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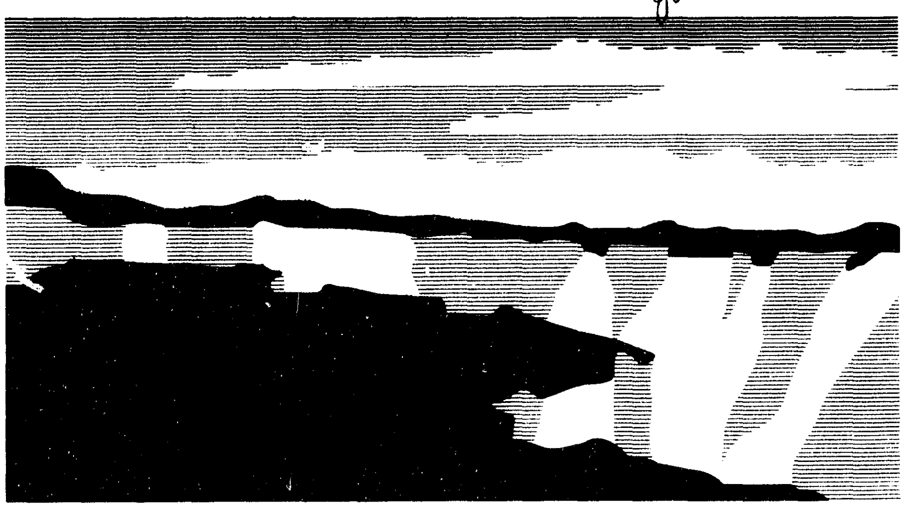

Los Alamos
NATIONAL LABORATORY

WATER BALANCE RELATIONSHIPS IN FOUR ALTERNATIVE COVER DESIGNS FOR RADIOACTIVE AND MIXED WASTE LANDFILLS

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ABSTRACT

Preliminary results are presented from a field study to evaluate the relative hydrologic performance of various landfill capping technologies installed by the Los Alamos National Laboratory at Hill Air Force Base, Utah. Four cover designs (two Los Alamos capillary barrier designs, one modified EPA RCRA design, and one conventional design) were installed in large lysimeters instrumented to monitor the fate of natural precipitation between 01Jan90 and 20Sep93. After 45 months of study, results showed that the cover designs containing barrier layers were effective in reducing deep percolation as compared to a simple soil cap design. The RCRA cover, incorporating a clay hydraulic barrier, was the most effective of all cover designs in controlling percolation but was not 100% effective. Over 90% of all percolation and barrier lateral flow occurred during the months of February through May of each year, primarily as a result of snow melt, early sp-ing rains and low evapotranspiration.

Gravel mulch surface treatments (70 -80% coverage) were effective in reducing runoff and erosion. The two plots receiving gravel mulch treatments exhibited equal but enhanced amounts of evapotranspiration despite the fact that one plot was planted with additional shrubs.

INTRODUCTION

Containment technologies and especially migration barrier cover technology will play a central role in remediating most of DOE's 3000+ waste sites[1]. The goal of hazardous waste management is to isolate waste in such a way that risk to humans and the environment are minimized. To some this means complete and total isolation of the waste; a goal which may be impossible to achieve given that there is currently no barrier available which has been "proven" to completely isolate waste in the long term. We should, however, be able to contain wastes in a manner which reduces risks to acceptable levels.

Summaries of past operating experience at major low-level radioactive waste disposal sites have shown that most containment failures have stemmed from interactions of water with the landfill covers[2, 3, 4, 5]. Given this and prevalence of EPA guidance[6], there is still a lack of data on the ability of design alternatives, including the EPA's RCRA design, to perform under field conditions. The objective of this study was to evaluate the hydrologic performance of various landfill capping technoiogies, providing data to support closure plans for hazardous waste landfills. This paper presents preliminary results on water balance relationships that were measured over a 45 month period.

WATER BALANCE CONCEPT

Precipitation interactions with the cover include runoff, soil moisture storage, and percolation. Water which falls on a cover and leads to runoff may result in exposure of waste due to erosion. Water that does not runoff can seep into the cover where it will either go into soil moisture storage, be "pumped" to the surface and atmosphere through evapotranspiration, or can percolate through the cover with the potential to leach soluble waste to ground water. It is important to note that all these interactions are interdependent. Modifications of one component can produce large changes in others. Collectively all these components are the water balance. Water balance on any site is simply the total of all inputs minus the total of all losses and can be described on a waste site by Equation 1, shown below:

$$\Delta S/\Delta t = (P - Q - ET - I - L)/\Delta t \qquad (1)$$

where $\Delta S/\Delta t$ = change in soil moisture over time Δt,
P = the precipitation per unit area,
Q = runoff per unit area,
ET = evapotranspiration per unit area,
I = interflow per unit area, and
L = leachate production per unit area.

Evapotranspiration (ET) was the only component of water balance not directly measured in this study. In order to estimate these values, Equation 1 was solved for ET.

EXPERIMENTAL DESIGN

In the summer and fall of 1989 four alternative cap designs (Figure 1) were installed in modular swimming pools at a finished dimension of 5 X 10 m at Hill Air Force Base (AFB), Utah. All plots were instrumented to monitor the fate of natural precipitation falling on the plots. The depth of each plot varied with design (Figure 2).

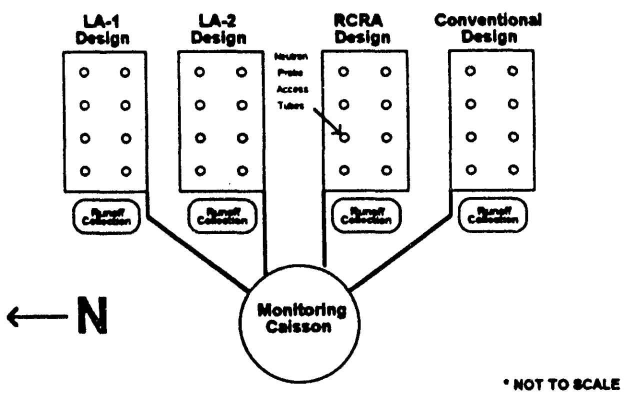

FIGURE 1 Overhead view of the experimental landfill cover design plots installed at Hill AFB, Utah.

The conventional soil cap (control) consisted of 90 cm of local Hill AFB topsoil and represented past practices of landfill closure. 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 based on Proctor tests and in-situ gamma density measurements. The average saturated hydraulic conductivity of this soil, as measured on field samples in the laboratory, was 2.8×10^{-4} cm/sec ($s = 3.2 \times 10^{-5}$ cm/sec). Complete saturation of the topsoil occurred at a volummetric water content of about 30% based on laboratory tests.

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 ($s = 1.81 \times 10^{-6}$ cm/sec). Complete saturation of the clay soil occurred at a volummetric water content of approximately 50%. The purpose of the clay barrier in the RCRA cap design was to divert soil water laterally preventing it from percolating through the cover. Considerable effort was expended in an unsuccessful attempt to achieve the EPA recommended conductivity of 10^{-7} cm/sec.

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 suggests will happen after some unspecified time[6].

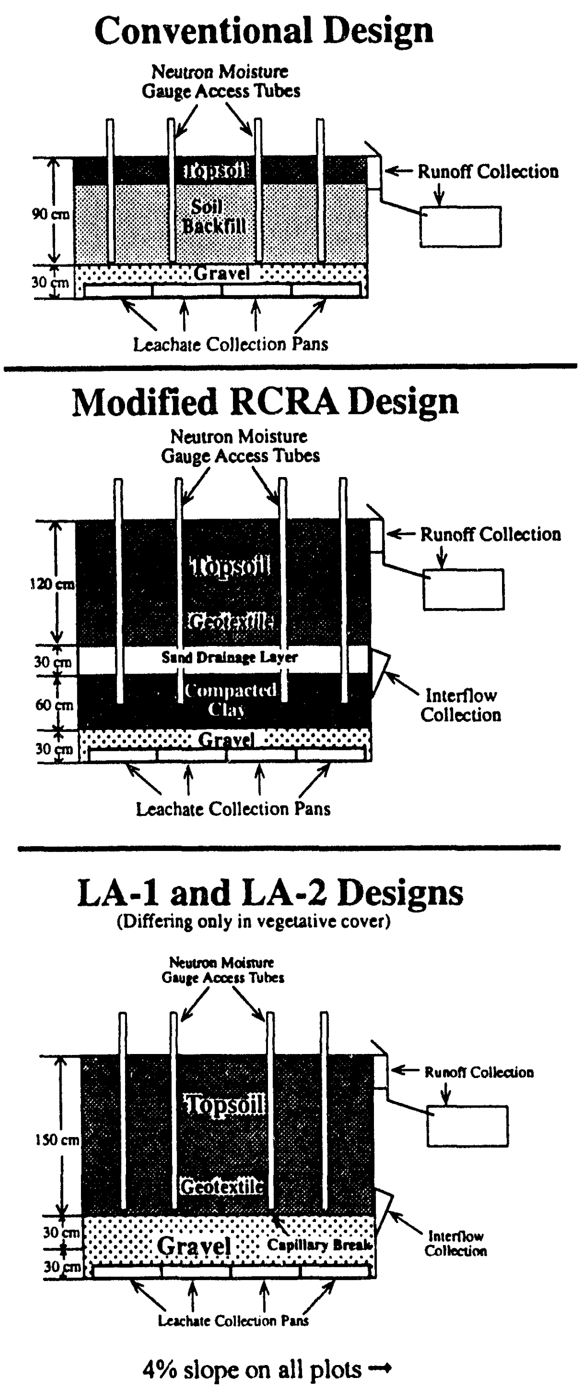

FIGURE 2 Cross sectional side view of the cover profiles in place at Hill AFB, Utah.

Finally the two Los Alamos designs (designated LA-1 and LA-2) consisted of 150 cm of topsoil over 30 cm of approximately 1 cm diameter washed gravel to serve as a capillary break. The concept of capillary barriers is based on the fact that differences in pore size between the topsoil layer and the gravel layer causes water to be held in the soil by capillary forces. Percolating liquid will penetrate the coarser material only after the overlying finer materials are near saturation. As long as the matric potential at the coarse/fine interface remains negative, water infiltrating the finer layer will not cross the interface. The downward slope of the plots would then allow gravity to convert the downward flow of water into a lateral flow component.

Both Los Alamos designs also included a thin gravel cover on the soil surface (70 - 80% cover) that has been shown to be very effective in controlling erosion in past studies[7,8]. The only difference between the two Los Alamos capillary barrier designs was the vegetative covers.

There was a 30 cm layer of gravel underlying all plot profiles which represented the location where waste would be and was put in place to aid in the collection of percolating water (leachate). All layers in all plots were built with a 4% slope and all plots were seeded with an equal mixture of native perennial grasses. The second Los Alamos design (LA-2) was additionally planted with seedlings of two shrub species in an effort to enhance the potential for evapotranspiration (ET).

Soil moisture was measured in each plot in eight locations at various depths using neutron moisture gauges (model 503Dr, Campbell Pacific Corp., Pacheco CA) . Runoff, erosion, leachate production, and water shed laterally at the capillary/hydraulic barriers (herein referred to as interflow) were also measured on all plots. Leachate was measured in four locations along the slope of the plots while runoff, erosion, and interflow were measured in one location for each plot. Measurements taken on the experiment site as a whole were precipitation, soil temperature, air temperature, relative humidity, wind speed, and wind direction. The precipitation measurements used in this study were taken using accumulating rain buckets.

RESULTS AND DISCUSSION

Precipitation

The precipitation total for the 45 month study period was 202 cm. Annual precipitation measurements ranged from 38 cm to 65 cm with an average of 51.7 cm (s= 13.5 cm) for the three complete years of study and 47 cm for final nine months of study. The long term averages for the area range from 51 cm (40 yr. ave.) at the Hill AFB meteorological station located one mile west of the study site, to 58 cm (30 yr. ave.) at a Utah State Climate Center station located approximately 12 mi. south of the study site. The annual precipitation total for the first year of study was well below the long term averages but in the following two years it was at or above the long term averages (Figure 3). In the final nine months of study the precipitation level was just short of the long term annual average for the Air Force Base meteorological station.

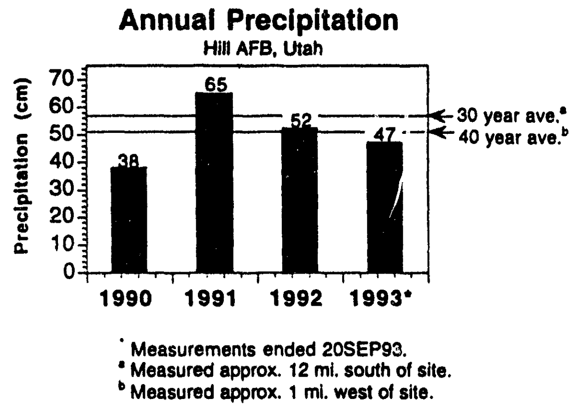

FIGURE 3 Annual precipitation as measured by accumulating rain gauges on the study site at Hill AFB.

Runoff and Erosion

The gravel mulch treatment on the two LA designs was effective in reducing runoff and erosional losses. Runoff totals for the entire 45 month study period were 5.8 cm, 5.5 cm, 1.4 cm, and 2.2 cm for the conventional , RCRA, LA-1, and LA-2 cover designs respectively. This represents 3% of all precipitation for the conventional and RCRA plots and only about 1% for the LA-1 and LA-2 plots. The effects of the gravel mulch can be seen even more dramatically by the amount of sediment associated with the runoff (erosion). Total sediment measured for the LA-1 and LA-2 plots was 102 g and 95 g respectively. This compares to 1534 g for the RCRA cover and 2374 g for the conventional cover. Though the erosional losses were 15 to 25 times higher on the RCRA and conventional designs, they were still well below the EPA limits of 4.4 metric tons per hectare annually[6].

Soil Moisture Inventories

Total soil water in storage ranged from 8 cm in the conventional design to 68 cm in the RCRA design. The patterns of soil water content over time reflect those expected in vegetated soils, in semi-arid climates. Soil moisture was recharged during the winter and early spring months, primarily due to snow melt, and decreased in response to low precipitation and evapotranspiration during the summer months.

The RCRA cover was found to have significantly higher volummetric water contents than all other plots while the remaining three plots were not significantly different from each other. The reason for thiswas due to the high water holding capacity of the clay layer within the RCRA cover. Not only did the RCRA cover have the highest water contents but it also was observed to have a net increase in total water at the end of each year of study (Figure 4). In order to better understand the cause of this continual gain, we will examine other components of water balance.

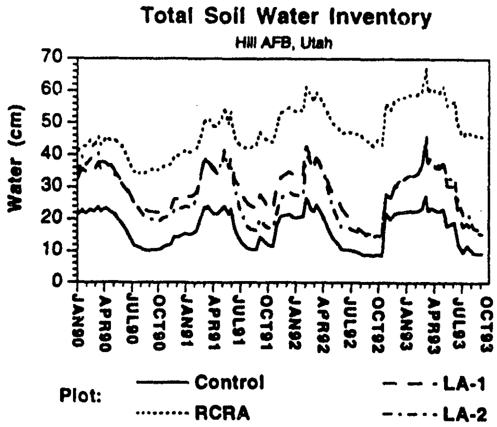

FIGURE 4 Total soil water inventory as a function of time for all cap designs at Hill AFB.

Interflow and Leachate

The vast majority of all interflow and leachate occurred during a relatively short time period early each year (primarily as a result of snow melt and early spring rains). Between 92 and 98 % of all interflow and leachate production occurred during the months of February through May.

All barriers were effective in reducing leachate production relative to the conventional design (Figure 5). Interflow accounted for about 20 cm (or 10 % of the total precipitation) and 12 cm (or 6 % of the precipitation) from the capillary barriers in the LA-1 and LA-2 designs respectively and about 43 cm (or about 21 % of the precipitation) from the clay barrier in the RCRA design.

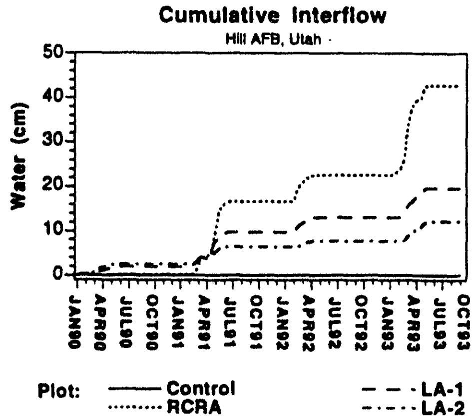

FIGURE 5 Cumulative barrier lateral flow as a function of time for all cap designs at Hill AFB.

Leachate was produced from all four cap designs during the 45 month study period although the frequency and volume produced varied dramatically with design (Figure 6). During several discrete flow events the control cap generated 41 cm of leachate representing approximatcly 20 % of the total precipitation. In the other extreme, the RCRA cap was almost completely effective in preventing leachate production due to the diversion of soil water through interflow and to the continuous wetting of the clay barrier soil (Figure 7). During the first year no interflow or leachate was generated from the RCRA plot but the clay barrier increased in water content approximately
7 % by volume. Interflow production began in the spring of the second year but leachate was not generated till after 27 months of study. After leachate production was observed, the moisture content in the clay layer continued to increase and reached a maximum of about 46 % volummetric water content (more than double its initial content and essentially at it's saturation level). Clearly the continual wetting of the clay layer was the cause of the net gains in water content on the

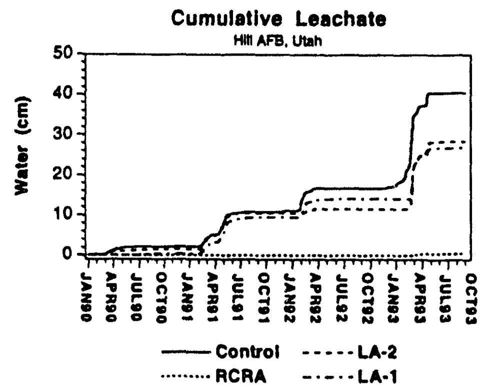

FIGURE 6 Cumulative leachate flow as a function of time for all cap designs at Hill AFB.

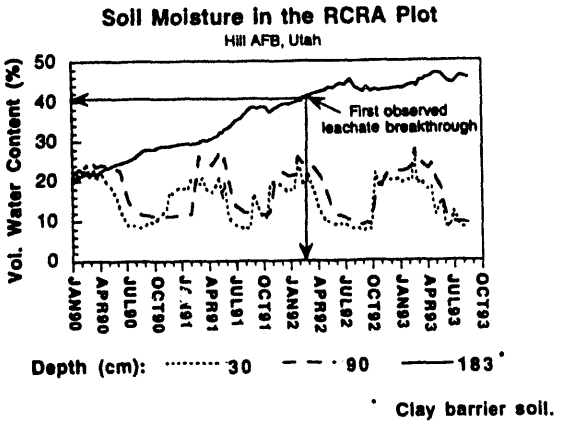

FIGURE 7 Volummetric water content as a function of time at selected depths within the RCRA plot soils at Hill AFB.

RCRA cover. In examining this layer closely certain trends are visible which call into question the ability of this design to perform in the long term. During the late summer months, when precipitation was low and ET was high, losses of water were observed in the clay barrier layer. The total leachate production measured out the bottom of the RCRA cover (0.5 cm) could only account for 3 % of this moisture loss, implying that ET was responsible for the majority of it. Because of the depth of the clay layer, it is felt the observed losses were a result of plant transpiration rather than evaporation. Future concerns of this action are the formation of preferential flow paths from plant root channels or from fractures in the clay due to desiccation during prolonged dry periods. The susceptibility of clay layers to desiccation cracking has been well documented[9,10] and there is evidence that these cracks may not "heal" themselves upon rehydration[11].

The LA-1 and LA-2 capillary barrier designs generated 42% and 27% less leachate than the conventional design respectively. Total leachate production was 24 cm (12% of precipitation) for LA-1 and 30 cm (15% of precipitation) for the grass/shrub covers LA-2.

Evapotranspiration

By far the majority of precipitation was returned to the atmosphere by ET. A total of 71%, 82%, and 86% of the total precipitation went to ET on the RCRA, conventional, and both LA capillary barrier designs respectively. The increased amounts of ET on the LA cover designs were a result of increased infiltration and a resultant increase in vegetational biomass. Successional changes on the plots increase homogeneity between plot covers and thereby reduced differences in ET expected between the LA-1 and LA-2 plots.

CONCLUSIONS

Carefully designed landfill capping alternatives can significantly enhance performance of landfills by controlling the hydrology of the site. The critical time period for leachate production at Hill Air Force Base was a result of snow melt and rain events between February and May of each year. The conventional cover design allowed 20% of the total precipitation to pass through the cover. This equals a volume of 2.05×10^4 liters over the area of the plot or more than 4 million liters of water allowed to enter the waste environment per hectare over the 45 month period.

The two capillary barrier designs improved over the conventional design but were still less effective compared to the RCRA cap. The RCRA cap was most effective in inhibiting leachate production but due to continued changes in the cover we believe 45 months of observation is inadequate to fully evaluate this design.

Gravel mulch surface treatments were effective in reducing runoff and erosion. Plots receiving this treatment showed increased vegetative biomass and enhanced evapotranspiration.

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