A Water Balance Study Of Infiltration Control Landfill Cover Designs At Marine Corp Base Hawaii

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Abstract

Preliminary results are presented from a landfill capping demonstration being conducted by the Naval Facilities Engineering Services Center at Marine Corp Base Hawaii (MCBH). Specific details about construction and sampling methods used in the study will not be presented here as they appear elsewhere (Hakonson 1996, Hakonson 1994). This paper summarizes some of the data that has been collected on precipitation, runoff, and percolation from the MCBH cover designs for the 9 month period between 11/95 - 12/96. Data from this analysis were also compared against corresponding data for a clay cap obtained from EPA's HELP, version 3, water balance model.

Our short term results support the concept of using runoff enhancement to manage landfill site water balance. The infiltration control designs increased runoff over the soil cover design and reduced percolation to about one quarter to one third of that measured from the soil cover. Results also demonstrate that the hydrologic response of the MCBH cover designs is highly dependent on season and a related variable, the amount of precipitation falling during a particular month. Should the performance characteristics of the RES designs that have been observed thus far be validated with further monitoring data, these designs would offer a simple and inexpensive alternative for interim stabilization or closure of landfills, particularly in more humid sites.

Keywords: Landfill, Capping, Water Harvesting

INTRODUCTION

The Naval Facilities Engineering Services Center initiated a landfill cover demonstration project at Marine Corp Base Hawaii (MCBH) to evaluate infiltration control (IC) cover designs as an alternative for closure of landfills. The study used relatively large scale lysimeters to estimate the hydrologic performance of three cover design alternatives to a clay barrier design. Field data are presented for two infiltration control and one soil cover design, including measurements on vegetation cover, precipitation, runoff, and percolation, for the 14 month period between 11/95 - 12/96. Soil moisture data are not presented as the analysis of the data are not complete at this time. The equivalency of the three MCBH cover designs in controlling runoff and percolation were compared to results for a RCRA clay cap design, obtained with version 3 of the Hydrologic Evaluation of Landfill Performance, or HELP3 model (EPA/600/R-94/168a).

TECHNICAL APPROACH

Most capping technologies incorporate design features which control one or more of the processes governing the fate of precipitation falling on the landfill. The fate of meteoric water falling on the landfill is referred to as the water balance of the site. A simplified representation of water balance describes surface runoff and one-dimensional movement of water in the soil profile to the plant rooting depth. For net rates and amounts, the water balance equation is:

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

where δS is the change in soil moisture storage, P is precipitation, R is runoff, ET is evapotranspiration, L is percolation below the root zone, and t is the unit of time used in solving the equation. Units of depth, or cm, are used in applying the equation in this paper.

The coupled nature of the processes comprising the water balance can be used to advantage in designing landfill caps that change terms in Equation 1 that reduce or eliminate contaminant migration (i.e. percolation) while enhancing other terms (i.e. ET) that do not. The concept of water balance and, especially methods to manipulate its various components, has served as the basis for several studies to design, test, and evaluate a variety of capping alternatives for radioactive and hazardous waste landfills. For example, past studies have emphasized the role of vegetation in removing soil moisture via evapotranspiration (Anderson et. al. 1993, Sejkora 1989) the use of subsurface barriers to intercept and laterally divert percolating water (Buckmaster 1993, Nyhan et al. 1990, Warren et al. 1996) and surface management practices to control runoff and erosion (Nyhan et al. 1984, UMTRA-DOE 1989).

Most of the past work on landfill covers has been conducted in arid or semi-arid environments with annual precipitation of less than 20 inches per year. In more humid climates, and especially those which average more than 30 inches of precipitation per year, the amount of soil moisture that can be potentially removed by vegetation is usually less than the annual precipitation. This leads to an excess of soil moisture that is available for subsurface percolation into the waste environment. Consequently, a cover design is needed for sites where the amount of water that infiltrates into the soil exceeds the potential for ET to remove it. This need especially applies to humid sites that receive more than 75 cm of precipitation per year or to more xeric sites where snow is an important source of annual precipitation.

There are several possible ways to manage soil moisture in a landfill cover including the use of hydraulic or capillary barriers to laterally divert percolating water away from the waste environment or methods to limit infiltration of precipitation into the cover soil (Hakonson et. al. 1992, Hakonson et. al. 1990, Nyhan et. al. 1990). The study at MCBH focuses on the latter approach by enhancing surface runoff (Fig. 1) as a means of reducing the amount of soil water that must be partitioned between the ET and percolation terms in Equation 1. The approach relies on diverting enough of the annual precipitation to runoff, using water harvesting structures so that the water that does infiltrate into the soil can easily be removed by evapotranspiration.

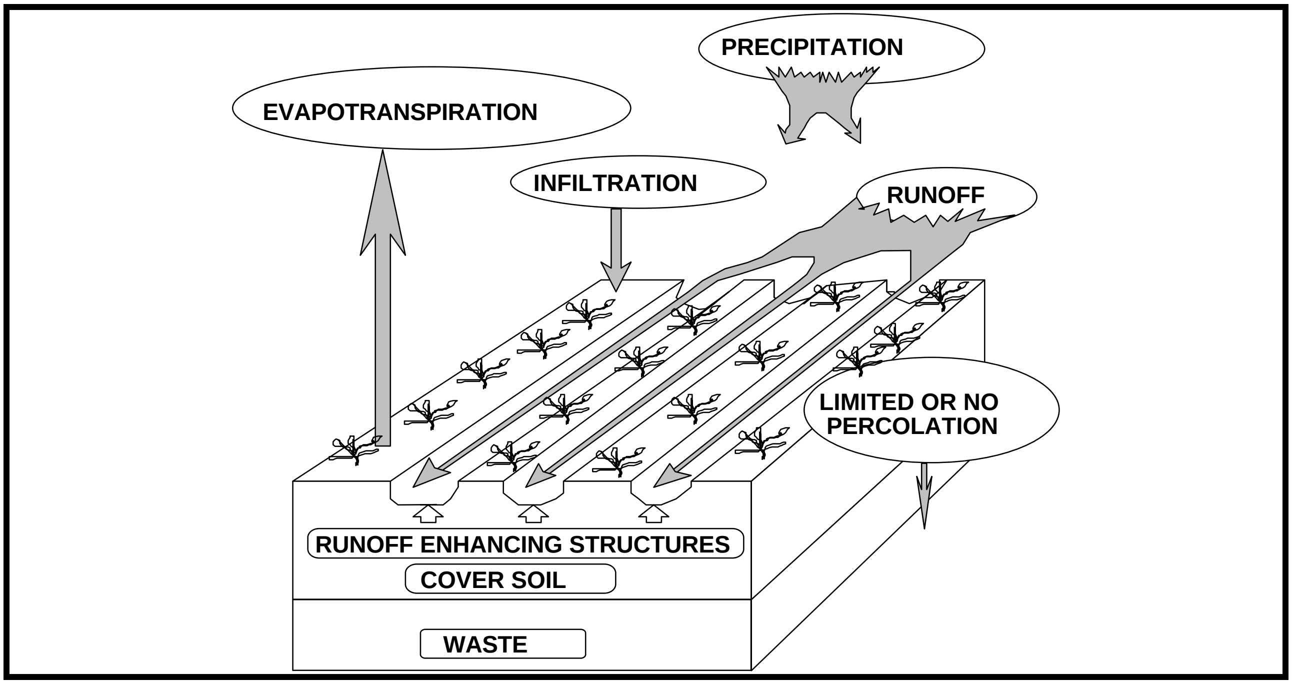

Fig. 1. Infiltration control cover design utilizing runoff enhancing structures at Marine Corp Base, Hawaii.

The use of infiltration control (IC) techniques for managing waste site water balance is potentially attractive because it can be applied to an existing landfill cover, where it is easily repairable, and involves a minimum of materials, equipment, and labor. Some of the pioneering work on infiltration control landfill covers in the U.S. was conducted by Dr. R. K. Schulz, University of California, Berkley, with Nuclear Regulatory Commission funding (Schulz et al. 1990). However, the technical basis for infiltration control as a means of water management has it's roots in ancient history. For example, Hebrew farmers developed and used infiltration control techniques 8000 years ago to support a flourishing agriculture in the Negev Desert (Evenari et al. 1961).

METHODS AND MATERIALS

Study Area- Marine Corp Base Hawaii is located on the eastern side of the island of Oahu. It receives about 970 mm of annual precipitation, primarily in the monsoons from October through April. Average monthly temperatures range from 23- 27°C and average 25°C for the year. Vegetation surrounding the study site consists of a mixture shrubs and grasses primarily of the Acacia and Panicum families.

Cover Designs- Six plots, 6 m x 9 m long (Hakonson 1994), were constructed to permit measurement of all of the water balance terms in equation 1, except evapotranspiration (Fig. 1). The latter was derived by solving equation 1. The IC cap designs consisted of replicates of a non-layered soil profile, 60 cm thick, with two levels of runoff enhancing structures on the cover surface (Fig. 2). Initial calculations, based on an average MCBH precipitation of 970 mm/yr, suggested that runoff enhancing structures installed on about 20% and 40 % of the cover surface should be sufficient to reduce percolation through the cover to very low levels. Runoff enhancing structures were constructed from 12 cm wide metal rain gutter placed on the ground surface and parallel to the slope. The monolithic soil design was constructed of 60 cm of the same single non-layered soil profile as above, but without runoff collectors on the surface. All of soils used in constructing the cover profiles were compacted to 95% of optimum on placement. The plots had a surface slope of 5% and were seeded with 6 native grasses and shrubs as described in Hakonson 1996.

Monitoring- Instrumentation was installed (Table 1, Fig. 3). to permit direct measurement of runoff, percolation through the cover, soil moisture status, and precipitation. A variety of sensors were used including flow meters, pressure transducers, Time Domain Reflectrometers, tipping bucket gages coupled to a Campbell Scientific data logger (Hakonson 1994). Stored data could be downloaded by cellular phone link to NFESC in Port Hueneme CA. The input data for simulating the RCRA, subtitle C cap with the HELP3 model is presented in Table 2. Briefly, the RCRA cap, from top to bottom, consisted of a 60 cm vegetated layer, a 30 cm drainage layer of sand, and a 30 cm layer of compacted clay with a hydraulic conductivity of 10-7 cm/sec. The model CLIGEN (Nicks and Lane 1989) was used to synthetically generate the precipitation files for MCBH. Also, a flexible membrane liner was not included as a design component of RCRA cap.

Canopy and ground cover was characterized on all of the plots in March, May, and July, 1995 using a modified point frame technique (Levy and Madden 1933) to estimate canopy and ground cover. The point frame was positioned at 10 equi-distant locations (Pieper 1973) perpendicular to the 9m axis of each plot resulting in 61 measurements per point frame position and 610

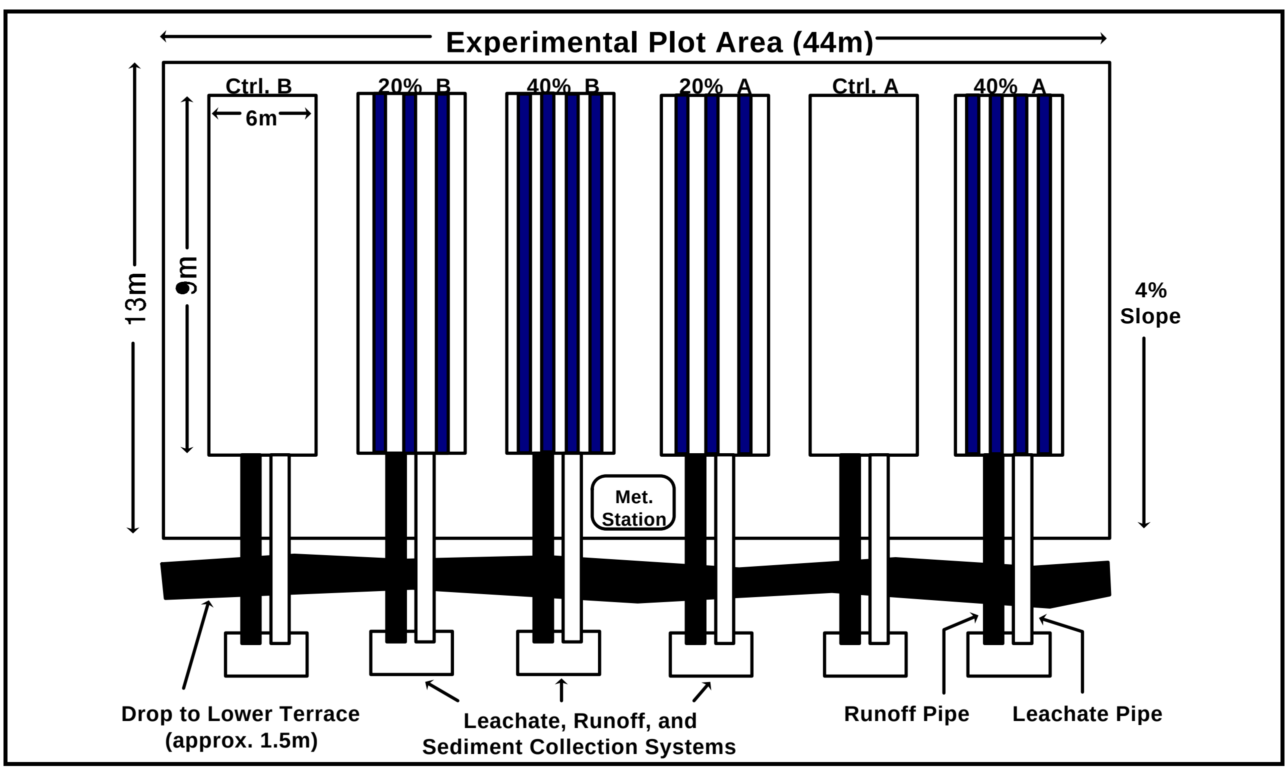

Fig. 2. Plan view of MCBH infiltration control landfill cover designs.

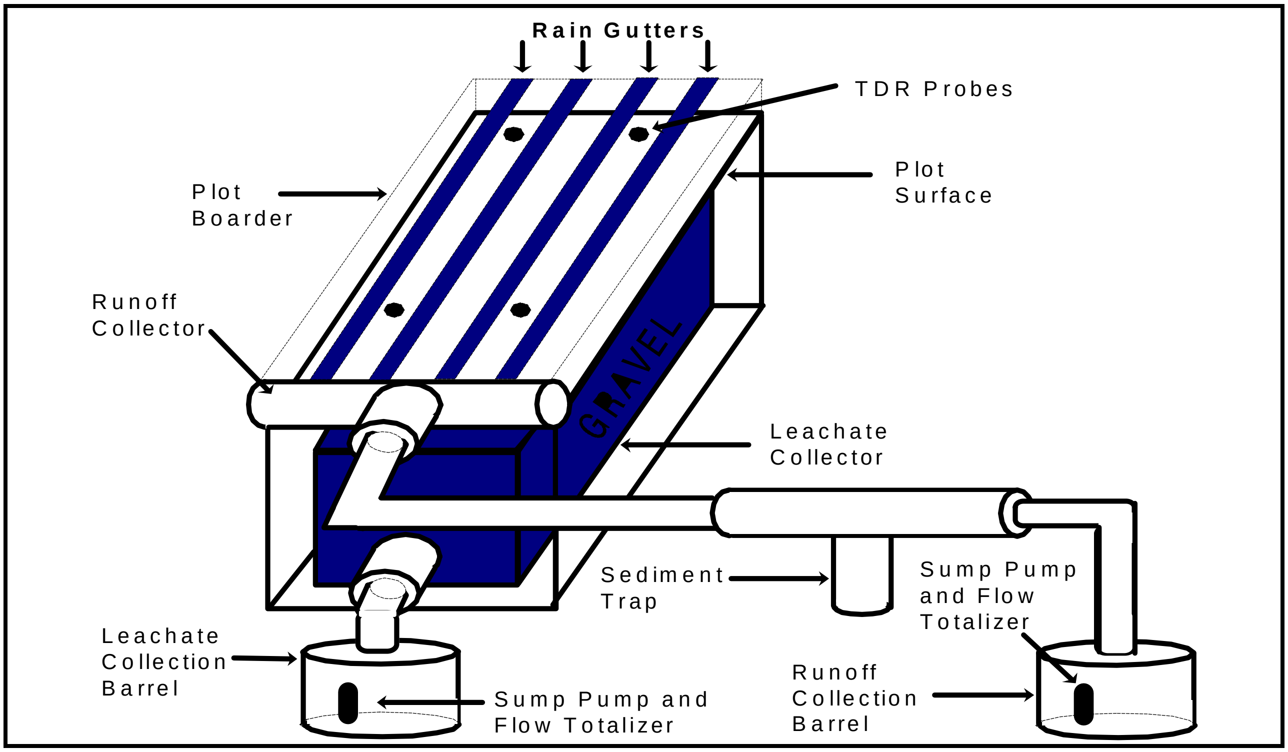

Fig. 3. Monitoring systems for MCBH infiltration control landfill cover study.

Table 1 Techniques for measuring water balance on MCBH infiltration control landfill cover demonstration plots.

Water Balance Component	Method of measurement	Frequency of measurement
Precipitation	Tipping Bucket at ground	Hourly
Soil Moisture	4 TDR probes/ plot @2 depths	Hourly
Runoff	Flow Meters/ Pressure Transducers	Every 15 min.
Leachate	Flow Meters/ Pressure Transducers	Every 15 min.
Evapotranspiration	Solve Water Balance Equation	
Sediment	Total Collection	Every 3 mo.

Table 2. HELP3 input data used in simulating the EPA RCRA Cap for MCBH conditions[1]

(Station latitude = 21.33 degrees).

Layer 1- Vertical Percolation Layer	
SCS Runoff Curve Number	80.50
Evaporative Zone Depth	24.0 Inches
Thickness	24.00 Inches
Porosity	0.4640 Vol/Vol
Field Capacity	0.3100 Vol/Vol
Wilting Point	0.1870 Vol/Vol
Initial Soil Water Content	0.2719 Vol/Vol
Effective Sat. Hyd. Cond.	6.4×10^{-5} cm/sec
Layer 2- Lateral Drainage Layer	
Thickness	12.00 Inches
Porosity	0.3970 Vol/Vol
Field Capacity	0.0320 Vol/Vol
Wilting Point	0.0130 Vol/Vol
Initial Soil Water Content	0.0328 Vol/Vol
Effective Sat. Hyd. Cond	0.3 cm/sec
Slope	4.00 Percent
Drainage Length	208.0 Feet
Layer 3- Barrier Soil Liner	
Thickness	12.00 Inches
Porosity	0.4270 Vol/Vol
Field Capacity	0.4180 Vol/Vol
Wilting Point	0.3670 Vol/Vol
Initial Soil Water Content	0.4270 Vol/Vol
Effective Sat. Hyd. Cond.	1×10^{-7} cm/sec
Evapotranspiration And Weather Data	
Maximum Leaf Area Index	5.00
Start Of Growing Season (Julian Date	0
End Of Growing Season (Julian Date	367
Average Annual Wind Speed	11.70 mph

[1]Precipitation file for MCBH was generated using CLIGEN (Nicks and Lane 1989)

measurements per plot. Canopy cover was determined by recording the type of vegetation first contacted by the point frame pin. Biomass estimates were made by dividing each plot into 3 sections, the upslope 3 meters, a midslope 3 meters, and a lower 3 meters. A quadrat of 0.0804 m2 was randomly thrown into each section and the subtended vegetation clipped, dried, and weighed. Canopy and ground cover was characterized on all of the plots in March, May, and July, 1995 using a modified point frame technique (Levy and Madden 1933) to estimate canopy and ground

RESULTS

Vegetation Characteristics- The structural characteristics of the vegetation canopy on all plots was dominated by grass species, and particularly *Panicum repens*. All other grass, forb, and shrub species contributed only minor amounts (<5% each) to canopy cover in 1995. Surprisingly, the relative amount of cover on all three treatments were very similar despite the presence of runoff collectors on 20% and 40% of the surface of the IC designs (Fig. 4).

Seasonal changes in live vegetation cover were statistically significant and declined from highs in March to lows in July as shown by the data for grass cover in Fig. 4. These changes probably reflect the relationship of vegetation phenology to precipitation patterns at MCBH. The months of May-September are relatively dry and much of the vegetation is senescent.

Ground cover changed markedly from March through July. These changes were characterized by decreasing bare soil as litter cover increased from near zero in March to 90-100% in July, exclusive of the gutters on the ground surface. Live biomass ranged from about 200-300 g/m^2 and total biomass (live + dead) from 400-600 g/m^2. A complete description of the vegetation data for CY 1995 is presented in Hakonson (1996).

Precipitation- The distribution and amounts of precipitation predicted with CLIGEN and that measured at MCBH over the last 30 years (Fig. 5) were very similar (i.e. r^2= 0.72, 1, 14 df, slope = 0.81, p = 0.0001) over the 14 month period. While the monthly precipitation measured at the study site generally tracked 30 year averages, it was much more variable, ranging over an order of magnitude from the average during any given month (Fig. 5). The precipitation data for CY 1995 demonstrated that low amounts of precipitation fall in summer at MCBH (15% fell on the study site during April-July) and larger amounts fall in winter (85% fell during November-March).

The total precipitation received at the site from 11/95 - 12/96 was 120.3 cm. This is about equal to the 119.6 cm, based on 30 year monthly averages at MCBH, and about 6% above the 113.8 cm that was predicted by CLIGEN for the 14 month period. During the month of November, 1996, a large storm at the MCBH study site produced precipitation that was about 3.5 times higher (38.5 cm) than the long term average for November of about 11 cm and about 32% of the total recorded during the study period.

Runoff Data- A summary of monthly runoff as measured at the MCBH plots and as calculated using HELP3 for the RCRA clay cap design are presented in Tables 3. Differences in total runoff between plots pairs A and B of a given cover design were not significant (p = 0.05) even though monthly runoff often varied by an order of magnitude. In contrast, differences in runoff between cover treatments were significant both within months ($p<0.001$) and between months ($p=0.02$).

The IC cover designs generated 2 to 5 times more runoff than the soil design within any given month and about 2-2.5 times as much over the 14 month study period (Table 3). There appears to be no clear advantage of using 40% IC over 20% IC since differences in runoff between the two were not significant for any of the comparisons made (p = 0.07).

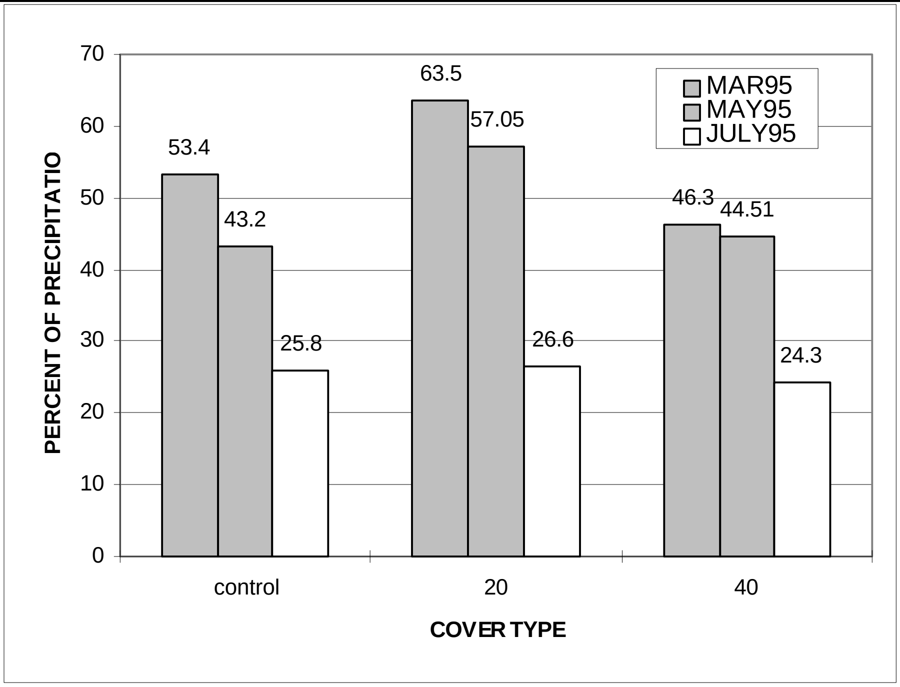

Fig. 4 Seasonal Changes in Grass Cover at MCBH Infiltration Control Plots, March-July, 1995.

After 14 months, total runoff was 6.0 and 14.5 cm for the two control plots, 20 and 26.2 cm for the 20% treatment, and 18.6 and 30.4 for the 40% treatment (Table 3). Plot pair averages were 10.2, 23.1, and 24.5 cm for the control, 20%, and 40% cover treatments, respectively. The RCRA cap, based on HELP3 simulations, was estimated to produce 9.0 cm of runoff over the 14 month period, similar to the amount measured on the control plot.

Depending on cover design, the number of months when runoff was measured ranged from 9-11 over the 14 month study period. As would be expected, runoff frequency was higher on the IC cover designs and lowest on the soil cover design (Table 3). Runoff from the RCRA clay cover was predicted by HELP3 to occur in all months except June.

Runoff distribution over the 14 month period (Fig. 6) paralleled that observed for precipitation in that >97% was generated during the months of November-March and <3% during April-July (Table 3). Linear regression coefficients relating measured and HELP3 predicted monthly runoff (Y) to measured monthly precipitation (X) are presented in Table 4. Based on the slopes of the regression curves, runoff accounted for about 11% (4% and 18%) of the precipitation on the control, 32% (28% and 36%) on the 20% IC, and 32% (21% and 40%) on the 40% IC designs. The regression slope for HELP3 predicted runoff versus precipitation generated with CLIGEN was also significant (p=0.02).

The intercepts of the regressions equations for the MCBH plots were all negative reflecting the fact that below a certain levels of precipitation, no runoff was produced. The amount of monthly precipitation needed to produce runoff (intercept/slope) ranged from about 2-3.5 cm for the all three cover designs. For example, April, May, and October each had less than 2 cm of precipitation and no runoff while January, March, June, and November in 1996 each had >10 cm precipitation and produced at least 90% of the runoff.

Over the 14 month period, the relative amount of runoff, as a percentage of the precipitation, averaged 20%, 19%, 8.5%, and 7.5% from the 40% IC, 20% IC, soil, and RCRA designs, respectively (Fig. 6). On a month to month basis, the relative amount of runoff generated by the various cover designs was as high as 35% and as low as zero reflecting the influence of changing soil moisture status, vegetation phenology, and duration and intensity of individual rain storms.

Percolation Data- A summary of monthly percolation as measured at the MCBH plots and as calculated using HELP3 for the RCRA clay cap design are presented in Tables 5. Differences in total percolation between plots pairs A and B of a given cover design were not significant (p = 0.05) even though monthly percolation varied by an order of magnitude. Additionally, differences

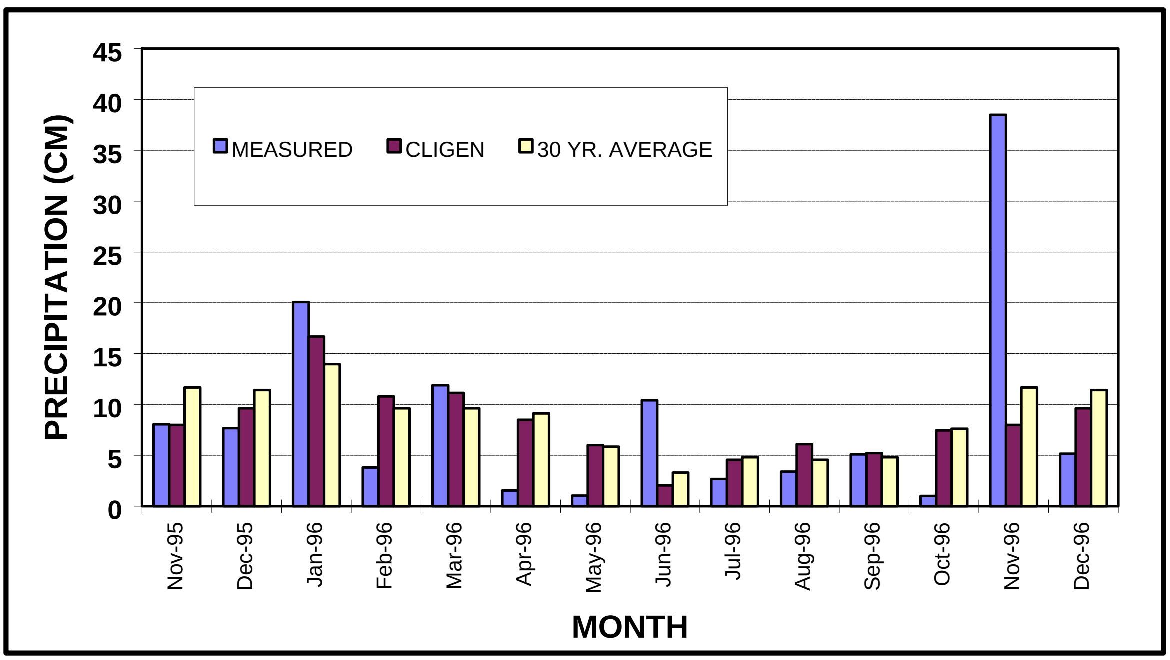

Fig. 5. Measured, 30 yr average, and CLIGEN predicted monthly precipitation at MCBH.

Table 3. Monthly runoff data for individual plots at MCBH landfill cover demonstration site.

% Runoff Enhancement							
	Control (0%)		20%_		40%_		HELP3
Month	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B	RCRA
Nov-95	0	0.02	0.09	0.09	0	0.30	0.63
Dec-95	0.30	0.72	0.50	0.23	0.58	0.72	0.90
Jan-96	2.61	4.92	5.20	7.12	6.33	7.39	1.76
Feb-96	0.14	0.01	0.31	0.19	0.84	0.59	0.41
Mar-96	1.77	2.69	3.19	4.10	3.25	5.01	0.60
Apr-96	0	0	0	0	0	0	0.24
May-96	0	0	0	0	0	0	1.15
Jun-96	0.20	0.11	0.73	0.76	0.17	1.24	0.00
Jul-96	0.01	0	0	0.01	0.04	0.08	0.01
Aug-96	0	0	0	0	0.09	0.10	0.05
Sep-96	0.10	0.13	0.04	0.37	0.23	0.24	0.02
Oct-96	0	0	0	0	0	0	1.66
Nov-96	0.77	5.77	9.80	12.89	6.75	14.23	0.63
Dec-96	0.05	0.08	0	0.49	0.34	0.50	0.90
Sum	6.0	14.5	19.9	26.2	18.6	30.4	9.0
Plot Pair Mean (SD)	10.2 (6.0)		231 (4.5)		24.5 (8.3)		9.0
# of Months Producing Runoff	9	9	8	10	10	11	13

Table 4. Linear regression coefficients for comparisons of monthly measured or predicted runoff with measured precipitation on various cover designs.

DESIGN	Intercept	Slope	R^2	probability slope≠0
Control				
Plot A	0.05	0.04	0.32	0.04
Plot B	-0.52	0.18	0.85	<0.0001
Mean	-0.23	0.11	0.72	0.0001
20% IC				
Plot A	-0.95	0.28	0.94	<0.0001
Plot B	-1.25	0.36	0.94	<0.0001
Mean	-1.1	0.32	0.94	<0.0001
40%IC				
Plot A	-0.49	0.21	0.81	<0.0001
Plot B	-1.24	0.40	0.95	<0.0001
Mean	-1.1	0.32	0.94	<0.0001
HELP3 RCRA	-0.21	0.11	0.40	0.02

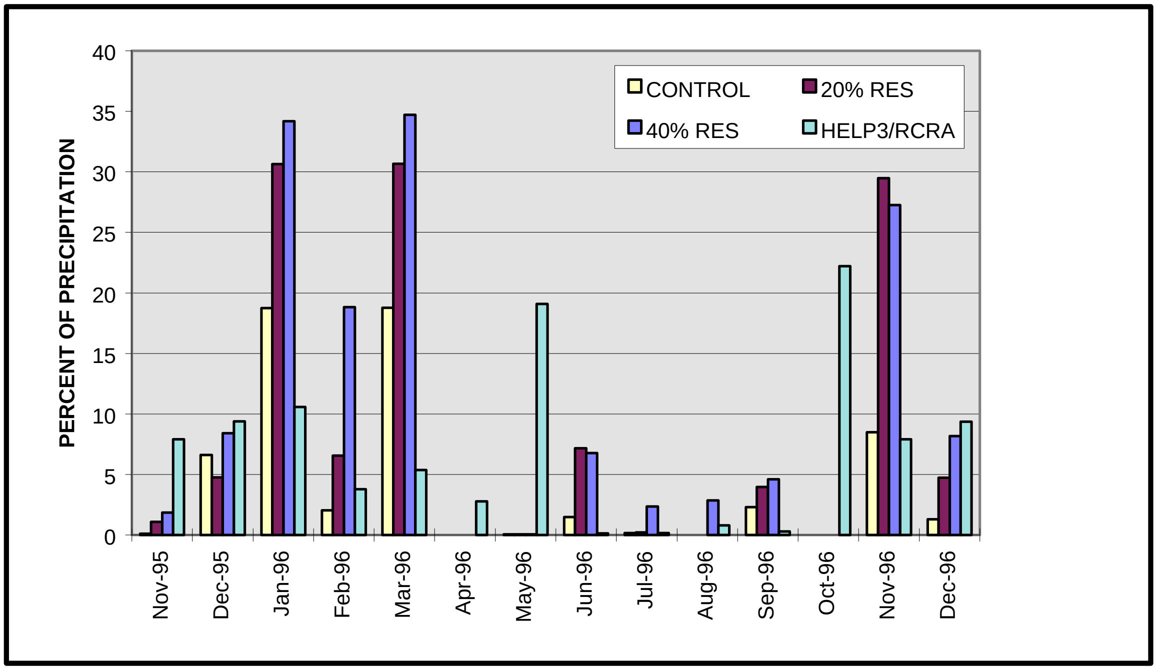

Fig. 6. Relative runoff, as a percentage of precipitation, from various landfill cover designs at MCBH.

in percolation from the cover treatments were not significant between months based on the complete set of data (p=0.41) or plot pair means (p=0.13) owing to the large variability and low amounts of percolation for most of the study period.

After 14 months, total percolation was 9.5 and 3.1 cm for the two control plots, 4.3 and 0.87 cm for the 20% treatment, and 1.5 and 0.74 for the 40% treatment (Table 5). Plot pair averages were 6.3, 2.6, and 2.1 cm for the control, 20%, and 40% cover treatments, respectively. The RCRA cap, based on HELP3 simulations, was estimated to produce 0.74 cm of percolation over the 14 month period, similar to the amount measured on the control plot. Percolation distribution over the 14 month period paralleled that observed for precipitation in that 92-97% was generated during the months of November-March and 3-8% during April-July (Table 5). Depending on cover design, the number of months when percolation was measured ranged from 7-9 over the 14 month study period (Table 5). As would be expected, the number of months with percolation was higher on the soil cover design and lowest on the IC designs (Table 5). Percolation from the RCRA clay cover was predicted by HELP3 to occur in all months except July and September.

Linear regression coefficients relating measured and HELP3 predicted monthly percolation (Y) to measured monthly precipitation (X) are presented in Table 6. Based on the slopes of the regression curves, percolation accounted for about 11% (19% and 2%) of the precipitation on the soil design, 5% (0.9% and 9%) on the 20% IC, and 3% (1.2% and 5%) on the 40% IC designs. The regression slope for HELP3 predicted percolation versus precipitation generated with CLIGEN was also significant (p=0.0001).
The intercepts of nearly all of the regressions equations relating percolation and precipitation were negative reflecting the fact that below a certain levels of precipitation, very little percolation was

produced. The amount of monthly precipitation needed to produce percolation (intercept/slope) ranged from about 2-5 cm for the all three cover designs. For example, during each of the months of April, May, August, and October less than 5 cm of precipitation fell resulting in no percolation. While small amounts of percolation were measured during most of the remaining months, from 75-90% of the total percolation measured during the study occurred in January and November, 1996, months when precipitation exceeded 20 cm.

Over the 14 month period, the relative amount of percolation, as a percentage of the precipitation, averaged 1.8%, 2.3%, 5,3%, and 0.62% from the 40% IC, 20% IC, soil, and RCRA designs, respectively (Fig. 7). On a month to month basis, the relative amount of percolation generated by the various cover designs was as high as 11% and as low as zero reflecting the influence of changing soil moisture status, vegetation phenology, and duration and intensity of individual rain storms.

DISCUSSION

The relative performance of the various cover types in effecting runoff and percolation is summarized in Fig. 8. Based upon 14 months of data, our results support the concept of using runoff enhancement to manage landfill water balance. For example, we were able to increase runoff by a factor of 2-3 on the IC cover designs over that measured on the soil design. While differences in percolation were not statistically significant ($p=0.05$), the trend in the data indicated a factor of 2-3 reduction in percolation from the IC designs over the soil design. Statistical tests also indicated that there was no clear advantage of using 40% runoff enhancement over 20% as both produced about the same amount of runoff and percolation. The lack of these differences cannot be explained at this time but undoubtedly are related to the complex relationships between the physical and biological processes operating on the plots. Ongoing analysis of the soil moisture data should help identify processes contributing to the similarity in hydrologic performance of the 2 IC designs.

Results also demonstrate that the hydrologic response of the MCBH cover designs was highly dependent on season and a related variable, the amount of precipitation falling during a particular month. Most of the runoff and percolation was generated during a few months in winter when most of the precipitation was measured. Furthermore, at least 75% up to 98% of the runoff and percolation was generated during the four months with precipitation exceeding 10 cm. Most months receiving less than 10 cm of precipitation contributed only minor amounts to the total runoff and precipitation measured during the study.

Linear regression analysis indicated that a runoff or percolation was not generated until a threshold monthly precipitation of 2-5 cm was exceeded. The relative amount of runoff or percolation form the field plots was significantly related to monthly precipitation. In contrast, HELP3 predicted runoff and percolation was either not related or weakly related to measured precipitation. Better correspondence of predicted data to precipitation was obtained when synthetic precipitation was used in the regressions.

Table 5. Monthly percolation totals for individual plots at MCBH landfill cover demonstration site

	Control		20% IC		40% IC		HELP3
Month	A	B	A	B	A	B	RCRA
Nov-95	0.12	0.00	0.00	0.00	0.00	0.00	0.04
Dec-95	0.12	0.82	0.18	0.08	0.05	0.09	0.12
Jan-96	1.01	1.43	0.20	0.46	0.26	0.06	0.14
Feb-96	0.05	0.22	0.05	0.01	0.13	0.16	0.13
Mar-96	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Apr-96	0.00	0.00	0.00	0.00	0.00	0.00	0.03
May-96	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Jun-96	0.10	0.11	0.09	0.02	0.10	0.05	0.01
Jul-96	0.02	0.01	0.01	0.01	0.01	0.01	0.00
Aug-96	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Sep-96	0.04	0.05	0.04	0.04	0.06	0.04	0.00
Oct-96	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Nov-96	8.02	0.47	3.71	0.24	0.49	2.39	0.04
Dec-96	0.06	0.00	0.00	0.00	0.35	0.00	0.12
Sum	9.54	3.11	4.28	0.87	1.45	2.80	0.74
Plot Pair Means	6.33		2.58		2.13		–
# Months w/ Percolation	9	7	7	7	8	7	12

Table 6. Linear regression coefficients for comparisons of monthly measured or predicted (CLIGEN) percolation with measured precipitation on various cover designs.

Design	Intercept	Slope	R^2	probability slope≠0
Control				
Plot A	-0.96	0.19	0.81	<0.0001
Plot B	0.04	0.02	0.27	0.06
Mean	-0.46	0.11	0.88	<0.0001
20% IC				
Plot A	-0.43	0.09	0.77	<0.0001
Plot B	-0.02	0.009	0.50	0.0004
Mean	-0.23	0.05	0.83	<0.0001
40%IC				
Plot A	0.001	0.012	0.60	0.001
Plot B	-0.26	0.05	0.74	<0.0001
Mean	-0.13	0.03	0.78	<0.0001
HELP3 RCRA	-0.05	0.01	0.72	0.0001

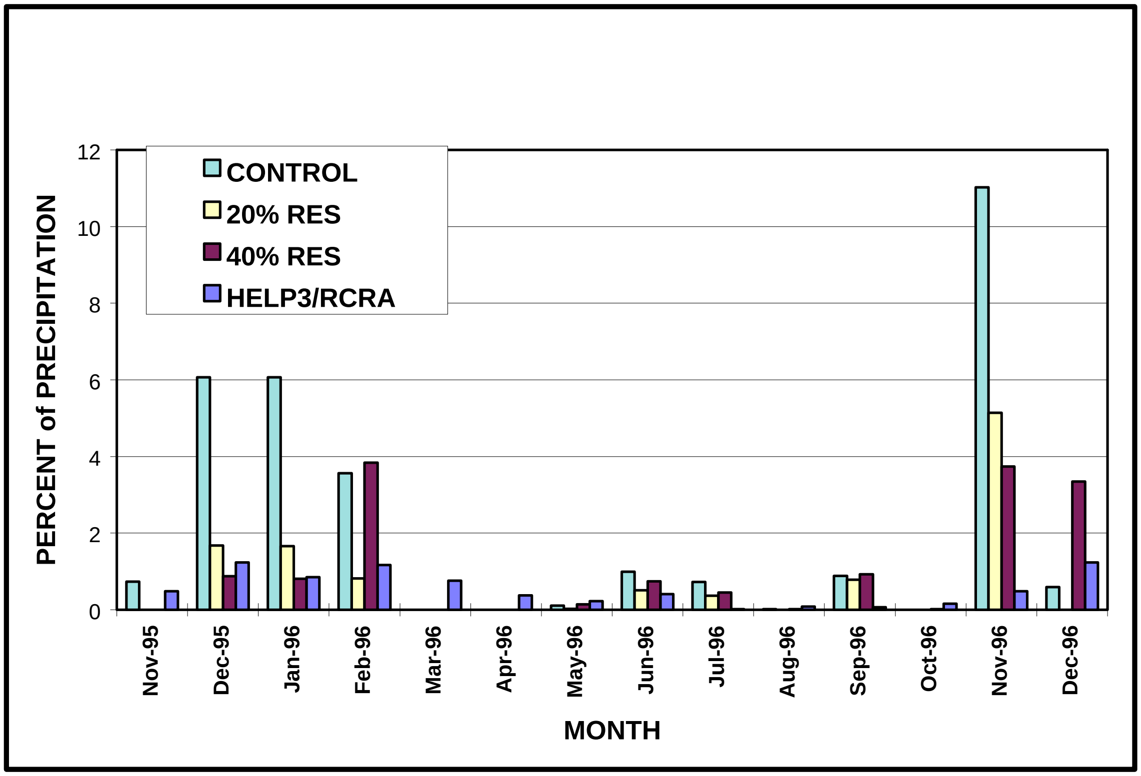

Fig. 7. Relative amount of percolation from various cover designs at MCBH.

Based upon a comparison of the predicted hydrologic performance of a modified RCRA cover and the two IC designs, these preliminary results suggest about they were within a factor of 2-3 in their ability to limit percolation. While the IC designs rely on limiting infiltration, the RCRA design relies on lateral diversion of soil moisture in a drainage layer to prevent percolation. In the HELP3 simulation of the RCRA design, about 15% of the precipitation was predicted as lateral flow from the drainage layer.

Should the performance characteristics of the IC designs, as observed thus far in the MCBH study, be confirmed with further monitoring data, these designs could offer a simple and inexpensive alternative for interim stabilization or final closure of landfills in humid sites. The IC cover technology is simple in design, easy to install over an existing landfill cover, and easy to remove if other uses for the land emerge in the future.

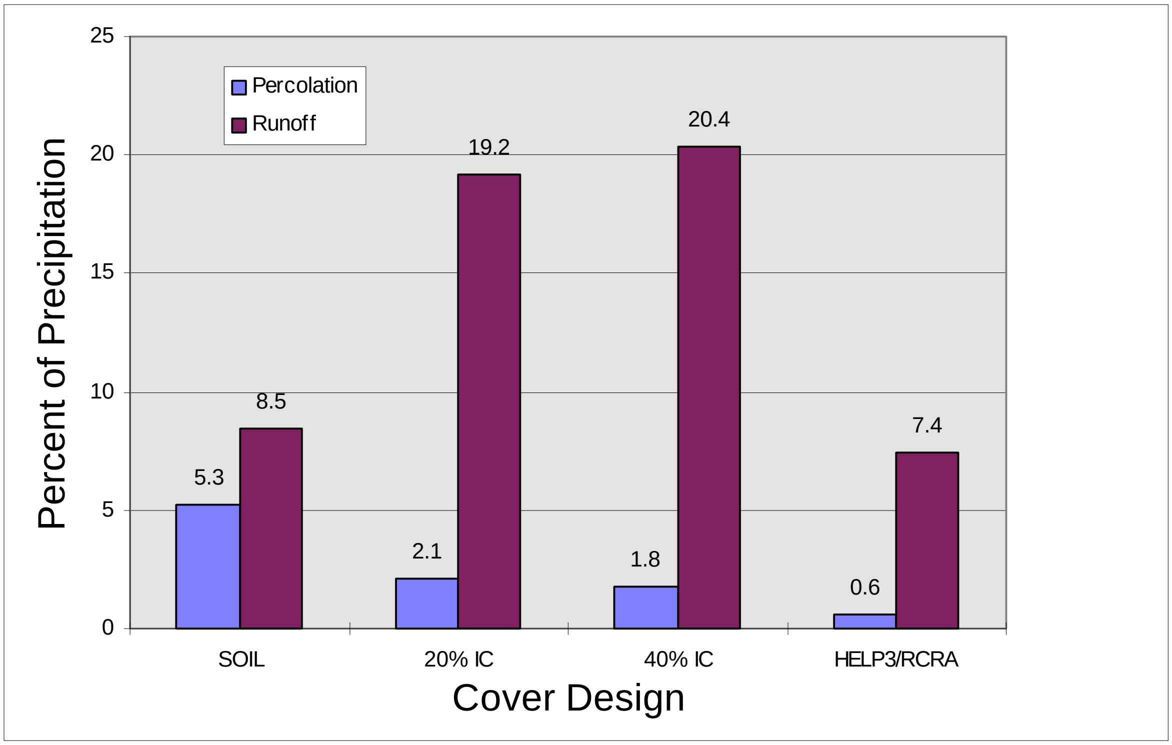

Fig. 8. Relative performance of various landfill cover designs in limiting percolation and runoff at MCBH.

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