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# HANFORD SITE PERMANENT ISOLATION SURFACE BARRIER DEVELOPMENT PROGRAM: FISCAL YEAR 1992 and 1993 HIGHLIGHTS


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MASTER

## EXECUTIVE SUMMARY

The Hanford Site Permanent Isolation Surface Barrier Development Program was jointly developed by the Pacific Northwest Laboratory and Westinghouse Hanford Company to design and test an earthen cover system that can be used to inhibit water infiltration; plant, animal, and human intrusion; and wind and water erosion. Kaiser Engineers Hanford Company provided engineering design support for the program. Work on barrier design has been under way at Hanford for nearly 10 years. The comprehensive development of a long-term barrier, formerly the Hanford Site Protective Barrier Development Program, was initiated in FY 1986, and a general field-tested design is expected to be completed by FY 1998.

Highlights of efforts in FY 1992 and FY 1993 included the resumption of field testing, the completion of the prototype barrier design, and the convening of an external peer review panel, which met twice with the barrier development team. The review panel provided helpful guidance on current and future barrier development activities, while commending the program for its significant technical contributions to innovative barrier technology development. A Value Engineering (VE) workshop was also convened to focus barrier development efforts into a comprehensive, yet streamlined, plan that will bring the program to a successful closure. Stakeholders in barrier technology participated in the VE workshop.

To date, research findings support the initial concepts of barrier design for the Hanford Site. A fine-soil surface is planned to partition surface water into runoff and temporary storage. Transpiration by vegetation and evaporation will return stored water to the atmosphere. A capillary break created by the interface of the fine-soil layer and coarser textured materials below will further limit the downward migration of surface water, making it available over a longer period of time for cycling to the atmosphere. Should water pass the interface, it will drain laterally through a coarse-textured sand/gravel layer. Tested barrier designs appear to work adequately to prevent drainage under current and postulated wetter-climate conditions.

Animal intrusion studies focused on the effect of large and small animal burrows on potential increases in soil water. Small animal burrows had no effect on soil water storage. Large animal burrows had a small effect, which disappeared after a short period of time because of increased soil evaporation and transpiration of plants established in the nearby disturbed soils.

The prototype vegetation establishment sub-task concluded that plants from the McGee Ranch (*Artemisia tridentata, Sitanion hystrix, Poa sandbergii*) should be transplanted and seeded onto the barrier surface. Root studies found the maximum depth of the majority of cheatgrass roots to be 60 cm, while the deeper-rooted perennial shrubs naturally growing on the soils to be used for the barrier surface extend to a depth of at least 210 cm.

Water infiltration control is a key component in barrier design. Results from the Field Lysimeter Test Facility experiments indicate that a surface layer of fine soil with deep-rooted vegetation precludes drainage even with three times normal precipitation, while drainage consistently occurs when soils are coarse textured, even with vegetation present. Asphalt was tested as a redundant layer for the prevention of drainage and as a diversion layer. Lysimeter results indicate no leakage and that asphalt meets the infiltration requirement of 0.05 cm/yr. There was no drainage for similar tests using clay and chemical grout. The Small Tube Lysimeter Facility experiment demonstrated that vegetated lysimeters prevent drainage while some of the gravel- and sand-covered lysimeters have drained. Simulation studies of storage dynamics of the Field Lysimeter Test Facility lysimeters revealed significant discrepancies when longer time series were simulated using parameters settings that worked for a shorter time series. Efforts are under way to ascertain the cause of the underpredictions. Other simulation models were successfully used to predict the shorter time series.

Erosion studies have provided insight into improved barrier design. Wind erosion studies have been conducted to assess the effects of surface conditions on deflation and saltating sand on surface deflation. The optimum armor is pea gravel, which protected the surface even under extreme erosive conditions. Water erosion studies concluded that the presence of vegetation greatly reduced erosion.

Analog studies at McGee Ranch revealed a significant relationship between soil water storage and the proximity of plants. Results of the gravel admix study indicate that after 5 years, vegetative cover doubled and was not affected by the admix surfaces. In addition, admix surfaces developed a significant surface gravel armoring. Analyses of ancient mounds suggest that the threat of human intrusion is significant, and that human intrusion issues must be considered when remediating waste sites. Analysis of long-term climate change effects indicates that warmer and dryer periods occurred 6000 to 8000 years ago, which potentially could have significant effects on barrier stability and performance.

The completion of FY 1992 and FY 1993 marks a transition point for the program: one in which the functional principles, upon which the permanent isolation barrier design is based, have been shown through laboratory and small-scale field tests to be technically sound. The full-scale performance issue and the need to demonstrate long-term durability of the design barrier remain as program goals to assure technical suitability, public confidence, and regulatory acceptance of the barrier for the permanent isolation of hazardous and nuclear contaminants.

## ACKNOWLEDGMENT

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# CONTENTS

## FIGURES

# 1.0 INTRODUCTION

The exhumation and treatment of wastes may not always be the preferred alternative in the remediation of a waste site. In-place disposal alternatives, under certain circumstances, may be the most desirable alternative to use in the protection of human health and the environment. The implementation of an in-place disposal alternative will likely require some type of protective covering that will provide long-term isolation of the wastes from the accessible environment. Even if the wastes are exhumed and treated, a long-term barrier may still be needed to adequately dispose of the treated wastes or any remaining waste residuals. Currently, no "proven" long-term barrier is available. The Hanford Site Permanent Isolation Surface Barrier Development Program (BDP) was organized to develop the technology needed to provide a long-term surface barrier capability for the Hanford Site. The permanent isolation surface barrier technology also could be used at other sites.

Permanent isolation barriers are being developed to isolate wastes disposed of near the earth's surface at the Hanford Site in southeastern Washington. Permanent isolation barriers use engineered layers of natural materials to create an integrated structure with redundant protective features. The natural construction materials (e.g., fine soil, sand, gravel, riprap, and asphalt) have been selected to optimize barrier performance and longevity. The objective of current designs is to use natural materials to develop a permanent isolation barrier that isolates wastes for a minimum of 1000 years by limiting water drainage; reducing the likelihood of plant, animal, and human intrusion; and minimizing erosion-related problems. The development of permanent isolation barriers is a joint effort being conducted by Westinghouse Hanford Company (WHC) and the Pacific Northwest Laboratory (PNL). Kaiser Engineers Hanford Company (KEH) has provided engineering support for numerous projects associated with the BDP. The bulk of funding for the development of permanent isolation barriers is being provided by the Department of Energy's Environmental Restoration Program. Carryover funding was provided in FY 1993 by the Underground Storage Tank - Integrated Demonstration.

## Functional Performance of Permanent Isolation Barriers

Permanent isolation barriers consist of a variety of materials placed in layers to form an above-grade mound directly over a waste zone. A typical permanent isolation barrier, illustrated in Figure 1.1, consists of (from top to bottom) a fine-soil layer, a sand/fine-gravel layer, and a layer of coarse materials such as pitrun gravel or crushed basalt riprap. A layer of crushed basalt riprap also may be used on the shoulder, side slopes, and toe of the structure. Each layer serves a distinct purpose (Figure 1.2).

The fine-soil layer acts as a medium in which moisture can be stored until the processes of evaporation and transpiration can recycle excess water back into the atmosphere. This layer also provides the medium for establishing plants, which are necessary for transpiration to take place. Gravel may be admixed into or spread onto the surface of the fine-soil layer to minimize wind and water erosion. Engineering this surface with a slight slope or crown maximizes runoff and minimizes erosion. The sand/fine-gravel layer serves a dual purpose. First, the textural difference at the interface between the sand/fine-gravel layer and the fine-soil layer creates a capillary break. This capillary break inhibits the downward movement of moisture from the overlying unsaturated fine-soil layer past the interface. Second, the sand/fine-gravel layer acts as a filter to prevent fine soils from penetrating into the void spaces of the coarser materials below. Layers of low-permeability materials are being tested as redundant infiltration barriers. Should the fine-soil layer fail to capture and recycle precipitation back into the atmosphere, a low-permeability layer (or layers) would direct water away from the wastes. The low-permeability layer(s) would also function to check the upward movement of noxious gases from the waste zone.

Coarse materials such as pitrun gravel and crushed basalt riprap are used in the permanent isolation barrier as a deterrent for burrowing animals, deep-rooting plants, and human intruders. Crushed basalt riprap also may be used to provide wind and water erosion protection of the barrier shoulder, side slope, and toe.

Surface markers are being considered for placement around the periphery of the waste sites to inform future generations of the nature and hazards of the buried wastes. In addition, throughout the permanent isolation barrier, subsurface markers may be placed to warn any inadvertent human intruders of the dangers of the buried wastes.

Because of the need for the barrier to perform for a minimum of 1000 years without maintenance, natural construction materials have been selected to optimize barrier performance and longevity. Most of these natural

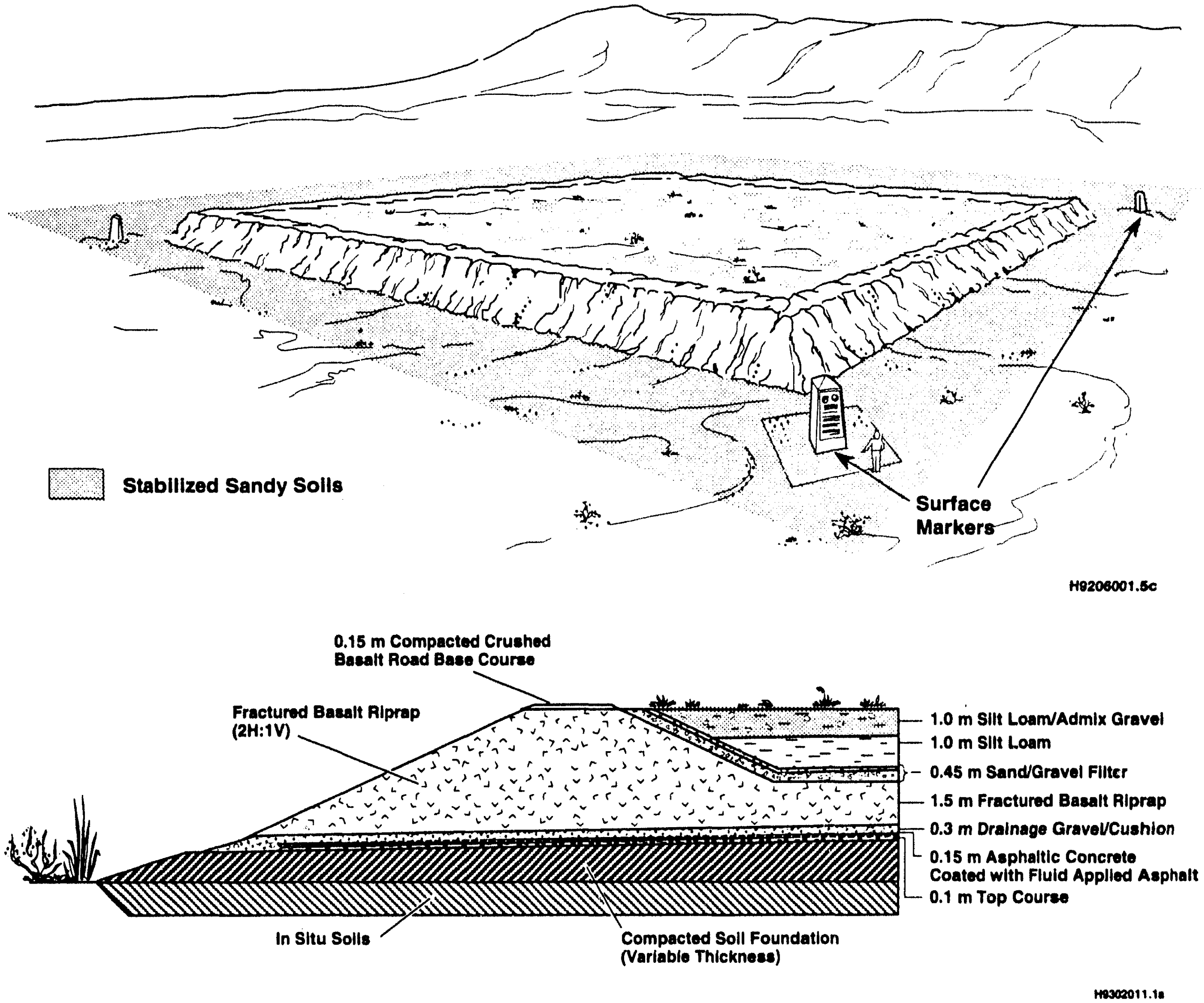


**Figure 1.1**. Typical Isolation Barrier

construction materials exist in large quantities on the Hanford Site. Manufactured construction materials cannot be relied on, because it is unknown if they can survive and function properly for the necessary period of time.

## Hanford Site Permanent Isolation Surface Barrier Development Team

Before implementing permanent isolation barriers in the final disposal of wastes at the Hanford Site, much development and evaluation work must be conducted to assess barrier performance. To accomplish this, engineers and scientists from Pacific Northwest Laboratory and Westinghouse Hanford Company formed the Hanford Site Permanent Isolation Surface Barrier Development Team in FY 1986. The team is responsible for planning and directing the barrier development activities.

Groups of tasks have been identified to resolve the technical concerns and complete the development and design of permanent isolation barriers (Figure 1.3).

Specific test plans and other detailed documents have been or are being prepared to plan, schedule, execute, and report on each of the technology development activities within these task groups. The results of activities performed will be used to develop detailed final barrier designs.

Section 2.0 of this document summarizes the tasks and activities, that were conducted during FY 1992 and FY 1993.

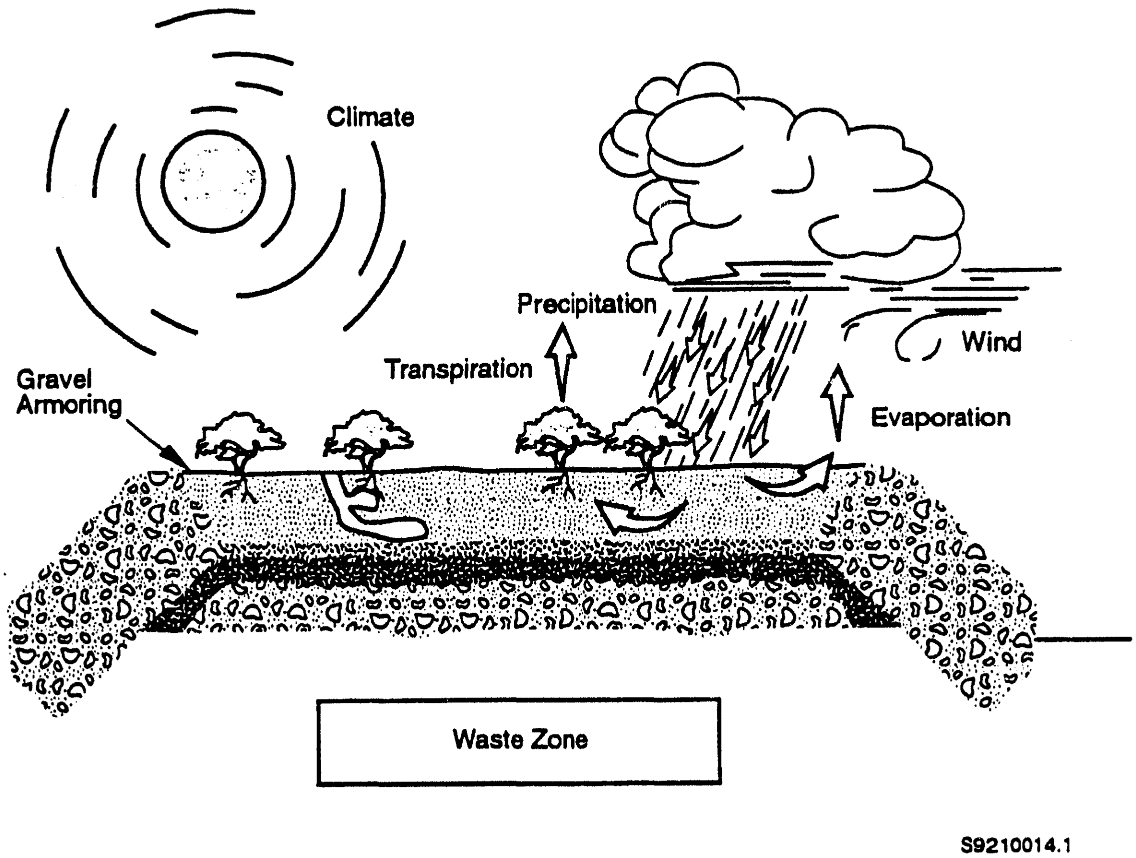


**Figure 1.2**. Functional Performance of Barriers

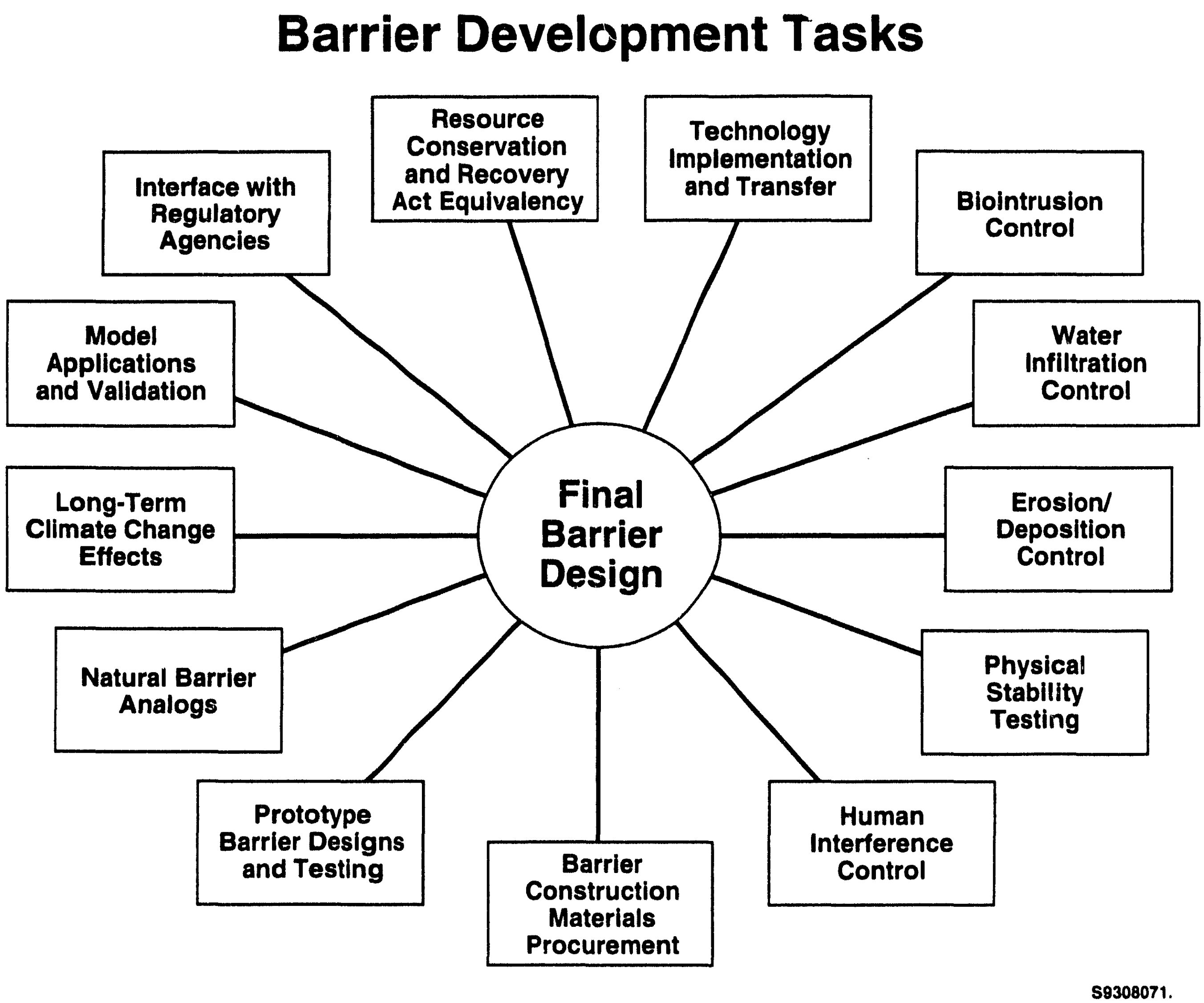


**Figure 1.3**. Barrier Development Task Groups

# 2.0 STATUS OF INDIVIDUAL TASKS

Permanent isolation surface barriers are being considered for use in the disposal of certain types of waste at the Hanford Site and elsewhere. The BDP has been designed to address the various technical issues associated with the performance of permanent isolation surface barriers. All of the tasks the BDP comprises have been designed to provide crucial information needed to address these technical issues.

This document provides a summary of the technical accomplishments of various barrier development tasks and activities that were conducted during FY 1992 and FY 1993. Specifically, highlights of the following tasks and activities will be provided: prototype barrier design, Value Engineering workshop, biointrusion control, water infiltration control, erosion/deposition control, model applications and testing, natural and manmade analogs, and long-term climate change effects.

## 2.1 PROTOTYPE PERMANENT ISOLATION SURFACE BARRIER

The design of permanent isolation barriers is an evolving process. Each year, as tasks are performed, new data and information are collected, valuable experience is acquired, and insights into the approaches for solving barrier design problems are gained. The data and insights gained from conducting barrier development tasks have enabled the BDP to progress to the point where the design and construction of a prototype is vital to continued barrier development. Although the results of development and testing efforts conducted heretofore are not final, and additional work needs to be performed, enough information and data exist to allow the design and construction of a prototype barrier. A full-scale prototype permanent isolation surface barrier will enable engineers and scientists to gain insights and experience with issues regarding barrier design, construction, and performance that have not been possible with individual tests and experiments that have been conducted to date.

The design, construction, and testing of a prototype barrier at this stage of the BDP is an important activity. The program, as currently structured, has been in existence since FY 1986. During this time, the emphasis of the program's efforts has been on the development and testing of various barrier components that are based on preliminary barrier conceptual designs. For the most part, these development and testing efforts have been performed either in the laboratory or on relatively small-scale field plots. Although not completely resolved, issues pertaining to protective barrier performance with respect to water infiltration; biointrusion; erosion and deposition; physical stability; and climate change are being addressed. Natural analog studies of various barrier components are also being conducted, and computer simulation models are being used to predict the performance of preliminary barrier conceptual designs.

The design of a prototype barrier enables engineers and scientists to use the data and insights collected to date from BDP field and laboratory tests. In addition, a prototype barrier will enable barrier development team members to obtain field experience in constructing protective barriers. Constructibility issues that were not readily apparent on the engineering drawings may be more easily detectable in the field. Another valuable benefit is that the constuction of prototype barriers forces all the various components of the barrier to be brought together into an integrated system. This integration is particularly important because some of the components of the protective barrier have been developed independently of other barrier components.

Once constructed, the prototype barrier will be tested and monitored to evaluate its performance over a range of conditions representative of those expected to be experienced during the design life of a permanent isolation surface barrier. A number of tests and experiments are planned to be conducted on the prototype barrier to assess its performance vis a vis water infiltration, biointrusion, erosion, and physical stability. Because only a finite amount of time exists to test a prototype barrier that is intended to function for at least 1000 years, the testing program has been designed to "stress" the prototype so that barrier performance can be determined within a reasonable time frame. Other BDP elements (e.g., natural analogs, long-term climate change, modeling, etc.) are part of the base program and provide data necessary to increase confidence in long-term barrier performance.

**Status of the Prototype Barrier**

The design of the prototype barrier at a site near the Hanford Meteorological Station (HMS) was initiated during FY 1990 but had to be terminated prior to completion because of funding constraints. Funding was restored during FY 1992, and the design of the prototype was completed in September 1992. Efforts during FY 1992 focused on 1) preparing a draft project management plan, 2) preparing a draft functions and requirements document, 3) preparing a draft design basis document, 4) preparing a draft prototype barrier testing and monitoring plan, 5) completing the appropriate level of National Environmental Policy Act (NEPA) documentation (for the prototype construction site and for the borrow pits from which construction materials would be obtained), 6) completing definitive design drawings, and 7) developing detailed construction specifications.

A Barrier Design Team (BDT) was assembled to lead the design of the prototype barrier. The BDT consisted of representatives from WHC, PNL, and KEH. The BDT met frequently with and received technical support from the Barrier Technical Advisory Board (BTAB)--a group of engineers and scientists on the barrier development team who represent the various areas of technical expertise in the BDP. Appendix A lists members of the BDT and the BTAB. Review comments and design suggestions from other barrier development team members also were solicited and incorporated as appropriate. Kaiser Engineers Hanford Company was responsible for transforming conceptual ideas from the BDT/BTAB into definitive, detailed construction drawings. These drawings were subjected to numerous technical reviews--including an offsite expert technical peer review panel.

## Expert Technical Peer Review

A panel of technical experts was organized during FY 1992 to peer review the BDP and to provide a specific review of the preconceptual prototype barrier design initiated during FY 1990. The technical peer review of the BDP and the prototype was conducted in three phases.

A contract was established with Ebasco Environmental (Ebasco) to assemble a peer review panel made up of individuals with expertise in various barrier-related disciplines. The peer review panel assembled by Ebasco was comprosed of the following individuals. (The general areas of technical expertise and the company to which of each of the panel members was affiliated is also noted.)

Barrier Design/Construction/Monitoring

Dr. David E. Daniel
University of Texas at Austin

Dr. Gregory N. Richardson
Hazen and Sawyer

Hydrogeology/Modeling/Monitoring

Dr. Lorne G. Everett
Metcalf and Eddy Consultants, Inc.

Plants/Biointrusion/Erosion

Dr. Charles C. Reith
Jacobs Engineering

Climate/Natural Analogs

Dr. W. Geoffrey Spaulding
Dames and Moore

These individuals were considered to have backgrounds broad enough to suitably address the technical diversity of the BDP, yet focused enough to provide a meaningful review as well.

As noted previously, the peer review of the BDP and prototype barrier was conducted in three phases. The first phase of the peer review process was conducted on March 9-11, 1992. The objectives of the first phase of the peer review process were twofold: 1) assess the scope, need, and results of tasks being conducted or planned as part of the BDP, and 2) evaluate the most recent prototype barrier design. The first objective was aimed primarily at obtaining an independent assessment regarding the scope of and need for performing the various barrier development tasks that have been identified by the BDT. In the second objective, the experts were to review, assess, and comment on the preconceptual prototype design initiated during FY 1990.

Following the conclusion of the first phase of the peer review process, the experts were requested to provide a written report containing their comments on and recommendations for the overall BDP and the prototype barrier.

The peer review panel's findings and observations on the first phase of the peer review process have been documented in their entirety in a detailed report (Wing 1992). The report represents a consensus position of the peer review panel regarding each major issue of concern. Although a consensus position was required, panel members were also encouraged to provide relatively focused recommendations based on their specific areas of technical expertise.

The peer reviewers were generally supportive of the BDP. Several recommendations for improving the prototype design were suggested. In addition, the peer reviewers strongly recommended enhanced interactions between the barrier development team and the appropriate regulatory agencies. These enhanced interactions would increase the probability of regulatory acceptance of permanent isolation barriers when the technology development effort has been completed and the technology has matured to the point that it is ready for implementation in actual waste site remediation activities.

Following the receipt of the panel's comments and recommendations from the first phase of the peer review process, the barrier development team began an aggressive effort to modify (as appropriate) the prototype barrier design. This effort was conducted over approximately a 3-month period. On June 22-23, 1992, the peer review panel was again brought to the Hanford Site to review the progress made. Presentations were given on the latest revision of the prototype barrier design with its corresponding schedule. In addition, the status of the prototype barrier testing and monitoring plan were also presented.

The peer review panel was pleased with the progress made since the first phase of the review process. Only relatively minor modifications to the prototype design were recommended. These comments and recommendations were summarized in succinct statements and are included in their entirety in the detailed report mentioned previously (Wing 1992).

The peer review panel provided an additional review of the definitive design drawings and construction specifications during the first part of September 1992. Comments were incorporated as appropriate.

**Change In Direction**

In August 1992, the Environmental Protection Agency (EPA) in conjunction with the Department of Energy, Richland Operations Office (RL), and WHC discussed moving the prototype barrier from the original uncontaminated site located near the HMS to a location situated on top of a contaminated crib (216-B-57) within the 200-BP-1 Operable Unit (OU). Westinghouse Hanford Company's initial position was to construct the prototype barrier at the HMS, as originally envisioned, and construct a second barrier over the 200-BP-1 OU. After several meetings between WHC, RL, and the EPA, it was decided that one prototype barrier would be constructed over the 216-B-57 Crib as a technology demonstration. Provisions were made to monitor barrier performance for a minimum of 3 years, followed by an option to conduct partial or full destructive testing of the barrier to determine overall performance. Formal change control was initiated in October 1992, and a change request (M-15-92-5) was written to document these, and other, changes to the 200-BP-1 OU work scope. Kaiser Engineers Hanford Company was directed to complete a site-specific engineering study to redesign the prototype barrier for construction over the 216-B-57 crib and to identify the associated costs.

Construction of the prototype barrier over the 216-B-57 crib will provide insights into barrier constructibility over actual waste sites and under radiologically controlled conditions. Although actual barrier performance data will not be available for several years following the completion of barrier construction, lessons learned during the construction of the prototype and actual costs incurred will provide information in support of the final "Record of Decision" for remediation of the 200-BP-1 source area and the subsequent remedial design. Furthermore, the prototype barrier demonstration will constitute the first full-scale test of the integrated barrier design and allow collection of data necessary to verify barrier performance or provide a basis for design modifications.

During FY 1993, the definitive design drawings for the prototype barrier over the 216-B-57 crib were modified and approved. In addition, a construction specification supporting the construction of the prototype barrier was completed and approved. The design media supporting the construction of the prototype barrier has been extensively reviewed both internally (Hanford Site contractors) as well externally (expert technical peer reviewers). These reviews have increased the confidence of BDP members in the prototype barrier design.

Construction of the prototype barrier was initiated at the end of FY 1993. Onsite construction forces will perform activities in which the potential exists for contacting contamination. Specifically, the onsite construction forces will clear and grub the site, install water lines, and relocate a fence in the vicinity of the prototype barrier construction site. The remainder of the "clean" construction effort will be conducted by an offsite contractor. Prototype barrier construction is scheduled to be completed in FY 1994.

**Prototype Barrier Testing and Monitoring**

The design, construction, and testing of a prototype barrier will require several years to complete. As mentioned previously, the design of the prototype was completed in FY 1993. Construction of the prototype is planned to be completed during FY 1994. Testing and monitoring of the prototype's performance will be required for at least 3 years following the construction of the prototype. Approximately 1 year is expected to be required for the prototype barrier to stabilize after construction is completed, instruments are installed, and experiments are initiated. Once the experiments have begun, a minimum of 2 years of testing and monitoring the performance of the prototype will be required. Continued monitoring of prototype barrier performance over extended periods of time is desirable but will be subject to the availability of funding as well as to the types of monitoring techniques used (i.e., destructive sampling). Additional performance data would provide increased confidence in long-term predictions of barrier stability and performance.

As mentioned previously, following prototype construction, a period of about 1 year is expected to be required for the prototype to stabilize.

During this year following construction, it is expected that the soil in the prototype barrier will experience some amount of uniform settlement. In addition, the moisture contents of the soils are expected to adjust from construction levels to natural field conditions, and vegetation will become established on the barrier surface. Once the prototype barrier has stabilized, a baseline will exist from which test data on prototype performance can be collected. Performance data on water redistribution, drainage, erosion, stability, and intrusion by plants and animals should then be collected over a minimum of two complete growing cycles (fall and winter rainfall seasons and spring and summer growing seasons). Thus, a minimum of 3 years of rigorous monitoring and analysis of test data will be required.

Properties of the prototype barrier including (but not limited to), succession of vegetation types, the full development of root profiles, and the natural colonization of the barrier surface by burrowing animals will occur over a longer period of time. Consequently, it is desirable to maintain a reduced level of monitoring beyond the 3-year period of rigorous monitoring. Funding will be sought to maintain the prototype as long-term monitoring studies and in the assessment of the long-term performance of cover systems at Hanford.

It should also be noted that just the construction of the prototype barrier is, in itself, a test. Constructibility issues, raised during the construction of the prototype, will be analyzed and incorporated into future barrier designs.

During FY 1993, two documents were prepared to support the testing and monitoring of the prototype barrier. One of these documents is a treatability test plan (DOE-RL 1993). The treatability test plan is intended to be relatively general in scope and provides the general methodology or approach for conducting a treatability study on the prototype barrier. This document is necessary to support the remediation of the 216-B-57 crib within the 200-BP-1 operable unit. The writing of the treatability test plan was followed by the preparation of a more comprehensive and technically-oriented testing and monitoring plan (Gee et al. 1993).

## Conclusions

The design, construction, and testing of a prototype barrier is just one part, albeit an important one, of a larger program designed to address the various technical issues associated with the performance of permanent isolation surface barriers. All of the tasks that comprise this overall barrier development program have been designed to provide crucial information needed to address each of the technical issues. Consequently, the utility of the prototype project is most readily understood by considering its role within the framework of the overall BDP.

## 2.2 VALUE ENGINEERING WORKSHOP

A Value Engineering (VE) workshop for the BDP was convened during the week of February 8-12, 1993. All BDP stakeholders (i.e., technologists, end users, regulators, and industry experts) were invited to participate in the workshop. The primary objective of the workshop was to assess the scope of, need for, and results of tasks being conducted or planned as part of the barrier program. This objective was selected as the primary focus of the VE workshop for the following reasons:

1. Most BDP tasks were at various stages of completion and a "rebaselining" of these tasks was needed, especially following the expert peer reviews mentioned previously.

2. Resources to conduct barrier development tasks were limited.

3. Multiple organizations and end users were and continue to express a need for permanent isolation surface barriers. Different types of barrier designs may be needed to satisfy the different technical and programmatic design requirements of the various organizations and end users.

4. Regulatory agencies have assumed much of the responsibility for ensuring the public of the technical adequacy of technologies being developed for use in the remediation of actual wastes sites.

The VE workshop enabled input to be received from each of the BDP's stakeholders regarding the scope of and need for performing barrier development tasks identified by the BDT. A technical expert, David E. Daniel, University of Texas at Austin, was contracted to serve as an independent technical peer reviewer and someone familiar with national barrier needs. Dr. Daniel provided a national perspective on current state-of-the-art barrier technology development. In addition to this national perspective, Dr. Daniel provided an outside independent assessment regarding the scope of, need for, and priority for performing the various barrier development tasks identified by Hanford's barrier development team. Another industry expert, R. David Bennett, U.S. Army Corps of Engineers, Waterways Experiment Station, participated in the VE workshop. Dr. Bennett's comments were insightful, and his participation in the workshop contributed significantly.

The primary objective of the VE workshop was successfully satisfied. One of the most significant accomplishments of the workshop included the "buy in" by all stakeholders on the approach for bringing the Hanford barrier development effort to completion. This approach is documented in a report on the proceedings of the VE workshop prepared by the U.S. Army Corps of Engineers, Kansas City District, who served as the facilitators for the workshop.

The results of the expert technical peer reviews (discussed previously) and the VE workshop have provided significant input to and helped to focus the BDP. This input also has been used to develop a comprehensive, yet streamlined plan that will direct Hanford's barrier development effort to a successful closure.

## 2.3 BIOINTRUSION CONTROL

**Animal Intrusion Studies**
***L. L. Cadwell, L. E. Eberhardt, M. A. Simmons (PNL), and D. S. Landeen (WHC)***

Burrowing animals ranging in size from small invertebrates (such as ants) to medium-size mammals (including badgers, coyotes, and marmots) may impact protective barrier effectiveness in three important ways. First, large burrows may provide a preferred path for the entry of surface water through the upper layers of the barrier, thus reducing the effectiveness of the barrier in limiting infiltration. Second, burrowing animals, by casting excavated soil to the barrier surface, may contribute to increased erosion of the fine-soil cover and thereby decrease barrier longevity. Finally, burrowing animals have the potential to dig through soils covers and to move contaminants to the surface after contacting buried wastes.

Studies conducted with small burrowing mammals suggested little or no impact of these animals on soil moisture content. However, field data collected through FY 1990 clearly show that larger burrowing mammals, such as badgers and coyotes, when digging shallow holes in search of prey, can cause an increase in soil water in the immediate vicinity of the burrows. Those observations further suggest that the soils may subsequently dry out by either evaporation or in response to enhanced plant growth that occurs in the moist, freshly disturbed soil. Field experiments that were terminated at the end of FY 1990 had been designed to obtain data required to evaluate the expected impact of burrowing caused by increases in soil moisture on the long-term performance of permanent isolation barriers. After a cancellation of fieldwork in FY 1991 resulting from the lack of funding, plans were made to conclude fieldwork in FY 1992 and complete data analysis. Unfortunately, the late (mid-fiscal year) arrival of funding and the death of the principal investigator left most of the work uncompleted. We did, however, convert a draft report on the earlier studies into a manuscript for publication; we also contributed to the design of the prototype barrier monitoring plan.

The design, construction, and, in particular, the monitoring planned for the prototype barrier do not lend themselves to stress tests involving the introduction and confinement of burrowing animals on the barrier surface as would be required for the evaluation of biointrusion layer performance. It is possible, however, to conduct observation and documentation of the natural colonization of the barrier surface by burrowing mammals. We plan to record the date and location of all burrows resulting from natural colonization of the prototype barrier, and then to excavate soils around the burrows (destructive testing) at the end of the effective test period for prototype evaluation (3 or more years after construction is complete. Observations will focus on loss of integrity of barrier layering and an evaluation of the effectiveness of the biointrusion layers as deterrents to animal burrowing.

**Root Intrusion, Root Distribution Studies**
***J. L. Downs, L. L. Cadwell, and S. O. Link (PNL)***

Vegetation is an important component of the isolation barrier design. It stabilizes the soil surface and extracts moisture from the soil, recycling it to the atmosphere through evapotranspiration. In the barrier design, where fine soils overlie graded layers, we believe that the optimal root distribution will be one in which the roots fully exploit the fine-soil layer. However, the establishment of deep-rooted plants may present a possibility of intrusion into the wastes and subsequent biotic transport of hazardous materials. Knowledge of root growth/soil interactions and water uptake patterns is also needed to model and predict the removal of soil water through evapotranspiration.

To evaluate the extent to which plant roots are expected to exploit the depth of the fine-soil layer and to determine whether the roots of established vegetation will penetrate the various biointrusion layers, we have collected root/soil cores beneath existing vegetation communities growing in fine soils. Intact core samples, collected at the Lower Snively old field, were processed and stained for analysis of root length and biomass. Lower Snively is dominated by cheatgrass (*Bromus tectorum*) and can be considered an analog for barrier surface conditions in the short term following a disturbance such as a fire or erosion. Intact core samples collected from the shrub community at the McGee Ranch were processed and weighed and a set of samples were processed and stained for analysis of root length and biomass. Data for the McGee Ranch climax vegetation community can be used as an analog for root behavior over the long term on the barrier.

Root biomass as a function of depth is shown for the Lower Snively community (Figure 2.1) and for the McGee Ranch shrub community (Figure 2.2). Root biomass distribution in the shrub-dominated community is related to the canopy structure and unique hummock and swale topography in that area. In the swales or interhummock areas, measured root biomass is lower at shallow depths than root biomass in the old field at shallow depths. However, root biomass directly beneath shrubs is greater by a factor of 10.

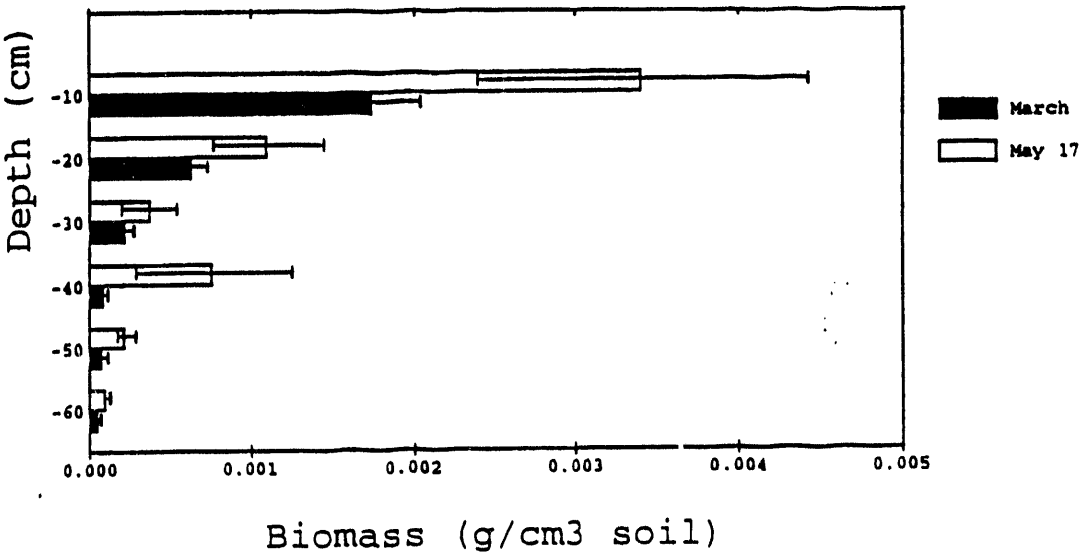


**Figure 2.1**. Root Biomass at Lower Snively Old Field: March and May

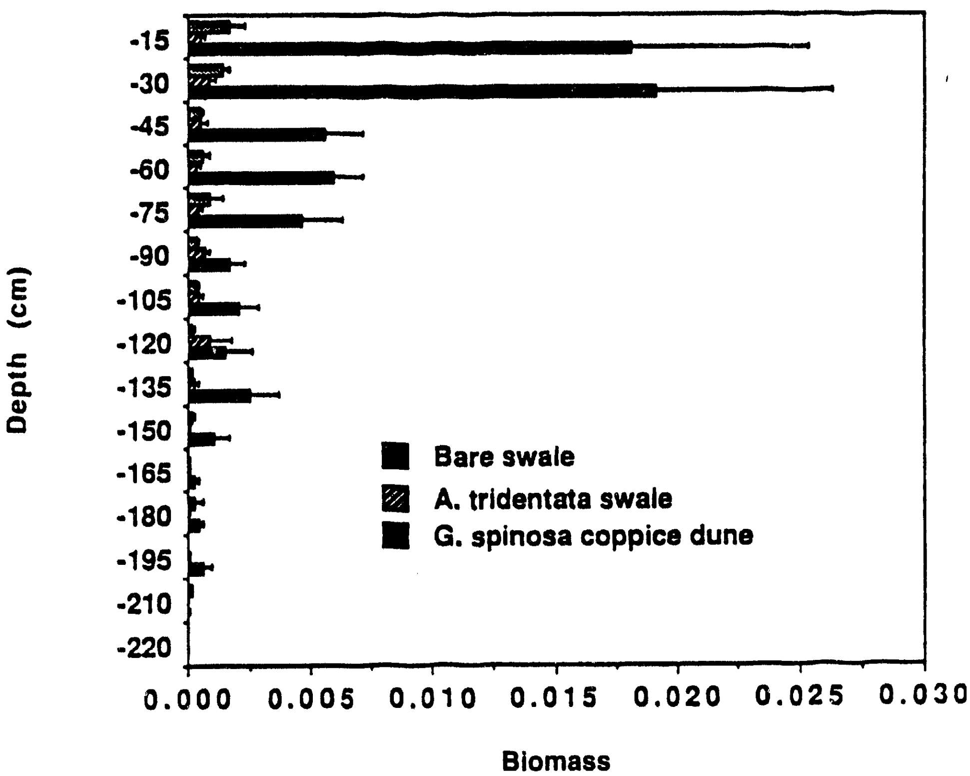


**Figure 2.2**. Root Biomass for the McGee Ranch Site Shrub Community

Samples from both areas are being analyzed to determine root length density numbers that are representative of the two community types. Data are also being analyzed for samples for plots in Lower Snively that received twice the normal wintertime precipitation to evaluate whether root density and distribution changes when additional soil moisture is available. These data are being included in a report on root distributions.

### Vegetation Establishment
***J.L. Downs, L.L.Cadwell, and C.A. Brandt (PNL)***

Establishment of a vegetation cover on the isolation barrier is important to barrier function because 1) during the growing season vegetation will act to cycle precipitation back to the atmosphere, thereby decreasing the amount of water stored in the soil profile, and 2) vegetation on the surface will slow or alleviate wind and water erosion of the fine-soil layer. During FY 1992, efforts on the vegetation establishment subtask were focused on developing a plan for establishing a vegetative cover on the prototype barrier in as short a time period as possible, identifying methods of propagation, and developing sources of propagules necessary to establish the cover. Criteria related to construction of the prototype were developed to facilitate vegetation cover.

To realistically simulate barrier performance, tests of the prototype barrier's ability to prevent water infiltration will require an active vegetation cover. The type of vegetation established preferably should be successful under current climate conditions, be effective in removing or recycling water from as much of the fine-soil layer as possible, act to prevent wind and water erosion, and be resilient in terms of perpetuation of a vegetation cover and re-establishing cover in the event of natural or anthropomorphic disturbance. We believe that a vegetation cover composed of a combination of plant species native to the fine-soil borrow area (McGee Ranch) will best exemplify these characteristics. Establishing a plant cover that includes shrubs and perennial grasses will provide a root distribution that will best exploit the depth of the fine-soil layer for water removal.

The native plant community of the McGee Ranch, in areas not previously disturbed by farming or construction activities, is composed of two dominant shrubs: big sagebrush (*Artemisia tridentata*) and spiny hopsage (*Grayia spinosa*), with an understory of perennial and annual grasses and forbs. The perennial bunchgrass at the McGee Ranch site include Indian ricegrass (*Oryzopsis hymenoides*), squirreltail (*Sitanion hysterix*), and Sandberg's bluegrass (*Poa sandbergii*). Common perennial forbs include balsamroot (*Balsamorhiza careyana*), Cusick's sunflower (*Helianthus cusickii*), and Gray's lomatium (*Lomatium grayi*). Annual grasses include cheatgrass (*Bromus tectorum*) and six weeks fescue (*Festuca octoflora*). Of these species, establishing sagebrush, squirreltail, Sandberg's bluegrass, and cheatgrass on the prototype is expected to be the best and most cost-effective combination in meeting our requirements for developing an adequate root distribution in the soil profile and developing a self-perpetuating and resilient vegetation cover.

Establishment methods for these species will involve combinations of transplanting selected species as well as late fall seeding of the prototype after construction is complete. A sampling of seeds of the two bunchgrasses was collected this year, and 150 squirreltail plants have been germinated and started in pots in the growth chamber. These plants will be transferred to an outdoor garden plot, after fall rains arrive in FY 1993, to overwinter and harden. Sagebrush seedlings from the McGee Ranch site or a similar community on the Arid Lands Ecology site will be identified for transplant where feasible. Numerous sagebrush seedlings can sometimes invade disturbed areas such as firebreaks or power-line roads, and these could provide a supply of climate-hardened plants for transplant without undue disturbance of native communities. Transplants of shrubs and grasses are needed to provide as mature a vegetative cover as possible to meet the requirements of the testing schedule for the prototype.

During FY 1993 and at the appropriate season, seeds of other selected species will be collected from either the McGee Ranch site or a similar community on the Arid Lands Ecology site. By collecting seeds from plants growing at the same elevation and in the same soil type, we can ensure that these propagules are adapted to grow under those specific conditions. Seeds purchased from outside suppliers may have been harvested from plants not so well adapted to growing conditions that exist at the low elevations of the Hanford Site.

Other planting efforts addressed the need to include soil amendments to the top 15 to 30 cm of the fine-soil layer on the prototype. Because borrow materials will be a mixture of fine soil from different depths it will most likely be necessary to add fertilizer and organic materials to meet plant nutritional requirements and to maintain soil water holding capacity. These efforts will aid in establishing a relatively mature and functional vegetation cover.

## 2.4 WATER INFILTRATION CONTROL

**Field Lysimeter Test Facility**
***G. W. Gee (PNL)***

**Facilities.** The Field Lysimeter Test Facility (FLTF), a unique facility for monitoring water balance of surface barriers at the Hanford Site, is completing its fifth year of operation. The facility consists of 24 lysimeters, 14 drainage lysimeters (2 m diameter by 3 m deep), 4 weighing lysimeters (1.5 m by 1.6 m), and 6 clear-plastic tube lysimeters (0.3 m by 3.0 m deep) (Figure 2.3). Lysimeter tests are quantifying the effects of climate, soils, and vegetation in controlling the water balance of surface barriers (covers) at the Hanford Site.

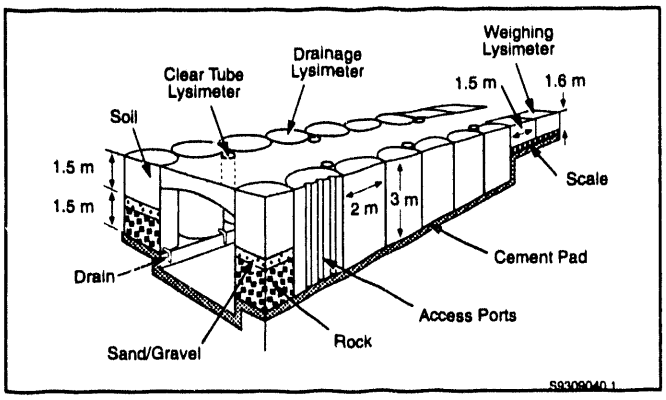


**Figure 2.3.** Schematic of the Field Lysimeter Test Facility

**Results.** The lysimeter tests show that surface barriers, composed of at least a 1.5-m-thick layer of fine soil (silt loam) overlying a capillary break (i.e., coarse layers of sands and gravel, over coarse rock), can effectively prevent drainage (recharge) for all but the most extreme conditions tested. Lysimeters tested plant cover (i.e., perennial shrubs and annual grasses), non-plant (bare) cover, gravel admix, no gravel admix, ambient precipitation, and accelerated precipitation (up to as much as 480 mm/yr) (Figure 2.4). An extreme condition (rapid snowmelt on irrigated lysimeters) occurred in early spring 1993 causing temporary breakthrough of water through the bare soil lysimeters. No other lysimeters exhibited drainage.

Warden silt loam, used as the surface soil in all 18 drainage and weighing lysimeters and two of the clear-tube lysimeters, has sufficient water holding capacity to retain as much as 500 mm of water (in 150 cm of soil) before significant drainage occurs. Figure 2.5 shows the water storage changes that have occurred in the weighing lysimeters during the past 5.8 years (November 1, 1987, through July 30, 1993).

It is apparent that soil characteristics play a major role in controlling recharge at the Hanford Site. Hydraulic properties (i.e., water retention/water holding capacity and unsaturated conductivity) of the surface silt loam soil sustain high evaporation rates. All applied water (precipitation and irrigation) has been removed annually from the soil profile, for all tests where silt loam is the surface soil (Figures 2.5 and 2.6). Figure 2.6 illustrates the effectiveness of vegetation. All treatments with vegetative covers exhibit peaks in water storage that are about half of the maximum storage capacity, suggesting that even in extreme events, such as record snowfall and irrigation (3X or 400 mm/yr treatment) were adequately stored in the surface soil when plants were present on the cover. The fact that no drainage has occurred from silt loam soils with vegetative covers after 5 years of testing suggests that cover designs, which include vegetated silt loam surfaces, will be successful in preventing recharge at waste sites at Hanford.

Coarse soils do not prevent recharge. Clear-tube lysimeter tests at the FLTF have shown that as much as 50% or more of the precipitation is lost as drainage when surface soils are coarse and covered with gravel. Figure 2.7 shows the drainage that has occurred from the clear-tube lysimeters from January 1990 through February 1993. The data clearly show that when soils are vegetated but surfaces are coarse textured, significant drainage can occur. These data are in agreement with previous observations in the 300-North Area at Hanford (Gee et al. 1989) and with studies conducted at the Small Tube Lysimeter Facility (STLF), located next to the FLTF (Waugh et al. 1991).

**FLTF Maintenance and Data Acquisition.** Key to the success of the FLTF is the attention paid to its maintenance. During FY 1992, one of the weighing lysimeters (WL 01, non-irrigated, vegetated silt loam) was found to be rubbing against the outer container, and the scale was not in calibration. The lysimeter was lifted out, the scale replaced and recalibrated, and the lysimeter successfully repositioned with minimal loss of data. All weighing lysimeters were checked and cleaned, and screen mesh placed over the surface air gaps to prevent debris from accumulating between inner and outer boxes of the lysimeter, thus minimizing lysimeter malfunction. Data acquisition has been automated so that precipitation, irrigation, scale, and temperature data are now plotted and tabulated on a weekly basis for review. This has made it easier to make necessary corrections in irrigation schedules and to check for weighing lysimeter malfunctions.

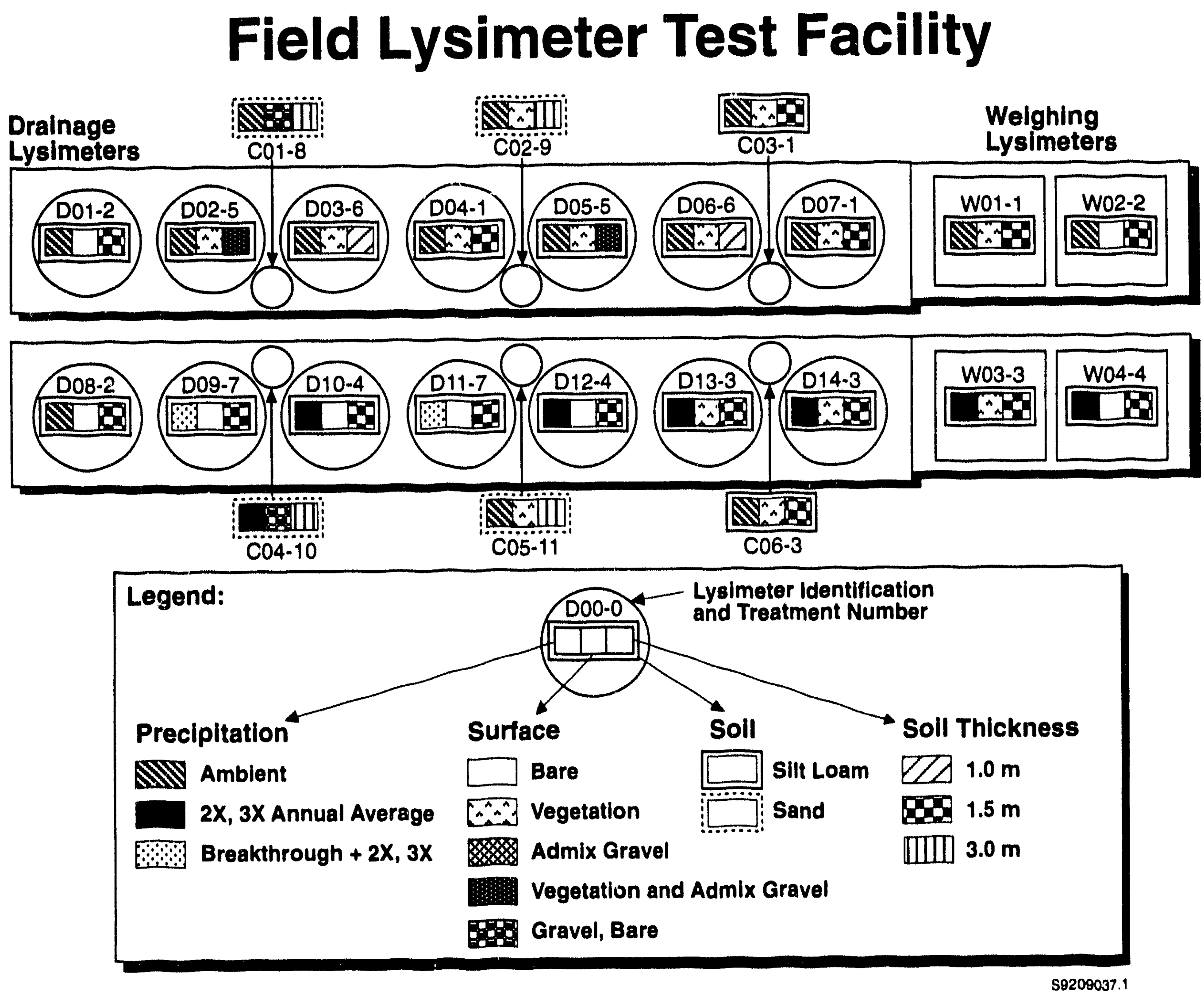


**Figure 2.4.** Description of Treatments for Lysimeters at the Field Lysimeter Test Facility

| Five-Year Lysimeter Water Balance (Nov 1987 - Jul 1993) | Precip. | Net Storage | E or ET | Drainage |
|---|---|---|---|---|
| Non-Irrigated | mm $H_2O$ | | | |
| Bare | 995 | -39 | 1034 | 0 |
| Vegetated | 995 | -191 | 1186 | 0 |
| Irrigated | | | | |
| Bare | 2337 | 49 | 2258 | 30 |
| Vegetated | 2337 | -173 | 2510 | 0 |

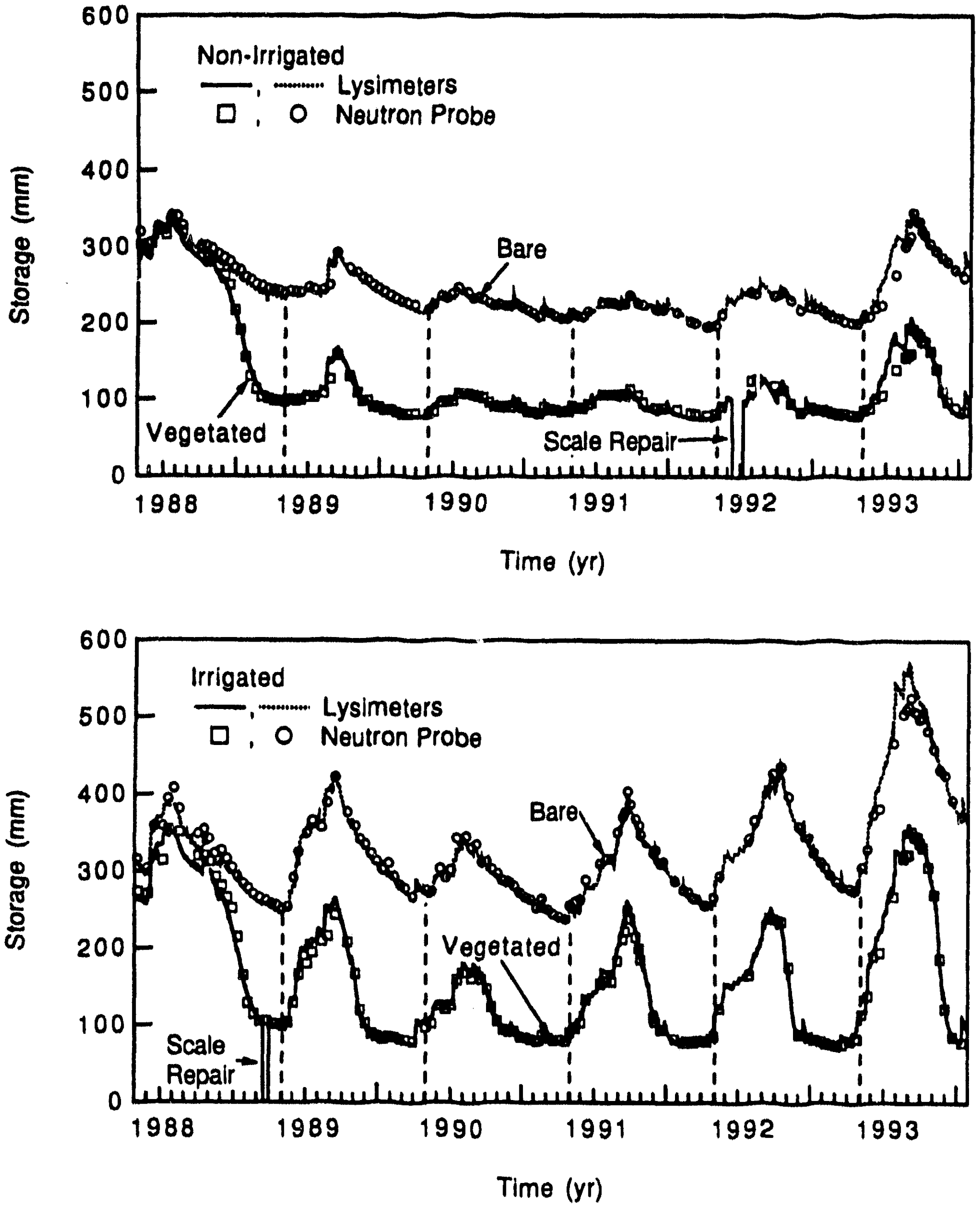


**Figure 2.5**. Four-and-One-Half-Year Water Balance for Weighing Lysimeters at the Field Lysimeter Test Facility

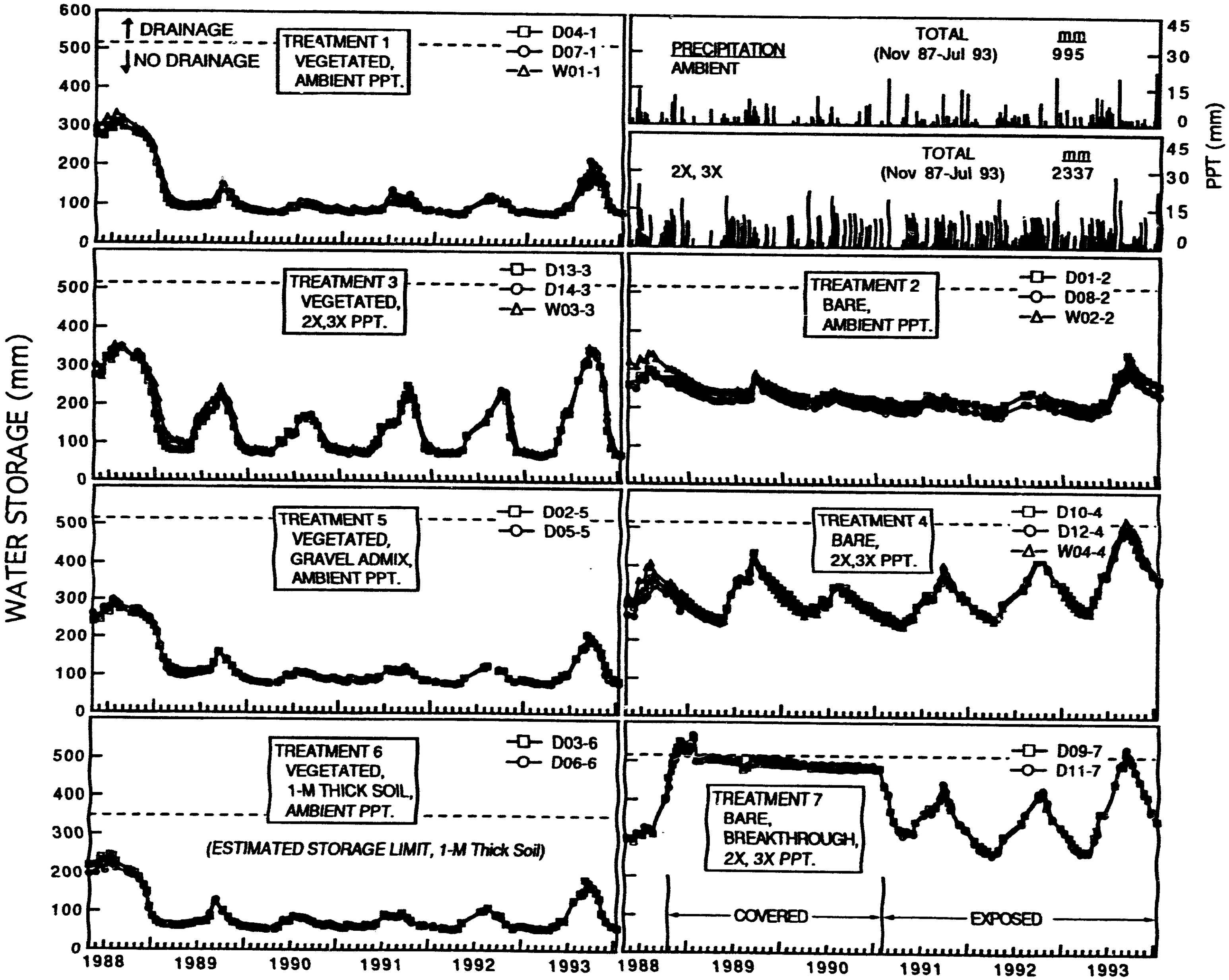


**Figure 2.6**. Water Storage and Precipitation for Seven Treatments at the Field Lysimeter Test Facility

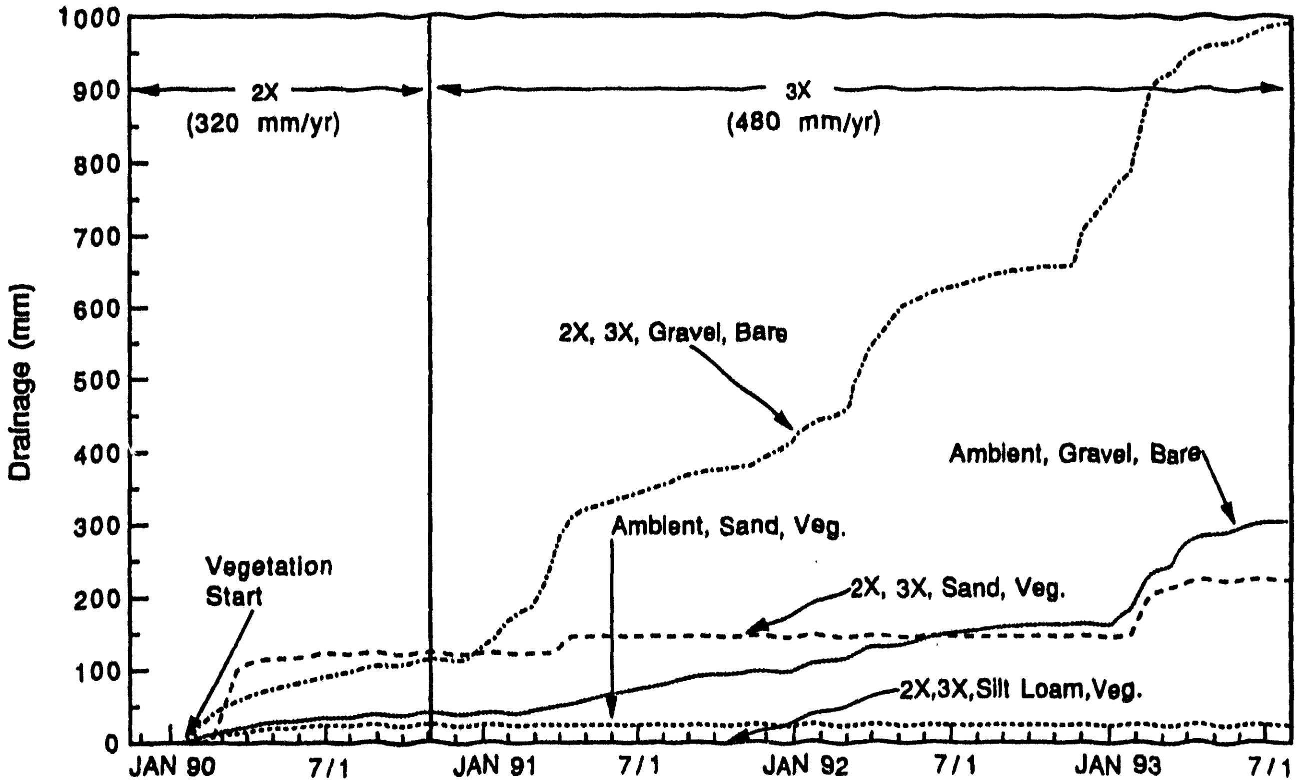


**Figure 2.7.** Drainage from Clear-Tube Lysimeters Under 2X, 3X Precipitation Treatments at the Field Lysimeter Test Facility (1/1/90 - 4/2/93)

**Future Plans.** Current studies at the FLTF are expected to continue for the next 3 years. Next winter (FY 1994) a study will be conducted, using manmade snow to simulate accelerated precipitation conditions. In the past several years, water applications during the winter have been limited because the irrigation system has not worked well at conditions below freezing. In wet soil, bare surfaces are frozen, and applied irrigation water tends to pond on the surface, making it difficult to supply specified amounts of water. Snow applications should eliminate this problem and will also provide a more realistic application of winter precipitation. Fiscal Year 1993 will be the third year of water application at the rate of 480 mm/yr (three times the annual average). Additional data sets will be assembled during the year for model validation purposes. Models that predict water balance under bare and vegetated conditions will be tested over a 5.5-year period. Detailed calibration of the models will rely heavily on the data obtained from the FLTF lysimeters.

**Publications and Field Tours.** Seven published documents describe the FLTF and/or data from this facility (Kirkham et al. 1987; Gee et al. 1989; Campbell et al. 1990, 1991; Campbell and Gee 1990; Phillips et al. 1991; Waugh et al. 1991). Two additional publications describing FLTF results were prepared (Gee et al. 1992a, 1992b). The FLTF test results have been used to guide the design, development, and testing program (Gee et al. 1992c) at the prototype barrier facility, which is slated for construction in FY 1994. Water balance data for both soil and gravel surfaces are available from the FLTF and will continue to guide the water balance tests at the prototype barrier. Additional publications, including one for GEOCONFINE (an international conference in France in June 1993) were prepared for presentation and distribution in FY 1993.

The FLTF continues to be one of the showcases of the barrier program, with field tours at the facility occurring on a regular basis. Facility tours that include descriptions of the activities of the barrier program are available upon request. Contact a barrier team member to arrange a tour; several days advance notice is appreciated.

**Asphalt Diversion Barrier Testing**
***H. D. Freeman (PNL)***

The BDP is evaluating materials for use as a redundant layer to provide a means of meeting stringent water infiltration requirements for the disposal of radioactive wastes at the Hanford Site. Materials considered during the last 4 years include asphalt, grout, and clay. The

Pacific Northwest Laboratory is evaluating asphalt, and Westinghouse Hanford Company is evaluating grout and clays. This section will present information on activities conducted in FY 1992 to evaluate asphalt barriers as a secondary impermeable diversion layer.

The objective of the asphalt barrier task is to develop information to provide a defensible basis for designing an asphalt diversion layer that will perform to regulatory standards for a minimum of 1000 years. Activities conducted in FY 1992 to support this objective include monitoring the 15 lysimeters in the Small Tube Lysimeter Facility, associated with the asphalt barriers; developing specifications for the asphalt layer in the prototype barrier; and developing plans to determine physical properties of asphalt materials after long-term aging in a buried environment.

The small tube lysimeters near the Hanford Meteorological Station have been monitored since July 1988. Initially, ten lysimeters (numbered 1 through 10) were installed: four contained a thin layer (1.5 cm) of hot polymer-modified asphalt, four contained a 15 cm layer of cationic asphalt emulsion and concrete sand with 24 wt % residual asphalt, and two lysimeters, containing only Hanford sand, served as controls. Five additional lysimeters (numbered 11 through 15), using a clear-tube design, were added in June 1990 to evaluate the impacts of root penetration and to provide a means of easily identifying any leaks through the asphalt. Four of the new lysimeters contained 1.5-cm hot polymer-modified asphalt, and the fifth lysimeter served as a control, containing only Hanford sand. Four of the original and three of the new lysimeters were each vegetated with a single sagebrush plant. This was done to evaluate the effects of vegetation on the water balance in the lysimeters. All lysimeters have a 15-cm washed, rounded gravel surface treatment to enhance the infiltration of water. In addition, NaCl solution was injected above the asphalt layers to provide a means of identifying the origin of drainage water collected from lysimeters.

To date, water balance data collected from the asphalt-treated lysimeters have shown that asphalt can meet infiltration requirements of 0.05 cm/yr. Based on visual observations and conductivity measurements of collected drainage water, only one lysimeter has shown any signs of leakage through asphalt layers. The cause of this single case of leakage is likely because of separation of the asphalt from the walls of the lysimeter. In comparison, the two control lysimeters (numbers 9 and 10), neither of which had asphalt or vegetation treatment, had an average of 41% of the precipitation measured at the HMS during July 1988 through July 1992 collected as drainage. The clear lysimeter control (number 15), which received sagebrush treatment, had 24% of the precipitation measured at the HMS during May 1990 through July 1992 collected as drainage. This data clearly demonstrated that a gravel mulch can result in a substantial water infiltration rate, even in the presence of vegetation.

During FY 1992, asphalt-based materials were selected for use as the redundant layer in the prototype barrier to be constructed in FY 1993. The asphalt layer in this barrier will probably be a composite of a 15-cm hot asphalt.

The preliminary specifications for the asphalt layer calls for an asphalt concrete mix similar to that used for the Hanford Grout Vault asphalt diffusion barrier. This material consists of a graded aggregate with an asphalt content of 7.5 wt% containing less than 4% air voids. This material will be placed in two 7.5-cm lifts with the second lift overlapping the seams of the first. The 15-cm asphalt concrete will provide a stable base for construction of the overlying materials. To further enhance the overall properties of the asphalt layer, a 1.0- to 2.5-cm layer of polymer-modified asphalt will be sprayed on the surface of the asphalt concrete. This will seal any imperfections in the seams and provide an elastic layer that will withstand subsidence without sacrificing permeability properties.

The primary emphasis for the asphalt barrier task in the near future will be to develop data on the long-term properties of asphalt in a buried environment. This will be accomplished by developing accelerated aging tests that will simulate 1000 or more years of aging in several months. The mechanical and permeability properties of these materials will then be determined as a function of age to provide a basis for predicting the overall long-term performance of the Hanford permanent isolation surface barrier. These data will be obtained in cooperation with two other DOE programs: the Hanford Grout Technology Program and the In Situ Remediation Integrated Program.

### Clay and Chemical Grout Tests

***M. R. Sackschewsky and C. J. Kemp (WHC)***
***L. L. Cadwell and M. E. Thiede (PNL)***

The use of clay and chemical grout components to control infiltration of water through the isolation barrier is currently being evaluated by the BPD. Several tests are being conducted in small tube lysimeters located within the Small Tube Lysimeter Facility. The purpose of the tests is to evaluate the performance of a clay component (25% bentonite clay, 75% McGee soil) and a chemical grout component (25% sodium silicate solution mixed with McGee soil to form a pourable grout mixture, about 30% water by volume) under an environment in which the precipitation conditions are three times the average. Five small tube lysimeters are being used to test each of these alternative barrier components.

Each lysimeter used in the tests of clay and chemical grout consists of a 15-cm thick pitrun gravel layer covered with 30 cm of either clay or chemical grout. A 120-cm layer of McGee soil is placed on top of the infiltration barrier. The performance of these infiltration barrier lysimeters is compared with control treatments consisting of either "bimodal" capillary break configuration, McGee soil over pitrun gravel, or a graded sand capillary break configuration. All of the lysimeters in this experiment are vegetation free and receive enough irrigation to result in a total water input equal to three times the long-term average precipitation.

There were no significant differences in the total evapotranspiration or total storage change among any of the treatments (Figure 2.8). Total evapotranspiration has exceeded total water input for all of the treatments, thus total water storage was observed to decrease over the period of measurement, at least during the wetter winter months. No drainage was observed from any of the lysimeters. From these results, we have concluded that the infiltration barriers and the different capillary break configurations all prevent infiltration, even under three times average precipitation conditions.

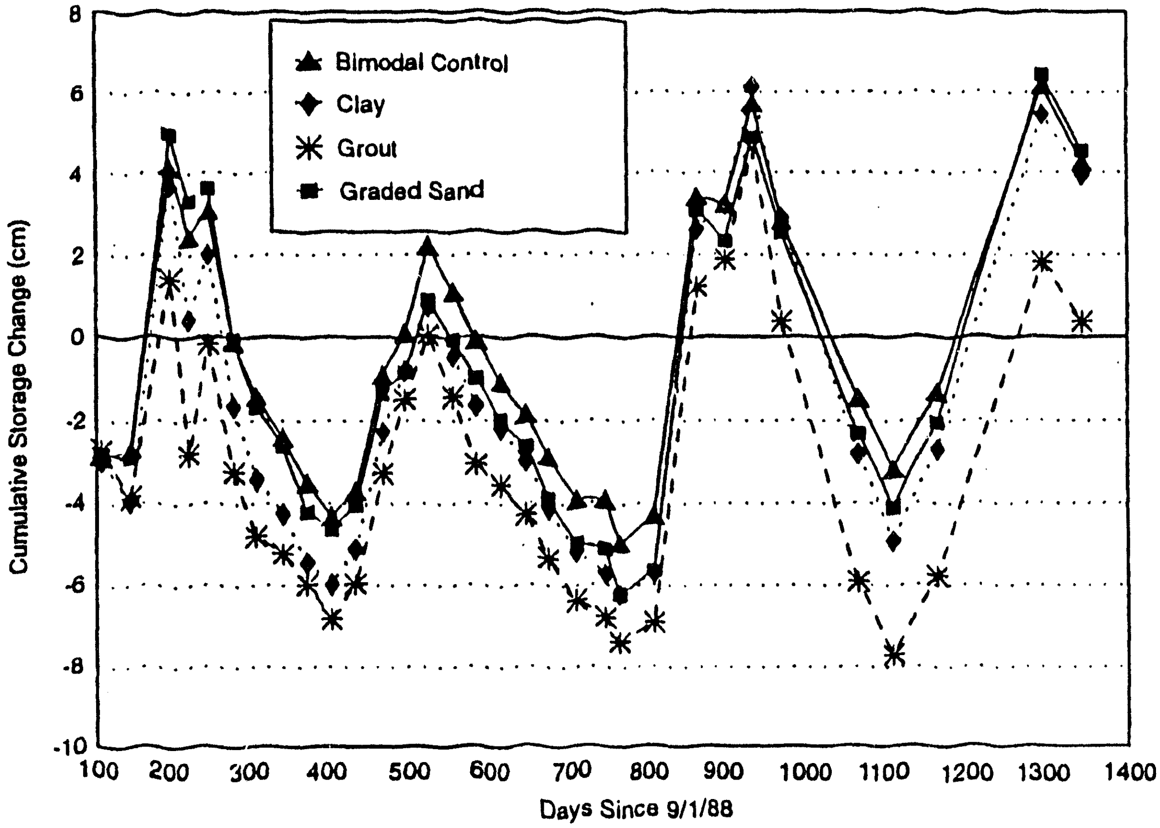


**Figure 2.8.** Comparative Evapotranspiration Among Treatments

## 2.5 EROSION/DEPOSITION CONTROL

**Field Study of Gravel Admix, Vegetation, and Soil/ Water Interactions**
***L. L. Cadwell and M. E. Thiede (PNL), C. J. Kemp (WHC), and W. J. Waugh (RUST Geotech)***

Several studies, funded by the BDP, are testing surface additions of gravel mulches and admixtures (gravel uniformly mixed into the top 20 cm of soil) for long-term control of winds and runoff erosion. Although adding gravel to the barrier topsoil may control erosion, there was a question as to whether the gravel component would compromise the ability of a barrier to cycle water back into the atmosphere. This original field study was designed to evaluate the effects of gravel admixtures on soil water storage and plant growth. Field plots were installed in the fall of 1986 on the site selected as a source of topsoil for isolation barriers at the Hanford Site. Gravel admixture, vegetation, and enhanced precipitation treatments were randomly assigned to the field plots, using a split-split-plot design structure. The admixture treatments designs included 1) no gravel, 2) a 20-cm-thick admixture of 15 wt% pea gravel (1.0 cm diameter), and 3) a similar 30% pea gravel treatment. Twice-average precipitation was added monthly to half the plots to simulate a wet climate. Changes in soil water storage were monitored monthly with neutron moisture meters. Spring and fall plant cover measurements were made using an ocular point-intercept method. The active routine data collection period for this study ended in September 1990, and plans were made to conduct destructive testing in FY 1991, but that was delayed for 1 year because of funding limitations. Preliminary analysis showed that gravel admix surfaces perform well, with no appreciable impact on soil water balance and that the admix surfaces do not limit plant establishment or growth. This section describes the final sampling, some of it destructive in nature, conducted in FY 1992 to complete the descriptive characterization of the test surface.

The objectives of this final phase of the study were to characterize the composition of gravel admix surface after having 4 years of added precipitation on the 2X plots, five plus seasons of vegetation growth and being subjected to natural environmental elements including rain, wind, freeze-thaw, and mid-summer high temperatures.

In late spring of 1992, the surface vegetation had a visual appearance similar to that of past years. Apparently there was sufficient residual effects from past herbicide application, causing the bare treatment plots to remain nearly devoid of vegetation. Final plant cover measurements were made on the vegetated plots, and surface gravel measurements were made on the non-vegetated plots. Plant litter and plant cover on the vegetated plots were abundant enough that making measurements of exposed surface gravel cover was impractical. Figure 2.9 combines vegetation cover data from the vegetated plots with gravel cover data from the bare treatment plots to compare initial and final (1987 versus 1992) plot treatment characteristics. It is noteworthy that the final vegetation cover is approximately twice that of the first year (1987) and that there is no apparent difference in total cover among treatment combinations (gravel and precipitation). Note also that exposed surface gravel cover did increase on the non-vegetated plots from 1987 to 1992 in apparent response to the forces of erosion and/or the differential settling of the fine particles.

After the plant and gravel cover measurements were made, a trencher was used to expose the top 30 cm of the soil profile in selected plots. Approximately 6 years after plot construction, the actual admix layer thickness was determined to be 11.9 cm, with a minimum thickness of 10 cm and a maximum thickness of 14 cm. It was necessary to confine our sampling for composition analysis to the well-mixed layer rather that to extend below the gravel to adequately characterize the admix test surface. Thus we selected a total sample thickness of 9 cm and arbitrarily divided it into a 2-cm-thick top layer and a remaining 7-cm-thick subsurface layer. For the 15% design treatment, the top 2 cm on the surface admix contained 25.4 wt% gravel; whereas, the next 7 cm contained 22.0%. The 30% design treatments were 42.0% and 37.9% gravel, respectively, for the surface and subsurface layers. The greater measured weight percent contributions of gravel to the surface layers and the data from Figure 2.10 showing an increase in surface exposed gravel from 1987 to 1992 suggest that the admix treatments did produce a surface gravel armoring of the test plots from 1987 to 1992. These data also suggest that the original treatment designs of 15% and 30% gravel admix were actually nearer 25% and 40% and that the naturally compacted thickness of the admix surface was about 12 cm rather than the design thickness of 20 cm.

**Small Tube Lysimeter Tests**
***M. R. Sackschewsky and C. J. Kemp (WHC)***
***L. L. Cadwell and M. E. Thiede (PNL)***

The Small Tube Lysimeter Facility was constructed to determine the influence of erosion control practices and alternate barrier layer configurations on soil water balance. The experiment was devised to measure the effects of surface gravel admix (gravel uniformly mixed into the top 20 cm of soil) and gravel mulch, sand deposition, supplemental irrigation, loss of vegetation, and two types of subsurface capillary break configurations on water

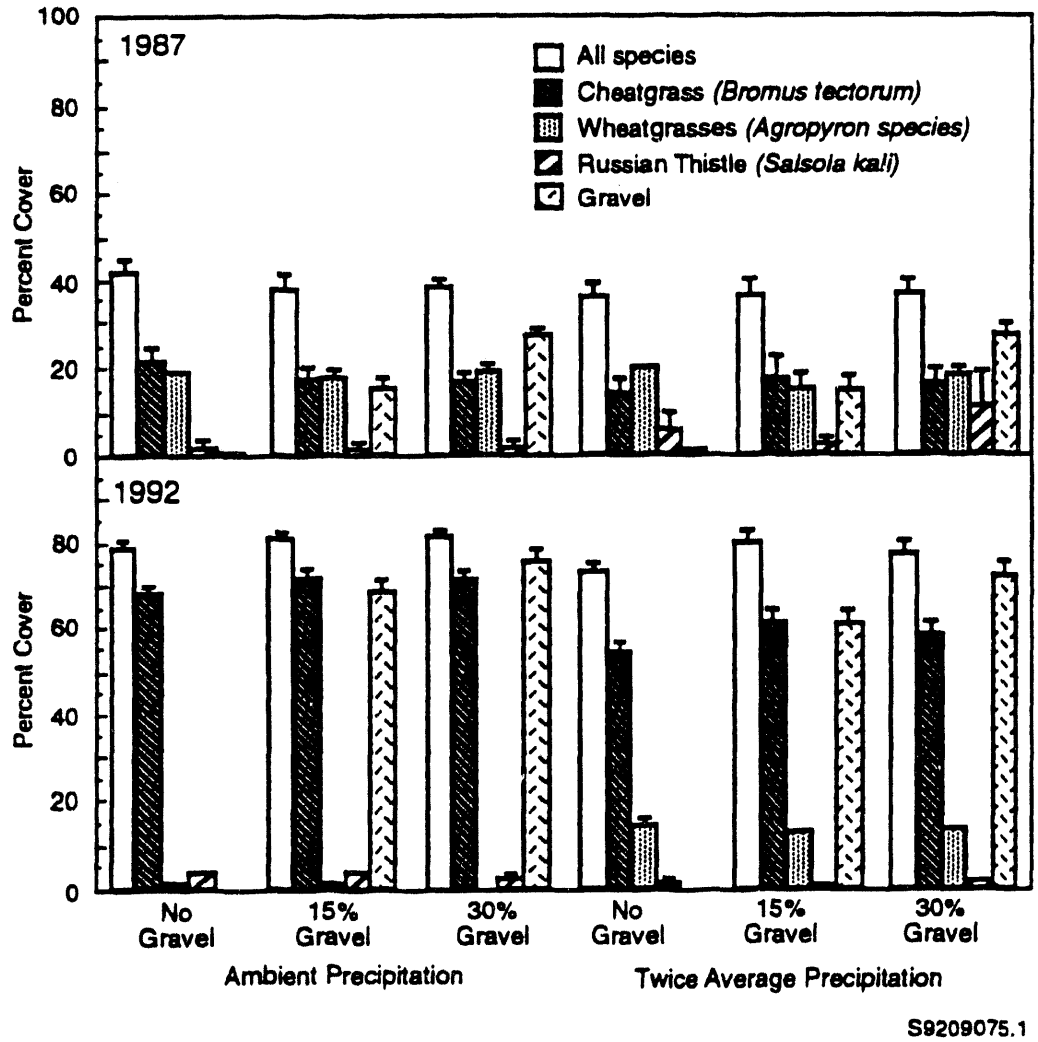


**Figure 2.9**. Vegetative Cover Data from Plots with Gravel Cover and Bare Treatment Plots

storage, evapotranspiration, and drainage. The array of small tube lysimeters consists of 21 rows of five lysimeters each that are irrigated, weighed, and checked for drainage monthly. Sixty lysimeters are used in the main test that examines the effects of gravel admixtures and gravel mulch. Ten tubes are used to test the effects of a surface sand deposition layer, and ten additional tubes are being used to test the effects of pitrun gravel versus a graded filter layer as a capillary break. The final 25 lysimeters are being used in a companion alternate barrier test of asphalt, clay, and chemical grout infiltration barriers. The facility was completed in September 1988, and data has been collected for the last 4 years.

The main surface treatment experiment is a 3 X 2 X 2 factorial design, with main effects consisting of surface treatment (plain soil, gravel admix, surface gravel mulch), vegetation (presence or absence of cheatgrass), and precipitation (ambient and three times average). Under non-irrigated conditions, all of the plain soil and gravel admix lysimeters had a net decrease in stored soil water (Figure 2.10). The presence of vegetation resulted in a greater decrease in stored water than the non-vegetated condition. Under the enhanced precipitation conditions there was a small net increase in stored soil moisture in the non-vegetated, plain soil and admix gravel lysimeters, but a net decrease in the vegetated lysimeters (Figure 2.11).

The presence of a gravel mulch or a sand deposition layer greatly increased the amount of stored soil moisture (Figure 2.12), especially under supplemental irrigation conditions. The presence of vegetation allowed the non-irrigated, gravel mulch lysimeters to remain at a relatively steady water content over the past 3 years of measurement. The water content of the non-vegetated, non-irrigated, gravel mulch lysimeters has slowly increased since the start of the experiment so that they are now similar in net water storage to the irrigated gravel mulch and sand covered lysimeters. Several of the non-vegetated, non-irrigated, gravel mulch lysimeters have produced detectable amounts of drainage. All of the irrigated gravel mulch and sand covered lysimeters have produced measurable amounts of drainage.

At this time there are no discemible differences in the performance of the bimodal (McGee soil overlying pitrun gravel) or graded filter (McGee soil over fine sand) capillary break configurations (data not shown). Evapotranspiration from all of the treatment lysimeters exceeded total water input and no drainage was detected from any of these lysimeters.

### Wind Erosion

***M. W. Ligotke and J. F. Cline (PNL)***

Maintaining an intact, erosion-resistant surface layer during periods of extended (dry) climatic stress is the goal of the wind erosion subtask. Reduced vegetative cover, caused during droughts by water deprivation and wildfires, may expose the fine soil reservoir of the waste site barrier to the scouring effects of wind and sand storms. Wind tunnel tests are being used to study the formation and function of natural surface armors (i.e., pea gravel) during periods of simulated extreme climatic stress. Such surface armor has been shown in the tests to reduce erosion rates. Eolian, or wind, erosion is influenced by surface creep, saltation, and suspension. Surface creep is wind-driven sliding and rolling of sand and soil aggregates along the surface. Saltation is the transport mechanism of sand-sized particles and consists of vertical leaps followed by low-angle returns to the surface. Suspension is the long-distance transport of soil particles away from exposed surfaces. Saltation and, to a lesser extent, creep are often the primary causative mechanisms of soil erosion in arid lands; the energy of windborne or rolling grains is imparted to dry soil surfaces and causes suspension and surface deflation.

The objectives of wind erosion studies in support of natural-material isolation barriers are to 1) develop a method of preparing the surface layer to be naturally protected during periods of climatic stress, 2) investigate

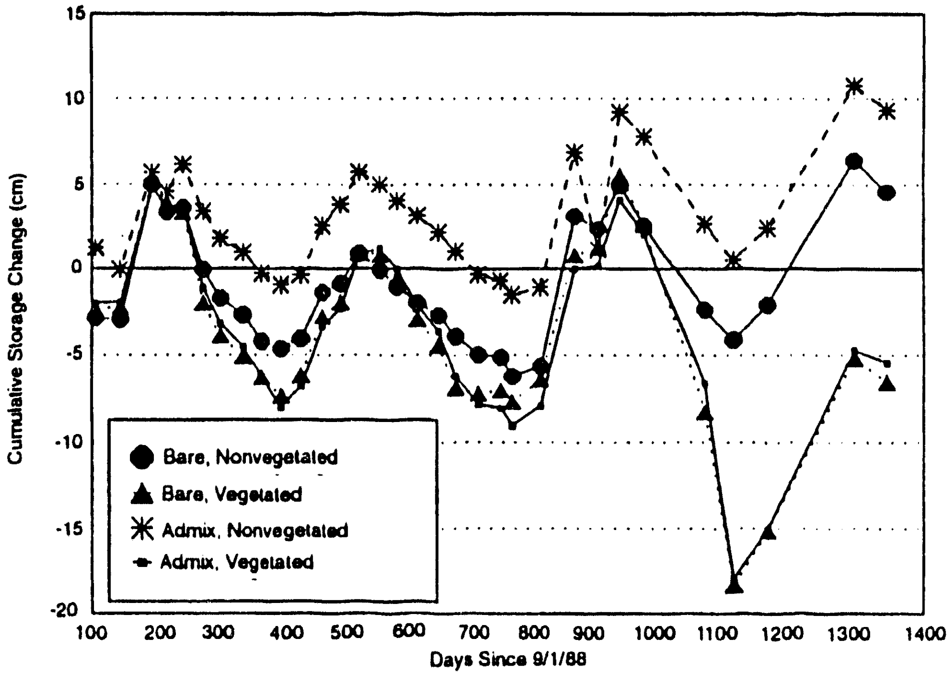


**Figure 2.10**. Small Tube Lysimeter Facility Cumulative Storage Change: Non-Irrigated Conditions

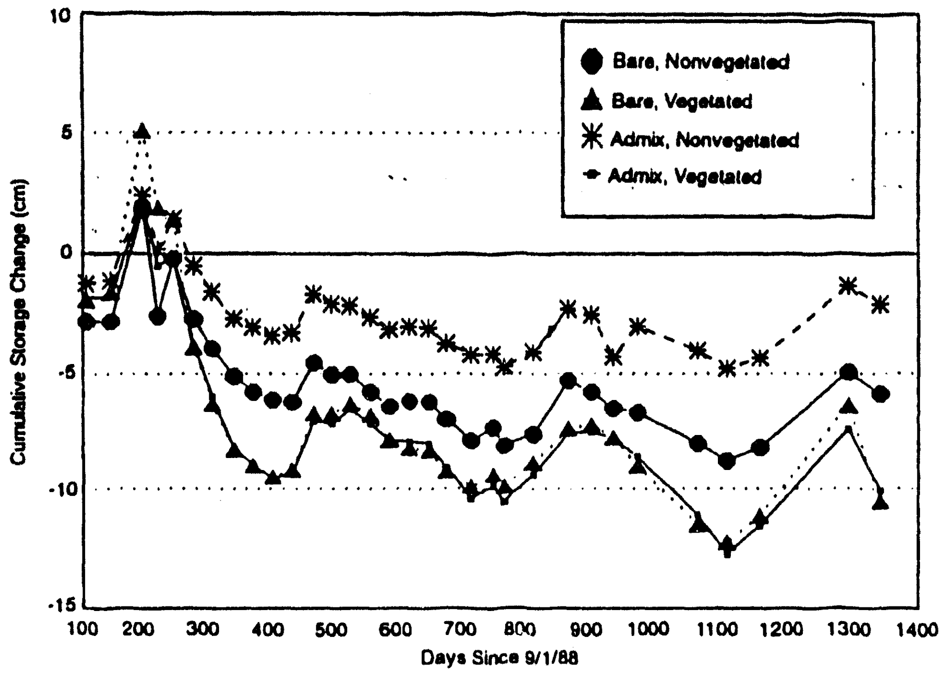


**Figure 2.11.** Small Tube Lysimeter Facility Cumulative Storage Change: Enhanced Precipitation Conditions

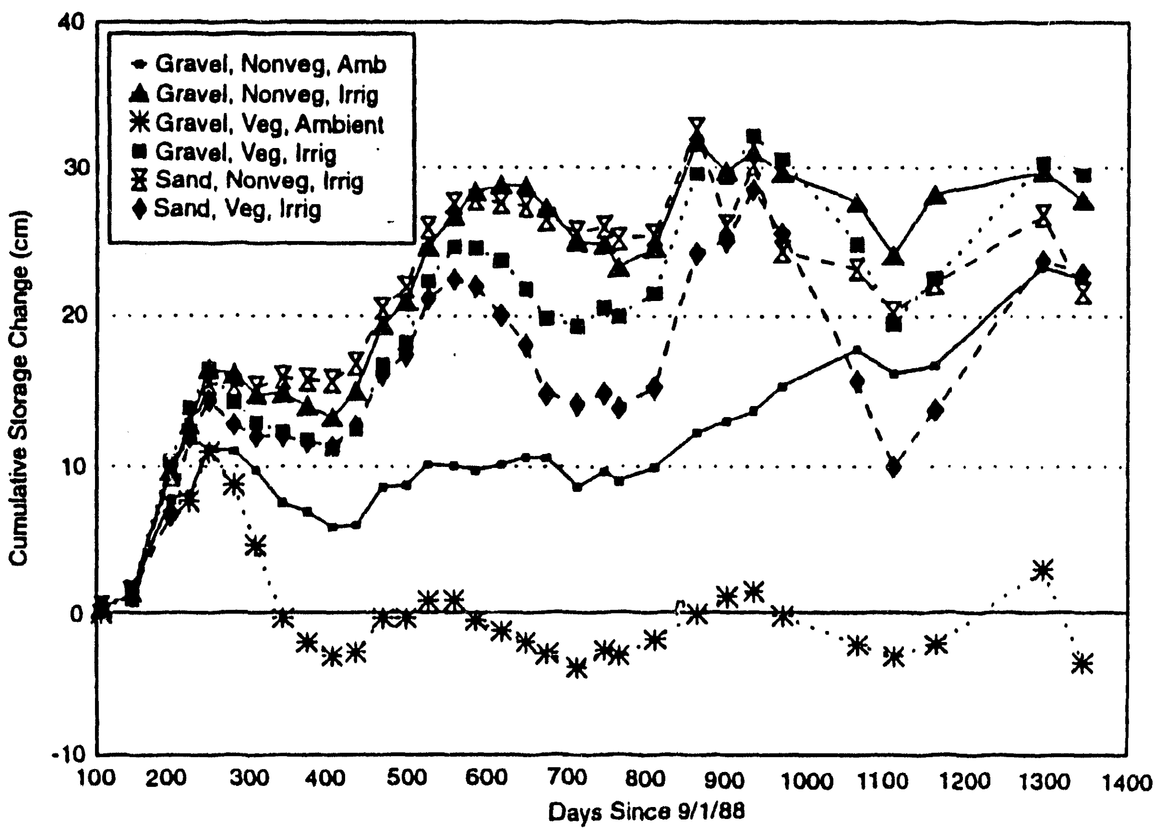


**Figure 2.12.** Small Tube Lysimeter Facility Cumulative Storage Change: Presence of Gravel Mulch or Sand Deposition Layer

the erosive mechanisms and impacts of wind and sand on soil and armor, 3) develop a predictive model of erosion and deflation, and 4) contribute to the design and monitoring of a prototype barrier. These objectives are being met by determining typical and extreme wind and sand erosive stresses expected in the field. A wind tunnel was used to test candidate surfaces and armors, investigate surface properties, characterize eolian mechanisms influencing erosion, and plan monitoring activities for a prototype barrier.

Past wind tunnel test results, based primarily on wind stresses, have indicated that pea gravel is the optimum gravel armor for the fine-soil reservoir (Ligotke 1993; Ligotke and Klopfer 1990). Tests were performed in FY 1992 to investigate the impact of saltating sand stresses, the incorporation of sand of various sizes in the surface layer, and the ability of crusted surfaces and armors to withstand wind erosion. The tests indicated that the selected armor material is sufficient to protect the surface even under extreme erosive conditions. In support of these tests, data on peak wind gusts at the Hanford Site (Stone et al. 1983) were augmented and peak gust return periods were calculated. Sand transport potentials (Glantz et al. 1990) were also considered before to performing sand saltation tests.

A wind tunnel was used to test the influence of the particle size of material mixed with soil at an admixture concentration of 30%. These tests were performed to study the composition of the barrier surface as it ages and incorporates wind-blown sand. The inclusion of sand-sized grains may educe the capacity of the surface to resist eolian erosion. Possible sources of such material include natural deposits and nearby areas disturbed by construction activities. Particle sizes tested ranged from about 0.075 mm (no material admixed, McGee Ranch soil only) to 5.6 mm (pea gravel). The deflation rate from surfaces protected by pea gravel admixture was much less than those containing admixtures of sand. The particle size of sand used in each admixture also influenced deflation rates and it is anticipated that inclusion of the sand sizes most impacted by saltation will provide poorer surface protection than even the baseline case (McGee soil without any admixed material).

The capacity of surfaces to resist the erosive stresses of saltating sand were studied by supplying wind-sorted sand, upwind of soil and gravel admixture surfaces. The influence of simulated sand storm intensity and wind speed were both studied. Tests performed on soil surfaces having a sand saltation rate of about 178 g/ms (grams per meter per second) at a wind speed equivalent to about 30 m/s (67 mph) resulted in deflation rates that were about 46 times those occurring in the absence of saltating sand. In contrast, deflation rates from the weathered gravel admixture surfaces were not impacted by sand saltation. When a gravel armor was added to the gravel admixture, the surfaces actually gained mass as coarse sand was trapped in the surface gravel layer. Continued tests of the armored surface indicated that little soil particle erosion occurred. At wind speeds equivalent to about 30 m/s (67 mph) deflation rates from soil surfaces increased from about 10 to 70 g/($m^2$-s) and sand saltation rates increased from 7 to 178 g/ms. In comparison, deflation rates in the absence of sand were about 1 to 2 g/($m^2$-s). Simulated sand storms at wind speeds equivalent to about 15 to 37 m/s (33 to 84 mph) yielded increased deflation rates from soil surfaces from about 5 to 90 g/($m^2$-s) as the wind speeds increased. Deflation rates in the absence of sand ranged from <0.1 to 10 g/($m^2$-s).

Additional tests are planned to address soil moisture, a variety of surface crusts, vegetation, and the impact of burrowing mammals. In two preliminary tests, surface crusts caused by wetting and drying were shown to be resistant to sand saltation, although the (non-armored) crusted soil surface was visibly abraded by the sand and would have eventually failed. Thus, the life span of a surface crust was estimated to be much greater in the presence than in the absence of a gravel armor.

The composition of the fine soil layer of a planned prototype barrier was based in part on results of wind tunnel tests. With a 15% admixture of pea gravel in the top 1 m of the layer, the worst-case deflation may be about 10 cm. Because the prototype barrier will provide an ideal location to obtain field data on eolian erosive stresses and soil erosion rates, a monitoring plan was developed, and instrumentation was obtained. The objectives of this plan include: 1) quantification of surface deflation or inflation rates, 2) characterization of wind and saltating sand stresses impacting the barrier, and 3) studies of the impacts of a sand dune and a wildfire on the surface of the barrier. The first objective would include, in addition to surveying methods to monitor surface elevation, monitoring the surface layer composition and morphology as it ages under natural conditions.

We intend to perform evaluations of surface composition, uniformity, armor, and a comparison of surface deflation with that predicted using wind tunnel models. Wind boundary layer stations and saltation traps are planned to be used to meet the second objective. Further studies will include an evaluation of barrier shape on wind saltating sand stresses, sand transport rates, and a comparison of field and wind tunnel conditions. The third monitoring objective is proposed to be carried out after the primary water balance data has been collected-perhaps after 3 to 5 years. An induced sand dune will cause increased erosive stresses, displace vegetation, and alter water storage and transport characteristics in the fine-soil reservoir. A simulated wildfire will remove protective vegetation and increase deflation potential. These studies will include an evaluation of armor formation and function under worst-case erosion conditions and also water balance measurements.

**Water Erosion**
***W. H. Walters and B. G. Gilmore (PNL)***

The Pacific Northwest Laboratory is conducting water erosion studies to determine the ability of a barriers top surface, composed of Warden silt-loam, to withstand the erosional and destabilizing effects of rainsplash and overland runoff. The energy of raindrop impact loosens soil particles for transport by overland flow and sheet erosion, resulting in soil loss. Erosion on the barrier surface could lead to the development of rills, small gullies, and the eventual failure of the barrier soil cover.

To test the proposed barrier soil cover design, a sequence of field tests began in FY 1989 at the McGee Ranch site, which is the area (borrow area) from which the Warden silt-loam will be obtained. The initial tests applied high-intensity rainfall, using a rotating-boom rainfall simulator, on small plots (1 $m^2$ in area) composed of Warden silt-loam with gravel admix applied to some plots. These tests were for scoping purposes to develop larger plot studies (32.5 $m^2$ in area) for more accurate testing of the barrier cover design using a 2% surface slope with bare soil, soil with gravel admix, and vegetation cover. The plot layout is shown in plan view in Figure 2.13. The large plots were constructed in FY 1990, and initial tests were conducted at the end of that year. No laboratory or mathematical analysis of the water-sediment samples were completed before the end of the year. By the time that field testing was resumed in FY 1992, the plots had developed significant vegetation cover. The percent of cover was determined by optical scanning, which indicated that the cover on the gravel admix plot exceeded 90%; that of the unmodified soil plot was slightly less. High-intensity storms of 60 min (60 mm/h) and 30 min (about 80 mm/h) duration were then simulated. Following those tests, the vegetation was removed from one plot and gravel admix (15% dry weight) was tilled into the soil for further testing. These tests began in late August 1992 but were not completed in FY 1992.

Initial results of the plots with vegetation cover indicated that rain splash, which had been a very dominant process on the bare plots, was relatively ineffective with vegetation. The volume of overland runoff was also greatly reduced as was the volume of sediment yield for the plots. Preliminary observations indicate that vegetation cover has a more significant effect on the reduction of erosion than gravel admix for relatively young plots that have not yet developed a full surface gravel armor. However, the admix does contribute to the reduction of erosion through surface armoring and tends to hold more moisture which enhances vegetation development.

Testing of the 15% admix plots was resumed during late FY 1993. Mobilization began in June, which included the construction of another test plot with 15% gravel admix (dry weight). The initial tests conducted in FY1992 with this weight of admix, under bare soil conditions, were not satisfactory, and another plot was considered necessary for comparison of results. Activities for FY 1993 included testing the 15% gravel admix plots under vegetated-soil and bare-soil conditions and, if possible, a burned vegetated plot at the end of testing.

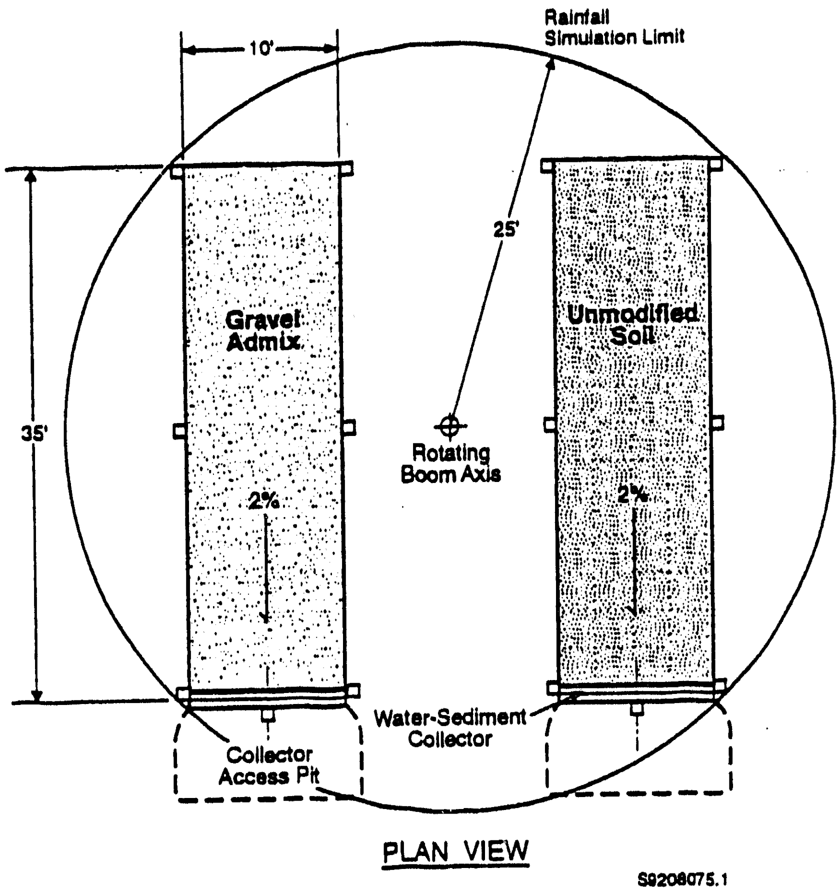


**Figure 2.13**. Rainfall Simulation Plots

## 2.6 MODEL APPLICATIONS AND VALIDATION

**Model Testing with Field Data**
***M. J. Fayer (PNL)***

The Field Lysimeter Test Facility (FLTF) lysimeters represent a unique opportunity to test soil water balance models. The reasons include the level of monitoring detail (hourly weight changes, drainage, bi-weekly water contents, and a nearby meteorological station) as well as the design (multilayer, like the proposed isolation barrier). Perhaps most important of all is that the lysimeters have been monitored since 1987. This length of record, nearly 5 years, is unusual for a field experiment but is vital to the barrier program for two reasons. First, the program must demonstrate that the concept works in the field. Second, the program must demonstrate the ability of computer models to simulate the behavior of the barrier in the field if the models are to be used for predictive purposes. In previous work, the FLTF lysimeter WL-4 was simulated for a 1.5-year period, first with independently determined parameters, then with roughly calibrated parameters. This year, the simulation of the lysimeter was extended to 4.5 years using the calibrated parameters. The result was that the simulated storage values closely followed the trend of the measured values (Figure 2.14). In the sumer, simulated values were always within 10 to 15 mm of the measured values. In contrast, the simulated storage for the winter of 1991-1992 was more than 50 mm less than measured. The reasons for the discrepancy are not yet clear but certainly appear to be related to the cold winter months.

A similar simulation effort using the WL-2 lysimeter produced different results. Using the calibrated parameters from WL-4, the simulation produced storage values that were progressively lower than the measured values (Figure 2.15). By April 1992, the simulated storage values were 50 mm less than measured. The results indicate that the parameters calibrated from WL-4 may not be the ideal parameters for WL-2. More fundamentally, the differences may indicate that the calibration done on WL-4 may not have stressed the most important processes. Until further work is conducted, the speculation is that the calibration produced a better fit for WL-4 but may not have reflected reality.

In previous work, the phenomenon of hysteresis was identified as potentially important to correct simulation of water behavior in the lysimeters, especially in the lysimeters that were irrigated until drainage occurred. The UNSAT-H computer code was modified to include the hysteresis model proposed by Lenhard et al. (1991). Three test cases from Lenhard et al. (1991) were performed that showed the hysteresis code was correctly implemented in the UNSAT-H code. Lysimeter D-9 was then simulated. The results showed that the inclusion of hysteresis in the model did not appreciably improve the match to the measured water contents. However, simulated matric potentials were sufficiently changed by the inclusion of hysteresis that drainage into the gravel was able to occur.

In FY 1993, the three major areas of work were to 1) lengthen the simulation period to May 1993 (to include the first-ever drainage from lysimeter WL-4), 2) evaluate field-measured retention data relative to laboratory-measured data, and 3) apply the hysteresis model to lysimeter WL-4.

Two simulations of lysimeter WL-4 were conducted with the laboratory retention function using the standard parameters and the calibrated parameters. While the simulation with the calibrated parameters slightly improved the match to the measured storage values, neither simulation produced drainage. Matric potentials at the silt-sand interface were never high enough to allow a significant flux of water to move downward.

The field retention data did not correspond to the typical laboratory retention data. During the first 5 years, the field data were adequately described by a single retention function, albeit one that was different from the function used in all previous simulations. In early 1993, following a brief drainage period in lysimeter WL-4, the field retention data deviated from the behavior of the previous 5 years. Analysis revealed that the field data were displaying hysteretic behavior.

The hysteresis model was used to simulate lysimeter WL-4 for the 5.5-yr period. Simulated water contents were similar to those of the standard simulations, but the hysteresis model predicted drainage after 5 yr (the other simulations did not). Further work will include efforts to reconcile the field and laboratory retention data with a single hysteretic retention function that can be used in simulations.

**Evaluating Plant Models For Isolation Barriers**
***S. O. Link, R. N. Kickert, M. J. Fayer, and G. W. Gee (PNL)***

The isolation barrier design is intended to prevent or minimize the infiltration of water into the wastes. The design of the uppermost layer relies largely on plants to recycle precipitation back to the atmosphere. It is the first layer called upon to prevent water from draining into the waste. To gain confidence in the barrier's ability to prevent

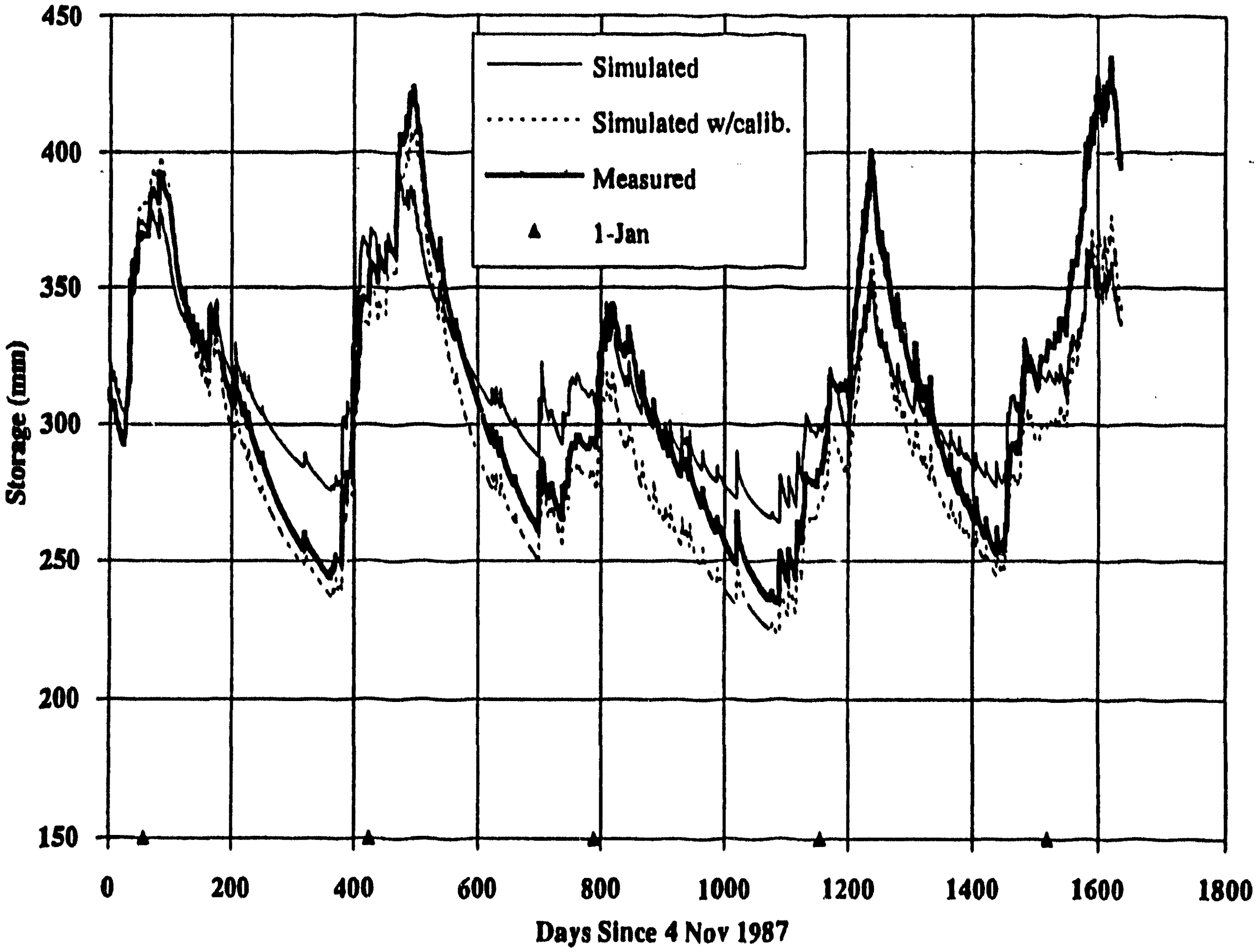


**Figure 2.14**. Storage Changes in Lysimeter WL-4

precipitation from becoming drainage, we have initiated efforts to predict the effect plants will have on water balance. Evapotranspiration is the combined loss of water from the soil via soil evaporation and plant transpiration. Plants extract a significant amount of water from the soil, relative to water that is evaporated from the soil. For instance, observation of the FLTF demonstrated that plants will reduce soil water storage to about 100 mm late in the summer compared to a value of about 200 mm for the bare soil lysimeters. It has been demonstrated that plants will reduce soil water storage to about 100 mm even when irrigated.

We have chosen to develop a modeling capability that will predict soil water extraction by plants. It is important to develop the capability to predict how much water various species will extract from the soil. For example, if the lysimeters, which are dominated by deep-rooted sagebrush, had been planted with cheatgrass, a shallow-rooted annual, we would predict more soil water storage.

It is possible for fire to kill sagebrush, allowing cheatgrass to gain a competitive advantage of the surface of the barrier. Climate change will change plant communities which could influence soil water storage. Our computer model must be able to predict soil water storage, given changes in plant community structure caused by climate change, fire, and competition with invasive species, some of which are very aggressive. We have initiated the modeling task by comparing two existing models; SWIM and SPUR.

The SWIM model allows up to 101 soil layers and 4 plant species, while the SPUR model allows up to 8 soil layers and 7 species. The original SPUR model was developed for shortgrass rangelands in northeastern Colorado (Wright

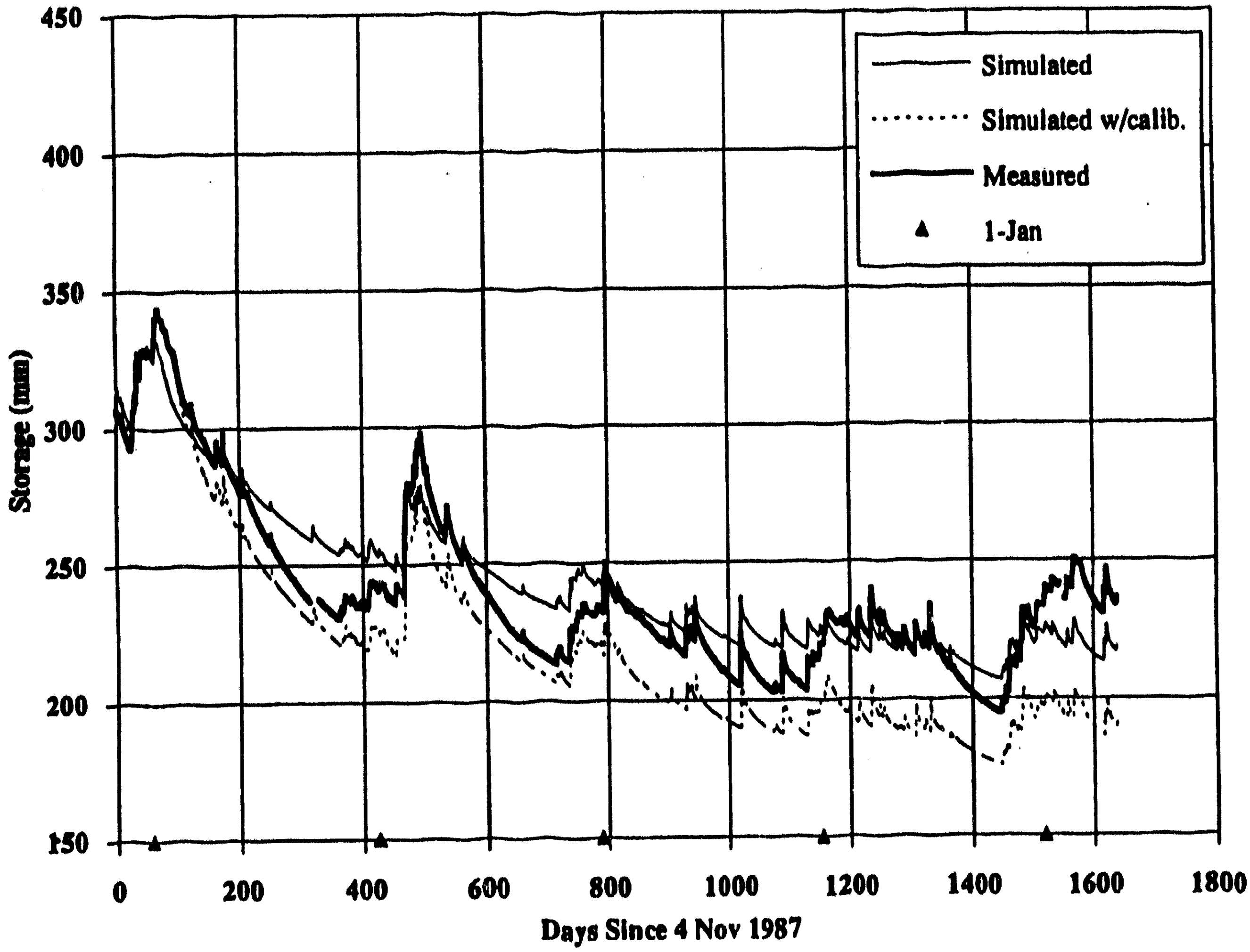


**Figure 2.15**. Storage Changes in Lysimeter WL-2

and Skiles 1987). We are determining the ability of these models to predict soil water extraction in the four FLTF weighing lysimeters, two of which are bare and two which have plants. The models are being compared with the predictions of the UNSAT-H, Version 2.0, code (Fayer et al. 1992) for the bare lysimeters. The UNSAT-H code allows only one plant species and, therefore, was not considered for our studies.

The SWIM model performed better than the original SPUR model under our test conditions. The model predictions were considered using the criteria of the root mean square error (RMS) if RMS < 2. The simulation of the bare ambient precipitation lysimeter (W2) had a RMS = 0.92 (Figure 2.16). There was a pattern in the residuals with time as can be seen in Figure 2.16. The model underpredicts in all seasons except summer, when it overpredicts. The simulation of the bare, irrigated lysimeter (W4) had a RMS = 1.31 (Figure 2.17) with a similar error pattern as in the W2 lysimeter. This compares well with an RMS value of 0.81 for the simulation of the W4 lysimeter with the UNSAT-H code. We can improve the SWIM model's predictive capabilities by further optimizing parameter values (calibrate the model) and decreasing the time step during the simulation. A new version of the SPUR model, named SPUR-91, with improved soil dynamics was acquired for further analysis.

We will continue our efforts to improve our ability to predict soil water storage by considering the planted lysimeters given our initial success with the bare lysimeters. With success we can then move on to the consequences of climate change and fire. We will use the model to evaluate the barrier's ability to prevent drainage for various future plant community possibilities.

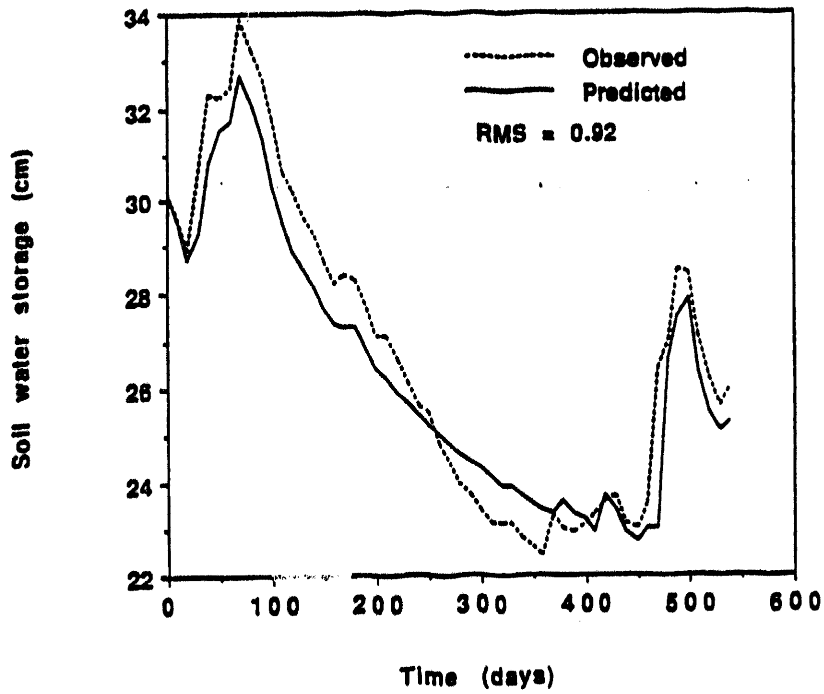


**Figure 2.16.** Prediction of Soil Water Storage Dynamics for the Bare Ambient Precipitation Field Lysimeter Test Facility Weighing Lysimeter

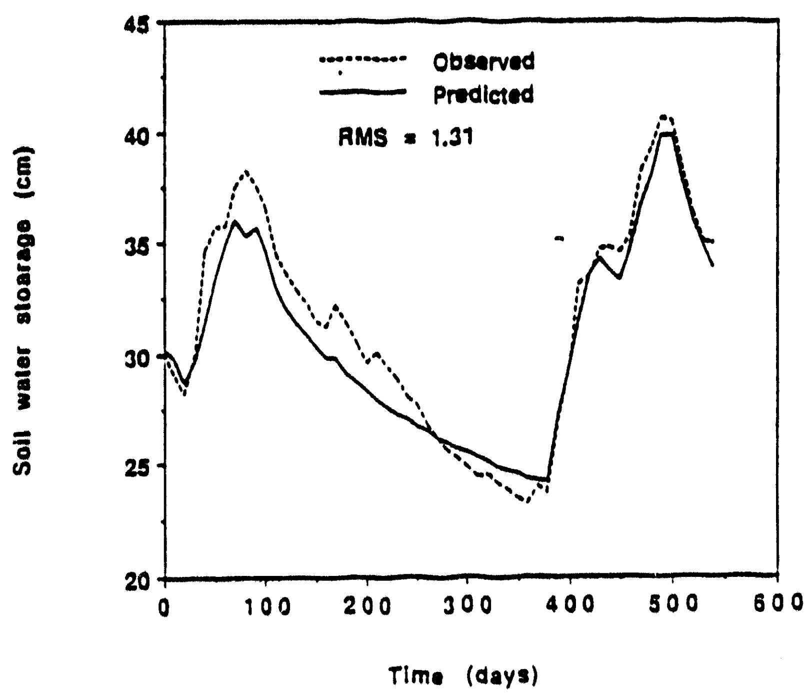


**Figure 2.17.** Prediction of Soil Water Storage Dynamics for the Bare Irrigated Field Lysimeter Test Facility Weighing Lysimeter

# 2.7 NATURAL AND MANMADE ANALOGS

**Hummock/Swale Studies: The Use of a Plant Intensity Measure As a Covariate to Reduce Error In Neutron Probe Data**

***S. O. Link, M. E. Thiede, and J. M. Thomas (PNL)***

We have been working at the McGee Ranch site, considered to be a natural vegetative analog to the ultimate barrier surface, to determine if soil water storage variability in the landscape is related to hummock/swale topography. We found that bare swales were wetter than hopsage hummocks or sagebrush swales, while soil water beneath hopsage hummocks and sagebrush swales was not significantly different. Soil water storage data gathered in the field can be highly variable, depending on landscape heterogeneity. In previous work we considered topographic condition as treatments (bare swales, hopsage hummocks, sagebrush swales), but did not include in the analysis any measure of the effect plants have on the response. Plant density was different within each of the treatments. For instance, sagebrush swales had one or more individual sage plants in a swale. It is likely that soil water storage will be less in an area with many plants than in an area with few plants. We hypothesized that including a plant density measure as an explanatory variable in our analyses (a covariate) would account for a significant amount of variation in the data and thus allow us to detect smaller treatment differences.

Shoot observations, which we term plant intensity, were taken to create a second variable for use in an analysis of covariance. An estimate was made of the green leaf area of all spiney hopsage (*Grayia spinosa*) and big sagebrush (*Artemisia tridentata*) plants within a 2-m radius of the neutron probe ports. Leaf area was measured by double sampling, using a model relating leaf area to canopy measures. This model was developed by measuring the height, greatest projected canopy diameter, and the diameter perpendicular to the greatest diameter and relating these measures to harvested leaf area. Fifteen shrubs of each species were measured to encompass all possible shrub sizes. Shrubs were measured and then harvested to determine leaf area. Single-sided leaf area was measured with a LI-3100 leaf area meter (Li-Cor, Inc., Lincoln, Nebraska). The model for *A. tridentata* is

$$Y = 303.35\,x - 228.08\,y - 110.67\,z - 1.421\,x^2 + 1.222\,y^2 + 0.9009\,z^2 + 0.01057\,xyz, \quad (1)$$

and for *G. spinosa* is

$$Y = 172.15 - 78.1\,x + 79.84\,y - 22.65\,z + 1.127\,x^2 + 0.7954\,y^2 + 0.6126\,z^2 - 0.02646\,xyz, \quad (2)$$

where Y is the leaf area ($cm^2$), x is the greatest projected canopy diameter (cm), y is the diameter perpendicular to x (cm), and z is the height (cm). Adjusted $R^2$ values were 0.957 for the *A. tridentata* relationship and 0.996 for the *G. spinosa* relationship. The sum of all such measures is defined as

$$p = \sum_{i=1}^{n} \left(\frac{Y}{d}\right)_i \quad (3)$$

where Y is whole plant leaf area ($m^2$), d is the distance from the center of the plant to the neutron probe port (m), and is the plant intensity (the sum of all such measures [i =1 to n] within a 2 m radius of the neutron probe port).

When plant intensity was used as an explanatory variable in an analysis of covariance, soil water storage (day 55, 1990) in the upper 125-cm profile (Figure 2.18) was negatively correlated with in the hopsage hummocks ($F=0.69$, $p=0.443$). On day 88, 1990, soil water storage was again found to be negatively correlated ($F=2.11$, $p=0.065$) with in the hopsage hummocks. No significant relation was found for any of the topographic conditions on subsequent dates in 1990. There were six observation dates between day 55 and day 215.

The purpose of analysis of covariance is to reduce experimental error so the statistical analysis can detect smaller treatment differences. If plant intensity has no relation to the soil water storage there is nothing to be gained from covariance analysis. Only the first two observation dates for the hopsage hummock areas showed such a relationship. In addition, the use of covariance requires that the slopes of all within treatment regression lines be the same (i.e., soil water storage as a function of plant intensity in hopsage hummocks, sagebrush swales and bare swales). This condition was not achieved in our analysis. Including a plant measure in our analyses as a covariate did not allow treatment effects to be compared with increased precision. However, both for bare and sagebrush swales, the range of soil water values observed was narrow. A larger range could result in a useful regression. The fact that there was a significant relationship between soil water storage and for the hopsage hummock condition means that significant amounts of variation in neutron probe data can be accounted for by the plant intensity variable. In future work in heterogeneous landscapes such as the prototype barrier, we can more efficiently and powerfully test treatment effects by considering the effect plants have on soil water storage.

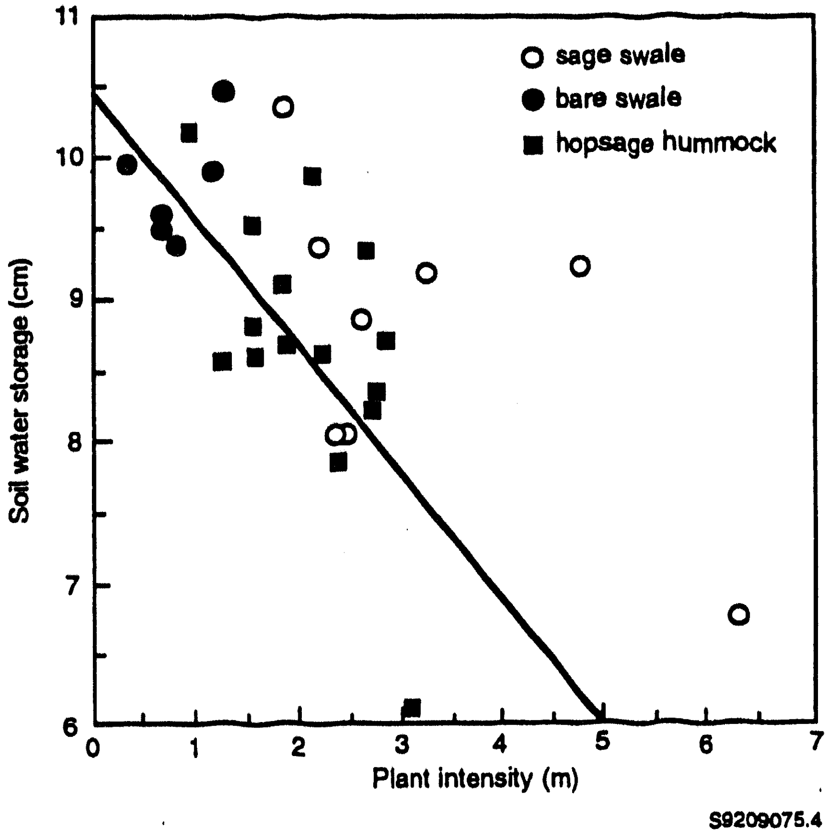


**Figure 2.18.** Regression of Soil Water Storage on Plant Intensity for Hopsage Hummocks

**Manmade Analogs: Ancient Mounds**
***J. C. Chatters, H. A. Gard, and R. Romine (PNL)***

Analogs provide data on the long-term performance of structures, media, or settings that resemble or are identical to those used in barriers. Whereas experimentation informs about short-term behavior of barrier media and designs, analogs tell us how well these may be expected to function on the time scale of centuries.

Closure caps for low-level radioactive waste disposal facilities are typically designed as layered earthen structures, the composition of which is intended to prevent the infiltration of water and the intrusion of the public into waste forms for centuries. Archaeological mounds, hundreds to thousands of years old, are closely analogous to closure caps in form, construction details, and intent, and are being studied to obtain an understanding of design performance.

Apparently, the most durable archaeological mounds are conical and are built in successive layers on a prepared surface during one or more closely spaced construction phases. Durable mounds typically have a revetment around their base, normally of stones, and a stone sheathing. The sheathing need not be continuous, but may simply be an admixture of stones with the mound matrix. Rectilinear designs built of homogeneous materials and lacking revetment or sheathing are not durable.

While mound age and the presence of a below-ground burial vault could be expected to be inversely related to mound durability, this is not the case. Design characteristics appear to be the controlling factor. Mound degradation is most often attributed to agricultural activity, slope wash, vandalism, and borrowing for fill material. The existence of certain design features, particularly the use of stone in construction, do control slope wash and the effects of agricultural activity; however, they have no effect on the frequency of borrowing or vandalism. Borrowing, vandalism, and destruction by agricultural activity result, respectively, from the burial of valuable items beneath mounds and the raised relief of mounds in otherwise level areas. Vandalism, or more accurately, looting, is exacerbated by the obviously manmade appearance of mounds, which identifies them as potential sources for objects or materials of value.

### Asphalt Analogs

***J. C. Chatters, H. A. Gard, and R. Romine (PNL)***

Asphalt is a low-permeability component of planned permanent isolation barriers, but serious questions exist concerning its durability and performance for periods of 1000 years or more. This subtask is designed to investigate the effects of aging on asphalt by studying the effect of intentional long-term burial on rates of oxidation and volatile loss.

A draft test plan for the asphalt analog subtask has been completed and follows a five-step procedure to obtain data on the aging of buried asphalt from artifacts of asphalt manufactured by the ancients. These involve:

- identification of museum collections of asphalt artifacts from selected areas where natural asphalt occurs, and samples of artifacts and associated organic materials obtained

- collection of samples from the natural asphalt seeps that were the source of material for the artifacts

- radiocarbon dating the organic material associated with the artifacts to establish the time of asphalt artifact manufacture and burial

- performance of elemental analysis on artifacts and natural asphalt to verify origin from the same source

- chemical analyses by infrared spectroscopy and high-pressure liquid chromatography, of the artifacts and natural samples to discern changes attributable to long-term burial.

The result of these steps will be a trajectory of aging, useful for assessing the extent to which contemporary barrier designs can effectively employ asphalt as redundant features for limiting the downward penetration of surface water. The first suite of 14 archaeological asphalt samples and associated marine shell and animal bone have been obtained from the Santa Barbara Museum of Natural History. These samples are estimated to range in age from less than 400 to over 3000 years. The first radiocarbon date taken from a sample of shell associated with an asphalt fragment dated to 100 B.C. Natural asphalt were also obtained from sites at Goleta and Carpenteria, California, the location from which the archaeological materials are thought to be derived. Elemental and chemical analyses are under way.

# 2.8 LONG-TERM CLIMATE CHANGE EFFECTS

**Long-Term Climate Change Effects**
***K. L. Petersen (WHC) and J. C. Chatters (PNL)***

A multi-disciplinary approach to climatic data acquisition is being relied on to obtain defensible information that will aid in satisfying 1) design and regulatory requirements, 2) barrier performance assessment requirements, and 3) hydrologic and other barrier task input needs. The strategy being applied to accomplish this is a series of task studies that provide for an understanding of the range and probability for recurrence of past climate change and for a projection of potential future climate at the Hanford Site. These tasks focus on identifying and characterizing historic and prehistoric climatic patterns through literature review and specialized field studies. A local climate forecast model is being considered that will couple the past climate patterns with models of regional and global climate change to provide test scenarios that can be used in barrier performance assessment. The ultimate objective of these efforts is to obtain defensible probabilistic projections of the long-term climate variability in the Hanford Site and Pasco Basin region.

Late in FY 1989, an independent third-party technical peer panel reviewed a draft study plan for the climate change task. That draft study plan reflected an integration of plans first developed for the Basalt Waste Isolation Project (BWIP), with the needs of the Permanent Isolation Barrier Development Program. In FY 1990 the study plan was completed but, due to funding limitations during FY 1991 and early FY 1992, was not submitted for clearance until late FY 1992. It was published in 1993 (Petersen et al. 1993). The study plan contains task and subtask descriptions, preliminary budget estimates, and schedules. Based largely on the recommendations of the third-party review, the program has become more focused and the cost of performing the work has been reduced from an initial estimate, based on applicable BWIP costs in FY 1988, of $3.4 million to a current estimate of about $1.9 million. A modular test has been designed to provide an overall research strategy that can be scaled to accommodate future funding uncertainties or can accommodate changes in the goals and objectives of the Permanent Isolation Surface Barrier Development Program.

The tasks and subtasks in the climate program have been numbered as follows:

0. Task Administration
1. Identification of Climatic Data Needs
2. Synthesis of Existing Information
   - 2.1 Modern Climatic Patterns
   - 2.2 Holocene Paleoclimate Literature
   - 2.3 Late Quaternary Literature
   - 2.4 Flood Records
   - 2.5 Global Climate Modeling
3. Pollen and Lake Sediment Studies
   - 3.1 Scablands Pollen Site Transect
   - 3.2 Full Glacial Pollen Study
4. Fluvial Sediments and Ground-water Studies
   - 4.1 Fluvial Indicators
   - 4.2 Episodic Groundwater Recharge
5. Terrestrial Sediment Studies
   - 5.1 Studies of Eolian Processes
   - 5.2 Faunal Indicators
6. Past Climate/Vegetation Variations
7. Future Climate/Vegetation Projections
8. Local Climate Forecast Model
9. Model Calibration and Validation
10. Projection of Future Climates
11. Generation of Weather Statistics
12. Identification of Future Spatial Analogs
13. Input to Barrier Performance Assessment

Notable highlights since those reported in the FY 1990 Highlights Document (Cadwell 1991) included five publications that support many of the above-listed tasks and subtasks. The defensibility of estimates of potential future climate in the Pacific Northwest and the Western United States is greatly enhanced by demonstrating an understanding of the present climate system and the range of change that has occurred in the past. Although these publications vary in their focus, they attempt to provide regional, continental, and global context for past, and possibly future, climate change. It is clear that to fully understand the underlying, driving mechanism, regional climate cannot be viewed in isolation but as part of a larger continental and global system.

Using a computer model developed by the Northwest Power Planning Council, Chatters et al. (1991) simulated climatic conditions which existed in the Columbia River System and Yakima sub-basin between 6000 and 8000 years ago, when temperatures were 1°C or 2°C warmer and slightly drier than conditions today. The authors drew on data collected by the Yakima Indian Nation as well as data concerning prehistoric Eastern Washington climate. From the reconstructed hydrological record it was concluded that 6000 to 8000 years ago:

- stream flows were less than 70% of modern
- many small, low-elevation, perennial streams became intermittent (dry during parts of the year)
- streams had finer bed loads (greater sedimentation)

- water temperatures were higher
- the spring peak flow (freshet) ended 3 to 4 weeks earlier than it does today.

Such conditions would be expected in a climate warmer than that of today, one with less precipitation and with a higher percentage of annual precipitation falling as winter rain. This is especially important since increases in atmospheric concentrations of greenhouse gases are predicted to raise global temperatures by as much as 3°C over the next 100 years. Such changes could impact the performance of the proposed isolation barrier and, therefore, would be important considerations when modeling barrier performance.

In a later article, Chatters and Hoover (1992) used a well-dated sequence of floodplain development in the Wells Region of the upper Columbia River, near Okanogan, Washington, to compare the paleoenvironmental history of the Columbia River Basin. Understanding the response of fluvial system to past climate changes is useful in predicting its response to future shifts in temperature and precipitation. Results of this comparison indicate that episodes of aggradation (sediment deposition), which occurred approximately 9000-8000, 7000-6500, 4400-3900, and 2400-1800 years ago, coincided with climatic transitions that shared certain characteristics.

The inferred climates associated with aggradation had at least moderate rates of precipitation, occurring mainly in the winter, coupled with moderate winter temperatures. Such conditions would have resulted in the buildup of snowpack and a high frequency of rain-on-snow events. The warming and precipitation increases predicted for the Pacific Northwest under most $CO_2$-doubling scenarios are likely to repeat these conditions and be important considerations in modeling isolation barrier performance. Chatters and Hoover (1992) provided a good summary of regional reconstructions.

Petersen (1991) examined climatic patterns in the west, contrasting mountain and desert climates, and reviewed the important features of the general atmospheric circulation patterns effecting the Western United States. Petersen describes the vast changes that took place during the height of the pleistocene climate in the Western United States contrasted with the present. Such contexts are important in attempting to understand the underlying driving mechanisms for future climate change in the Pasco Basin.

In a document entitled, *A Warm and Wet Little Climatic Optimum and a Cold and Dry Little Ice Age in the Southern Rocky Mountains, U.S.A.*, Petersen (1992) described a particularly well-documented case study of climate change in the southwestern United States over the past 2000 years. While this particular study can be applied directly to the development of isolation barriers at DOE's Monticello (Utah) Remedial Action Project for uranium mill tailings, it provides a test case to be compared and contrasted with the climate change history being developed for the Pasco Basin and surrounding regions.

The fifth publication, Petersen and Chatters (1993), describes the accomplishments of the Long-Term Climate Task from FY 1990 through 1992. Specific progress is reported for Task Administration (Task 0), Identification of Climatic Data Needs (Task 1), Synthesis of Existing Information (Task 2), Pollen and Lake Sediment Studies (Task 3), and Terrestrial Sediment Studies (Task 5).

Under Task 3, subcontracts have been put in place with Washington State University, Pullman, Washington, and with Golder Associates, Seattle, to collect, date, and analyze fossil pollen and other lake sediment data obtained from long sediment cores. This will allow further refinement of the developing climate history of the Pasco Basin region and will provide more location-specific climatic information with special emphasis on the periods 125,000, 18,000, and 3,500 years ago. This task has been divided into two subtasks.

The first subtask (3.1) is a transect of pollen sites across the scablands of the central Columbia Basin. It focuses on the pollen records contained in the lacustrine sediments from three Washington lakes. These are 1) Williams, near Cheney; 2) Wildcat, near Hooper; and 3) Sulphur, near Connell. Because the choice of these lakes extend from the present forest zone into the steppe zone of eastern Washington, they are expected to provide detailed information on the distributions of vegetation types and levels of groundwater in the Pasco Basin and vicinity. An opportunity to review the results was provided in FY 1991 at the ParkNet sponsored workshop (June 19-21), "Past Rates of Ecological Change," held at PNL under the auspices of the Environmental Sciences Division, Office of Health and Environmental Research, Office of Energy Research, DOE.

Subtask 3.2 is directed at coring and analyzing the pollen from Carp Lake, near Goldendale, Washington. This site completes the northeast to southwest transect of pollen cuts through the Pasco Basin. The lake coring operation, recovering nearly 20 m of lake sediment, providing a record of past climatic changes dating back approximately 100,000 years. The goal of the project was to obtain cores going deep enough to cover the last interglacial to glacial transition (nominally 115,000 years ago). This was not quite reached so efforts are underway to go back to Carp Lake to obtain deeper cores. However, the climate record that has been obtained from Carp Lake indicates that the Pasco Basin was under the influence of Ice Age climate 100,000 years ago. While continental glaciers expanded out of the area that's now Canada toward the present-day state of Washington, the Columbia Basin was much colder and drier than it is at present. These conditions lasted up until about 10,000 years ago with little interruption. Over the last 10,000 years, the climate in the Pasco Basin warmed significantly as the earth cycled out of the Ice Age and into climates more like the present. Over the last 10,000 years there has been periods that were both warmer and wetter than the present, but for the last 2,000 years climates of the Pasco Basin have been much like the present.

Because of the cyclical nature of past climate, scientists believe that the earth will soon be cycling back into another Ice Age as the geometry of the earth's orbit changes to one where the earth receives less solar energy. The Carp Lake record suggests that if this were to happen in the next few thousand years (some think in as little as two thousand) then colder and drier climate would again return to the Pasco Basin. The information being obtained from the Carp Lake studies will be used to provide defensible analogs for predicting potential future climatic changes that could affect barrier performance on a number of time scales into the future.

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# APPENDIX A

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# APPENDIX A

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# APPENDIX B

## Permanent Isolation Surface Barrier Development Teams

# APPENDIX B

## Permanent Isolation Surface Barrier Development Teams

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David L. Fort (KEH)
Glendon W. Gee (PNL)
Dennis R. Meyers (WHC)
Jack C. Sonnichsen (WHC)
Robert I. Watkins (KEH)

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| Biointrusion Control | Larry L. Cadwell (PNL) |
| Water Infiltration Control | Glendon W. Gee (PNL) |
| Erosion Deposition Control | Wallace H. Walters, Jr. (PNL) |
| Human Interference Control | Kenneth L. Petersen (WHC) |
| Barrier Construction Materials Procurement | Dennis R. Meyers (WHC) |
| Prototype Barrier Designs and Testing | N. Richard Wing (WHC) |
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