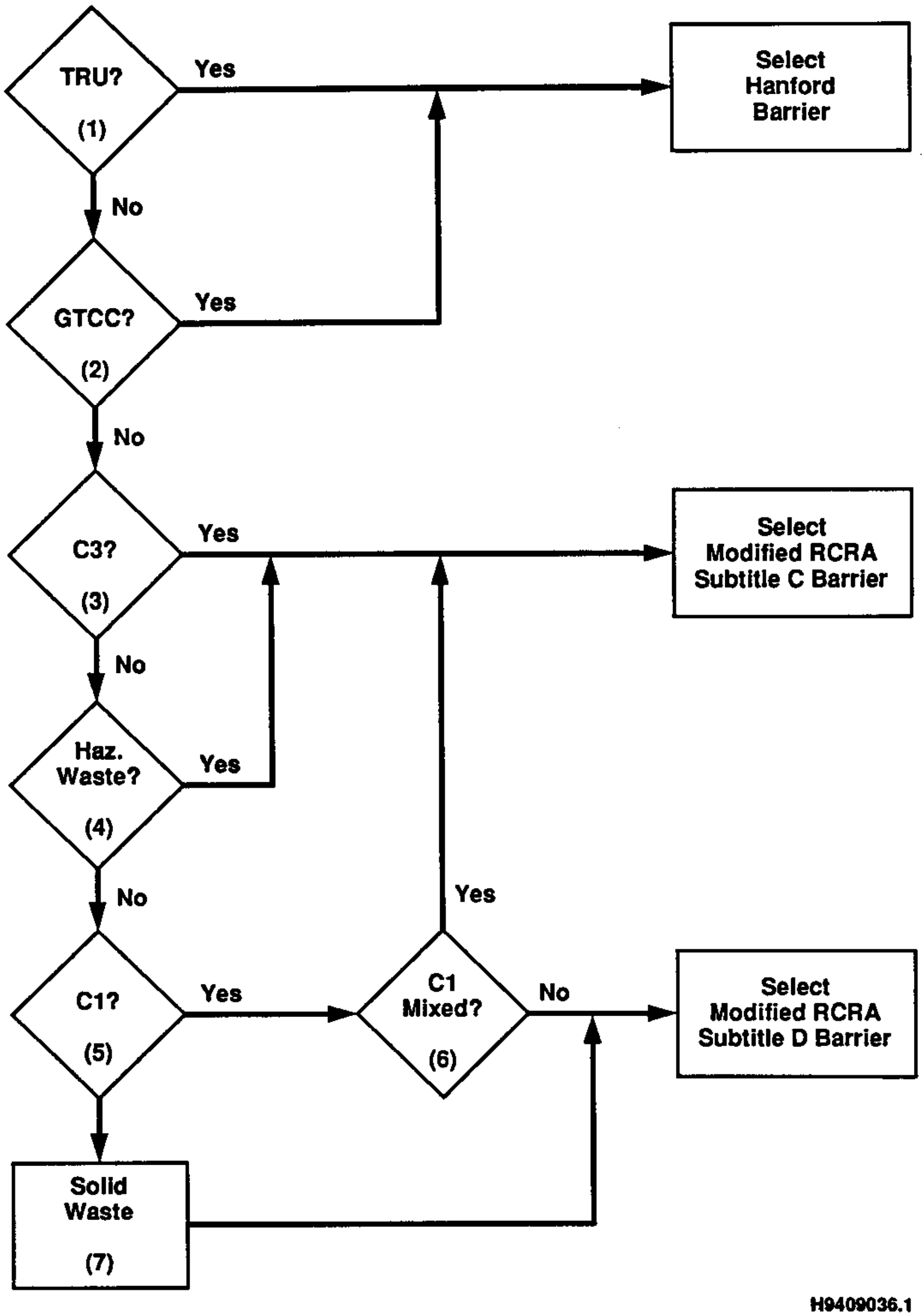
Application of the logic requires that sufficient information is available regarding contaminant constituents and concentrations to classify the radiological component of the waste against the activity limits in Appendix A and to determine whether hazardous constituents are present at levels of regulatory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

According to the waste site information in Appendix B and the summary in Table 1-1, there are 30 waste sites (predominantly in 200 West Area) with TRU contaminated soil or TRU mixed waste. According to Figure 5-1, these sites will all be 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 hazardous 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 Greater-Than-Class C activity would be candidate sites for the Hanford Barrier, and Category 3 sites and hazardous waste only sites would be candidates for the Modified RCRA Subtitle C Barrier. The Subtitle C Barrier would also be selected for Category 1 - mixed waste sites, in consideration of the hazardous 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 graded barriers.
The numbered notes refer to statements
listed in section 5.4.

Implementation Logic for the Graded Barrier Approach



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APPENDIX A

LOW-LEVEL WASTE ACTIVITY LIMITS

At the Hanford Site, low-level waste is divided into three categories as stipulated in WHC (1993)*: Category 1 (analogous to NRC Classes A and B), Category 3 (analogous to Class C), and Greater-Than-Class C as originally defined by NRC. Category 1 and 3 wastes are defined based on the constituents and corresponding activity limits listed in this appendix, which is reproduced from Section 3.0 of WHC (1993). A "sum-of-fractions" rule is used to evaluate wastes with multiple constituents [10 CFR 61.55(7) and WHC (1993)].

* WHC, 1993, *Hanford Site Solid Waste Acceptance Criteria*, WHC-EP-0063-4, Westinghouse Hanford Company, Richland, Washington.

Category 1 and 3 Activity
Limits for Disposal. (sheet 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

Category 1 and 3 Activity
Limits for Disposal. (sheet 2 of 3)

Nuclide	Activity limits (Ci/m^3)	
	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

Category 1 and 3 Activity
Limits for Disposal. (sheet 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

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

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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-PO-2	216-A-41	Crib	LL/Mixed Waste	Y
200-PO-2	216-A-45	Crib	LLW	Y
200-PO-2	218-E-1	Burial Ground	Pre-1970 TRU/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-BP-1	216-B-48	Crib	LL/Mixed Waste	N
200-BP-1	216-B-49	Crib	LL/Mixed Waste	N
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/Mixed Waste Contaminated Soil	Y

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-BP-2	216-B-53B	Trench	LL/Mixed Waste	Y
200-BP-2	216-B-54	Trench	LL/Mixed Waste	Y
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/Mixed Waste Contaminated Soil	Y
200-BP-4	216-B-7B	Crib	TRU/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/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-BP-6	216-B-60	Crib	LL/Mixed Waste	N
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/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-BP-11	216-B-3-1	Ditch	LL/Mixed Waste	Y
200-BP-11	216-B-3-2	Ditch	LL/Mixed Waste	Y
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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
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
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/Mixed Waste Contaminated Soil	Y
200-RO-2	216-S-2	Crib	TRU/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
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
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/Mixed Waste Contaminated Soil	Y
200-TP-2	216-T-13	Trench	LL/Mixed Waste	N
200-TP-2	216-T-18	Crib	TRU/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-TP-3	216-T-6	Crib	TRU/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
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/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
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
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/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/Mixed Waste Contaminated Soil	Y
200-UP-2	216-Z-11	Ditch	TRU/Mixed Waste Contaminated Soil	Y
200-UP-2	216-Z-19	Ditch	TRU/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

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-ZP-2	216-Z-1&2	Crib	TRU/Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-1A	Tile Field	LL/Mixed Waste	Y
200-ZP-2	216-Z-3	Crib	TRU/Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-4	Trench	LL/Mixed Waste	Y
200-ZP-2	216-Z-5	Crib	TRU/Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-6	Crib	LL/Mixed Waste	Y
200-ZP-2	216-Z-7	Crib	TRU/Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-8	French Drain	TRU/Mixed Waste Contaminated Soil	N
200-ZP-2	216-Z-8	Settling Tank	TRU/Mixed Waste	Y
200-ZP-2	216-Z-9	Trench	TRU/Mixed Waste Contaminated Soil	Y
200-ZP-2	216-Z-10	Reverse Well	TRU/Mixed Waste Contaminated Soil	N
200-ZP-2	216-Z-12	Crib	TRU/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/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/Mixed Waste	Y
200-ZP-3	218-W-1A	Burial Ground	LL/Mixed Waste	Y
200-ZP-3	218-W-2	Burial Ground	Pre-1970 TRU/Mixed Waste	Y

Operable unit	Unit name	Unit type	Waste category	AAMS Path[a] (IRM/LFI?)
200-ZP-3	218-W-3	Burial Ground	Pre-1970 TRU/Mixed Waste	Y
200-ZP-3	218-W-4A	Burial Ground	Low-Level and Pre-1970 TRU/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 Aggregate Area Management Study 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 Aggregate Area Management Study process. They are listed in this table because they are situated in the 200 Area National Priority List site and are scheduled and/or expected to be capped with surface barriers.

IRM = Interim Remedial Measure.
LFI = Limited Field Investigation.
LL = Low-Level.
LLW = Low-Level Waste.
NRDWL = Nonradioactive Dangerous Waste Landfill.
TRU = Transuranic.

APPENDIX C

NUMERICAL PERFORMANCE ASSESSMENTS

1.0 Contents and Organization of this Appendix

This Appendix presents information concerning numerical performance assessments of the three surface barrier designs proposed 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, multi-year periods of elevated (twice ambient) precipitation, and the design storm.

Performance of the three proposed barrier designs was evaluated using both the HELP (Version 2.0) and UNSAT-H (Version 2.0) codes. The HELP code is recommended by EPA for evaluating hydrologic performance of surface barrier designs. However, for arid site applications HELP has two significant limitations. HELP 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 often is received. Secondly, moisture movement in the unsaturated state is calculated by algorithms in HELP that are computationally efficient but do not accurately represent unsaturated flow. As a result, HELP 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 all three of the barriers proposed in this FFS.

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

1) HELP 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 36 in. (90 cm) 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 Appendix C-1, C-2 and C-3.

2) The three barriers were reevaluated using UNSAT-H. 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 code 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 simulations and the "calibrated" HELP 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 below. Selection of input information for the UNSAT-H simulations and the "calibrated" HELP Model simulations is described separately in Appendix C-4.

2.0 Notes on HELP Simulations reported in Appendix C-1, C-2 and C-3.

The HELP Model computes runoff, lateral drainage and infiltration through a multi-layer 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 proposed 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 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 Appendix C-1, C-2 and C-3, the cover area was defined as 1 acre (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 36 in. was assumed for the simulations as the limiting depth of evapo-transpiration.

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: 40 in. thick. Material properties for McGee Ranch silt for this simulation are the same as specified below for Layer 2, but porosity, field capacity and wilting point values were reduced by 7.9 percent 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. percent pea gravel (125 lb/ft^3 dry unit weight and 25 percent porosity) and 85 wt. percent silt (85 lb/ft^3 dry unit weight and 51.4 percent porosity).

Porosity = 0.4734
Field Capacity = 0.2381

Wilting Point = 0.0629
Saturated Hydraulic Conductivity = 9.9 x 10^{-4} cm/sec

A "poor" grass cover was specified.

Layer 2 -- lower silt layer: 40 in. thick. Material properties for uncompacted McGee Ranch silt for this simulation are from DOE-RL (1990); 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 x 10^{-4} cm/sec

Layer 3 -- sand filter layer: The layer was modeled as consisting of 6 in. of HELP 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 12 in. of HELP default textural type 1 soil (sand and gravel). This layer also was modeled as a compacted soil layer.

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

Layer 6 -- Lateral Drainage Layer: The lateral drainage layer was modeled as a 12-in. layer of uncompacted HELP default type 1 soil (sand and gravel), sloping at 2 percent. 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/sec).

Layer 7 -- Asphalt Layer: The asphalt was modeled as a barrier soil layer with a saturated hydraulic conductivity of 1 x 10^{-8} cm/sec 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 percent. 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: 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: 20 in. thick. The following adjustments were made to reflect compaction of layer 2:

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

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 6 in. of HELP 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 6 in. of HELP default textural type 1 soil (sand and gravel). This layer also was modeled as a compacted soil layer.

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

Layer 6--Asphalt Layer: The asphalt was modeled as a 6-in. barrier soil layer with a saturated hydraulic conductivity of 1 x 10^{-8} cm/sec 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 design was modeled as consisting of three layers as follows:

Layer 1--upper silt layer with pea gravel admixture: 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: 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/sec

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

Layer 3--lower (compacted) silt layer: 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 design.

3.0 References

DOE-RL, 1990, *Closure and Postclosure Plan Nonradioactive Dangerous Waste Landfill*, DOE/RL-90-17, Rev. 0, U.S. Department of Energy, Richland, Washington.

Gee, G.W., M.L. Rockhold and J.L. Downs, 1989, *Status of FY 1988 Soil-Water Balance Studies on the Hanford Site*, PNL-6750, Pacific Northwest Laboratory, Richland, Washington.

Schroeder, P.R., B.M. McEnroe, R.L. Peyton, and J.W. Sjostrom, 1988, *The Hydrologic Evaluation of Landfill Performance (HELP) Model*, Volume III, User's Guide for Version 2; and Volume IV, Documentation for Version 2, U.S. Environmental Protection Agency, Washington, D.C.

Skelly, W.A., 1990, *Hanford Site-Specific Climate Data Input Files for Use with the HELP Model Software*, WHC-SD-EN-CSWD-028, Westinghouse Hanford Company, Richland, Washington.

APPENDIX C-1

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

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/SEC

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/SEC

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/SEC

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/SEC

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/SEC

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/SEC
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/SEC

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

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 (INCHES)	0.778	0.304	0.208	0.452	0.611	0.262
	0.090	0.285	0.295	0.137	0.350	0.531
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0040	0.0036	0.0040	0.0039	0.0040	0.0039
	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

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 (INCHES)	0.487	1.188	1.943	0.511	1.681	2.054
	0.285	0.020	0.383	0.364	0.293	0.324
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0041	0.0038	0.0041	0.0040	0.0041	0.0040
	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

MONTHLY TOTALS FOR YEAR 1981

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION (INCHES)	0.56 0.19	0.60 0.03	0.70 0.60	0.02 0.39	0.99 1.08	0.43 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 (INCHES)	0.698 0.182	1.506 0.030	0.949 0.102	0.394 0.347	0.336 0.538	1.571 0.558
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002 0.0002	0.0002 0.0002	0.0002 0.0002	0.0002 0.0002	0.0002 0.0002	0.0002 0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0041 0.0041	0.0037 0.0041	0.0041 0.0039	0.0040 0.0041	0.0041 0.0039	0.0040 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

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 (INCHES)	0.688	1.161	0.866	0.588	0.697	0.472
	0.704	0.196	0.295	0.402	1.036	0.568
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0040	0.0037	0.0040	0.0039	0.0040	0.0039
	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

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 (INCHES)	0.596	0.998	2.199	0.870	0.605	1.791
	0.747	0.123	0.460	0.157	0.703	0.461
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0039	0.0036	0.0039	0.0038	0.0039	0.0038
	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

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 (INCHES)	0.467	1.340	1.959	0.510	0.729	2.337
	0.162	0.000	0.214	0.269	0.468	0.601
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0038	0.0036	0.0038	0.0037	0.0038	0.0036
	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

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 (INCHES)	0.681	1.218	0.921	0.010	0.144	0.165
	0.026	0.104	0.335	0.262	0.281	0.630
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0037	0.0033	0.0037	0.0036	0.0037	0.0035
	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

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 (INCHES)	0.535	1.400	1.859	0.287	0.363	0.420
	1.165	0.020	0.328	0.270	0.236	0.273
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0037	0.0033	0.0037	0.0036	0.0037	0.0036
	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

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 (INCHES)	0.276	1.031	0.775	0.405	0.594	0.941
	0.500	0.070	0.010	0.000	0.224	0.389
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0037	0.0034	0.0038	0.0037	0.0038	0.0037
	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

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 (INCHES)	0.818	0.642	0.531	0.483	0.582	0.791
	0.130	0.000	0.165	0.205	0.289	0.279
LATERAL DRAINAGE FROM LAYER 6 (INCHES)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
PERCOLATION FROM LAYER 7 (INCHES)	0.0039	0.0037	0.0039	0.0038	0.0039	0.0038
	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

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

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

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

APPENDIX C-2

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/SEC

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/SEC

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/SEC

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/SEC

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/SEC
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/SEC

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

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

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

MONTHLY TOTALS FOR YEAR 1981

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION (INCHES)	0.56 0.19	0.60 0.03	0.70 0.60	0.02 0.39	0.99 1.08	0.43 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 (INCHES)	0.663 0.186	1.429 0.030	1.050 0.114	0.389 0.357	0.350 0.513	1.569 0.542
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 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

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

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

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

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 (INCHES)	0.656	1.176	0.971	0.037	0.144	0.171
	0.031	0.099	0.356	0.266	0.276	0.615
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 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

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 (INCHES)	0.534	1.357	1.798	0.362	0.362	0.415
	1.229	0.020	0.353	0.263	0.230	0.270
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 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

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 (INCHES)	0.479	0.952	0.643	0.386	0.577	0.978
	0.500	0.070	0.010	0.000	0.222	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

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 (INCHES)	0.796	0.664	0.538	0.506	0.580	0.722
	0.130	0.000	0.173	0.196	0.284	0.274
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 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

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

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	

APPENDIX C-3

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

APPENDIX C-3

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/SEC

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/SEC

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/SEC

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

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 (INCHES)	0.774	0.580	0.209	0.468	0.510	0.010
	0.090	0.276	0.304	0.159	0.362	0.518
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 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

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 (INCHES)	0.485	1.159	1.894	0.678	1.678	2.003
	0.233	0.020	0.382	0.383	0.291	0.314
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 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

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 (INCHES)	0.665	1.433	1.066	0.452	0.406	1.426
	0.182	0.030	0.113	0.358	0.516	0.543
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 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

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 (INCHES)	0.660	1.109	1.032	0.607	0.676	0.408
	0.697	0.199	0.300	0.400	0.988	0.547
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 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

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 (INCHES)	0.577	0.965	2.210	0.848	0.720	1.989
	0.758	0.121	0.460	0.161	0.578	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

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 (INCHES)	0.444	1.276	2.100	0.539	0.753	2.115
	0.729	0.000	0.230	0.260	0.468	0.577
PERCOLATION FROM LAYER 3 (INCHES)	0.0000	0.0000	0.0000	0.0000	0.0002	0.0003
	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 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 (INCHES)	0.652	1.169	1.033	0.010	0.142	0.150
	0.031	0.099	0.362	0.273	0.278	0.612
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 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

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 (INCHES)	0.533	1.350	1.805	0.452	0.364	0.406
	1.136	0.020	0.365	0.267	0.233	0.271
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 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

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 (INCHES)	0.274	1.012	0.697	0.406	0.597	1.007
	0.500	0.070	0.010	0.000	0.226	0.423
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 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

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 (INCHES)	0.776	0.655	0.550	0.529	0.590	0.711
	0.130	0.000	0.177	0.200	0.287	0.276
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 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

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

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

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	

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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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.

CONTENTS

FIGURES

TABLES

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

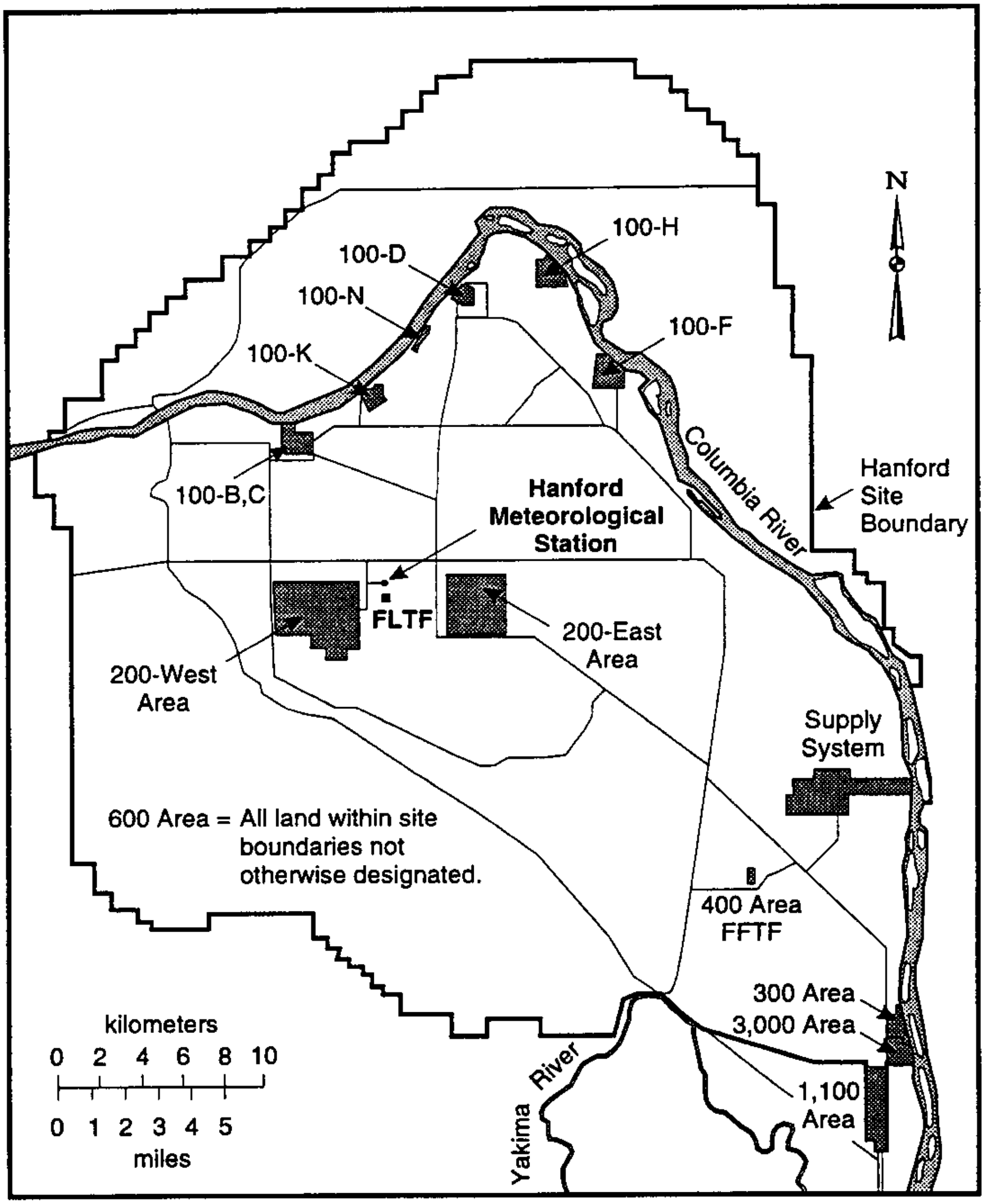

Figure 1. Hanford site, showing locations of numerically designated areas.

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

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K_T(h)\frac{\partial h}{\partial z} + K_L(h) + q_{vT}\right] - S(z,t)\ , \tag{1}$$

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

$$PT = PET\left[-0.21 + 0.70\,(LAI)^{1/2}\right]\ , \tag{2}$$

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.

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

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}, \tag{3}$$

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

$$PET = \frac{1.28AH}{(A + G)\,25.4}, \tag{4}$$

where

H = net solar radiation

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

$$K_s \cos^2\alpha \frac{\partial}{\partial x}\left(y\frac{\partial h}{\partial x}\right) + R - K_B\left(1 + \frac{y}{T}\right) = 0 , \qquad (8)$$

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.

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 80 years of operation and approximately 4,500 years after closure. Default hydraulic parameters for fine loamy 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.

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.

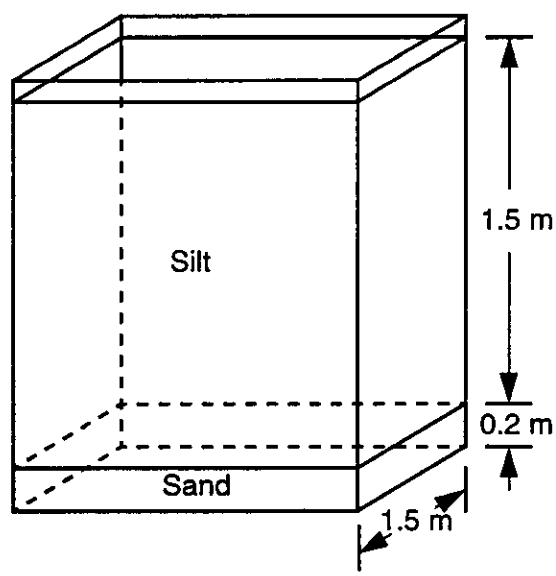

Figure 2. Weighing lysimeter configuration

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.

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.

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 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.

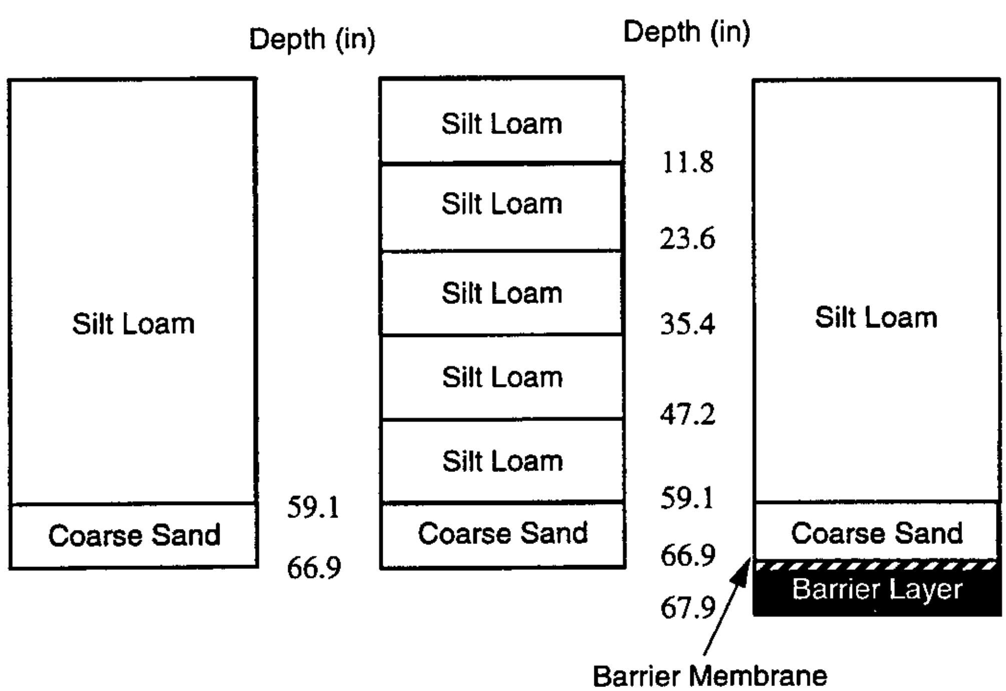

Figure 3. Weighing lysimeter representations used in HELP simulations.

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.

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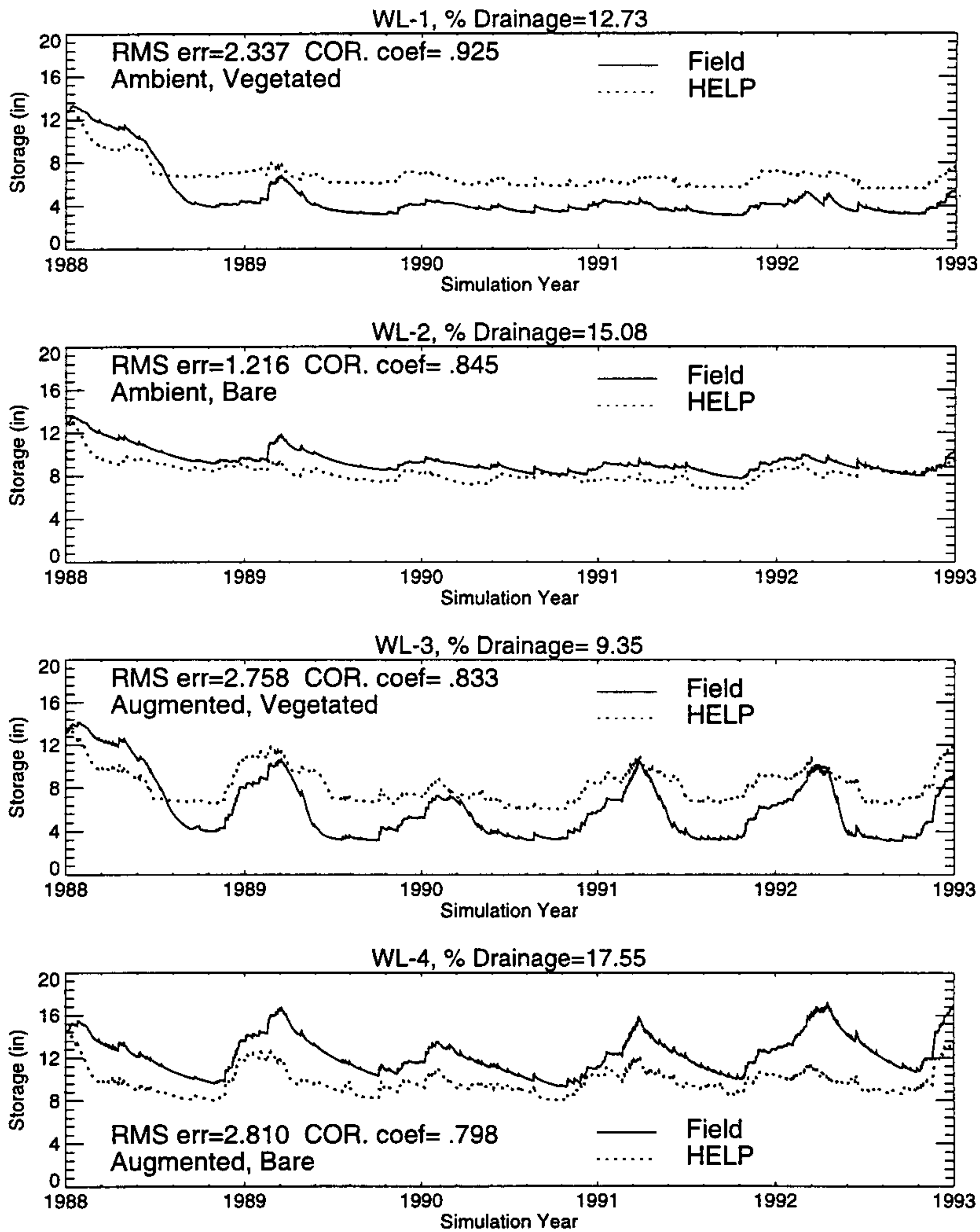

Figure 4. Simulation results of storage for the uncalibrated two-layer lysimeter representation.

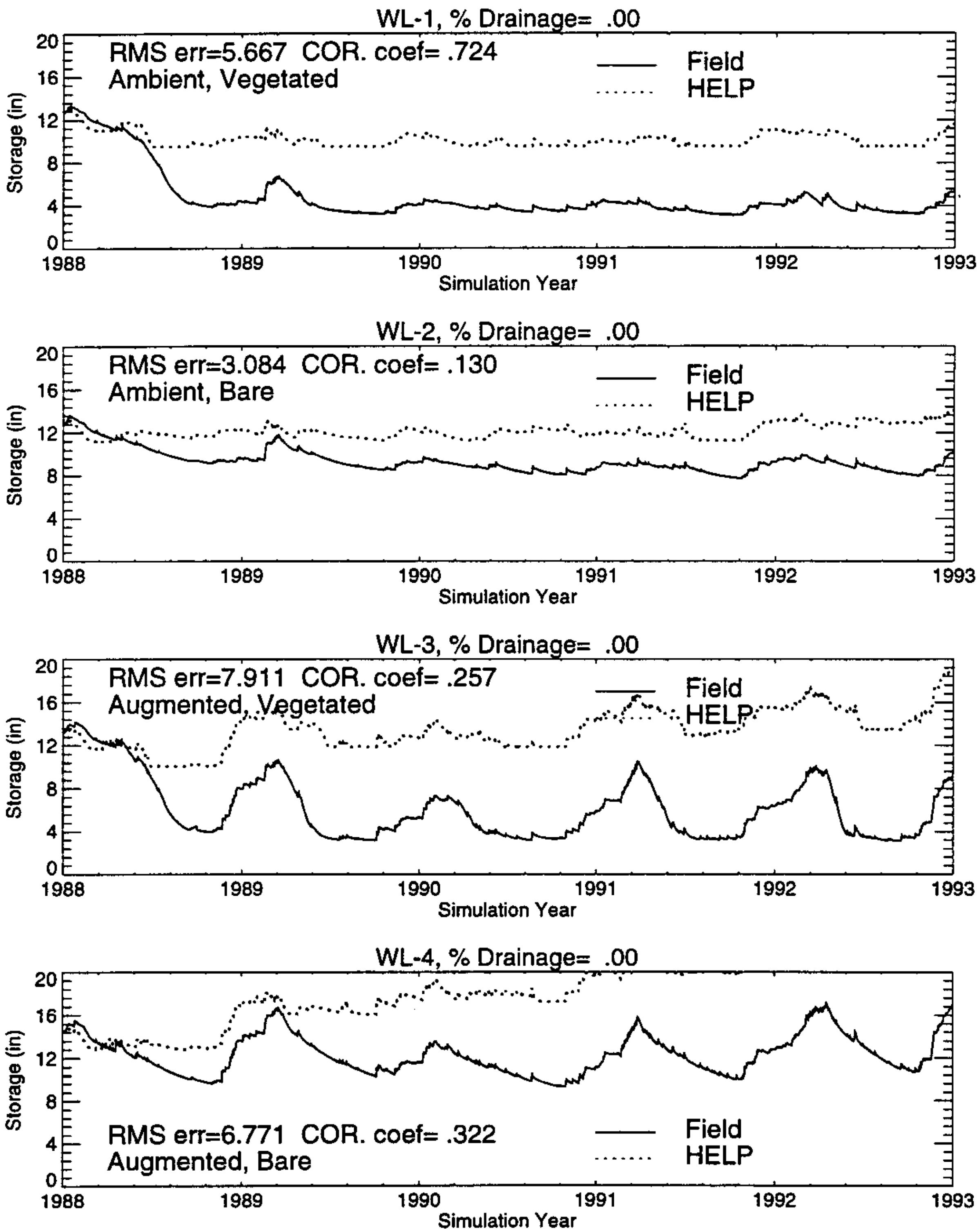

Figure 5. Simulation results of storage for the uncalibrated four-layer lysimeter representation.

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

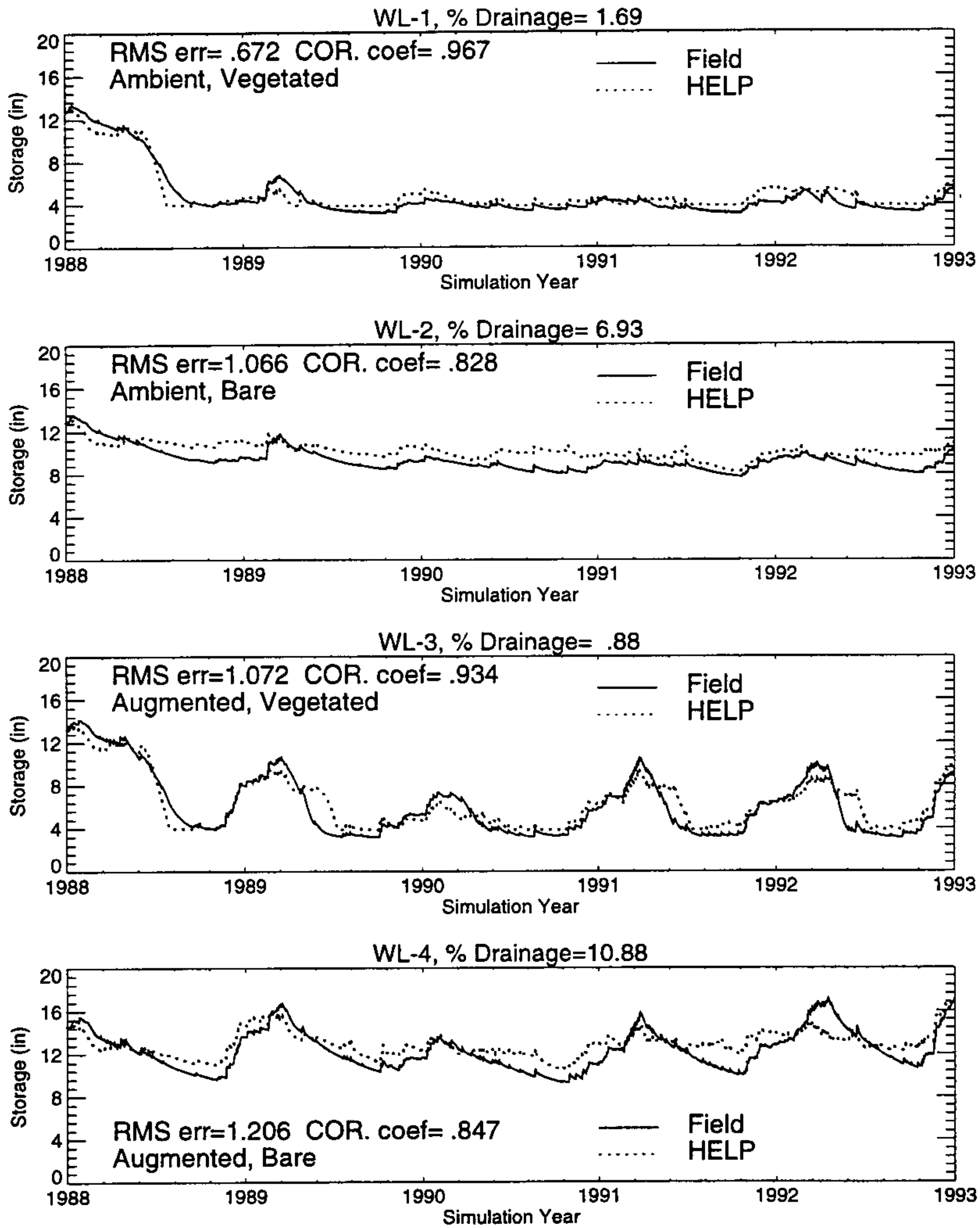

Figure 6. Simulation storage results using best-fit parameters for the two-layer lysimeter representation.

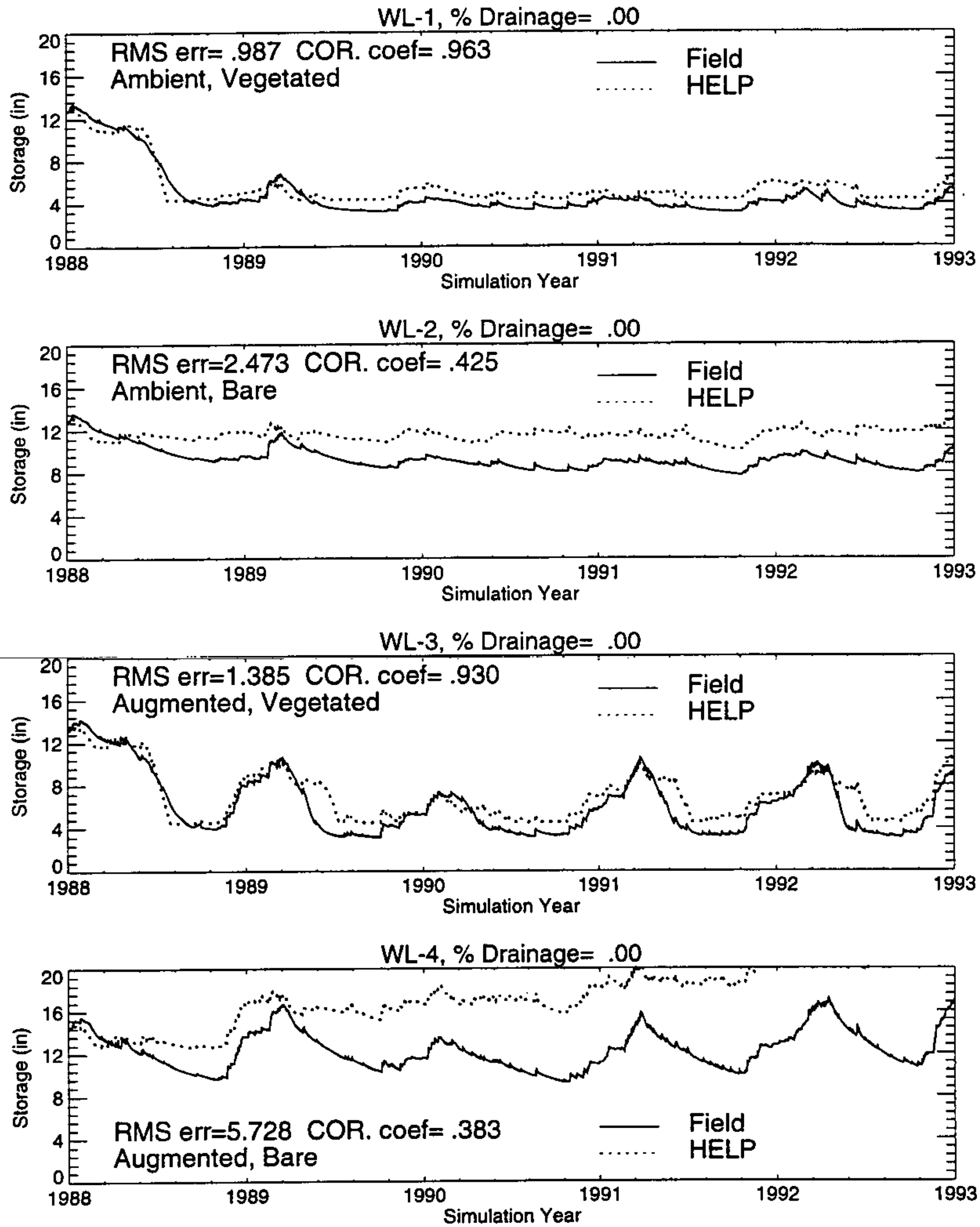

Figure 7. Simulation storage results using best-fit parameters for the four-layer lysimeter representation.

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.

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.

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.

- 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.

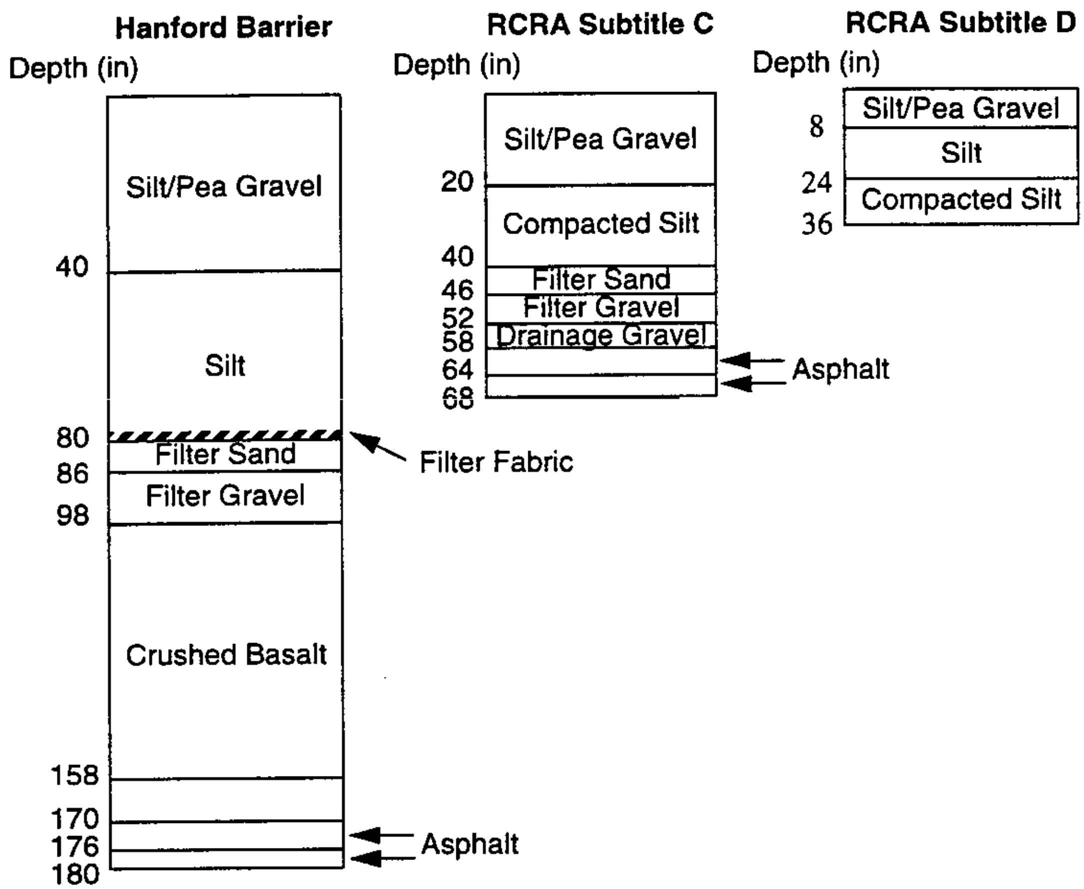

Figure 8. Barrier layers.

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.

- 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 hydraulic conductivity. The van Genuchten equations were used to represent these constitutive relationships. The equation for the characteristic curve is

$$\theta = \theta_r + (\theta_s - \theta_r)\left[1 + (\alpha h)^n\right]^{1-\frac{1}{n}} \qquad (12)$$

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

$$K(h) = K_s \frac{\{1 - (\alpha h)^{n-1}\left[1 + (\alpha h)^n\right]^{1-1/n}\}^2}{\left[1 + (\alpha h)^n\right]^{l(1-1/n)}} \qquad (13)$$

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 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.

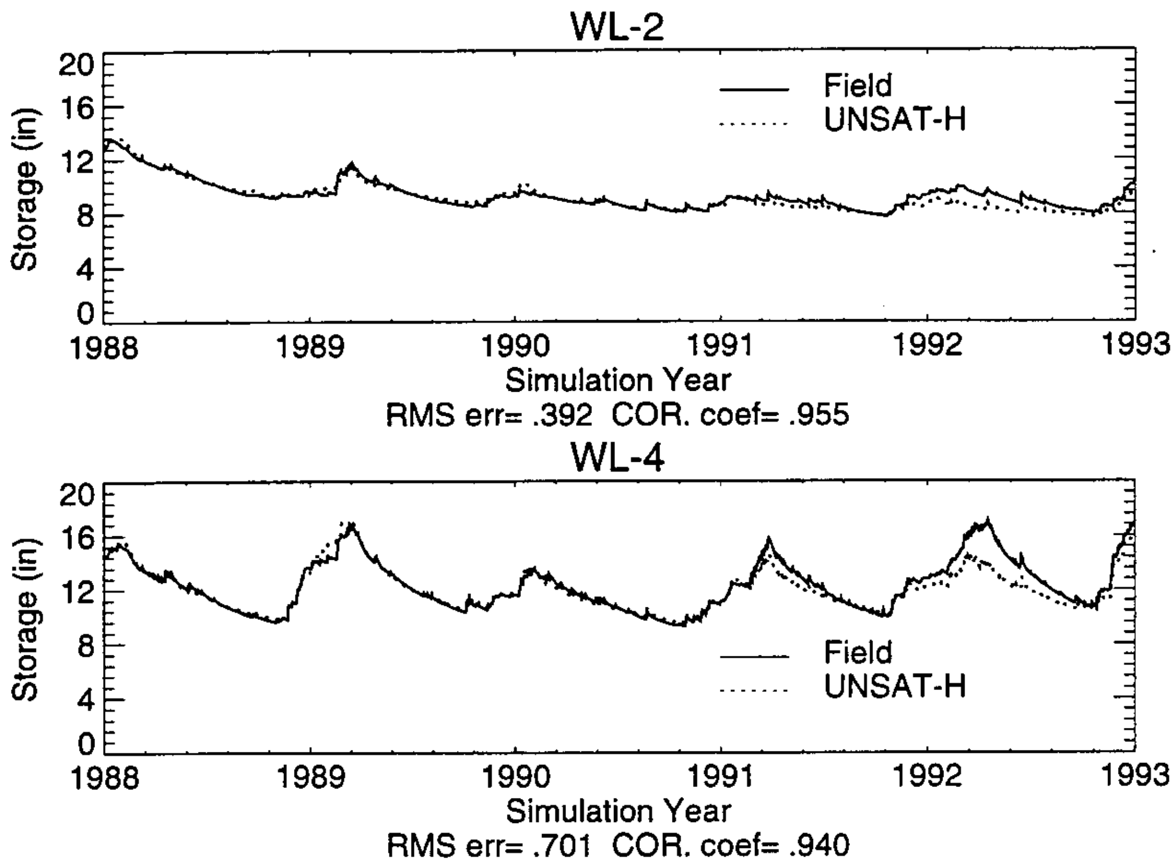

Figure 9. Validation results for McGee Ranch silt.

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

$$\psi_e = \psi_{es}(\rho_{bc}/\rho_{buc})^{0.67b} \tag{14}$$

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

$$\rho_p = \frac{\rho_{buc}}{1 - \theta_s} \tag{15}$$

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

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 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.

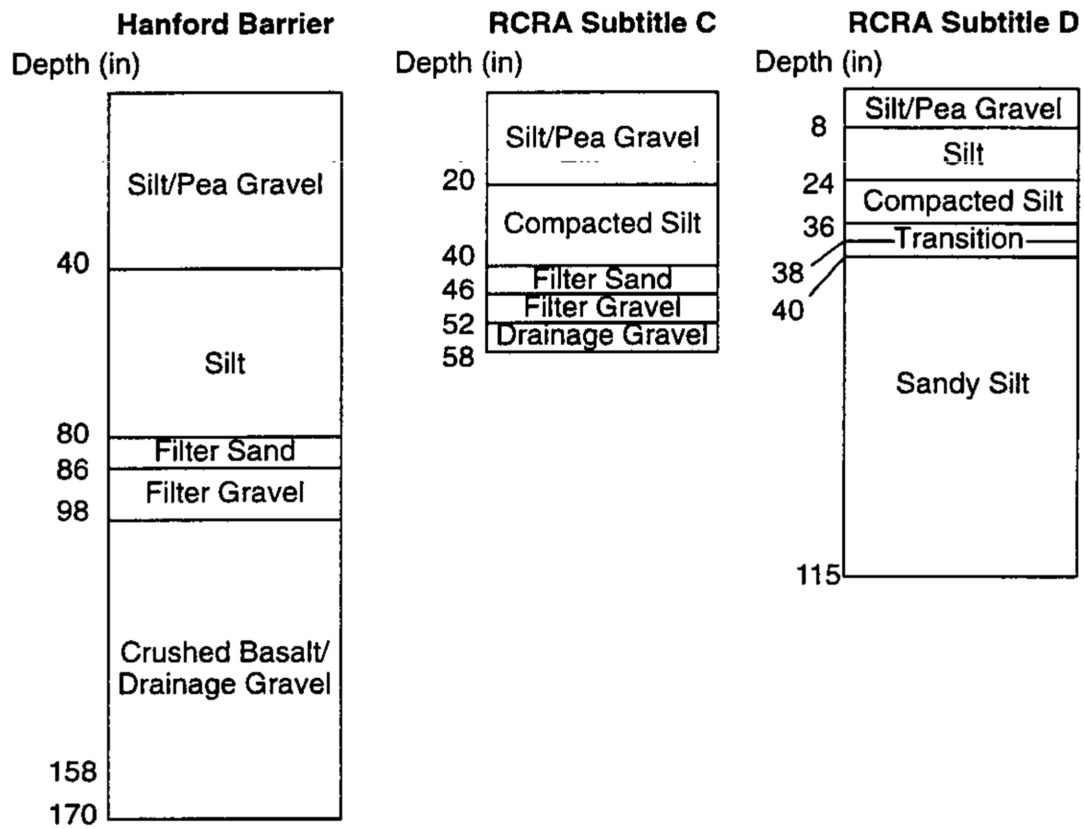

Figure 10. UNSAT-H simulation profiles.

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 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

$$f \approx 100\left(\frac{112 - 0.1T + T_d}{112 + 0.9T}\right)^8, \tag{16}$$

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 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.

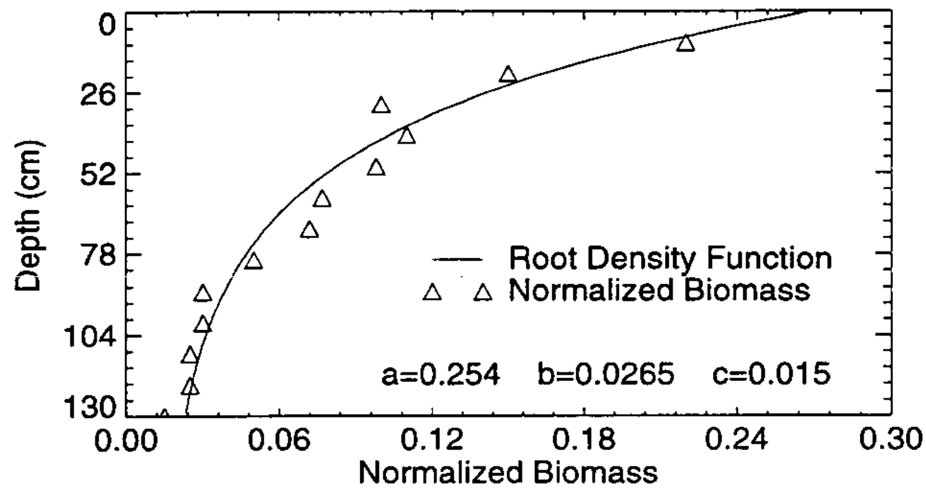

Figure 11. Fitted root density function.

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.

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.

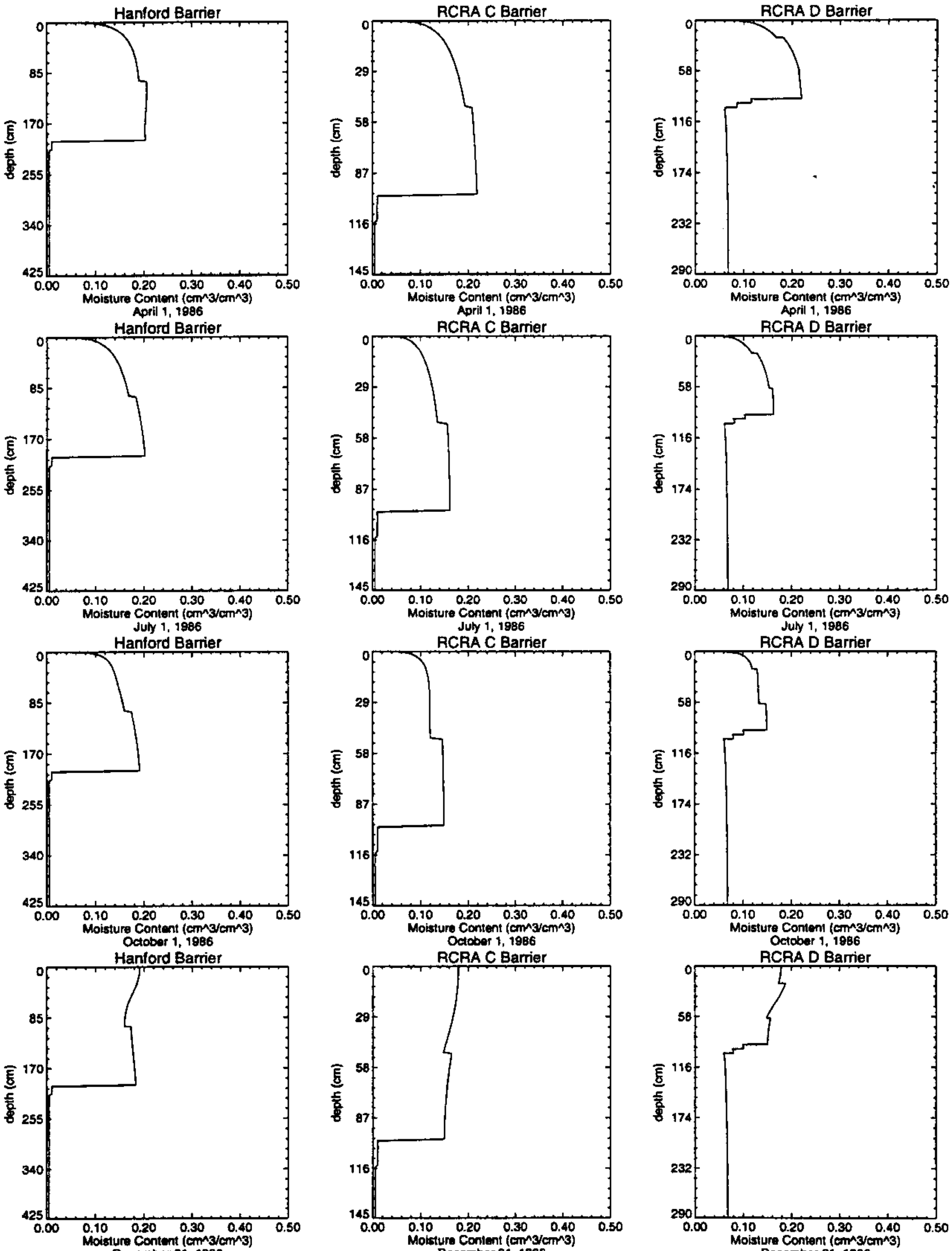

Figure 12. Hanford, RCRA C, and RCRA D ambient precipitation moisture content profiles.

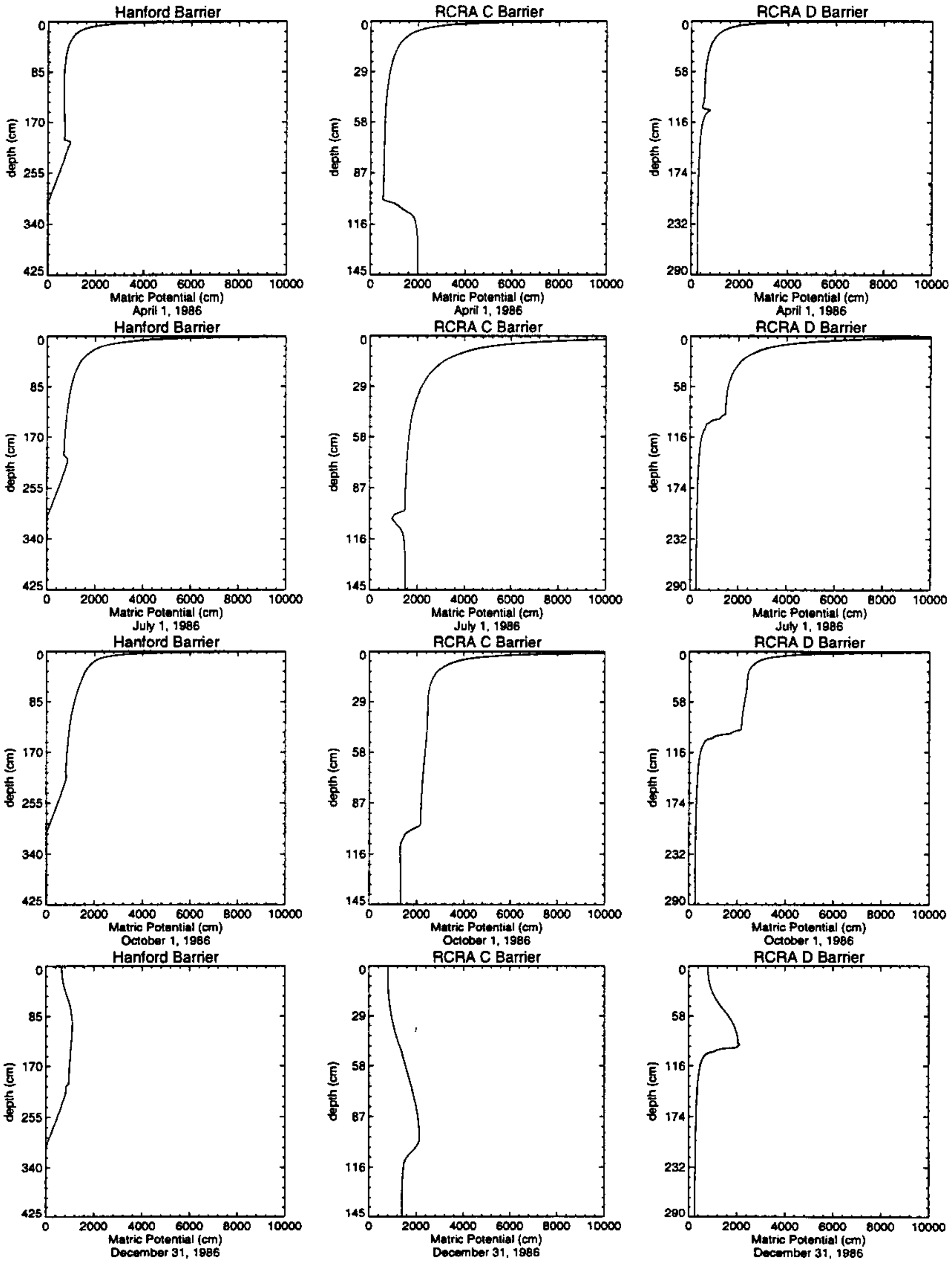

Figure 13. Hanford, RCRA C, and RCRA D ambient precipitation matric potential profiles.

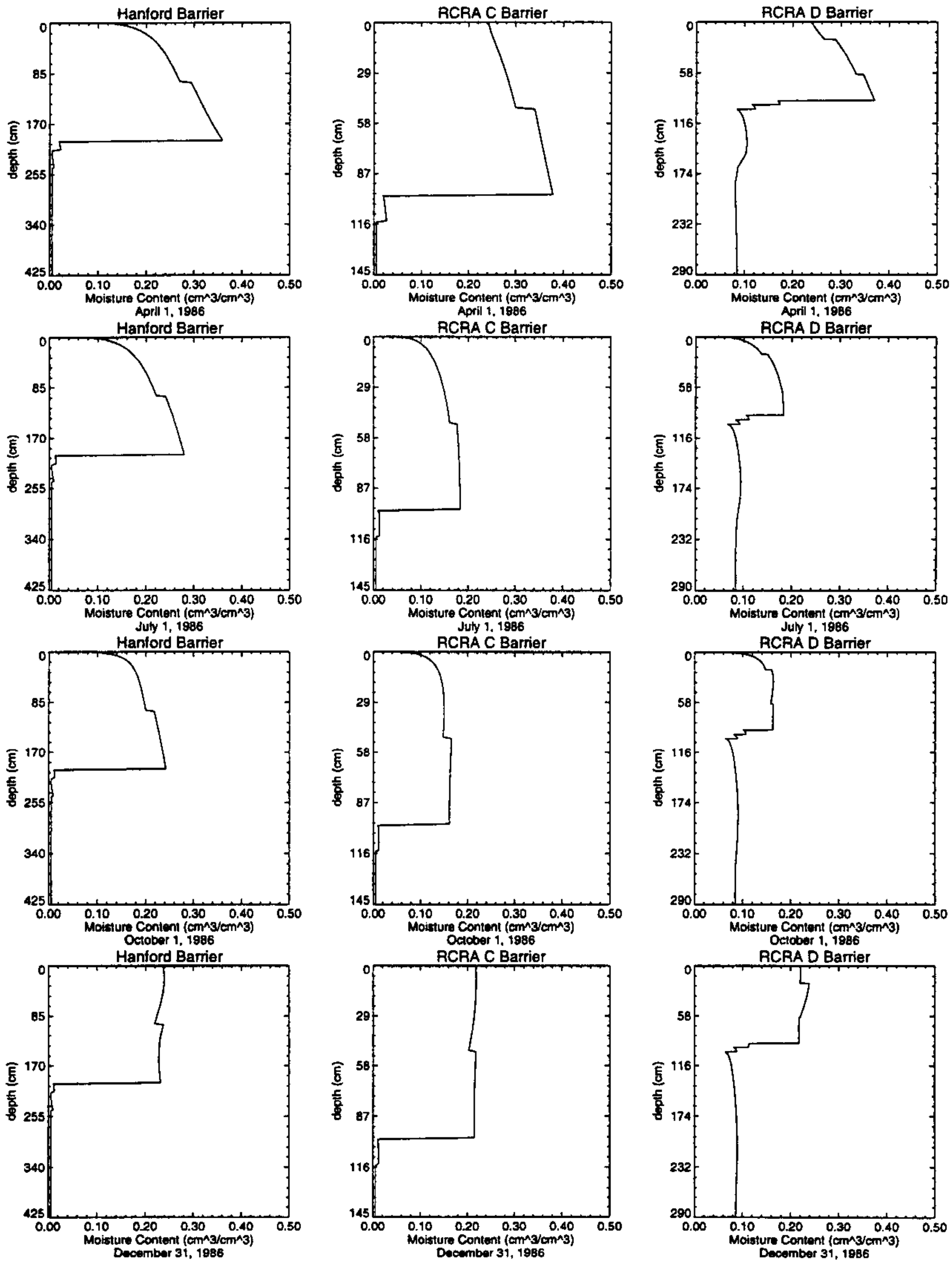

Figure 14. Hanford, RCRA C, and RCRA D 2x ambient moisture content profiles.

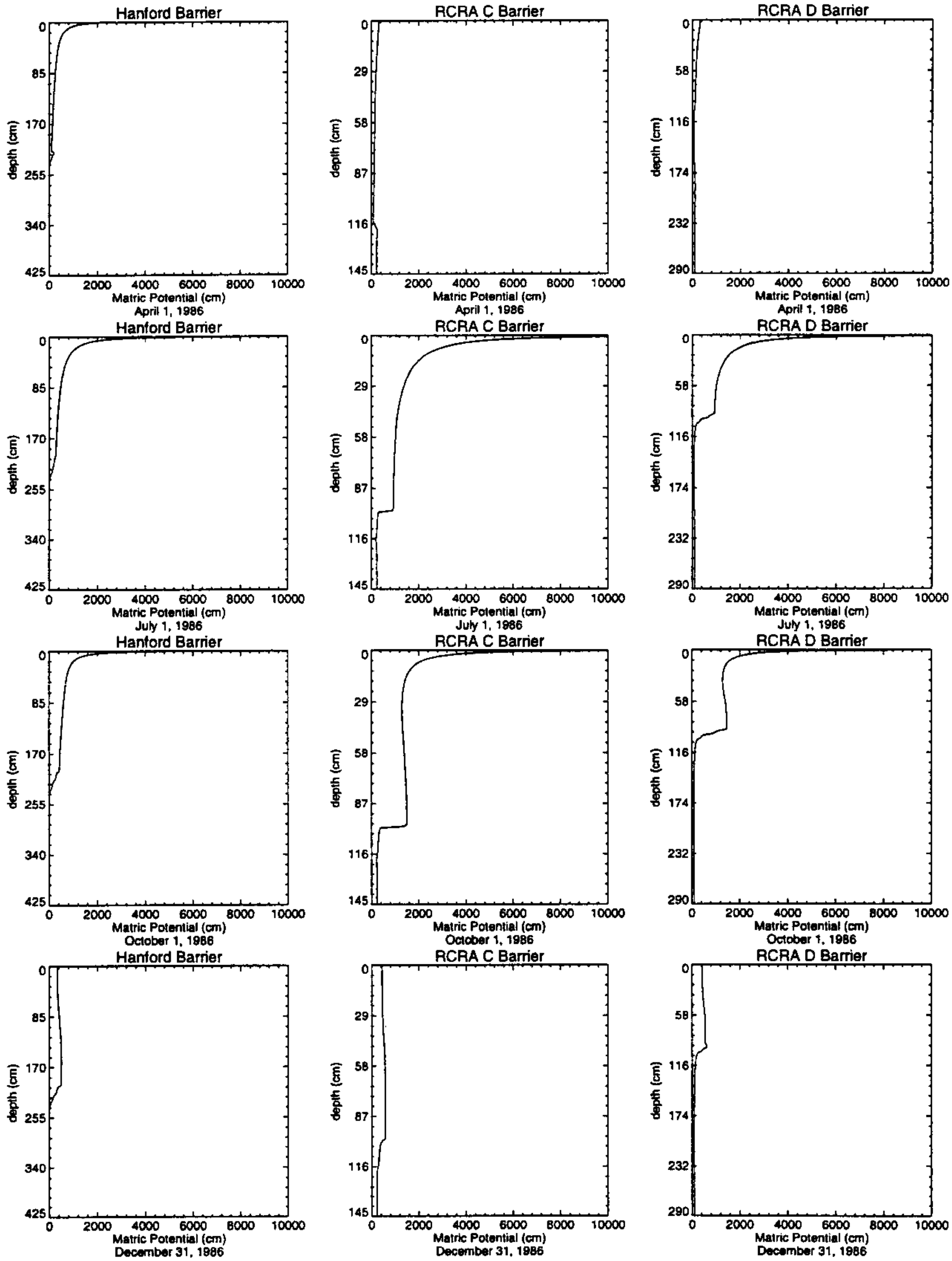

Figure 15. Hanford, RCRA C, and RCRA D 2x ambient matric potential profiles.

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}

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.

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.

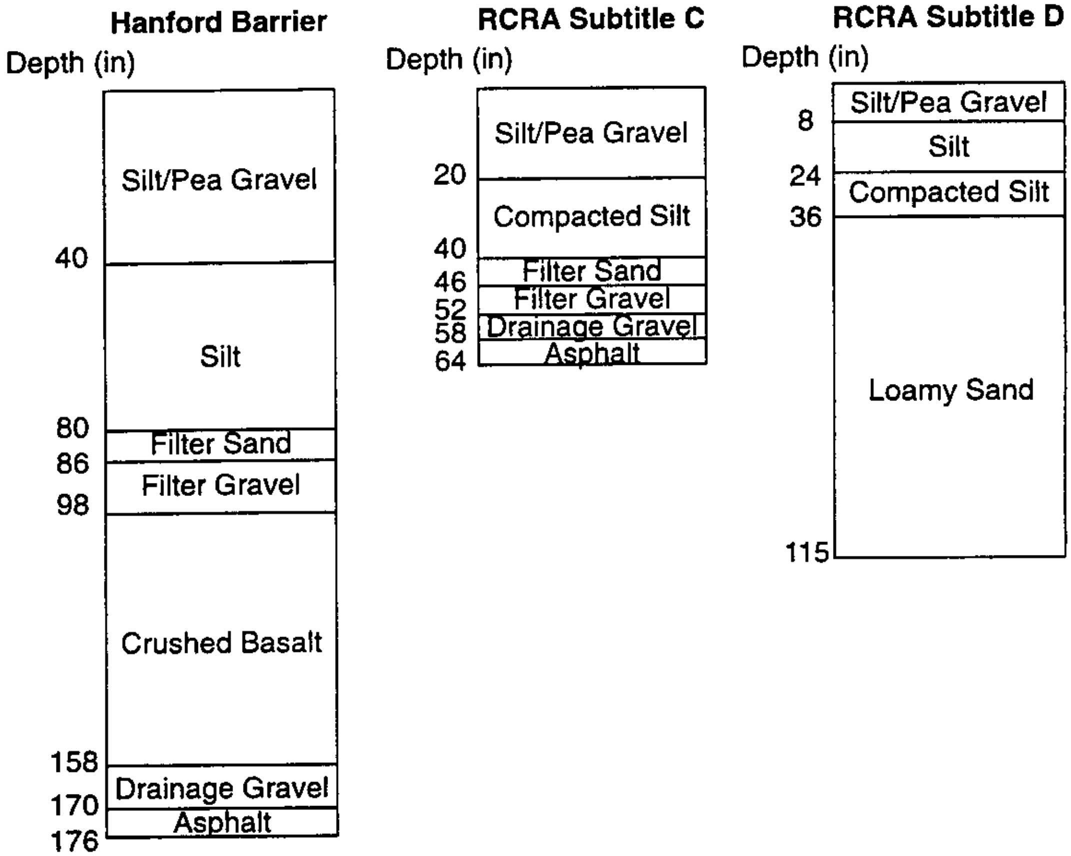

Figure 16. Barrier profiles for the HELP simulations.

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 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

$$\frac{dh}{dl} = \frac{TH + TS}{TS}, \tag{19}$$

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.

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 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.

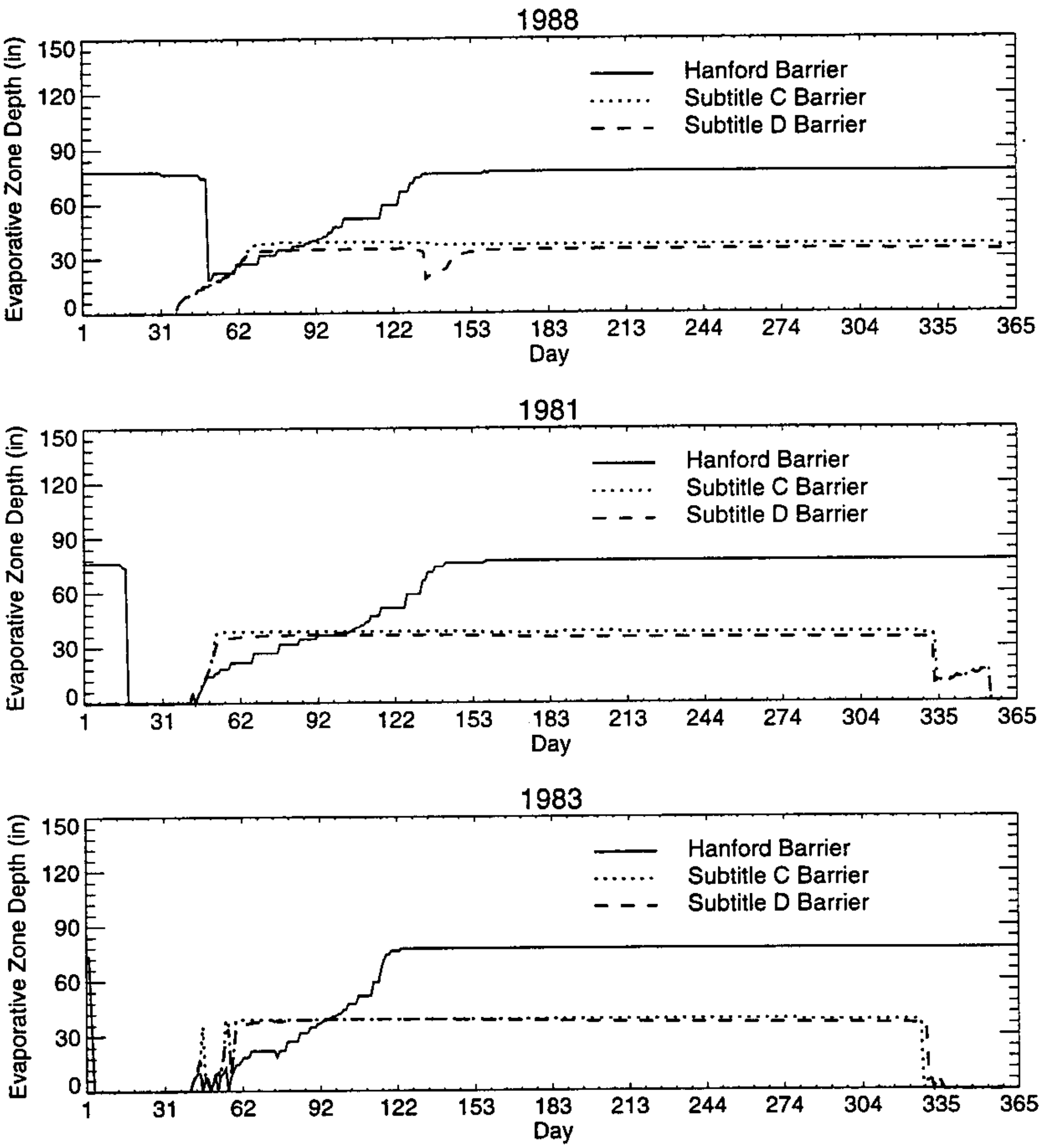

Figure 17. Evaporative zone depths from UNSAT-H barrier simulations.

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.

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Appendix A
UNSAT-H Input Data Decks

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
```

```
  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
```

```
    .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
```

```
  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
```

```
  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
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   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
```

Appendix B
HELP Input Data Decks

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
```

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

CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX D

SAMPLE CALCULATIONS OF WIND AND WATER EROSION FOR ENGINEERED SURFACE BARRIERS

1.0 INTRODUCTION

Three different barrier designs are proposed in this Focused Feasibility Study for environmental restoration applications in the 200 Areas. The three designs employ a common top layer design treatment consisting of silt loam topsoil material containing a 15 wt. percent admixture of pea gravel, constructed with a slope angle of 2 percent, 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 for mitigating 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 are useful for evaluating soil loss potential from surfaces made up of fine-textured soils such as McGee Ranch silt loam, the proposed topsoil material. 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 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 the State of Washington 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 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 percent.

The I factor is dependant 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 percent 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 percent surface slope yields an I value of about 40. If the surface slope of the barrier is increased by just 1 percent, 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 500 ft is assumed. Unbroken slope lengths much larger than 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 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 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 200 pounds in unfavorable years to 500 pounds in favorable years (USDA 1981), yielding a median value for V of 350 pounds of air-dry material. Based on data for crested wheatgrass in Table D-2, the flat small-grain equivalent quantity is roughly 1,100 pounds 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 500 ft, and V equals 4,000 lb per acre for the first year and then 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 continue to assist in reducing wind erosion for two to three years after placement, depending on actual weather conditions experienced during that time span.

For a 3 percent slope angle and the same 500-ft slope length, for which I equals 48, and K, C, and V defined as above, predicted wind erosion would average between about 2.0 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 dependant 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 (500 pounds 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, p. 40-1):

$$A = RKLSCP$$

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 percent
- Estimated percent sand (coarser than 0.1 mm): 18 percent
- Estimated percent silt and sand finer than 0.1 mm: 77 percent
- Estimated percent clay: 5 percent
- Cover slope: 3 percent
- Slope length: 231.5 feet
- Cover vegetation: (first year) 2 tons of straw mulch crimped into the soil surface; (subsequent years) 60-80 percent 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).

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 percent slope angle and 500-ft slope length is about 0.32. (For a 3 percent slope angle and 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; p. 11). 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 percent grass cover will be attained over the cover area within a three- to five-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 percent 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 percent.

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. percent pea gravel admixture in the topsoil surface layer, actual losses should be significantly below these projections.

1.9 tons/acre/year = 3,800 lb/acre/year
3,800 lb/acre/year x 1 acre/43,560 ft^2 = 0.0872 lb/ft^2/year
0.0872 lb/ft^2/year / 86.3 lb/ft^3 = 0.00101 ft/year
0.00101 ft/year x 12 in./ft = 0.0121 in./year

For the Hanford Barrier (design life of 1,000 years):

0.0121 in./year x 1,000 years = 12.1 in. per 1,000 years

For the Modified RCRA Subtitle C Barrier (design life of 500 years):

0.0121 in./year x 500 years = 6.0 in. per 500 years

For the Modified RCRA Subtitle D Barrier (design life of 100 years):

0.0121 in./year x 500 years = 1.2 in. per 100 years

5.0 REFERENCES

EPA, 1979, *Design and Construction of Covers for Solid Waste Landfills*, EPA-600/2-79-165, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Ecology, 1987, *Solid Waste Landfill Design Manual*, by Parametrix, Inc., Bellevue, Washington, No. 87-13, for Washington State Department of Ecology, Olympia, Washington.

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Ligotke, M.W., and D.C. Klopfer, 1990, *Soil Erosion Rates from Mixed Soil and Gravel Surfaces in a Wind Tunnel,* PNL-7435, Pacific Northwest Laboratory, Richland, Washington.

Lyles, L., and B. E. Allison, 1980, "Range Grasses and Their Small Grain Equivalents for Wind Erosion Control," *Journal of Range Management*, Vol. 33, No. 2, March 1980, pp. 143-146.

USDA, 1981, *Technical Guide*, Section II.E.MLRA-B-7, U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

USDA, 1987, *General Manual*, Part 502, U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

2 Figure D-1. Knoll Adjustment (a) From Top of Knoll and
3 (b) From Upper Third of Slope (EPA 1979).

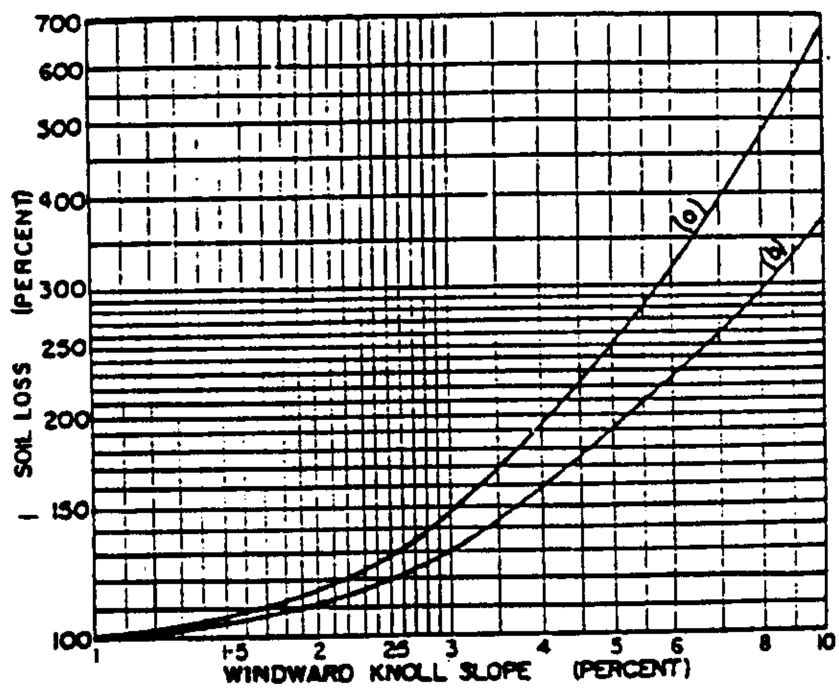
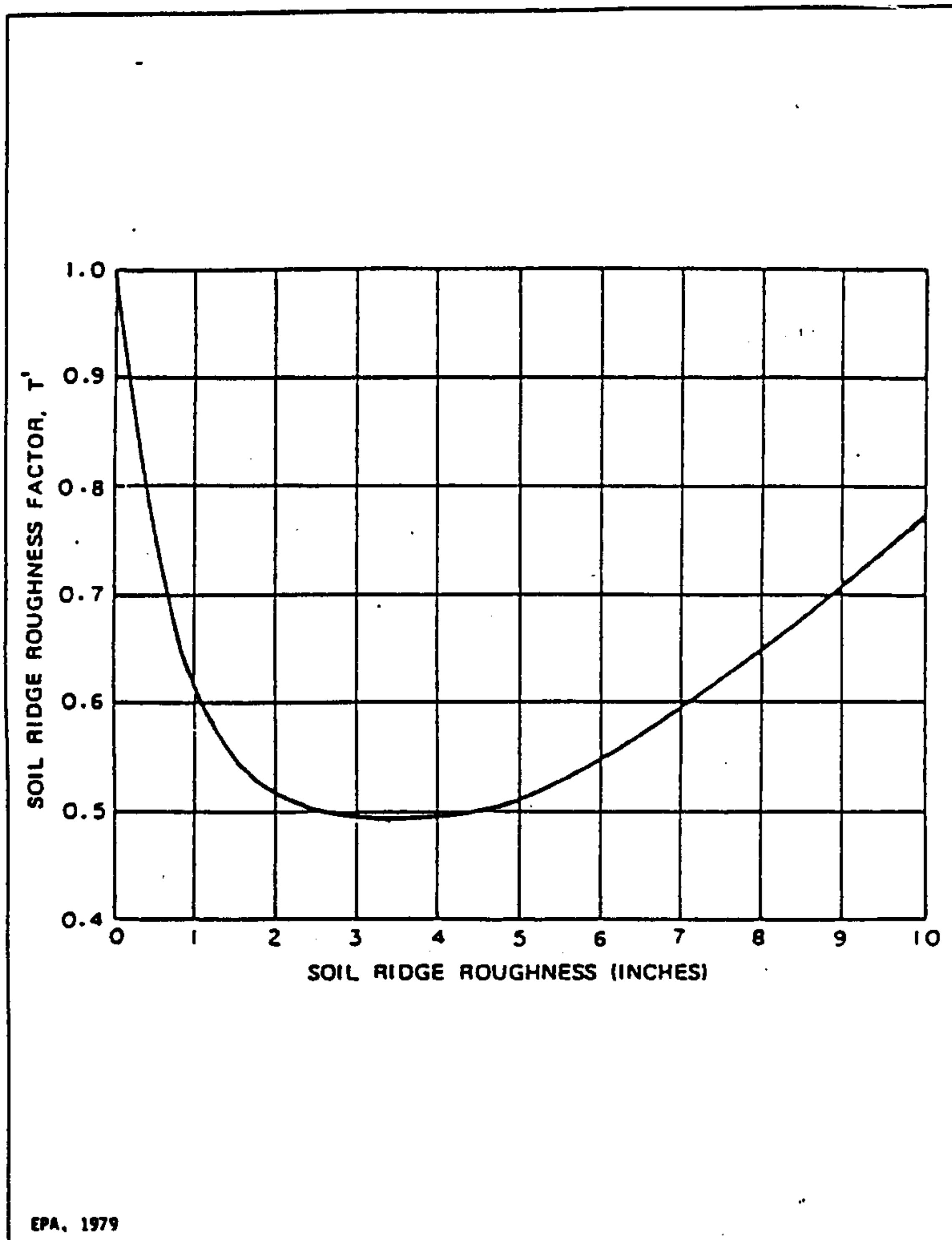


Figure D-2. Soil Ridge Roughness Factor K from
Actual Soil Ridge Roughness (EPA 1979).



883-1706/13715

Figure D-3. Annual Wind Erosion Climatic 'C' Factor in Percent (USDA 1987).

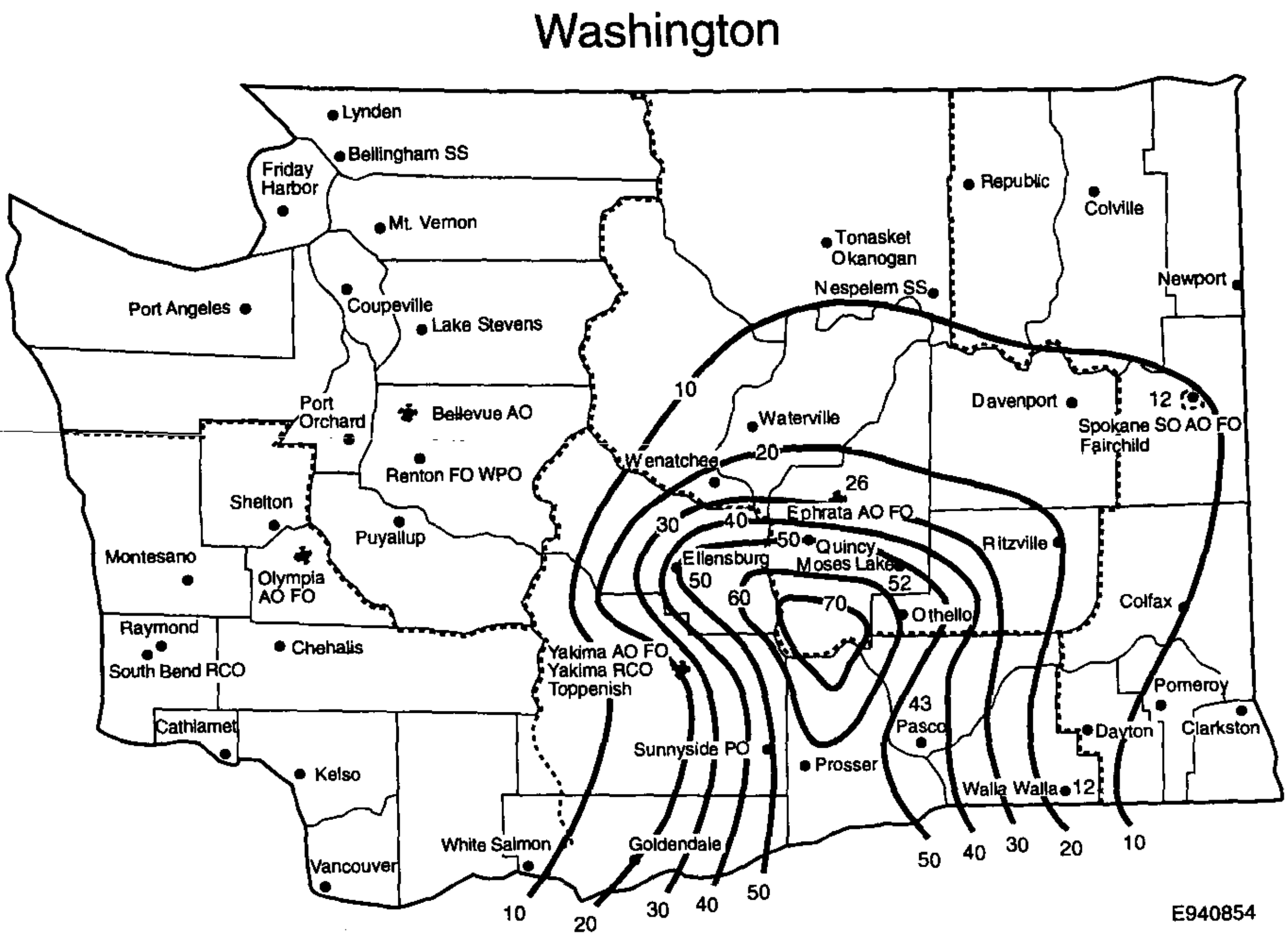


Figure D-4. Average Annual Values of Rainfall-Erosivity Factor R (EPA 1979).

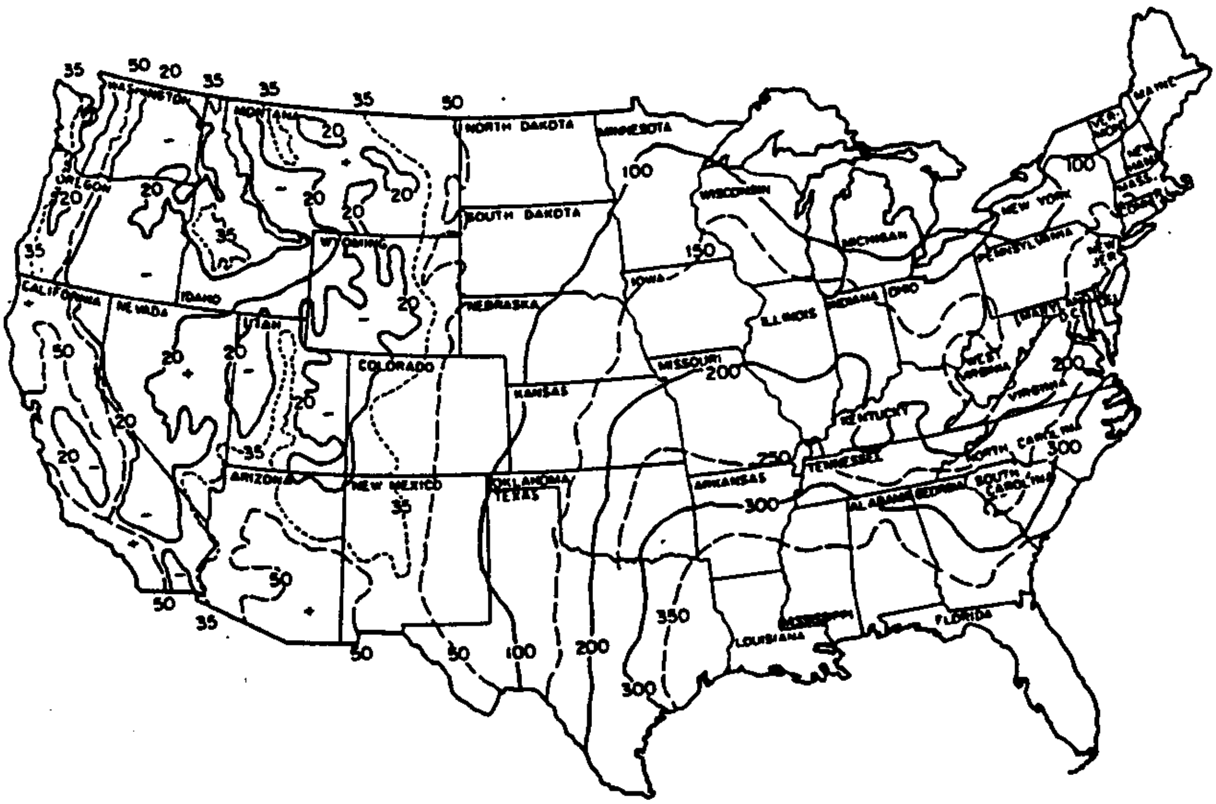


Figure D-5. Nomograph for Determining Soil Erodibility Factor K for U.S. Mainland (EPA 1979).

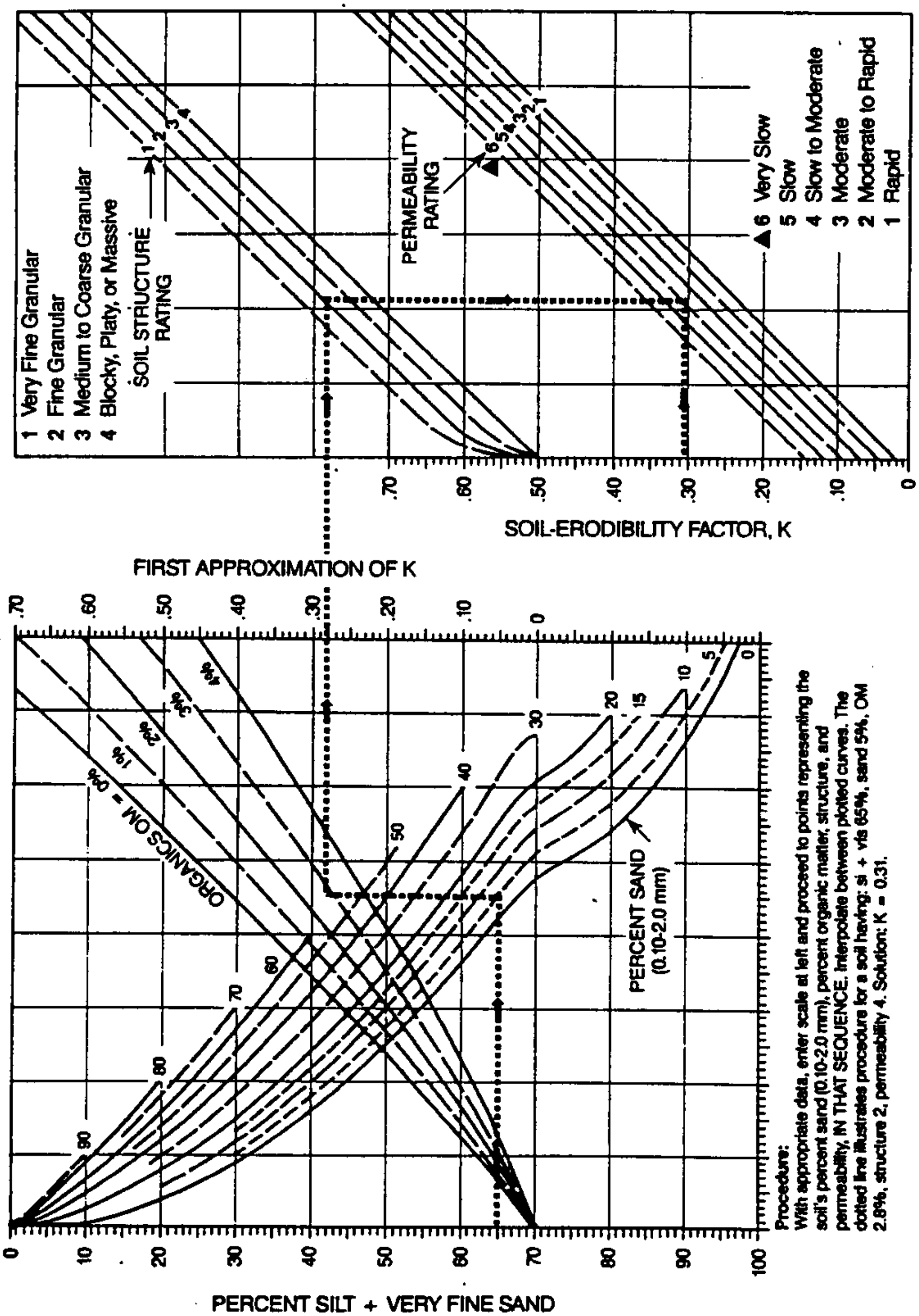


Figure D-6. Length-Slope Factor (LS) for Different Slopes (Ecology 1987).

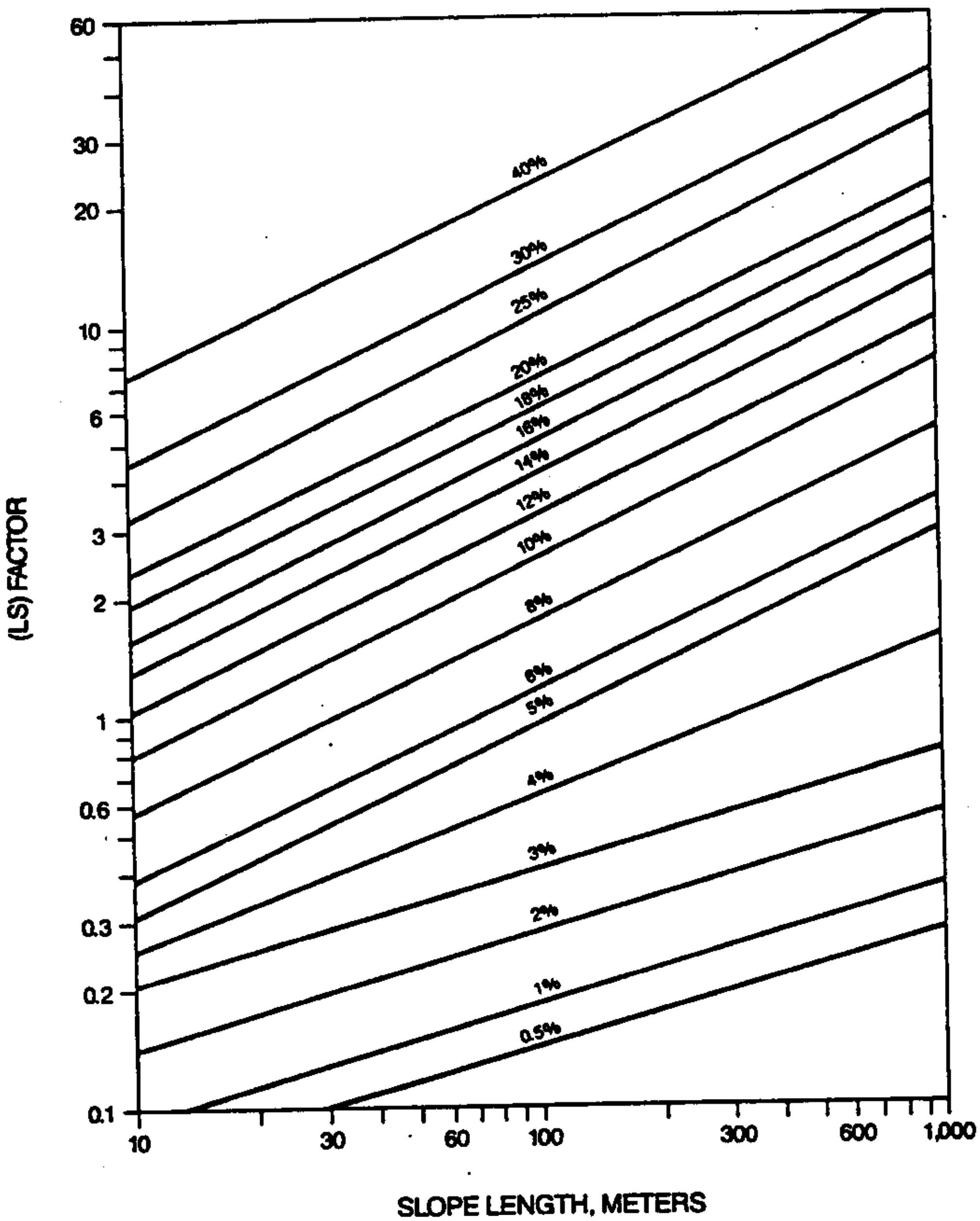


Table D-1. Soil-Wind Erodibility Index I (Israelsen et al. 1980).

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-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-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													

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

APPENDIX E

COST ESTIMATES

Appendix E presents cost estimates for each of the barrier designs: Section 1.0 and Table E-1 for the Hanford Barrier; Section 2.0 and Table E-2 for the Modified RCRA Subtitle C Barrier; and Section 3.0 and Table E-3 for the Modified RCRA Subtitle D Barrier.

1.0 HANFORD BARRIER COST ESTIMATE

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 $25,250 per test (per proposal), or a total of $50,500.

IMPROVEMENTS TO LAND

Site Grading, Compaction and Placement of Grading Fill: Construction will be performed by a qualified contractor. Costing is based on a site surface measuring approximately 415 ft (E-W) by 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 prior to 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 65,900 bank yd^3 of grading fill will be needed (corresponding to 79,000 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 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 sub-base 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 5,350 tons of material (corresponding to approximately 3,300 yd^3). These quantities were determined based on placing 4 in. of material over an area of $(530+48)(415+48) ft^2$ and a dry unit weight of 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 6 in. thick and will be placed over an area of $(530+48)(415+48)\ ft^2 = 267,600\ ft^2 = 29,700\ yd^2$. 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/sec. Material will be sourced from Pit 30 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 4 mi. Construction of the gravel drainage layer will require hauling and placing approximately 16,300 tons of material (corresponding to approximately 10,200 yd^3). These quantities were determined based on placing 12 in. of material over an area of $(530+56)(415+56)\ ft^2$; a material density of 0.70 ft^2 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 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 15-ft-wide perimeter access road bed for service vehicles at the crown. The maximum thickness of basalt, 13 ft + 2 in., will be beneath the access road. The coarse basalt layer will be a uniform 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 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 17 mi. It is estimated that barrier construction will require hauling and placing approximately 128,000 tons of material (corresponding to approximately 75,000 yd^3). These quantities were determined using a material density of 0.75 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 126.4 lb/ft^3.

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 11,300 tons of material (corresponding to approximately 7,100 yd^3). These quantities were determined based on placing 12 in. of material over an area of $(530-30)(415-30)\ ft^2$; a material density of 0.70 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to

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 required 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 5,600 tons of material (corresponding to approximately 3,600 yd^3). These quantities were determined based on placing 6 in. of material over an area of (530-30)(415-30) ft^2; a material density of 0.70 ft^3 solids per ft^3 volume and a specific gravity of 2.65, corresponding to 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 192,500 ft^2.

Place Lower Silt Layer: Silt loam soil will be sourced from the McGee Ranch site, which represents a 17-mi one-way haul. The layer will be 40 in. thick. Construction will require hauling and placing approximately 23,000 tons of material (corresponding to 19,700 yd^3). Quantities were computed based on the following dry unit weights -- bank unit weight of 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and placement at bank unit weight of 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 required 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 26,400 tons of material (corresponding to 21,700 yd^3). These quantities were determined based on placing material to a depth of 40 in. and the following dry unit weights -- bank unit weight of 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and placement to a unit weight of 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 1.5-in. material provided by a local commercial supplier. Construction will require hauling and placing approximately 1,700 tons of material (corresponding to approximately 1,000 yd^3). These quantities were determined based on placing 6 in. of material over an area of (415)(530)-(415-30)(530-30) = 27,450 ft^2 (i.e., a road width of 15 lineal feet); a material density of 0.75 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 126.4 lb/ft^3. A motor grader and a vibratory compactor will be used to spread, grade and compact the material.

2.0 MODIFIED RCRA SUBTITLE C BARRIER COST ESTIMATE

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 $50,500 (per proposal).

IMPROVEMENTS TO LAND

Site Grading, Compaction and Placement of Grading Fill: Construction will be performed by a qualified contractor. The site surface measures approximately 415 ft (E-W) by 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 prior to 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 56,600 bank yd^3 of grading fill will be needed (corresponding to 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 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 sub-base for barrier construction.

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 4,400 tons of material (corresponding to approximately 2,700 yd^3). These quantities were determined based on placing 4 in. of material over an area of (530)(415) ft^2; and a dry unit weight of 120 lb/ft^3. A track dozer will spread and grade the material. A vibratory compactor will be required 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 6 in. thick (nominally), and will be placed over an area of (530)(415) ft^2 = 220,000 ft^2 = 24,500 yd^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/sec. 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 4 mi. Construction of the gravel filter layer will require hauling and placing approximately 6,500 tons of material (corresponding to approximately 4,100 yd^3). These quantities were determined based on placing 6 in. of material over an area of (530)(415) ft^2; a material density of 0.70 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 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 4 ft + 8 in. thick. Mixed sand and gravel (pit run material from Pit 30) will be used as fill material. Approximately 4,400 yd^3 of fill will be required 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 1,000 yd^3. A track dozer will be used to spread and grade the material. A vibratory compactor will be required to support construction of this layer.

Placement of Gravel and Sand Filter Layers: Two 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 6,500 tons of material (corresponding to approximately 4,100 yd^3). These quantities were determined based on placing 6 in. of material over an area of (530)(415) ft^2; a material density of 0.70 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 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 required to support construction of this layer.

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 6,400 tons of material (corresponding to approximately 4,100 yd^3). These quantities were determined based on placing 6 in. of material over an area of (530)(415) ft^2; a material density of 0.70 ft^3 solids per ft^3 volume and a specific gravity of 2.65, corresponding to 115.8 lb/ft^3. A motor grader will spread and grade the material. A vibratory compactor will be required 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 17-mi one-way haul. Construction will require hauling, placing and compacting approximately (22,900-1,400) = 21,500 tons of material (corresponding to 13,600-800 = 12,800 yd^3). These quantities were determined based on placing and compacting material to a depth of 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 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and compacted unit weight of 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 required 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 of material (corresponding to 13,600-450 = 13,150 yd^3). These quantities were determined based on placing and compacting material to a depth of 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 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and compacted unit weight of 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 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 17 mi. Construction will require hauling and placing approximately 3,400 T of material (corresponding to approximately 2,000 yd^3). These quantities were determined based on placing 12 in. of material around a perimeter of 2(530+415) + 8(27)/2 = 1,998 lineal feet over a width of 27 lineal feet; a material density of 0.75 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 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.

3.0 MODIFIED RCRA SUBTITLE D BARRIER COST ESTIMATE

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.

IMPROVEMENTS TO LAND

Site Grading, Compaction and Placement of Grading Fill: Construction will be performed by a qualified subcontractor. Costing is based on a site surface measuring approximately 415 ft (E-W) by 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 prior to 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 56,600 bank yd^3 of grading fill will be needed (corresponding to 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 4 mi. Grading fill and existing site soils will be densified by making several passes with a vibratory compactor to create a suitable sub-base for barrier construction.

Placement of Compacted (Lower) Silt Layer: The silt loam soil will be sourced from the McGee Ranch site, which represents a 17-mi one-way haul. Construction will require hauling, placing and compacting approximately 8,100 yd^3 or 13,700 tons of material. These quantities were determined based on placing and compacting material to a depth of 12 in. over an area of (530)(415) ft^2 and the following dry unit weights -- bank unit weight of 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and compacted unit weight of 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 required to support construction.

Placement of Uncompacted (Middle) Silt Layer: The silt soil will be sourced from the McGee Ranch site. The middle silt layer will be 16 in. thick. Construction will require hauling and placing approximately 12,700 tons of material (corresponding to 10,900 yd^3). Quantities were computed based on the area and layer thickness and the following dry unit weights -- bank unit weight of 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and placement at bank unit weight of 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 required 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 6,600 tons of material (corresponding to 5,400 yd^3). These quantities were determined based on placing material to a depth of 8 in., the area defined previouslyand the following dry unit weights -- bank unit weight of 86.5 lb/ft^3, loose unit weight loaded on haul trucks of 72.1 lb/ft^3 (assumes 20% swell), and placement to a unit weight of 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 providesufficient compaction; no additional compaction equipment will be required).

Placement of Coarse, Fractured Basalt Surfacing Material on Perimeter Berm: The fractured basalt will be minus 12-in. material sourced from the existing quarry overlooking Vernita Bridge. The one-way haul will be approximately 17 mi. Construction will require hauling and placing approximately 3,400 tons of material (corresponding to approximately 2,000 yd^3). These quantities were determined based on placing 12 in. of material around a perimeter of
$2(530 + 415) + 8(27)/2 = 1,998$ lineal feet over a width of 27 lineal feet; a material density of 0.75 ft^3 solids per ft^3 volume and a specific gravity of 2.70, corresponding to 126.4 lb/ft^3. A track dozer will be used to spread and grade the material. Compacting equipment will not be required.

Table E-1. Hanford Barrier Conceptual Cost Estimate. (sheet 1 of 2)

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
SRDI Test on Asphalt Layer (Technical Services)					
Subtotal	50,500	0	50,500	7,575	58,075
TOTALS	800,500	0	800,500	120,075	920,575
Site Grading, Compaction & Fill					
- Load, haul & dump soil from pit 30, 8 mile round trip using 5 dump trucks @ 12 CY each, and one 4 CY loader.	359,312				
- 65,900 CY plus 20% swell = 79,000 CY to haul. Ten man crew will average 816 CY per day for 97 days (20 week job).	0				
- Spread soil and level with dozer/grader.	79,040				
- Compact site with vibratory roller, 415 ft x 530 ft area 6" lifts, 2 passes.	20,441				
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, 4" deep.	3,307				
- Compact with vibratory roller, 2 passes.	1,288				
- Sales Tax at 7.8%	3,860				
- OH&P (on markups only)	579				
Subtotal	65,945	9,232	75,177	11,277	86,454
Placement of Asphalt					
- 6" 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
Placement of Gravel Drainage Layer					
- Load trucks with screened run-of-pit gravel.	76,245				
- Haul and dump gravel at site, assume 8 miles round trip	31,416				
- Spread and level gravel with dozer/grader, 6" 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

Table E-1. Hanford Barrier Conceptual Cost Estimate. (sheet 2 of 2)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Crushed Basalt Layer/Side Slopes					
- Load, haul and spread 8 to 12 inch crushed basalt. Existing quarry is 17 miles 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 8 mile round trip.	21,868				
- Spread and level gravel with dozer/grader, 6" 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 8 mile round trip.	11,088				
- Spread and level sand with dozer/grader, 6" layer.	3,613				
- Compact sand with vibratory roller, 2 passes.	932				
- Place geotextile fabric, cost assumes polypropylene mesh, stapled, 6.5 oz/sy.	44,281				
- Sales Tax @ 7.8%					
- OH&P (on markups only)	9,035				
	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, 36 mile round trip	151,562				
	103,981				
- Spread and Static Compact to 40" depth using dozer/grader and water truck for dust control					
Subtotal	255,543	35,776	291,319	43,698	335,017
Placement of Silt/Pea Gravel Admix					
- Load, haul, and dump McGee Ranch silt at pit 30, 26 miles round trip.	141,959				
- Mix above silt with 3250 CY of local sourced pea gravel, load haul 4 miles, and dump.	146,324				
- Spread mix and level to depth of 40".	21,705				
- Sales Tax @ 7.8%	3,385				
- OH&P (on markups only)	338				
Subtotal	313,711	43,920	357,631	53,645	411,276
Base for Perimeter Access Road					
- Base course material, 1-1/2" minus, delivered to site.	18,084				
- Spread gravel and level with dozer/grader, 6" deep.	1,001				
- Compact with vibratory roller, 2 passes.	403				
- Sales Tax @ 7.8%	1,226				
- OH&P (on markups only)	183				
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	5,828,296	718,892	6,547,188	982,080	7,529,268

Table E-2. Modified RCRA Subtitle C Barrier Conceptual Cost Estimate. (sheet 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
SRDI Test on Asphalt Layer (Technical Services)					
Subtotal	50,500	0	50,500	7,575	58,075
TOTALS	413,500	0	413,500	62,025	475,525
Site Grading, Compaction & Fill					
- Load, haul & dump soil from pit 30, 8 mile round trip using 5 dump trucks @ 12 CY each, and one 4 CY loader.	308,821				
- 56,600 CY plus 20% swell = 67,900 CY to haul. Ten man crew will average 816 CY per day for 85 days (17 week job).	0				
- Spread soil and level with dozer/grader.	67,922				
- Compact site with vibratory roller, 415 ft x 530 ft area 6" lifts, 2 passes.	17,584				
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, 4" 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					
- 6" polymer-modified asphalt. (Per Don @ 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
Placement of Gravel Drainage Layer					
- Load trucks with screened run-of-pit gravel.	30,648				
- Haul and dump gravel at site, assume 8 miles round trip.	12,628				
- Spread and level gravel with dozer/grader, 6" layer.	4,114				
- Compact gravel with vibratory roller, 2 passes.	1,075				
- Sales Tax @ 7.8%	2,078				
- OH&P (on markups only)	311				

Table E-2. Modified RCRA Subtitle C Barrier Conceptual Cost Estimate. (sheet 2 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Subtotal	50,854	7,120	57,974	8,696	66,670
Placement of Side-Slope Fill					
- Load, haul & 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, 6" lifts, 2 passes.	2,277				
Placement of Fill to Support Graded Filter Layer					
- Load, haul & dump pit run sand and gravel mix from pit 30.	4,548				
- Spread material along perimeter of the covered area at 2 to 1 slope with dozer/grader.	2,001				
- Compact berm with vibratory roller, 6" lifts, 2 passes.	518				
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 8 mile round trip.	12,628				
- Spread and level gravel with dozer/grader, 6" 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 8 mile round trip.	12,628				
- Spread and level sand with dozer/grader, 6" layer.	4,114				
- Compact sand with vibratory roller, 2 passes.	1,075				
- Sales Tax @ 7.8%	5,324				
- OH&P (on markups only)	798				
Subtotal	120,261	16,837	137,098	20,565	157,663
Placement of Compacted Silt					
- Load, haul and dump McGee Ranch silt, 36 mile round trip	98,477				
- Spread and Static Compact to 20" 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, 26 miles round trip.	86,025				
- Mix above silt with 1980 CY of local sourced pea gravel, load haul 4 miles, and dump.	88,673				
- Spread mix and level to depth of 20"	13,146				
- Sales Tax @ 7.8%	2,051				
- OH&P (on markups only)	205				

Table E-2. Modified RCRA Subtitle C Barrier Conceptual Cost Estimate. (sheet 3 of 3)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Subtotal	190,100	26,614	216,714	32,507	249,221
Placement of Coarse, Fractured Basalt on Perimeter Berm	50,744				
- Load, haul and spread 12" layer of 12" minus crushed basalt around perimeter berm. Existing quarry is 17 miles from site.					
- Sales Tax @ 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	2,828,962	353,166	3,182,128	477,321	3,659,449

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Table E-3. Modified RCRA Subtitle D Barrier Conceptual Cost Estimate. (sheet 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 & Fill					
- Load, haul & dump soil from pit 30, 8 mile round trip using 5 dump trucks @ 12 CY each, and one 4 CY loader.	308,821				
- 56,600 CY plus 20% swell = 67,900 CY to haul. Ten man crew will average 816 CY per day for 85 days (17 week job).	0				
- Spread soil and level with dozer/grader.	67,922				
- Compact site with vibratory roller, 415 ft x 530 ft area 6" lifts, 2 passes.	17,584				
Subtotal	394,327	70,206	464,533	69,680	534,213
Placement of Lower Silt Layer					
- Load, haul & dump McGee Ranch silt, 36 mile round trip. 8,1500 CY + 20% swell.	75,254				
- Spread & compact to 12" depth in 2 lifts, using dozer/grader, roller & water truck.	53,041				
Subtotal	128,295	17,961	146,256	21,938	168,194
Placement of Middle Silt Layer					
- Load, haul & dump McGee Ranch silt, 36 mile round trip. 10,900 CY + 20% swell.	100,642				
- Spread to depth of 16" with dozer/grader; use water as necessary for dust control.	69,029				
Subtotal	169,671	23,754	193,425	29,014	222,439
Placement of Silt/Pea Gravel Admix					
- Load, haul, & dump McGee Ranch silt at pit 30, 26 miles round trip. 85% x 5,400 CY + 20% swell.	42,366				
- Mix above silt with 810 CY of local sourced pea gravel, load, haul 4 miles, and dump. 5,400 CY x 15% = 810	42,594				
- Spread mix and level to depth of 8".	6,318				
- Sales Tax @ 7.8%	985				
- OH&P (on markups only)	98				
Subtotal	92,363	12,931	105,294	15,794	121,088

Table E-3. Modified RCRA Subtitle D Barrier Conceptual Cost Estimate. (sheet 2 of 2)

COST ITEMS	Estimated	Indirect	Subtotal	15% Cont.	Total
Placement of Coarse, Fractured Basalt on Perimeter Berm - Load, haul and spread 12 inch layer of 12" minus crushed basalt around perimeter berm. Existing quarry is 17 miles from site. - Sales Tax @ 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