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Title: MIGRATION BARRIER COVERS FOR RADIOACTIVE AND MIXED WASTE LANDFILLS

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MIGRATION BARRIER COVERS FOR RADIOACTIVE AND MIXED WASTE LANDFILLS

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INTRODUCTION

Migration barrier cover technology will likely serve as the remediation alternative of choice for most of DOE's radioactive and mixed waste landfills simply because human and ecological risks can be effectively managed without the use of more expensive alternatives. Conventional wisdom would suggest that landfill capping technology is well developed as evidenced by the availability of EPA guidance (EPA, 1989) for designing and constructing what has become known as the "RCRA Cap." In practice, however, very little testing and evaluation of the RCRA cap, or for that matter any other design, has been done, either before or after installation, to monitor how effective they are in isolating waste or to develop data that can be used to evaluate model predictions of long term performance. Notable failures of current, "off the shelf" capping technology (Richardson, 1990) and the need to isolate some waste forms for centuries or millennia would argue for better understanding of the performance characteristics of capping alternatives, particularly since some designs are expensive to install.

Los Alamos National Laboratory has investigated the performance of a variety of landfill capping alternatives since 1981 using large field lysimeters to monitor the fate of precipitation falling on the cap surface (Hakonson et al, 1992). The objective of these studies is to provide the risk manager with a variety of field tested capping designs, of various complexities and costs, so that design alternatives can be matched to the need for hydrologic control at the site (Nyhan et al, 1990; Hakonson et al, 1989; Hakonson, 1986).

Four different landfill cap designs, representing different complexities and costs, were constructed at Hill Air Force Base (AFB) in October and November, 1989. The designs were constructed in large lysimeters and instrumented to provide estimates of all components of water balance including precipitation, runoff (and soil erosion), infiltration, leachate production, evapotranspiration, and capillary/hydraulic barrier flow. The designs consisted of a typical soil cover to serve as a baseline, a modified EPA RCRA cover, and two versions of a Los Alamos design that contained erosion control measures, an improved vegetation cover to enhance evapotranspiration, and a capillary barrier to divert downward flow of soil water.

This paper presents preliminary results of the landfill capping demonstration at Hill AFB over the period January 1990 through July 1992. A comprehensive summary of the Hill AFB demonstration will be available in October 1993, when the project is scheduled to terminate.

EXPERIMENTAL DESIGN

The four cap designs (Figure 1) were installed in modular swimming pools at a finished dimension of 5 x 10 m and instrumented to monitor the fate of natural precipitation falling on the plots. Provisions were made to monitor runoff and erosion, change in soil moisture, leachate production, and interflow (in those designs with clay or capillary barriers). Evapotranspiration was estimated by solving the water balance equation:

$$dS/dt = P - ET - L - I - R \qquad \text{(Equation 1)}$$

where

- dS/dt = change in soil moisture over time interval, t (cm)
- P = precipitation (cm)
- ET = evapotranspiration (cm)
- L = leachate production (cm)
- I = barrier interflow (cm)
- R = runoff (cm)

The depth of each plot varied with cap design. A conventional soil cap (Control), representing past practice, consisted of 90 cm of local Hill AFB topsoil over 30 cm of a gravel drainage layer to promote rapid collection of leachate (Figure 2). The topsoil in this and all other plots was a sandy loam compacted to a density of 1.86 g/cc or 97% of optimum. The resulting saturated hydraulic conductivity was 2.8×10^{-4} (S.D. = 3.2×10^{-5} cm/sec). Complete saturation of the topsoil occurred at a volumetric water content of about 30%.

The modified RCRA cap design consisted of 120 cm of topsoil over 30 cm of a sand drainage layer over 60 cm of clay (a clay loam amended with bentonite) compacted to 1.76 g/cc, or 96% of optimum, with a saturated hydraulic conductivity of 3.4×10^{-6} cm/sec (S.D. = 1.81×10^{-6} cm/sec). Complete saturation of the clay soil occurred at a volumetric water content of about 34%. The purpose of the clay barrier in the RCRA cap design (EPA, 1989) is to divert soil water laterally to prevent it from entering the buried waste. Considerable effort was expended in an unsuccessful attempt to achieve the EPA recommended conductivity of 10^{-7} cm/sec. A 30 cm gravel drainage layer completed this cap profile.

EPA guidance on the RCRA cap recommends the use of a flexible membrane liner (FML) between the sand drainage layer and the compacted clay hydraulic barrier. The FML was not incorporated into the RCRA cap design under the assumption that it had already failed, as guidance (EPA, 1989) suggests will happen after some unspecified period of time. Assuming FML failure, the clay barrier would be the only remaining impediment to water penetration into the waste burial environment.

Two versions of a Los Alamos design (designated as LA-1 and LA-2) consisted of 150 cm of topsoil over 30 cm of ~1 cm diameter washed gravel to serve as a capillary break. A geotextile fabric, highly permeable to water (Mirafi Embankment and Railroad Stabilization Fabric #600X, Mirafi Inc., El Torro, CA), was placed between the soil and gravel layers to retard the rate of soil penetration downward into the gravel capillary break. A final 30 cm of gravel at the bottom of the profile served as a drainage layer for any leachate produced from the cap profiles. Both of the latter designs also included a thin gravel cover on the soil surface that past studies have shown to be very effective in controlling erosion (Simanton et al, 1986; Nyhan et al, 1990). This cover has the added benefit of increasing plant biomass by increasing infiltration, and thus, availability of water in the soil.

All plots had a 4% slope on the surface and on all profile interfaces to direct flow to collection areas. Provisions were provided in each plot, as necessary, to measure runoff and erosion, capillary or clay barrier interflow, soil moisture status, and leachate flow at several locations beneath each cap design. Runoff and sediment were collected in large tanks where total runoff volume and sediment yield could be measured. Leachate was directed into a large, below ground, caisson (Figure 1) where automated data acquisition systems, backed up by total flow collectors, monitored flow in real time. Soil moisture measurements as a function of depth in the various profiles were made with a neutron moisture gauge (Campbell-Pacific model 503). A variety of ancillary measurements were also made including soil temperatures at 30, 60, 90, and 120 cm depths, snow depth, precipitation, and air temperature. Leachate flow, interflow, soil temperature, and precipitation were continuously recorded on a data logger while soil moisture and snow depth were hand measured at weekly to bi-monthly intervals.

All of the plots were seeded with a mixture of native perennial grasses including Western Wheatgrass (*Agropyron smithii*), Great Basin Wild Rye (*Elymus cinereus*), Streambank Wheatgrass (*Agropyron riparium*), Viva Galleta Grass (*Hilaria jamesii*), Sand Drop Seed (*Sporobolus cryptandrus*), and Sheep Fescue (*Festuca ovina*). In addition, Los Alamos Plot 2 was planted with seedlings of two shrub species, Rubber Rabbitbrush (*Chrysothamnus nauseosus*) and Four Winged Saltbush (*Atriplex canescens*). The intent of the grass and shrub vegetation mixture was to enhance the potential for evapotranspiration.

A variety of characteristics of the vegetation cover was measured or estimated during June 1992 on the plots and on several other locations, including the adjacent hazardous waste Landfill No. 4. Estimates were made of relative

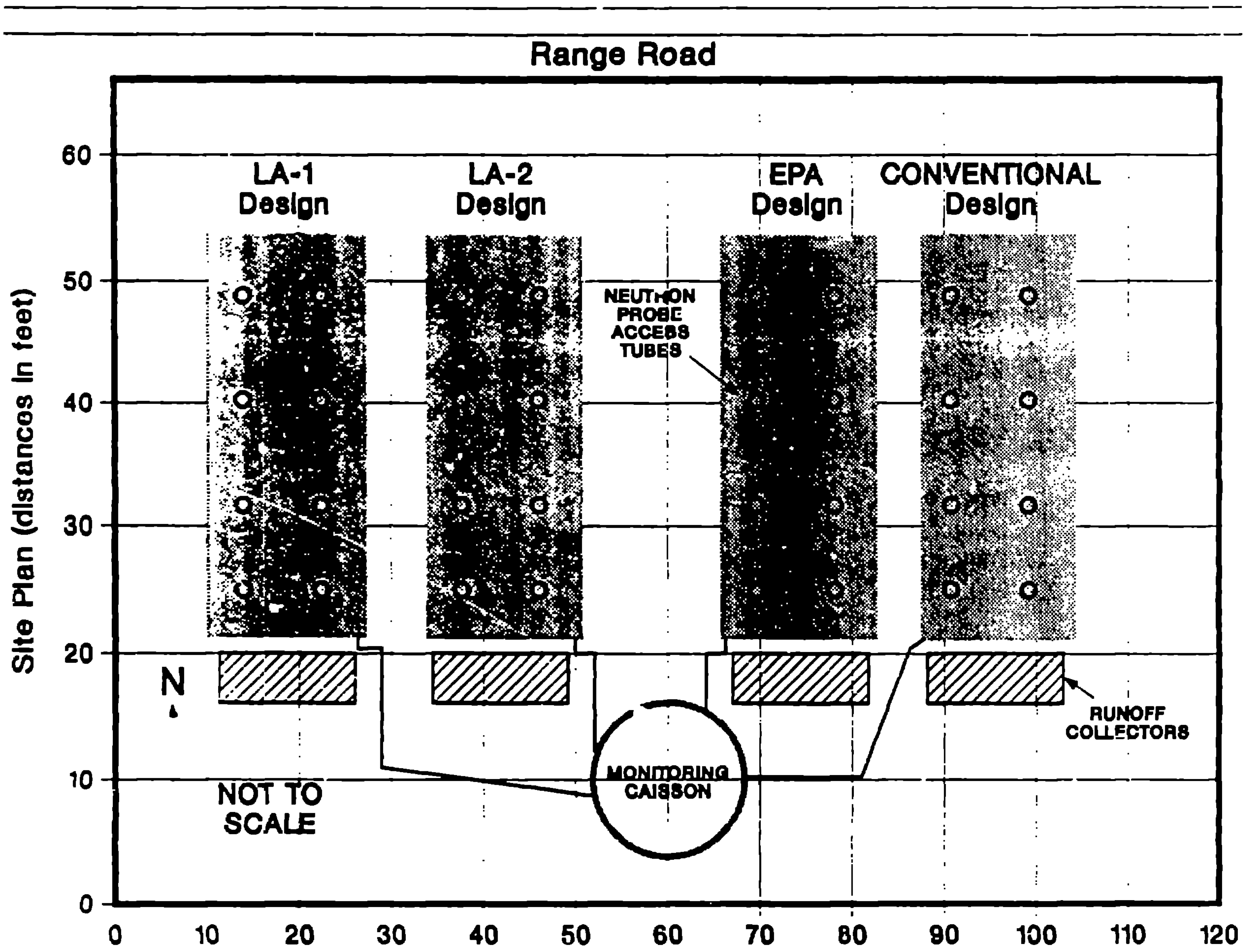
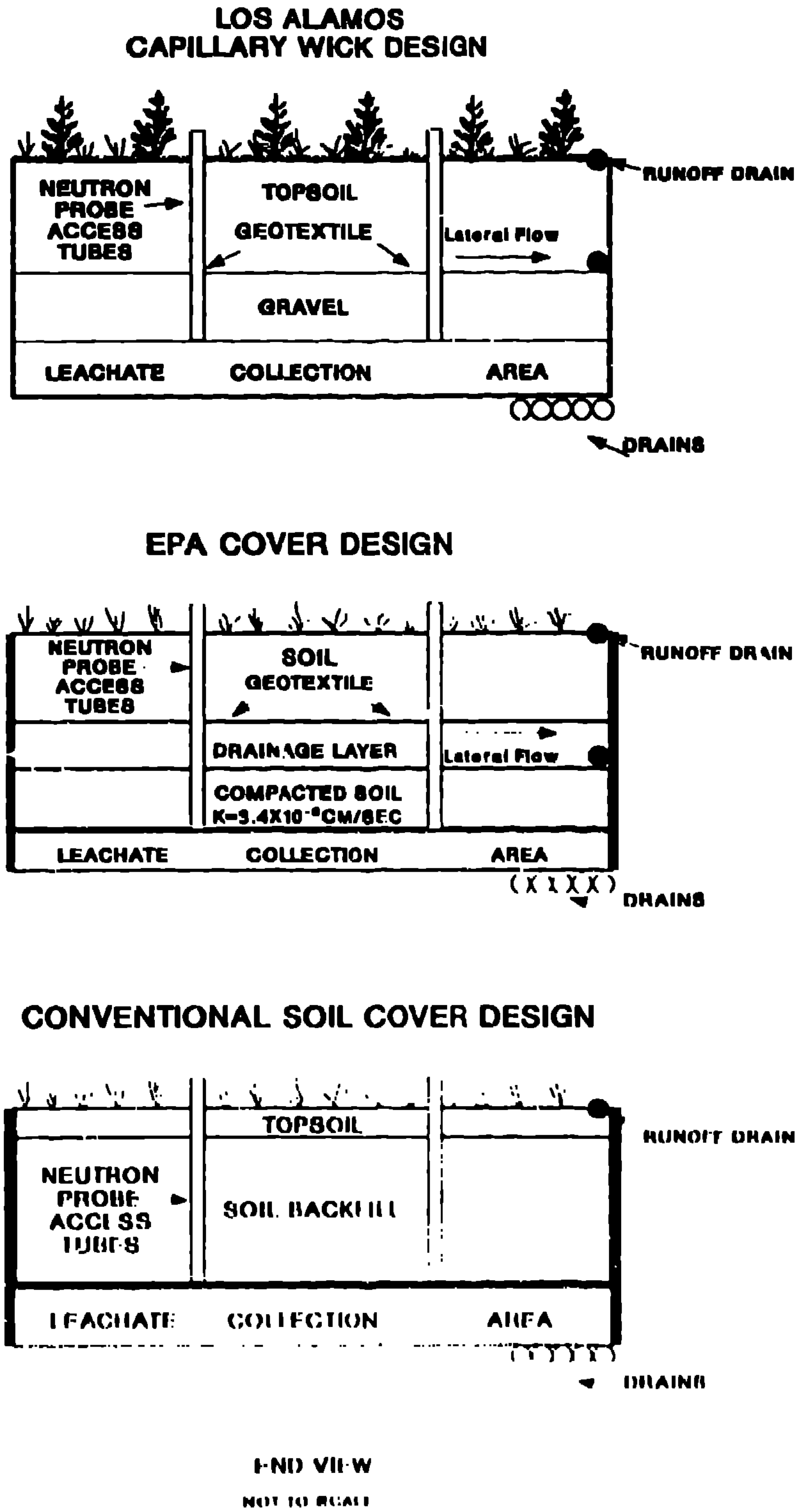


Figure 1. Plan view of the Hill AFB Landfill Capping Demonstration plots.

Figure 2. End view of all cap designs at Hill AFB.



cover, leaf area index, and biomass. A point frame was used to sample 460 discrete points on each 5 x 10 m plot following the systematic sampling protocol described by Levy and Madden (1933).

RESULTS

Precipitation

Daily precipitation and snow depth measurements are presented in Figures 3 and 4. Annual precipitation totals (Figure 3) were 36 cm in 1990 and 55 cm in 1992. From January through July 1993, a total of 26 cm of precipitation had fallen on the plots for a total input of 117 cm for the 31 month study period. The long term average annual precipitation for Hill AFB is about 51 cm. The above average annual precipitation of 55 cm in 1992 was primarily the result of snow melt sources of precipitation.

In general, snow cover (Figure 4) was present on the plots from November through March. Roughly 26 % (31 cm) of the total of 117 cm of precipitation that has fallen on the plots since January 1990 fell as snow for a snow to rain ratio of about 0.4.

Runoff and Erosion

Cumulative runoff and sediment yield from the four plots (Figures 5 and 6) was markedly lower on the two plots treated with a thin gravel cover on the surface (LA-1 and 2). This gravel cover can be described as a layer, one stone thick, covering about 70–80% of the ground surface. Relative to the untreated surfaces on the Control and RCRA plots, the stone cover reduced the frequency (8 versus 20 and 21 events) and amount of runoff (1.4 and 2.2 cm versus 4.8 and 5.6 cm) by factors of 2.5 and 2.5 to 4, respectively, over the 31 month study period. Sediment yields on the treated surfaces (102 g and 95 g), over the same period, were reduced by factors of 15 to 25 over those on the Control and RCRA plots (1494 g and 2290 g). While sediment yield from the RCRA and Control cap designs was much larger than on the LA designs, the rates of erosion were well within the EPA guidance of 4.4 metric tons per hectare (EPA, 1989).

Soil Moisture and Soil Water Inventory

The volumetric water content of soils in each cap design are presented in Figures 7–10. The patterns of soil water content with time reflect those expected in a vegetated soil in a semi-arid climate. Soil moisture increased during the winter and early spring months, primarily due to snowmelt, and decreased in response to very dry conditions during the summer months when vegetation and warmer air conditions removed soil moisture via evapotranspiration. Note that soil moisture recharge during the Spring of 1991 was especially high as a consequence of melting snow. The moisture content of soils in all plots was at or very near saturation (based on laboratory

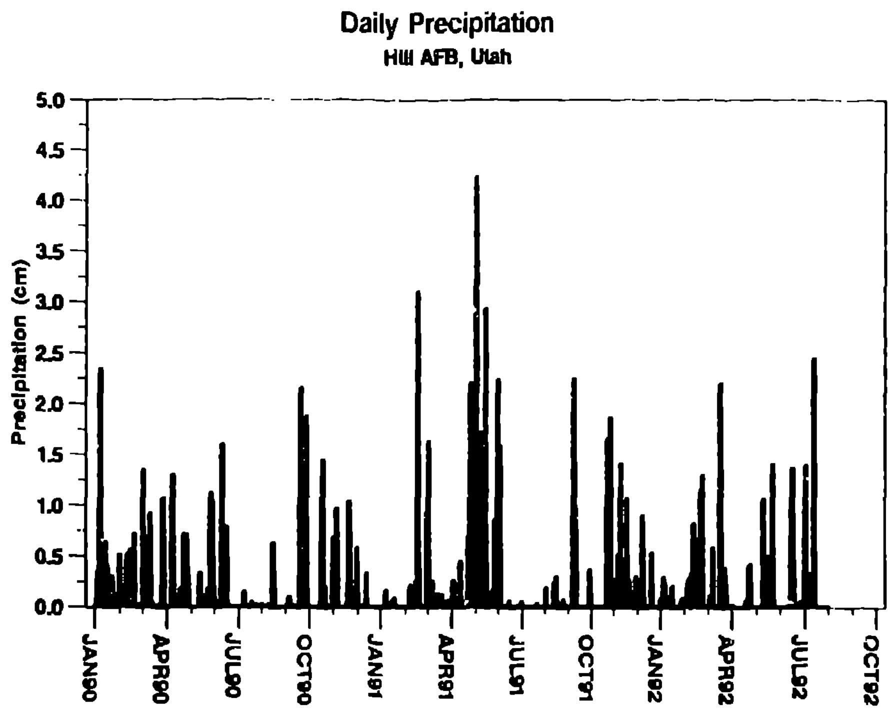


Figure 3. Daily precipitation at the Landfill Capping Demonstration site as a function of time at Hill AFB.

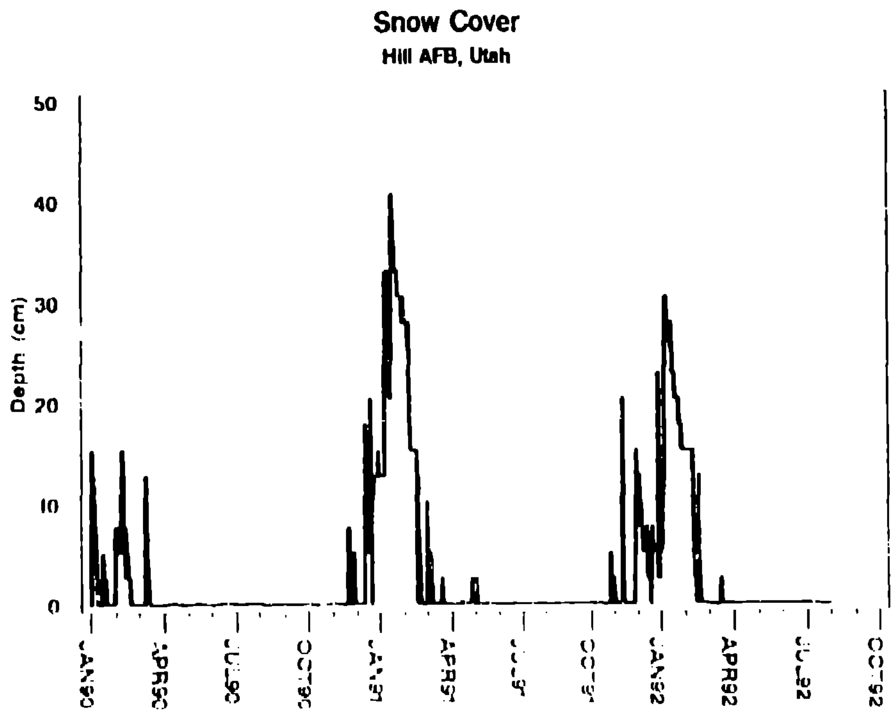


Figure 4. Daily snow cover at the Landfill Capping Demonstration site as a function of time at Hill AFB.

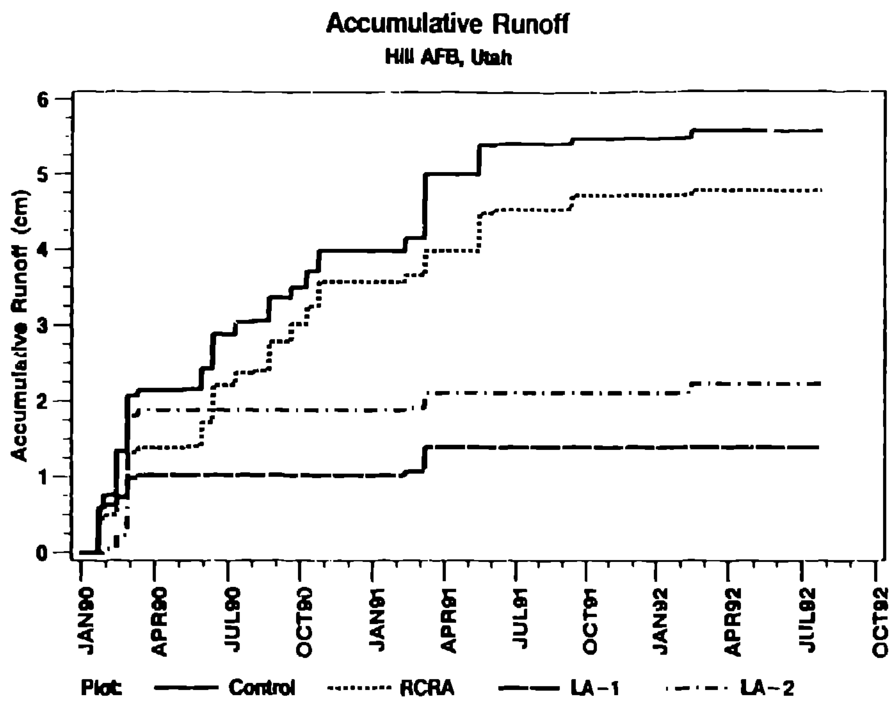


Figure 5. Accumulative Runoff from the Landfill Capping Demonstration plots as a function of time for all cap designs at Hill AFB.

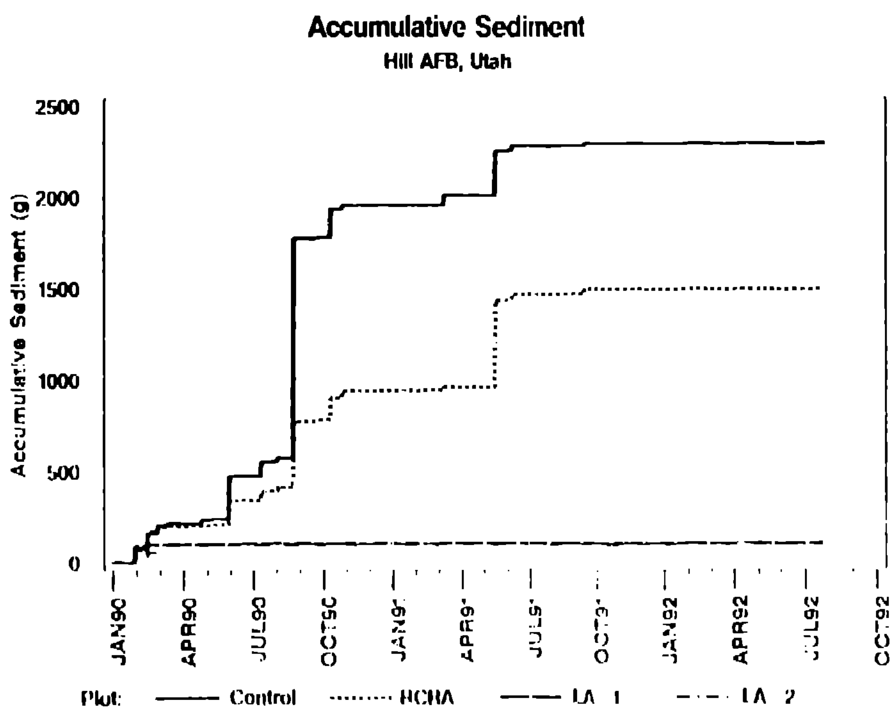


Figure 6. Accumulative Sediment from the Landfill Capping Demonstration plots as a function of time for all cap designs at Hill Air Force Base.

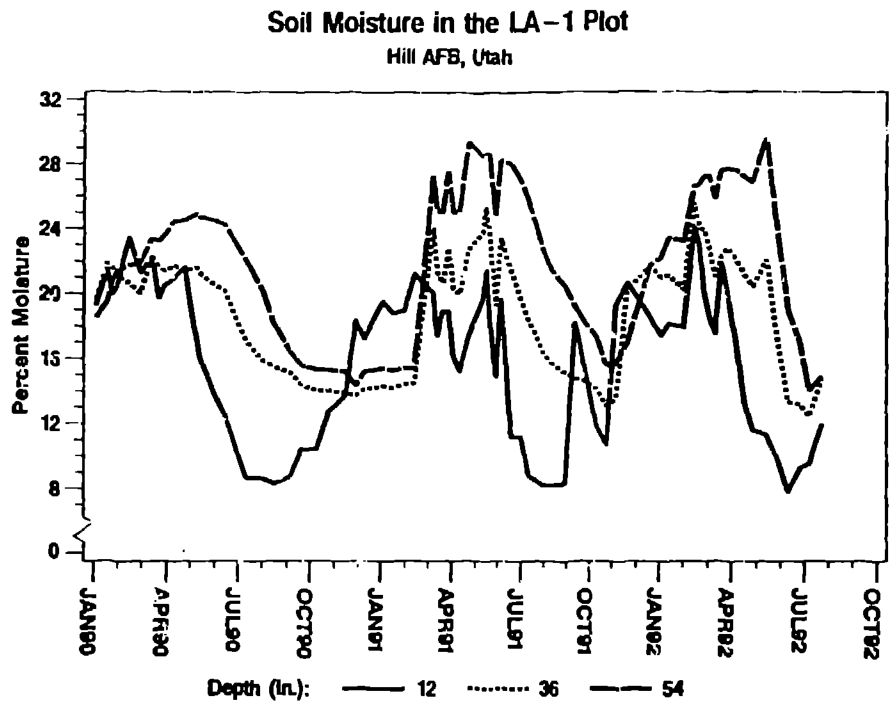


Figure 7. Volumetric Water Content as a function of time in Los Alamos Plot 1 soils at Hill AFB.

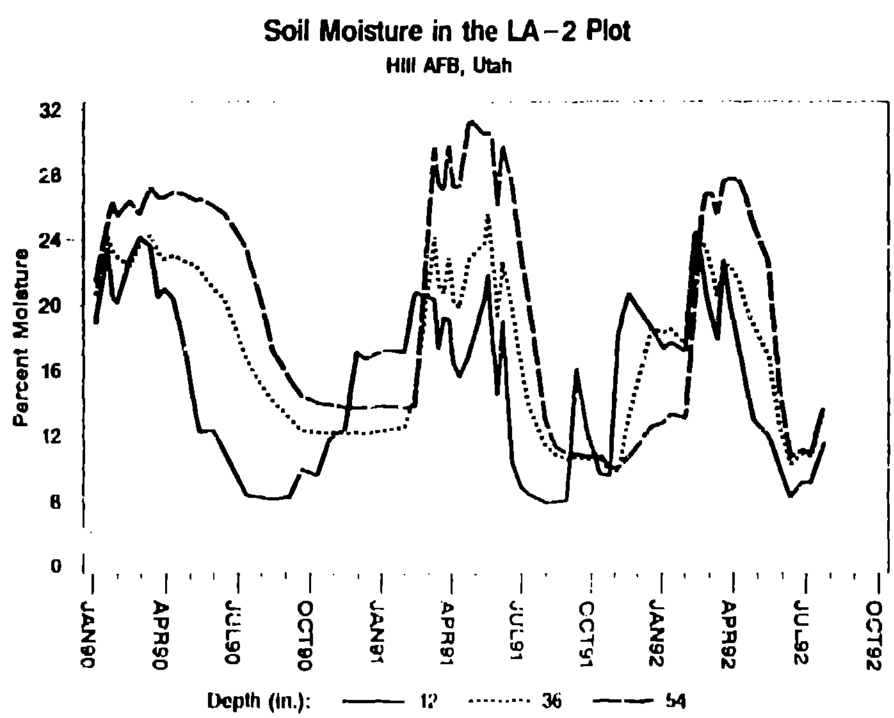


Figure 8. Volumetric Water Content as a function of time in Los Alamos Plot 2 soils at Hill AFB.

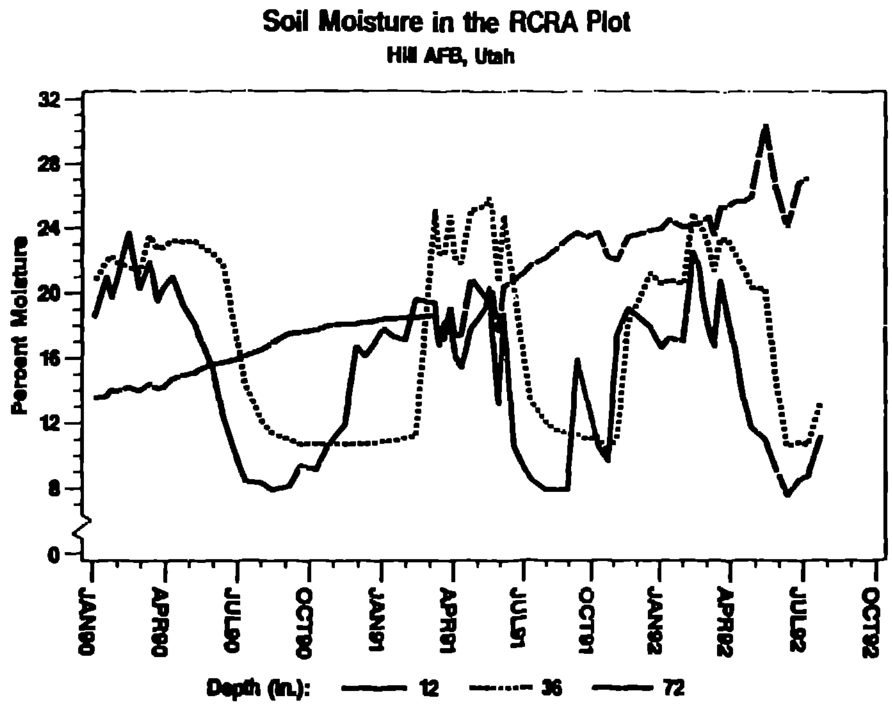


Figure 9. Volumetric Water Content as a function of time in the RCRA Plot soils at Hill AFB.

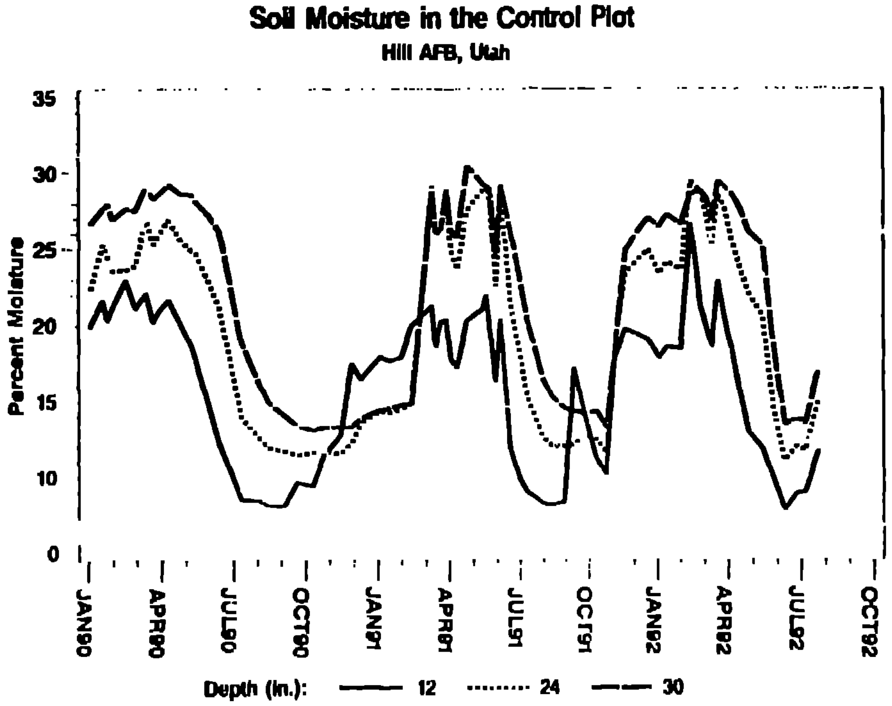


Figure 10. Volumetric Water Content as a function of time in the Control Plot soils at Hill AFB.

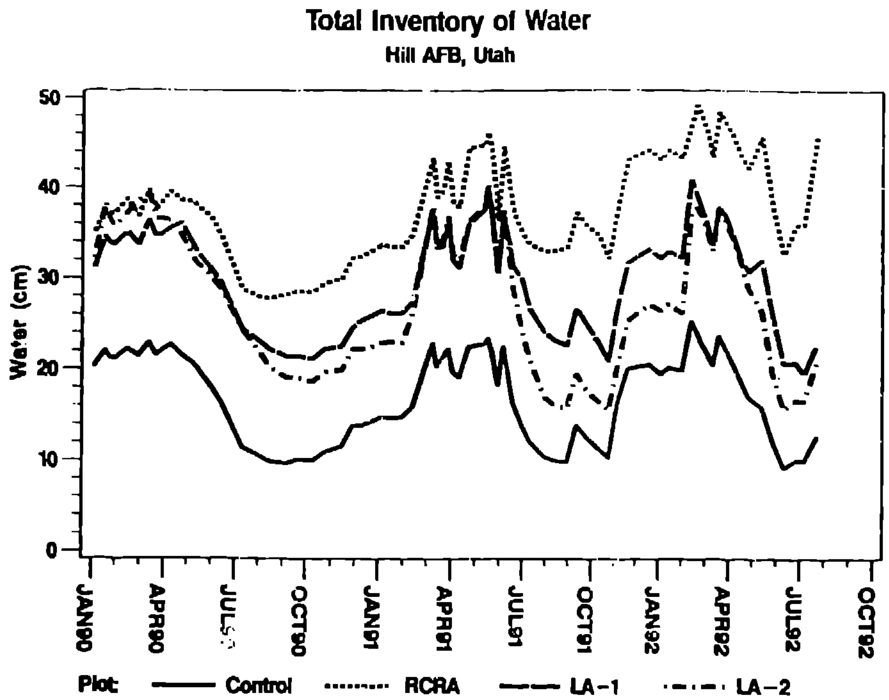


Figure 11. Total Soil Water Inventory as a function of time for all cap designs at Hill AFB

Capillary and Clay Barrier Interflow

The capillary and clay barriers in the RCRA and LA cap designs were effective in diverting some of the soil moisture that could have contributed to the production of leachate from the bottom of the cap profiles. A total of 13 cm (LA-1) and 7.6 cm (LA-2) of interflow was generated by the capillary barriers while 23 cm was diverted by the clay barrier in the RCRA design (Figure 12). The reduced flow of LA-2, when compared to LA-1, is considered significant in that the enhanced vegetation cover, leading to increased ET, on LA-2 is expected to decrease both interflow and leachate production over the same design with just the grass cover.

Capillary and clay barrier interflow was associated almost exclusively with the late winter and early spring season when snow melt events and early spring rains were contributing to soil water recharge. This is a period of time when evapotranspiration is low due to senescent vegetation and low ambient air temperatures. As seen in Equation 1, a reduction in ET must result in an increase in interflow and/or leachate flow during periods when the soil is wetting.

Interflow from the capillary barriers occurred every year during the study period. However, an interesting pattern was observed in the frequency and amount of interflow generated by the clay barrier in the RCRA cap design. During the entire first year of the study period, the clay barrier did not produce any interflow (Figure 12). The capillary barriers, on the other hand, leached produced about

3 cm of interflow. As mentioned above, the clay barrier was absorbing the soil water that "should have been" interflow. With the above normal input of precipitation, primarily during the spring and early summer of 1991, the clay barrier started generating interflow. During a single event over a four month period, the clay barrier produced 17 cm of interflow out of the total 23 cm produced over the study period. The remaining 6 cm of clay barrier interflow occurred during one event in the spring of 1992. In contrast, the capillary barrier interflow events were more frequent and smaller in magnitude (Figure 12).

Leachate Production

During construction of the plots, provisions were made to collect leachate at several locations beneath each cap profile to evaluate breakthrough as a function of slope length along the capillary and hydraulic barriers and also perimeter or "wall effect" contributions to leachate production. The impermeable side wall boundaries of the plot could provide preferential flow paths for percolating soil water, leading to an over estimate of leachate production. Observations over the study period show that "wall effect" contributions to leachate flows on an area basis, relative to the interior leachate collection areas, were abnormally high only during saturated soil moisture conditions. Furthermore, only the Control plot design had significant abnormal "wall effect" contributions to leachate production. In that case, about 50% of the leachate produced by the Control plot design resulted from the wall area, which only contributes about 20% to the total plot area. The dilemma in using or not using "wall effect" data is that it may lead to over estimates of leachate production if it is included in the leachate term of the water balance equation or, if not included as leachate, will result in over estimates of evapotranspiration, since "wall effect" water is lumped into the ET term when solving the water balance equation. A strong argument can be made that "wall effect" leachate represents primarily water that would truly have been leachate in the absence of the plot wall, particularly since leachate production through the study period occurred during the spring when evapotranspiration was low. The case for this argument will be fully developed in the final report on this project. In the meantime, the leachate data that follows includes contributions from the "wall effect" collection area.

Breakthrough of percolating water resulted in the production of leachate from all four cap designs during the 31 month study period although the frequency and volume produced varied dramatically with cap design (Figure 13). As with interflow, leachate production was associated with snowmelt and rainstorm inputs of moisture to the soil during the months of February through May The Control soil cap design generated 28 cm of leachate (Figure 13) during the study representing about 24% of the total precipitation. About 26% of the total leachate was produced during one period following the above average snowfall and early spring rains that occurred during the winter of 1990–1991. A similar pattern was observed for the LA capillary barrier designs although the total volume of leachate produced was a third to half of that produced by the Control Plot. LA-1 produced a total of 14 cm of water while LA-2, with the grass/shrub cover, produced 12 cm. About 56% and 75% of the total leachate was

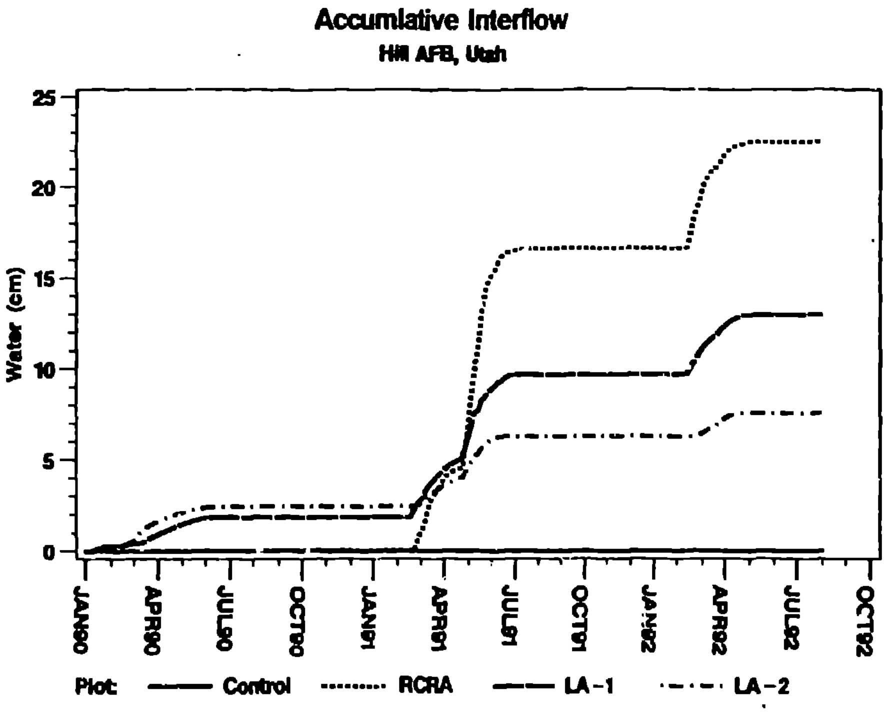


Figure 12. Accumulative Barrier Interflow as a function of time for all cap designs at Hill AFB.

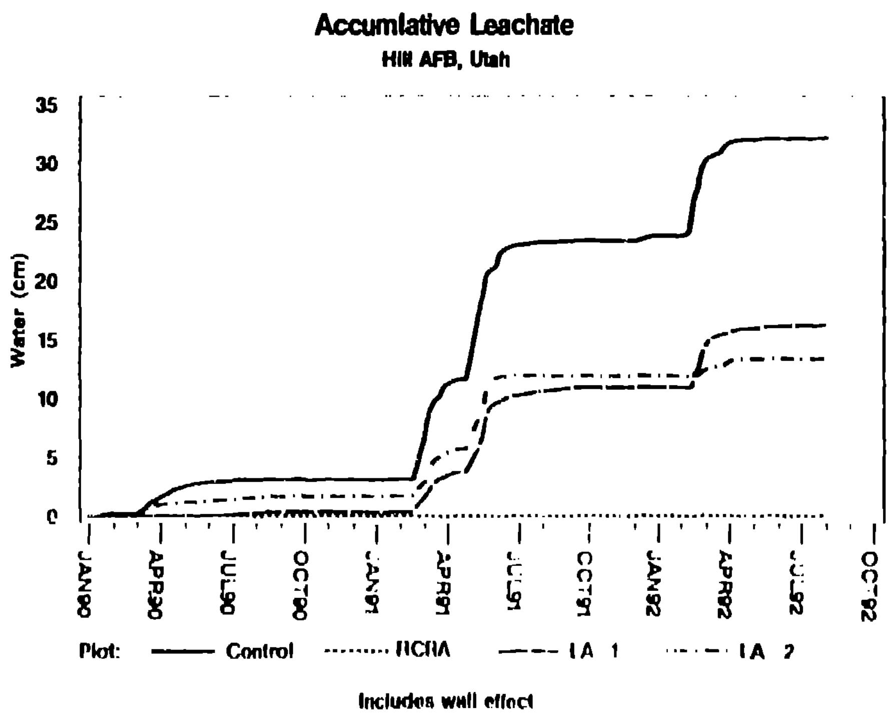


Figure 13. Accumulative Leachate Flow as a function of time for all cap designs at Hill Air Force Base.

produced during the same events of the spring of 1991, respectively. It is interesting to note that the volume of leachate produced by the LA designs during the Spring of 1992 suggest that the enhanced vegetation cover (grass and shrubs) on LA-2 resulted in much lower (4.5 cm versus 1.3 cm) total leachate than its grass covered counterpart. This may reflect the anticipated influence of the enhanced plant cover on LA-2 in increasing ET with a consequent reduction in leachate and/or interflow (see Figure 13) production.

The RCRA cap design was nearly 100% effective in preventing leachate production due to the diversion of soil water through interflow and to the continuous wetting of the clay barrier soil. However, breakthrough did occur, beginning March 20, 1992, about 27 months after the plot was constructed. This is not surprising given that the moisture content of the clay barrier soil has continuously increased through the study period to a volumetric water content of 32% (Figure 11) and is now very near the saturation level of 34%.

<u>Water Balance Estimates</u>

Estimates of the various components of water balance for each cap design are presented in Table 1. A total of 117 cm of precipitation was recorded at the demonstration site of which at least two thirds was returned to the atmosphere by evapotranspiration. The plot with a grass and shrub vegetation cover (LA–2) returned an estimated 104 cm, or 88%, of the 117 cm of precipitation back to the atmosphere. The LA-1, Control, and RCRA designs had estimated ET's of 100 cm (85%), 91 cm (78%), and 78 cm (67%), respectively. The higher estimates of ET on the two LA cap designs is consistent with the larger amounts of vegetation cover that were measured on these plots.

The characteristics of the vegetation cover on each plot are summarized in Table 2. A plant cover of 58% was measured on LA-2 (grass/shrub cover), 51% on LA-1 (grass only), and 35–37% on the RCRA and Control cap designs. The higher relative cover on the LA designs reflects the surface gravel treatment, and, in the case of LA-2, the shrub species. The ground cover averaged 80–88% on the LA designs and 47–60% on the RCRA and Control cap designs. Analogous patterns were observed (Table 2) in the calculated leaf area index supporting the higher ET estimates calculated from the water balance equation for the LA cap designs. Depending on design, leachate and/or interflow was the next largest component of the water balance (Table 1). Interflow accounted for 6–11% of the total precipitation in the LA designs while the RCRA design diverted 19% of the precipitation. The LA designs produced 10–14% of the precipitation as leachate while the Control cap design produced 24% as leachate. The RCRAdesign, at this point in time, has generated only a small amount of leachate. Based on the measured saturated conductivity of 3.4 x 10^{6}, the 60 cm of clay would experience breakthrough in about 1 year under the conditions inherent in measuring saturated conductivity. Under the variable moisture conditions that existed in the soils above the clay barrier, it took 27 months for breakthrough to occur.

Table 1: Water Balance Estimates on the Hill AFB Landfill Cover Demonstration Plots CY90–July 22, 1992.

	PLOT DESIGN			
	LA-1 (Grass)	LA-2 (Grass/Shrub)	EPA	Control
Precipitation (cm) (P)	117	117	117	117
Soil Water Storage At Beginning CY90 (cm)	32	31	35	20
Net Change in Soil Water Storage CY90–July 92 (dS/dt)	-11 (-9.4%)	-8.3 (-7.1%)	11 (9.4%)	-7.6 (-6.5%)
Leachate (cm) † (L)	14 (14%)	12 (10%)	0.0009 (0.0%)*	28 (24%)
Interflow (cm) (I)	13 (11%)	7.6 (6.0%)	23 (19%)	0 (0%)
Runoff (cm) (R)	1.4 (1.2%)	2.2 (1.8%)	4.8 (4.0%)	5.6 (4.6%)
Evapotranspiration (cm) (ET)	100 (85%)	104 (88%)	78 (67%)	91 (78%)
Sediment (g)	102	95	1494	2290

$$P = ds/dt + L + I + R + ET$$

† Includes wall effect

*Breakthrough began March 20, 1992 (27 months elapsed time)

Table 2. Some characteristics of the vegetation on the landfill capping demonstration plots at Hill AFB in July 1992.

	PLOT			
	LA–1	LA–2	RCRA	Control
Total Plant Cover (%)	51	58	38	35
Shrub Cover (%)	11	43	6.0	4.3
Ground Cover[1] (%)	80	88	47	60
Rock Cover[2] (%)	36	17	1.0	0
Leaf Area Index (cm^2/cm^2)	0.78	0.85	0.55	0.55

[1] Includes rocks and fallen litter but no live plant material
[2] Rock cover part of ground cover

Runoff (Table 1) accounted for less than 2% of the precipitation in the LA cap designs and about 4% in the RCRA and Control designs. Reductions by factors of 15–24 in sediment yield on the LA cap designs were attributed to the gravel surface cover and the enhanced vegetation growth compared to the RCRA and Control cap designs.

CONCLUSIONS

Based on 31 months of monitoring data, it appears that snowmelt and rainstorm sources of precipitation from February through May result in a relatively high potential for soil water to percolate into the waste burial environment at Hill AFB, particularly when the landfill is covered with a conventional soil cap. Our results show that about 24% of the total precipitation passed completely through the soil cap design (i.e. Control plot) as leachate. Since 1 cm of leachate, distributed over one hectare, is equivalent to 10^5 ℓ of water, the soil cap design used in this study, would have contributed an estimated 3 million liters of water to the waste environment for each hectare of landfill over the 31 month period. The capillary barriers and enhanced plant cover on the LA cap designs reduced leachate production by about a factor of 2 over the soil design but the barriers did "fail" during periods of rapid soil wetting in the Spring. The ability of the capillary barrier to divert soil water laterally is a strong function of the hydraulic conductivity of the fine grained topsoil immediately above the gravel capillary break and on the slope angle on the topsoil and gravel interface. Two possible capillary barrier design options, to further improve leachate control might be to increase the slope on the capillary barrier and/or to use a layer of material (i.e. sand) with a higher hydraulic conductivity, just above the capillary break, to promote faster lateral soil water flow rates.

There are, however, indications that the performance of the capillary barrier in LA-2 is improving in that it is producing less leachate (see Figure 13) compared to the same design with just the grass cover (LA-1). This trend is reinforced by the data for interflow (Figure 12) which also shows a reduced amount of interflow from LA-2 vs. LA-1 for the Springs of both 1991 and 1992 (8.57 cm vs. 5.71 cm). If the improved performance of LA-2 prevails upon further monitoring and analysis, it will be due to the increased potential to remove soil moisture via transpiration. Recall that LA-2, about 31 months into the study, had about a factor of 4 greater shrub cover, a 20% greater total plant cover, and a calculated LAI of about 10% greater than LA-1.

The RCRA cap has been the most effective in preventing soil water movement completely through the cap. Breakthrough occurred about 27 months into the study and is expected to resume with the Spring 1993 snowmelt season. Evaluation of the long term performance of the clay barrier in diverting soil water laterally or in preventing leachate production will require additional monitoring.

A potential concern about long term performance of the clay barrier stems from the natural establishment of deeper rooted plant species, such as shrubs, on the plot. These deeper rooted species will provide an important test of the barriers ability to withstand plant root intrusion and the potential desiccation of the clay during periods of moisture stress to the plants. Past experience (Hakonson, 1986) on the influence of plant roots on bentonite clay hydraulic barriers shows that transpiration losses of water stored in the clay, very quickly destroy the ability of the barrier to prevent downward flow of soil moisture.

The results presented in this report represent the performance characteristics of four cap design alternatives over a relatively short period of time. Further monitoring is needed to better define the relationship between the grass and shrub cover and the longer term performance of the capillary barrier. It is particularly important to continue the monitoring of the RCRA cap design to evaluate the leak characteristics of the clay barrier under current conditions and under those expected to occur as deeper rooted species invade the plot.

Current results should be useful to Hill AFB Environmental Restoration personnel in managing risks at the site by providing initializing data and rate constants for hydrologic models. These models are a necessary part of site characterization, assessment, and cleanup activities at Operable Units with landfills in that they can be used to define field sampling needs, calculate transport as a part of the risk assessment activities, and be used to help evaluate the consequences of various cleanup alternatives in reducing risks to acceptable levels.

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