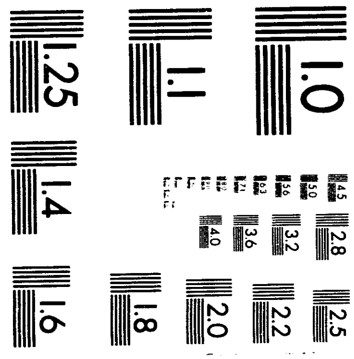
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THE DEVELOPMENT OF PERMANENT ISOLATION BARRIERS FOR BURIED WASTES IN COOL DESERTS: HANFORD, WASHINGTON.

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ABSTRACT

The Hanford Site Surface Barrier Development Program has been developed to design and test an earthen cover system (barrier) that can be used to inhibit water infiltration, plant and animal intrusion, and wind and water erosion. The barrier is designed to isolate buried wastes from environmental dispersion for at least 1000 years. The Hanford Site is located in south-central Washington, which is characterized as a cool desert. Yearly precipitation averages 160 mm, falling mostly in the winter.

The prototype barrier design includes a fine-soil surface with a relatively high infiltration rate to limit infiltration below the fine soil by inducing temporary storage near the surface. 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 material below will further limit infiltration and promote evapotranspiration. Should water pass the interface, it will drain laterally on a low permeability asphalt layer through a coarse-textured sand/gravel filter layer.

Water infiltration control is a key component in barrier design. Lysimeter studies indicate that a surface layer of fine soil with deep-rooted plants precludes drainage even with three times normal precipitation. Drainage on the Hanford Site occurs when soils are coarse textured even when plants are present.

Studies at the Hanford Site have shown that plants and animals will significantly interact with the barrier. Plants serve to transpire soil

water back into the atmosphere. Native deep-rooted (down to 3 m) perennials such as sagebrush and bunchgrasses will best recycle water, while shallow-rooted (~60 cm) introduced annuals such as cheatgrass can potentially lead to infiltration. Deep-rooted tumbleweeds potentially could intrude into the waste, but coarse rock layers and a redundant asphalt layer will prevent penetration. Animal intrusion studies indicate that small animal burrows have no significant effect on soil water storage, and that large animal burrows have a small effect in winter that disappears in spring or summer.

Current work tests our integrated scientific and engineering concepts on a large prototype barrier to determine if it can isolate buried wastes from environmental dispersion.

INTRODUCTION

Large amounts of radioactive and hazardous wastes are currently buried in shallow landfills at U.S. Department of Energy (DOE) facilities.[1] The Hanford Site contains 10.3% of all low-level nuclear waste in the United States.[2] Such wastes pose a potential threat to human health and to the environment.[3] Options for waste disposal include exhuming or isolating in place. A waste isolation option includes the use of surface cover systems. A major challenge in the development of surface cover systems or permanent isolation barriers is to design the barrier to ensure that buried wastes are isolated from dispersion by environmental forces for long periods of time.[4] In the case of radioactive wastes, the period of isolation has been suggested as being from at least 1000 years[5], to 10,000 years[6], to 24,000 years[7] and up to millions of years[8].

The need for permanent isolation for extended periods of time means that special consideration of dispersal factors needs to be taken into account in the design of barriers. Factors that can disperse wastes into the environment include water, wind, plants, and animals. Water is the primary agent for dispersion of wastes into the environment and has been the primary cause of barrier failures.[6] As a consequence, arid environments where, by definition, water is scarce, have been proposed as the best location for siting waste repositories.[3,7]

Research on the application of permanent isolation barriers to wastes at the arid Hanford Site, has been ongoing since the early 1980's.[9] It has been demonstrated that intrusion, by roots, animals, and ants, into buried waste could be prevented if a layer of loose rock covered with an asphalt emulsion was placed between the buried waste and the topsoil.[10] This soil structure, a fine top-soil over loose rock, also constitutes a capillary break.[11] Such a configuration limits downward water movement and tends to store water in the soil, where it can be lost to the atmosphere through evaporation and transpiration. The use of a capillary break is one of the major design features of the permanent isolation barrier and has been investigated extensively at Hanford.[12,13,14]

Plants and animals will have significant effects on the upper fine soil layer where they live and can, potentially, compromise the barrier. Thus, it is important to determine how plants and animals will affect the soil water balance, the stability of the surface subjected to wind and water erosion, and the potential for biointrusion into the waste.[9,15]

The purpose of this report is to present the results of research on surface hydrology and the role of plants and animals on permanent isolation barrier effectiveness at Hanford. These topics are a subset of a larger set of studies on permanent isolation barriers listed in Table 1. A complete review of these tasks has been documented.[16] We also discuss current work that tests our integrated scientific and engineering concepts on a large prototype barrier to determine if it can isolate buried wastes from environmental dispersion.

SITE DESCRIPTION

The study area is on the United States Department of Energy's Hanford Site in south-central Washington (Fig. 1). The Hanford Site is 1480 km^2 in area and varies in elevation from 120 to 1200 meters above sea level (m.a.s.l.). The area has an arid climate with hot dry summers and cool wet winters. Average yearly precipitation is about 162 mm, falling mostly in the fall and winter.[17]

The McGee Ranch site (244 m.a.s.l.), from which barrier surface soils are obtained (Fig. 1), is dominated by shrubs (*Grayia spinosa* and *Artemisia tridentata*) with several species of forbs, perennial grasses, and the annual grass *Bromus tectorum*. The soils have been classified as Xerollic Camborthids such as Warden silt loams.[4] A description of soil characteristics is given in Table 1. A complete site description has been documented.[18]

The site where the permanent isolation barrier is to be built is located on the 200 Area Plateau at an elevation of 223 m.a.s.l. (Fig. 1). It has the same floral makeup as the McGee Ranch site with the addition of the shrub *Purshia tridentata*. The soils are coarse-textured alluvial sands covered by a mantle of wind-deposited fine sands of the Quincy soil series (mixed, mesic Xeric Torripsamments).[4]

BARRIER ISSUES

Permanent isolation barriers use engineered layers of natural materials to form an integrated structure with redundant protective features. Natural construction materials such as fine soil, sand, gravel, riprap, and asphalt have been selected to optimize barrier performance and longevity. The main objectives of the barrier design are that the structure be maintenance-free, that wastes be isolated for a minimum of 1,000 years, that drainage be limited to near-zero amounts (0.5 mm yr^{-1}), and that the likelihood of biointrusion by plants, animals, and humans be minimized.[19]

The permanent isolation barrier (Fig. 2) consists of various materials placed in layers forming an above-grade mound over the waste zone. The design consists of a vegetated fine-soil layer overlying layers of sand, gravel, riprap, and asphalt. Each layer serves a distinct purpose. The vegetated fine-soil layer acts as a medium in which moisture is stored until the processes of evaporation and transpiration return the water to the atmosphere (Fig. 3). The coarser materials (sand, gravel, riprap) below the fine-soil layer create the capillary break that inhibits the downward infiltration of water through the barrier. The coarse materials also inhibit biointrusion below the fine-soil layer. The asphalt layer will be placed below the coarse layers just above the ground surface. This layer will divert any water that gets through the capillary break away from the waste zone.

Surface hydrology

We will discuss the results of surface hydrology studies done at two sites. The first study examines the effectiveness of capillary break configurations using weighing lysimeters[14] and the second considers the effect of surface conditions on soil water storage in small tube lysimeters.[1]

The study of the effectiveness of capillary break configurations on soil water storage was conducted at the 200 Area Lysimeter Facility (Fig. 1). We tested the hypothesis that a thick fine-soil layer over coarse sands would prevent drainage under four treatment conditions: ambient precipitation non-vegetated, ambient precipitation vegetated, additional precipitation non-vegetated, and additional precipitation vegetated.

The weighing lysimeters are 1.5 x 1.5 x 1.7 m and contain about 5,900 kg of soil (1.5 m deep) placed on top of about 0.2 m of sand (Fig. 4). Vegetation consists of the deep-rooted evergreen shrub *Artemisia tridentata*, the deep-rooted perennial bunchgrass *Oryzopsis hymenoides*, the shallow-rooted perennial bunchgrass *Poa sandbergii*, and the shallow-rooted winter annual grass, *Bromus tectorum*. Precipitation treatments consisted of ambient precipitation and twice ambient precipitation (~320 mm yr^{-1}). In the last 3 years of observation, precipitation was increased to 480 mm yr^{-1}. Scale weights are recorded every 20 s and have been recorded since November 1987. To measure drainage, these lysimeters have sloping bottoms and a drain port at the low point.

The soil water storage dynamics of the four lysimeters from 1987 through 1993 are presented in Figure 5. All four treatments exhibit a seasonal cycle of storage with maximum storage occurring in March after the winter rains and minimum storage occurring in October just before winter rains begin. The ambient precipitation lysimeters had the smaller seasonal amplitude compared with the irrigated lysimeters. The vegetated lysimeters had the smaller storage having minimum values near 90 mm in ambient or irrigated lysimeters. The non-vegetated lysimeters had the larger storage, which was over 200 mm over the entire period. The only period where drainage occurred was in the non-vegetated irrigated lysimeter in 1993 when storage exceeded the 500-mm level needed to cause drainage.

Vegetation plus soil evaporation is able to return at least 480 mm yr^{-1} to the atmosphere. Water storage in the vegetated lysimeters is reduced to a unique lower limit every year, which indicates that the plants use all the water available to them. Plant biomass in the irrigated lysimeters was more than twice as great as biomass in the ambient precipitation lysimeters, which indicates that water is limiting for biomass production even with twice ambient precipitation.[14] A capillary break system with vegetation verifies of the performance of capillary barriers for the Hanford Site even under extreme conditions.

The non-vegetated lysimeters always had more water stored in them than the vegetated lysimeters. In only one instance did drainage occur in the non-vegetated lysimeters. This occurred in the 3 times ambient precipitation treatment when the drainage limit was exceeded in February 1993. This indicates that a capillary barrier will prevent drainage under almost all worst-case scenarios for the barrier. The worst case scenario is a fire that destroys all vegetation with virtually no recovery followed by an extremely wet winter (e.g., more than 3 times ambient precipitation). This scenario is not very likely because vegetation usually recovers rapidly after fire in the shrub-steppe.[20] Thus, it is reasonable to conclude for the Hanford Site, that vegetated capillary barriers, similar the lysimeter design, will not allow drainage under present or enhanced precipitation regimes.[14]

The study of the effect of surface conditions on soil water storage was also done at the 200 Area Lysimeter Facility (Fig. 1) in small tube weighing lysimeters (Fig. 6). Soil water storage will be minimized if a surface gravel layer is not used and if plants are used to transpire water back into the atmosphere. We hypothesized that a gravel layer on the surface would eventually result in drainage through the capillary break, and that plants would minimize soil water storage. Because the environment where the barrier is to be built has high winds that could cause loss of fine surface soils, we observed the effect that an admixed surface (gravel mixed into the fine soil) would have on water budgets. Admixes lead to a surface armor development that reduces wind erosion.[21] Finally, because of high winds, it was hypothesized that dune formation or a sand on top of the barrier would increase soil water storage.

The purpose of this study was to determine the optimum surface condition to minimize the potential for drainage. We tested the effect of soil, admix, sand, gravel surfaces with and without vegetation on soil water budgets and drainage. We also added water (2 and 3 times annual precipitation) to the system to determine how much water these treatments could hold before drainage occurred.

The small-tube lysimeter facility consists of an array of 21 rows of 5 lysimeters (Fig.6). The lysimeters are 170 cm long by 30 cm wide sections of plastic pipe. The bottom ends are fitted with a cap and a drain port. The lysimeters are placed in larger plastic pipe sleeves. Weighing is done with a calibrated load cell attached to the gantry. Weighing and drainage measurements were taken monthly from December 1988 through August 1992. The lysimeters were filled with Warden silt loam overlying a capillary break consisting of sand on top of gravel. The surface treatments consisted of soil, an admix of gravel (30% by weight) in the top 20 cm of soil, gravel, and sand. These treatments were tested with and without vegetation and with and without additional water.

Since the beginning of the experiment under ambient precipitation conditions, all the soil and admix lysimeters have had a net decrease in soil water storage. Vegetation caused a greater decrease in storage than in non-vegetated lysimeters. Enhanced precipitation resulted in a small increase in storage in the non-vegetated lysimeters. Enhanced precipitation with vegetation still resulted in a decrease in storage over time. This is because of the associated increase in vegetation associated with additional water.

The presence of gravel or sand on top of the soil column has resulted in increased storage and drainage whether the lysimeters were irrigated or not. The presence of vegetation prevented drainage from occurring in the nonirrigated gravel mulch lysimeters. The addition of water to the gravel and sand surface lysimeters resulted in drainage whether they were vegetated or not.[1,22]

On the basis of on these results, we conclude that an admix surface with vegetation would minimize the chance of drainage and erosion.

Plants

Vegetation plays a significant role in the achievement of a successful barrier in arid environments.[4] Plants control soil water storage and dynamics, protect the surface from wind and water erosion, and can potentially compromise the barrier by extending roots into the waste. Work on these issues will be reviewed leading to recommendations for the type of vegetation that should be established on the prototype barrier to minimize the chances of recharge, erosion, and root intrusion into the buried waste.

It has been established at Hanford that areas dominated by shallow-rooted annuals such as *B. tectorum*[23] can accumulate water beneath the root zone which can, potentially, lead to recharge.[24] Variation in the rooting depth of deep rooted perennials is associated with variation in soil water storage.[20] Soil water storage increased below the 125 cm depth in a *Pseudoroegneria spicata* dominated community in comparison with a more deeply rooted community dominated by *A. tridentata* and *P. spicata*. The presence of deeply (200 cm) rooted shrubs such as *A. tridentata* and *Grayia spinosa* at McGee Ranch has been demonstrated to extract more water from the soil profile than areas dominated by sparse vegetation. Areas dominated by these shrubs were also able to extract two times normal precipitation from the soil profile.[18] We recommend that deep-rooted perennials be established on the barrier to minimize chances that recharge will occur.

The establishment of deep-rooted plants on the surface of the barrier brings up the issue of roots entering the waste zone. Deep-rooted plants (*Chrysothamnus nauseosus*[25]; *Salsola kali*[26]) have been observed to accumulate fission products when growing over buried radioactive wastes. The presence of fission products in the shoot is a consequence of roots penetrating the radioactive wastes. Past workers have sought to prevent the intrusion of roots into buried wastes by maintaining a loose rock layer between the waste and the surface soils.[10] They were successful as long as an asphalt layer was present to prevent soils, and thus roots, from filling cracks in the rock layer. Others have prevented roots from entering wastes by keeping the surface barren of plants. This has been done by placing gravel on the surface and maintaining an herbicide program. This practice, unfortunately, leads to drainage because of the presence of the gravel and the lack of plants.[4,27]

On the prototype barrier, the chances that roots will enter buried wastes are small because there will be a loose rock layer between the waste and the surface soils. As long as this zone is dry, roots will not enter. Even if this zone should become wetted, the asphalt layer below it should prevent roots from enter the waste below the asphalt.

Animals

Animal studies have addressed the impact of large and small mammal burrows on soil moisture dynamics. It was hypothesized that burrows would increase the accumulation of water by allowing water to drain into the holes. In addition, there was concern that burrows could provide a preferential pathway for water to bypass the fine-soil layer, enter the coarse layer, and eventually, enter the waste.[19] These studies were done in natural systems[28] and in large steel boxes buried at grade.[29] Supplemental rain was added to test the impact of higher rainfall on potential drainage. Measurements were taken using calibrated neutron probes down to a depth of 125 cm. The main result was that small animal burrows had no significant effect on soil water storage, and that large animal burrows had only a small effect in winter that disappeared in spring or summer. The addition of twice normal precipitation did not result in increased soil water storage. An explanation for these results is that evaporation was enhanced by a combination of soil turnover and subsequent drying and by ventilation into the soil column through the burrows. Although animals apparently do not significantly influence soil water budgets they still pose risks associated with uptake of wastes, wind erosion of soils brought to the surface, and plant community dynamics.[30]

The risk of animals intruding through the barrier structure is considered small given that intrusion into buried waste could be prevented if a layer of loose rock covered with an asphalt emulsion was placed between the buried waste and the topsoil.[10] The proposed permanent isolation barrier has a thick asphalt layer below 3 m of a layered structure of fine soil, sand, gravel, and riprap rock of coarse gravel (Fig. 2). The rock and asphalt should physically prevent intrusion and the 3 m depth of the cover is too deep for most animal burrow depths. Burrow depths are less than 1.5 m for a wide variety of potential animals.[30]

The potential for the loss of cast soil from burrows by wind erosion that could eventually lead to loss of the silt layer, which could compromise the barrier, has not been measured. The impact of animal burrow soil disturbance on plant community dynamics has not been carefully examined. It has been observed that weedy annuals established on soils disturbed by animals.[28] Disturbed soils potentially lead to a plant community dominated by weedy annuals that, if shallow rooted, could increase the potential for drainage.

Prototype Barrier

The Hanford permanent isolation barrier program has investigated how various subcomponents and processes interact under worst-case environmental conditions to assess the validity of our concepts for the long-term isolation of wastes from environmental dispersion. Some of these subcomponents are listed in Table 1. A complete review of progress has been documented.[16] Although we have gained significant experience on how subcomponents respond to stressful conditions, we still need to understand how a barrier behaves as an integrated unit. In addition, construction issues have not been addressed. To investigate how well our construction concepts reflect true operating conditions and test how an integrated barrier responds to stress, we have initiated construction of a prototype barrier.[9]

The barrier will be constructed on the 200 Area Plateau at the 200-BP-1 Operable Unit. It will be built over the B-57 Crib located in the northwest quadrant of the 200 East Area (Fig. 1). The surface area of the barrier will be about 6000 m^2. The surface will be elevated with one side relatively steep (2:1 horizontal to vertical) covered with basalt rip-rap. The other side will be shallow (10:1) and will consist of local gravel/sand backfill. The entire structure will be 105 m long and 64 m wide.

The prototype surface will be sectioned into four study plots, two of which will receive water at 3 times ambient precipitation. The surface will be vegetated with a combination of deep-rooted shrubs and grasses.

Water balance monitoring will be taken in vertical and horizontal access ports with neutron probes. Drainage measurements will be made with pan-type lysimeters under each plot. Drainage along the slopes will also be monitored.

Wind erosion testing will include documenting the wind profile of the prototype and evaluating wind erosion from the sides and top surfaces of the test plots, using standard erosion pin techniques. Water erosion will also be documented for each plot, and the erosion potential of the steep side slopes carefully assessed, particularly after the water application tests. Biointrusion testing will be confined primarily to observation of root penetration into soil and sublayers using mini-rhizotron systems, which allow for root observations during and after plant establishment.

The effectiveness of an asphalt sublayer to shed water will be investigated. This layer, placed beneath the entire barrier, will be designed to perform as a low-permeability barrier, diverting the water that infiltrates the barrier on the sideslopes. This diverted water will be captured at the toe of the barrier slope and will be used by riparian vegetation growing at the toe of the slope. It is intended that all water incident upon the barrier will cycle back into the atmosphere through evapotranspiration. Assessment of how well this process works will be an important feature of prototype testing and monitoring.[9]

SUMMARY

Progress in the Hanford Site Surface Barrier Development Program has been reviewed concerning the ability of engineered barriers to isolate buried wastes from environmental dispersion. A fine-soil surface with a relatively high infiltration rate is planned to limit infiltration below the fine soil by inducing temporary storage near the surface. 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 material below will further limit infiltration and promote evapotranspiration. Should water pass the interface, it will drain laterally on a low permeability asphalt layer through a coarse- textured sand/gravel filter layer.

Current work will integrate our scientific and engineering concepts on a large prototype barrier to determine if it can isolate buried wastes from environmental dispersion. This effort promises to provide an economically and environmentally sound solution to the waste problem at the Hanford Site.

ACKNOWLEDGMENTS

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Table 1. Permanent isolation barrier development task groups.

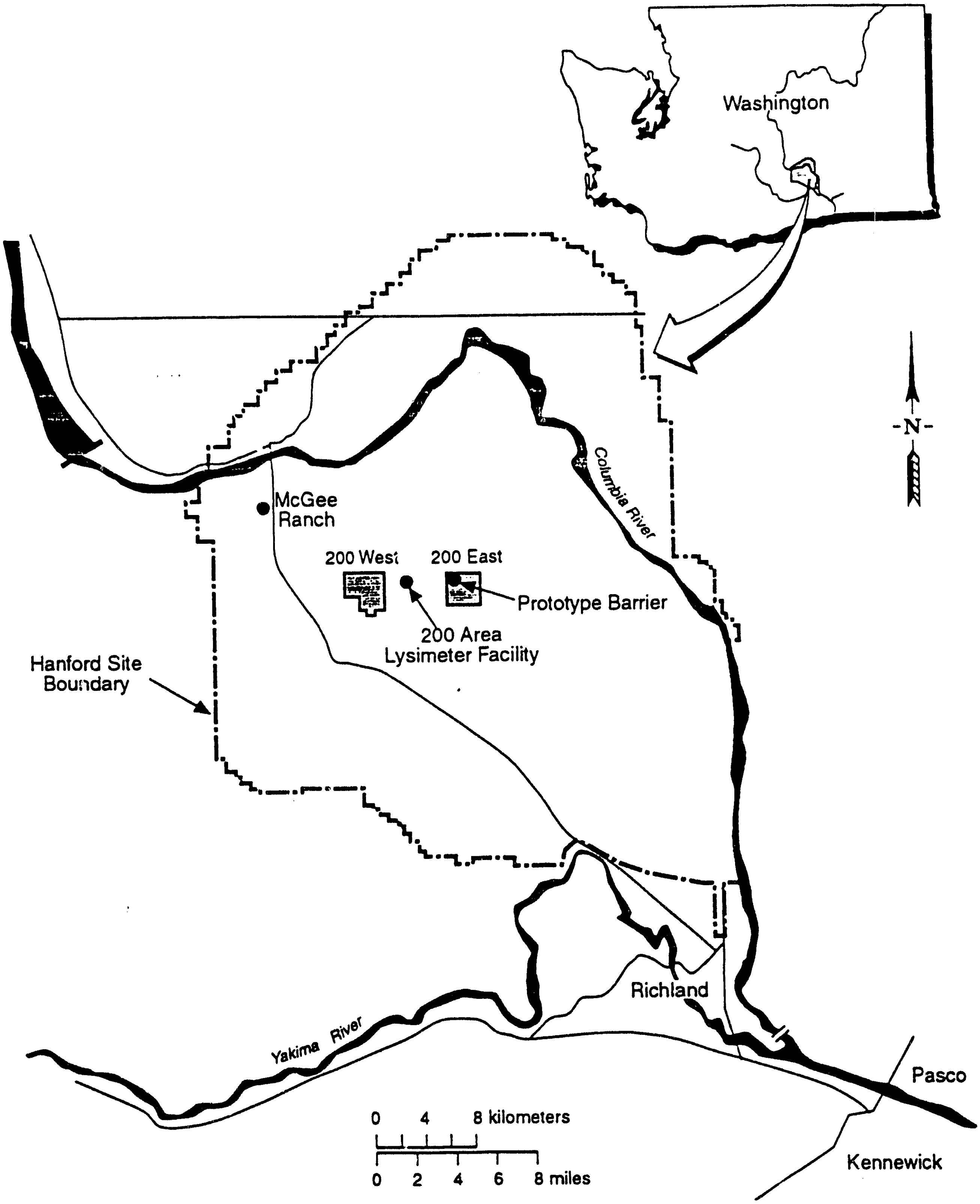
1. Biointrusion control
2. Water infiltration control
3. Erosion/deposition control
4. Physical stability testing
5. Human interference control
6. Barrier construction materials procurement
7. Prototype barrier designs and testing
8. Natural barrier analogs
9. Long-term climate change effects
10. Model applications and validation
11. Interface with regulatory agencies
12. Resource conservation and recovery act equivalency
13. Technology implementation and transfer

Table 2. Typical particle-size analysis for soils at McGee Ranch. The United States Department of Agriculture classification is used for texture.

Depth (cm)	% sand	% silt	% clay	texture
2	49.0	41.5	9.5	loam
6	46.0	45.5	8.5	loam
12	33.5	51.5	17.0	silt/loam loam
20	19.0	66.0	15.0	silt loam
34	24.5	65.5	10.0	silt loam
60	19.0	67.0	14.0	silt loam

FIGURES

Fig 1



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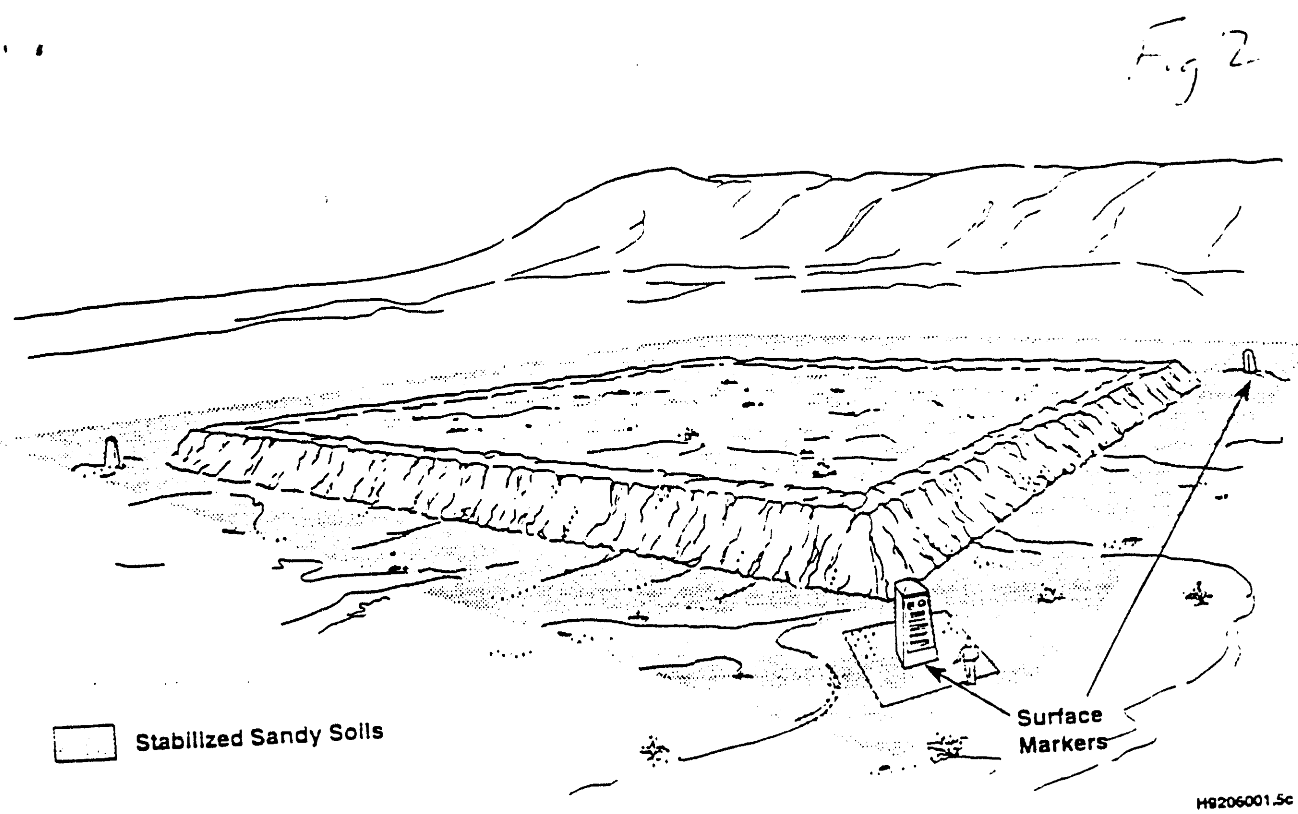

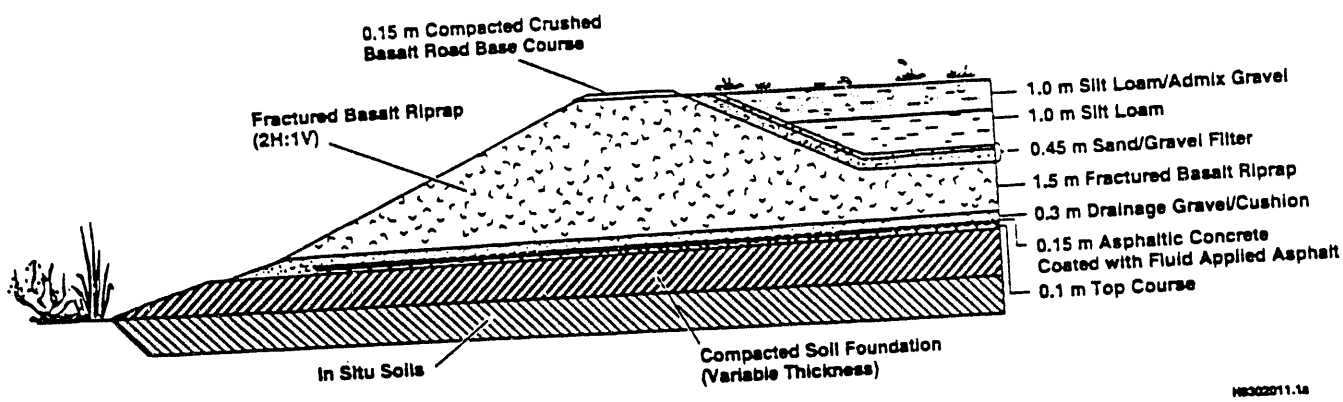

Figure 1.1. Typical Isolation Barrier

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.

Fig 3

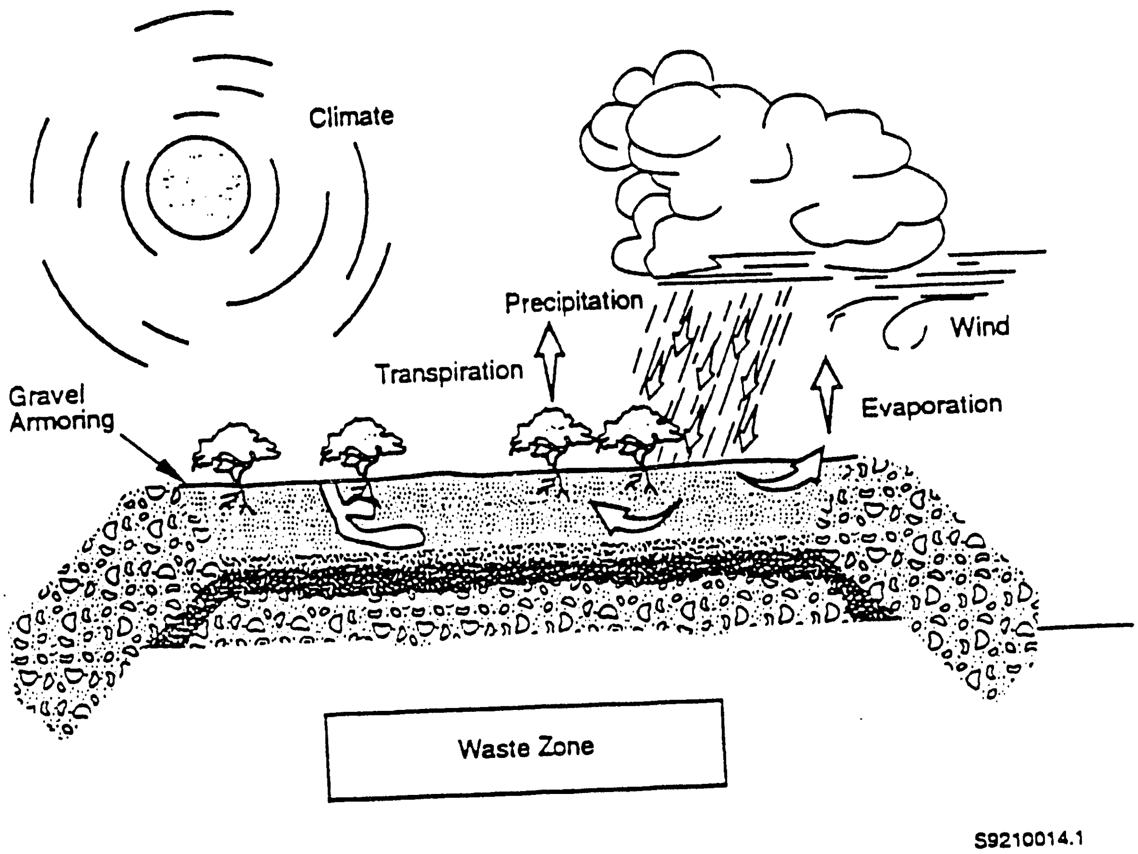

Figure 1.2. Functional Performance of Barriers

Fig 4

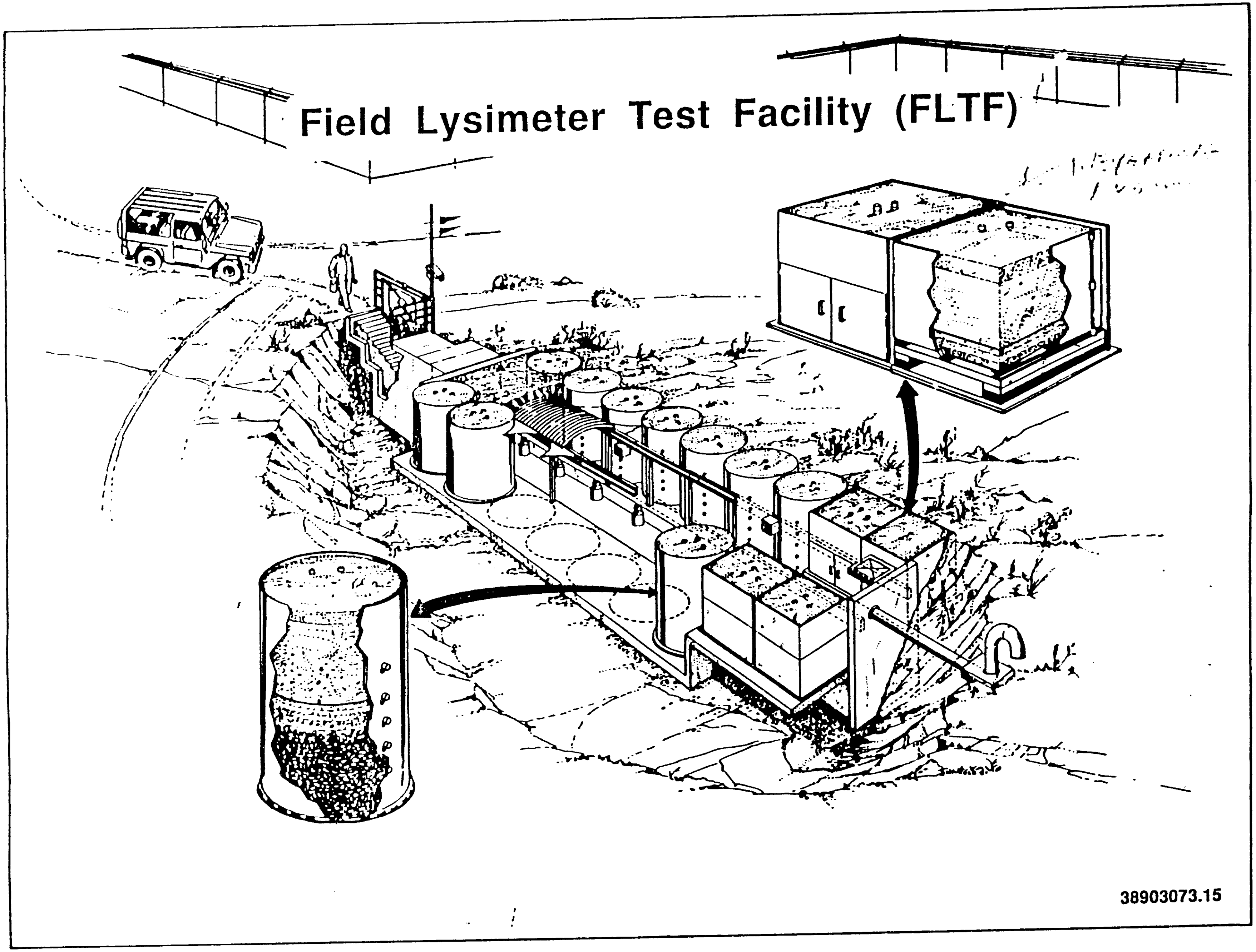

Fig 5

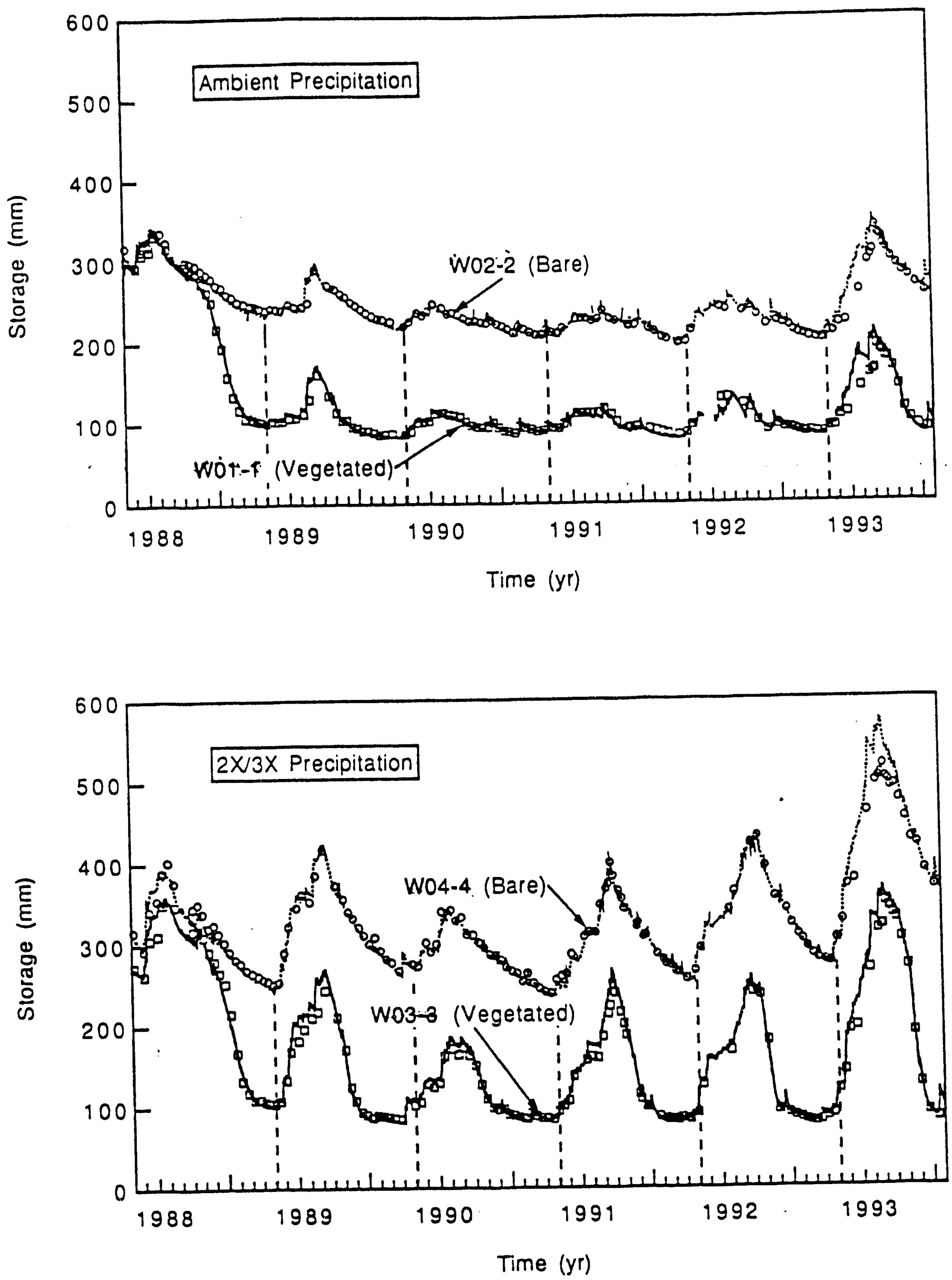

FIGURE 3.4. Water Storage for Weighing Lysimeters

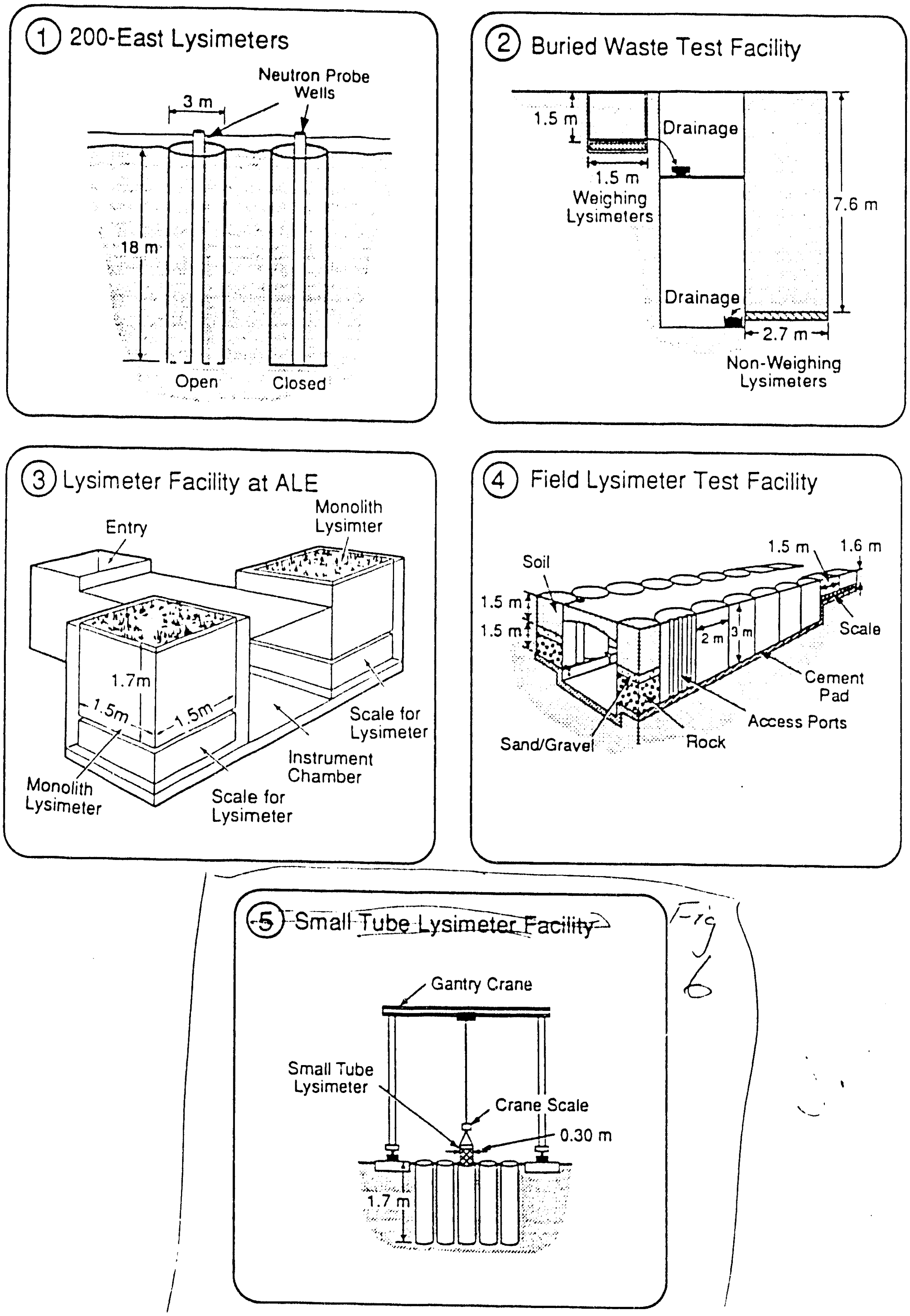

Figure 2. Schematics of lysimeter facilies.
Numbered circles are locations show on Figure 1.

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