Infiltration Control Cover Technology Demonstration At Marine Corp Base Hawaii-
Preliminary Results of Water Balance Monitoring

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Abstract

This paper presents some preliminary results 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 - 7/96. Data from this analysis were also compared against corresponding data for a clay cap obtained from EPA's HELP, version 3, water balance model (EPA/600/R-94/168a). Preliminary results from the RES designs appear encouraging in that they are producing results in line with the technical theory behind them.

Keywords

Landfill, Capping, Water Harvesting, Water Balance

Background

Surface covers to control water infiltration to waste buried in landfills will likely serve as an attractive remediation alternative for most of the Navy's hazardous and sanitary waste landfills. Surface covers can effectively manage the human and ecological risks of a site, along with offering ease of maintenance and lower costs than other remediation options. 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 and its several variations. In practice, however, very little field testing of the RCRA cap, or any other design, has been done to evaluate the long term effectiveness of various cover designs in limiting infiltration of water into the waste.

EPA encourages the use of alternative cap designs if they can be shown to be “equivalent” to the RCRA cap (EPA, 1989). Demonstrating “equivalency” presumably must involve the use EPA’s Hydrologic Evaluation Leachate Potential (HELP) model since few side by side comparisons of capping technologies have been done.

The Naval Facilities Engineering Service Center initiated a study of several capping methods at Marine Corp Base Hawaii (MCBH). These large scale lysimeters are used to perform a mass balance on the precipitation received at the site. The objective of the study was to evaluate three alternative cover designs including: a 20% water harvesting structure; a 40% water harvesting structure; and a control plot, as shown in Figure 1. The equivalency of the three MCBH cover designs to a modified RCRA clay cap design was also evaluated by comparing the data with that predicted with version 3 of the Hydrologic Evaluation of Landfill Performance, or HELP3 model (EPA/600/R-94/168a).

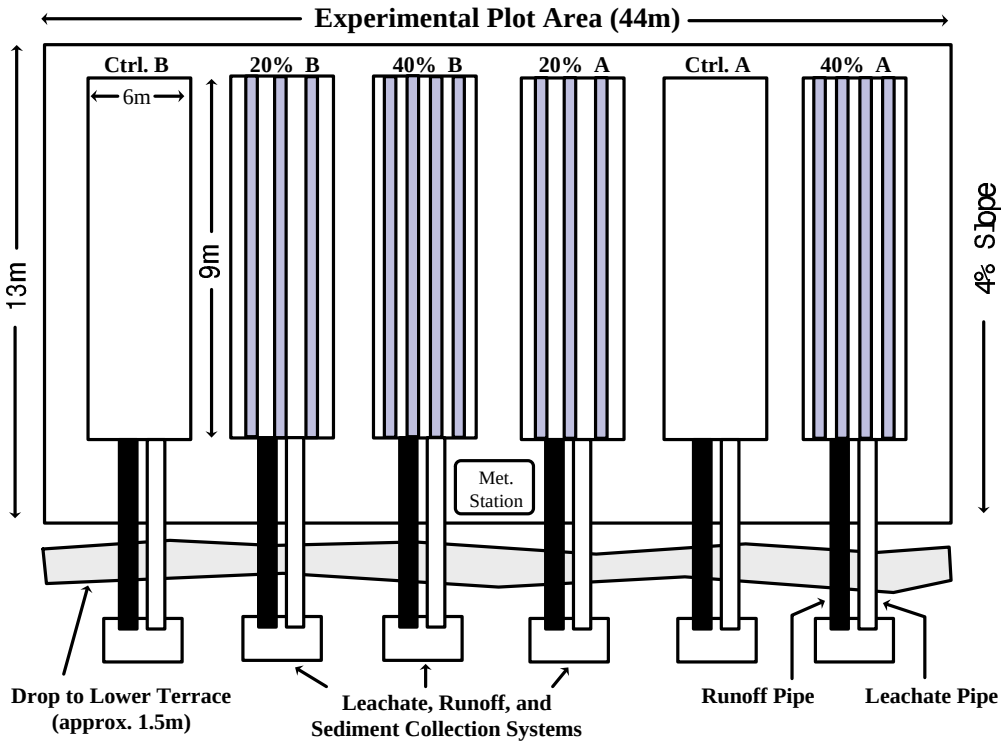


Figure 1. Plot Layout

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 often 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:

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

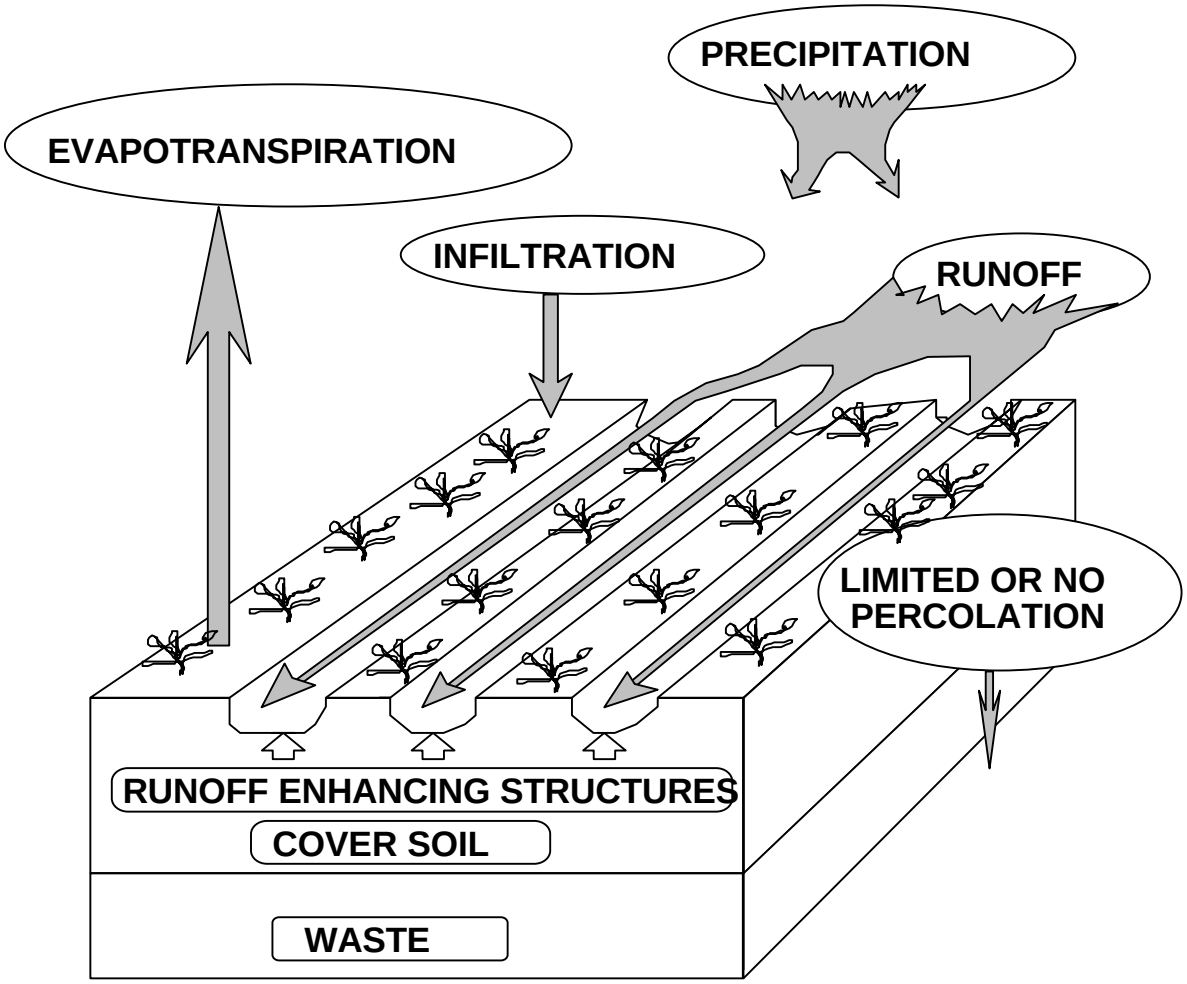
where δS is the change in soil moisture storage, P is precipitation, R is runoff, ET is evapotranspiration, L is percolation below the root zone, and t is the unit of time used in solving the equation. Units of depth, or cm, are used in applying the equation in this paper.

The concept of water balance, relative to design of landfill covers, accounts for the strong interactions between the various terms of Equation 1. For example, a reduction or elimination of the runoff term (R), increases infiltration of water into the soil, resulting in increased soil moisture storage followed by an increase in ET and/or percolation. Likewise, an enhancement of runoff must be followed by reduction in the amount of precipitation that infiltrates into the soil with a potential reduction in ET and/or percolation.

Because the maximum amount of soil moisture that can be removed by evapotranspiration has an upper limit that is defined by climate and other local conditions. 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). In either case, vegetation plays a key role in the ability of the cover to limit percolation by removing large amounts of stored soil

moisture via transpiration. The study at MCBH focuses on controlling infiltration by enhancing surface runoff as a means of reducing the amount of precipitation available for infiltration into the cover soil. The theory behind this design is to limit percolation of water through the cap to levels that the vegetation growing on the cover can remove via transpiration (Fig. 2). If the concept is viable, it could greatly simplify the construction and cost of cover closures where it can be used because the technology can be applied to an existing landfill cover, where it is easily repairable, and involves a minimum of materials, equipment, and labor.



$$\delta S/dt = (P - R - ET - L)/dt$$

Figure 2. Infiltration Control Cover

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 this means of water management was understood by ancient Hebrew farmers who developed and used infiltration control techniques to support a flourishing agriculture 8000 years ago in the Negev Desert (Evenari et al, 1961).

Methods and Materials

Six plots, 6m x 9m long (Hakonson, 1994), were constructed to permit measurement of all of the water balance terms in equation 1, excepting evapotranspiration. The latter was derived by solving equation 1. The cap designs to limit infiltration consisted of replicates of a non-layered soil profile, 60 cm thick, with two levels of runoff enhancing structures on the cover surface (Fig. 1). Initial calculations, based on an average MCBH precipitation of 99 cm/yr, suggested that runoff enhancing structures (RES) installed on about 20% and 40 % of the cover surface should be sufficient to reduce percolation through the cover to a very low level. Runoff enhancing structures were constructed from 12 cm wide rain gutter placed parallel to the slope on the ground surface. Figure 3 provides a more detailed layout of one of the test plots.

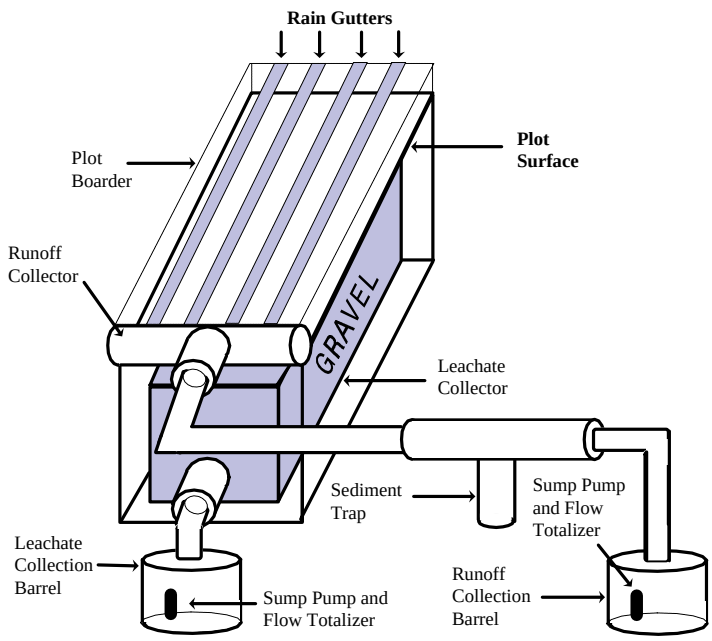


Figure 3 Individual Test Plot Diagram

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 native grasses and shrubs as described in Hakonson, 1996.

Instrumentation was installed to permit direct measurement of runoff, percolation through the cover, soil moisture status, and precipitation (Table 1). A variety of sensors were used including flow meters, pressure transducers, Time Domain Reflectometers, 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 the RCRA cap.

RESULTS

Precipitation Data

The distribution and amounts of precipitation predicted with CLIGEN and that measured at MCBH over the last 30 years (Fig. 4) were very similar (i.e. r^2= 0.80, 1, 7 df) over the 9 month period. While the monthly precipitation measured at the study site generally tracked 30 year averages, it was much more variable (Fig. 4), ranging over an order of magnitude during the 9 month period. The precipitation data demonstrated that low amounts of precipitation fall in summer (23% fell on the study site during April-July) and larger amounts fall in winter (77% fell during November-March). The total precipitation received at the site over the 9 month period was about 66 cm. This is about 85% of the 77 cm/yr that is the 30 year average at MCBH and about 84% of the 79 cm predicted by CLIGEN.

Runoff Data

Monthly runoff (based on plot pair averages) is plotted in Fig. 5 for 9/95 - 7/96. Statistical tests (Students t-test for paired data) for differences in runoff between cover treatments were all significant at $p \leq 0.05$. Results clearly show

Table 1 Techniques for Measuring Water Balance on MCBH Plots.

Water Balance Component	Method of measurement	Frequency of Measurement
Precipitation	Tipping Bucket at ground surface and 1 m height	Hourly

Soil Moisture	4 TDR probes/ plot	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
(Station Latitude = 21.33 Degrees)

Layer 1- Vertical Percolation Layer	
SCS Runoff Curve Number	80.50
Evaporative Zone Depth	0.61 Meters
Thickness	0.61 Meters
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	0.305 Meters
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	63.4 Meters
Layer 3- Barrier Soil Liner	
Thickness	0.305 Meters
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	18.83 km/h

Precipitation file for MCBH was generated using CLIGEN (Nicks and Lane, 1989)

FIG. 4. MEASURED, 30 YR AVERAGE, AND HELP3 PREDICTED MONTHLY PRECIPITATION AT MCBH

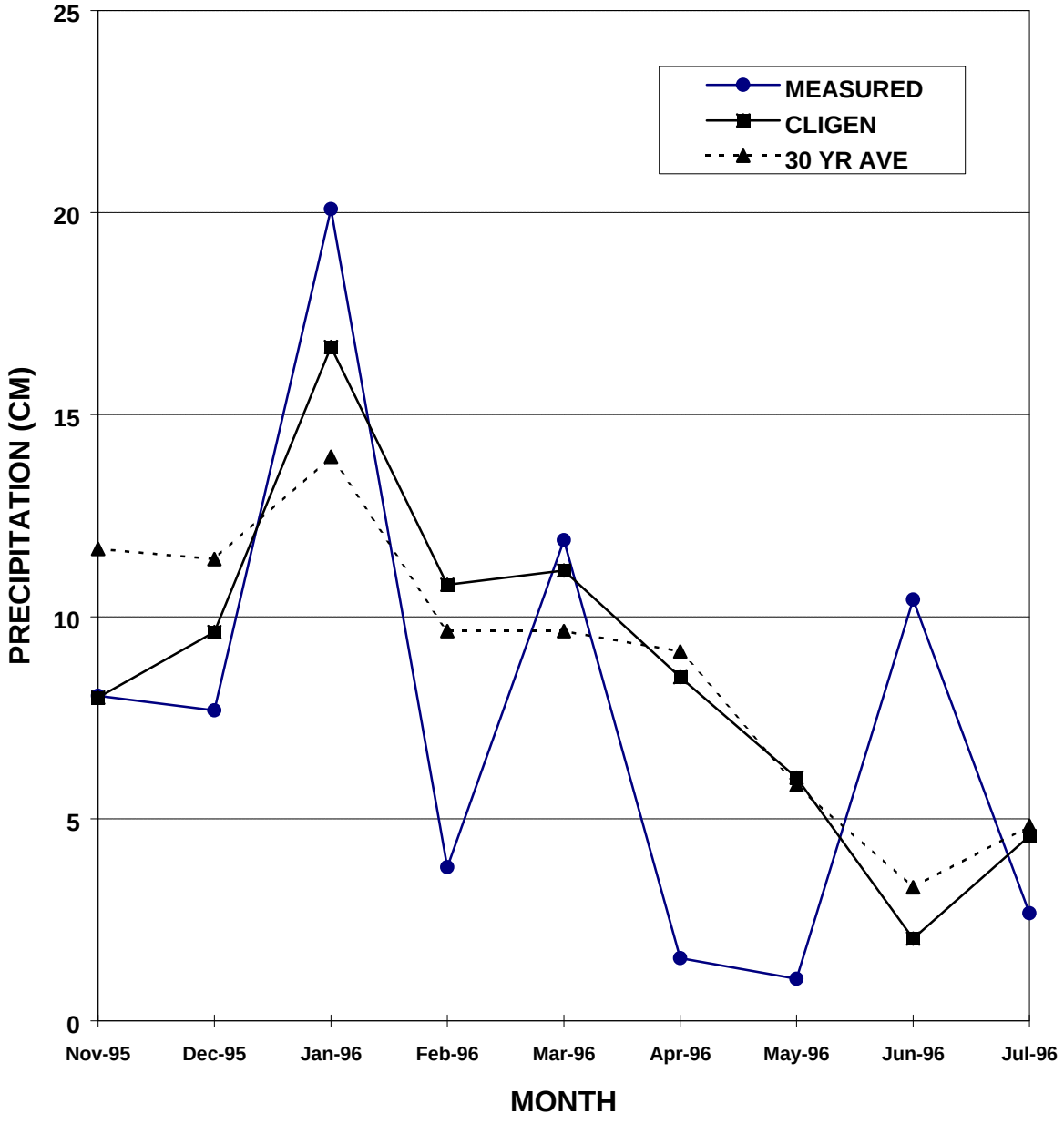
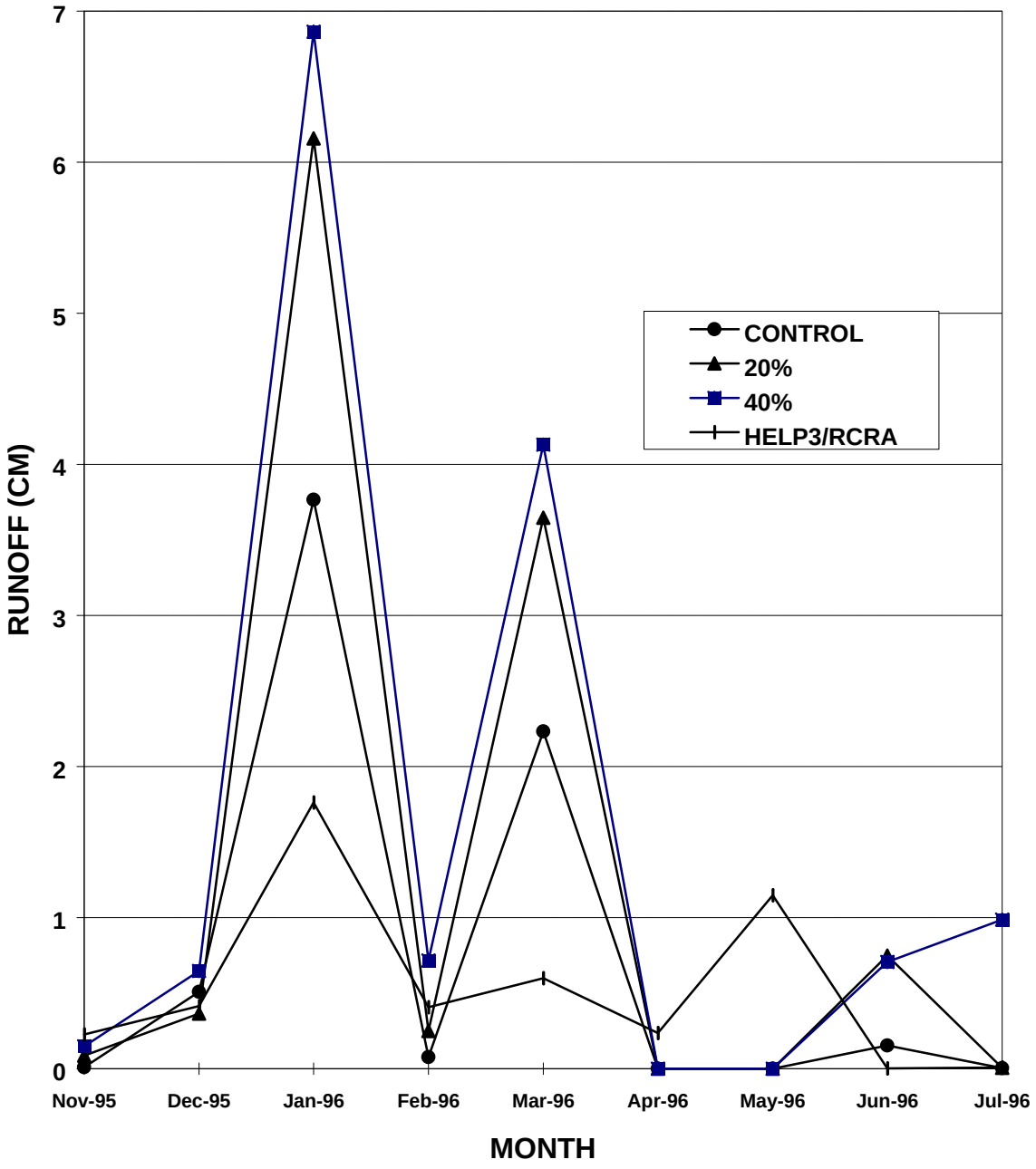


FIG. 5. AVERAGE MONTHLY RUNOFF FROM VARIOUS COVER TYPES AT MCBH



that runoff enhancement has occurred on those plots treated with RES compared to the untreated soil surface. Additionally, the amount of runoff generated was related to the level of runoff enhancement incorporated into the cover design. In general, the untreated soil cover design had the least runoff, the 20% enhancement was intermediate, and the 40% enhancement had the most.

Runoff distribution over the 9 month period (Fig. 6) paralleled that observed for precipitation in that 88-98% was generated during the months of November-March and 2-12% during April-July (Table 3). The total amount of runoff was strongly related to cover type with the 40% and 20% runoff enhancement designs producing 2.1 times (14.2 cm) and 1.7 times (11.3 cm) more runoff than the 6.8 cm produced by the monolithic soil cover design.

The RCRA cap, based on HELP3 simulations, was estimated to produce 4.8 cm of runoff. Over the 9 month period, the relative amount of runoff averaged 21%, 17%, 10%, and 6% from the 40% RES, 20% RES, soil, and RCRA designs, respectively. On a month to month basis, the relative amount of runoff generated by the various cover

Table 3. Distribution of Precipitation and Runoff from Various Cover Designs by Season at MCBH

Cover Design	% Runoff, April-July	% Runoff, Nov. - March
Precipitation	23	77
Soil Cover	2.3	97.3
20% RES	6.7	93.3
40% RES	12	88

designs (Fig. 6) 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

Percolation from both infiltration control designs and that estimated for the RCRA design was significantly lower ($p= 0.03$) than that produced from the soil cover (Fig. 7). In contrast, differences in percolation between the 2 RES designs were not significantly different ($p=0.35$). Additionally, differences in percolation rates from the RES

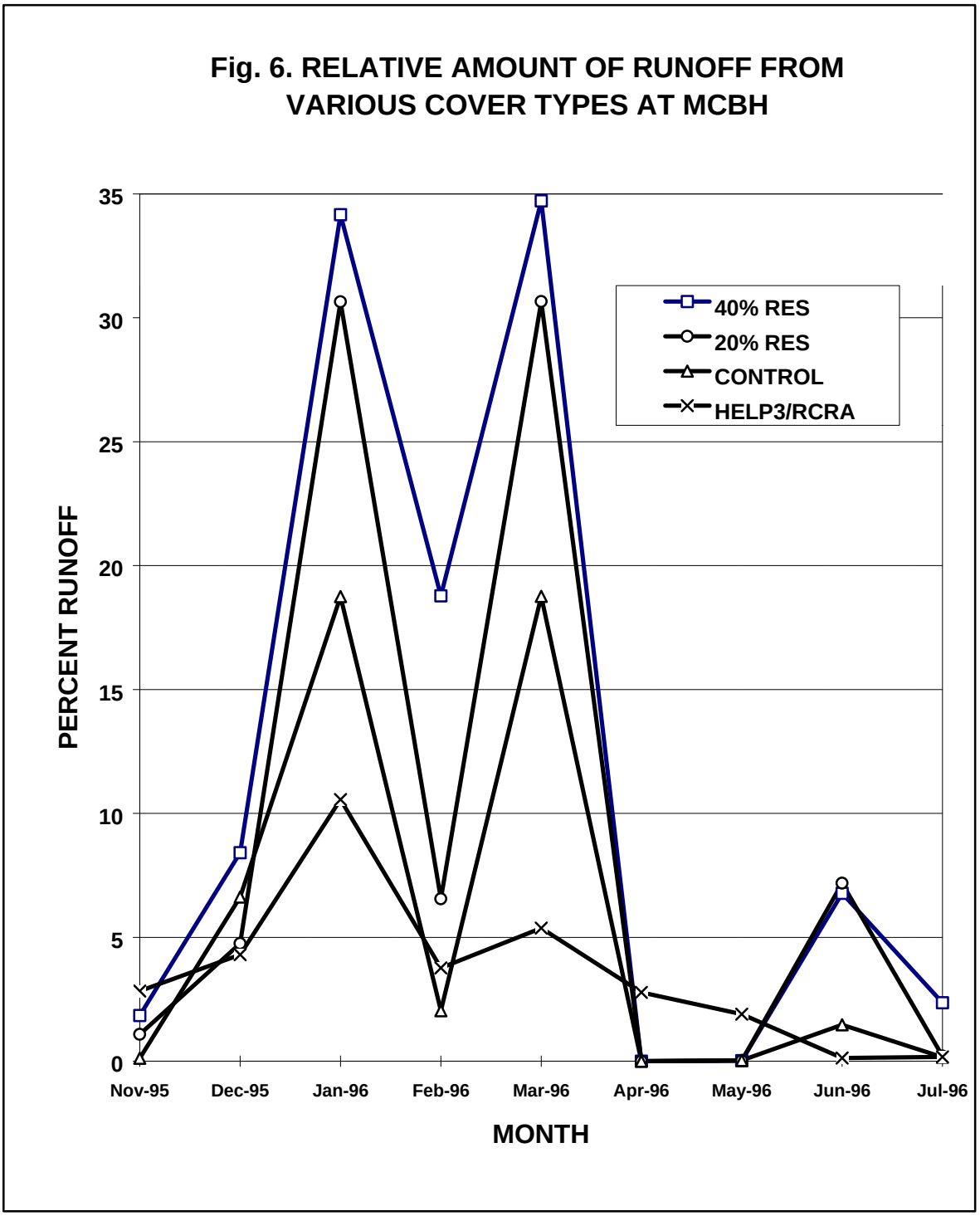
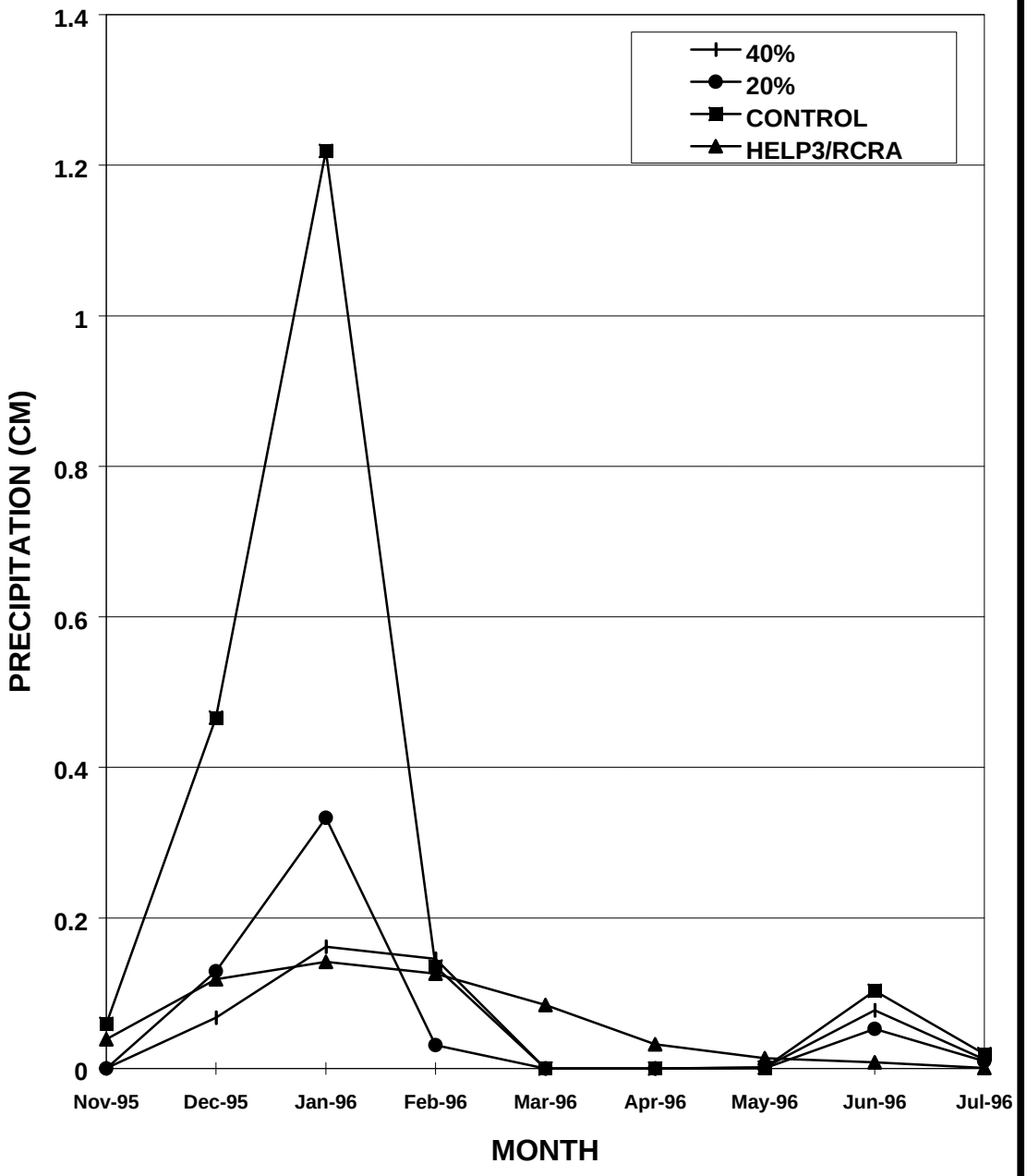


Fig. 6. RELATIVE AMOUNT OF RUNOFF FROM VARIOUS COVER TYPES AT MCBH
PERCENT RUNOFF
35
30
25
20
15
10
5
0
Nov-95
Dec-95
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
MONTH
40% RES
20% RES
CONTROL
HELP3/RCRA

FIG. 7. AVERAGE MONTHLY PERCOLATION FROM VARIOUS COVER TYPES AT MCBH



designs were also not significantly different (p= 0.25 and p= 0.48) from those predicted by HELP3 for the RCRA cover.

Percolation through all cover designs (Fig. 7) averaged 0.69% (40% RES), 0.83% (20% RES), 3.0% (soil cover), and 0.71% (HELP3/RCRA cover) of the total precipitation that fell during the 9 month period. On a month to month basis, the relative percolation varied from a high of 6% for the soil cover to zero (Fig. 8) again reflecting the changing soil moisture status, plant phenology, and intensity and duration of precipitation events.

A large percentage of the percolation from all of the cover designs occurred in December - February. About 80%, 89%, and 91% of the total percolation from the 40% RES, 20% RES, and soil cover plots occurred during these 3 months. HELP3 predicted that the RCRA design would have produce about 68% of the total percolation during this 3 month period.

Discussion

The relative performance of the various cover types in generating runoff and percolation is summarized in Fig. 9. These preliminary, short term results support the concept of using runoff enhancement to manage landfill site water balance. The RES designs statistically 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. Most of the runoff and percolation was associated with a few months in winter when most of the precipitation occurs. Additionally, months with threshold precipitation above about 10 cm, generated most of the runoff or percolation. Summer months generally received less than 10 cm and produced little of the runoff and percolation measured on the plots.

Based upon a comparison of the predicted hydrologic performance of a modified RCRA cover and the two RES designs, these preliminary results suggest about they are about equivalent in their ability to limit percolation. While

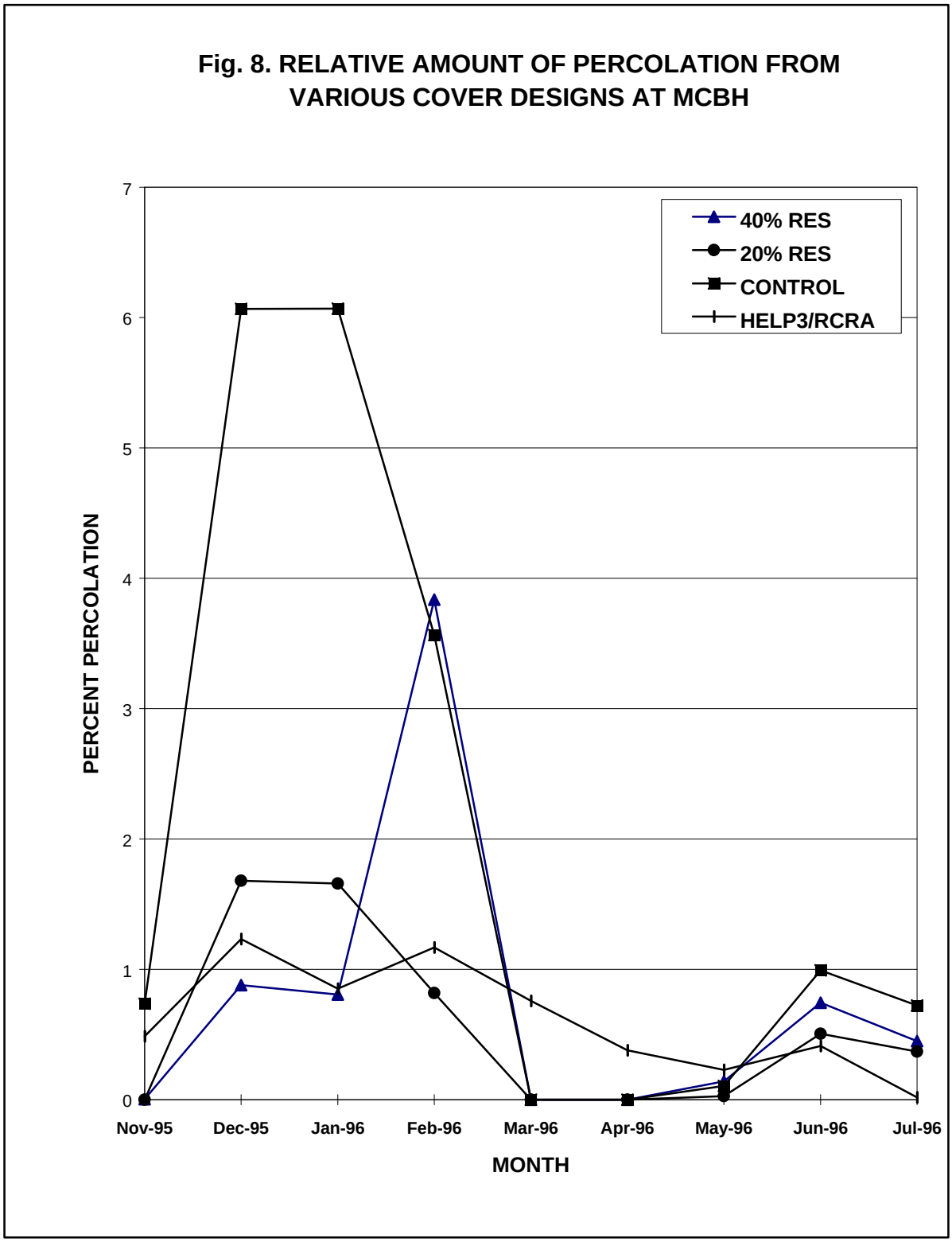
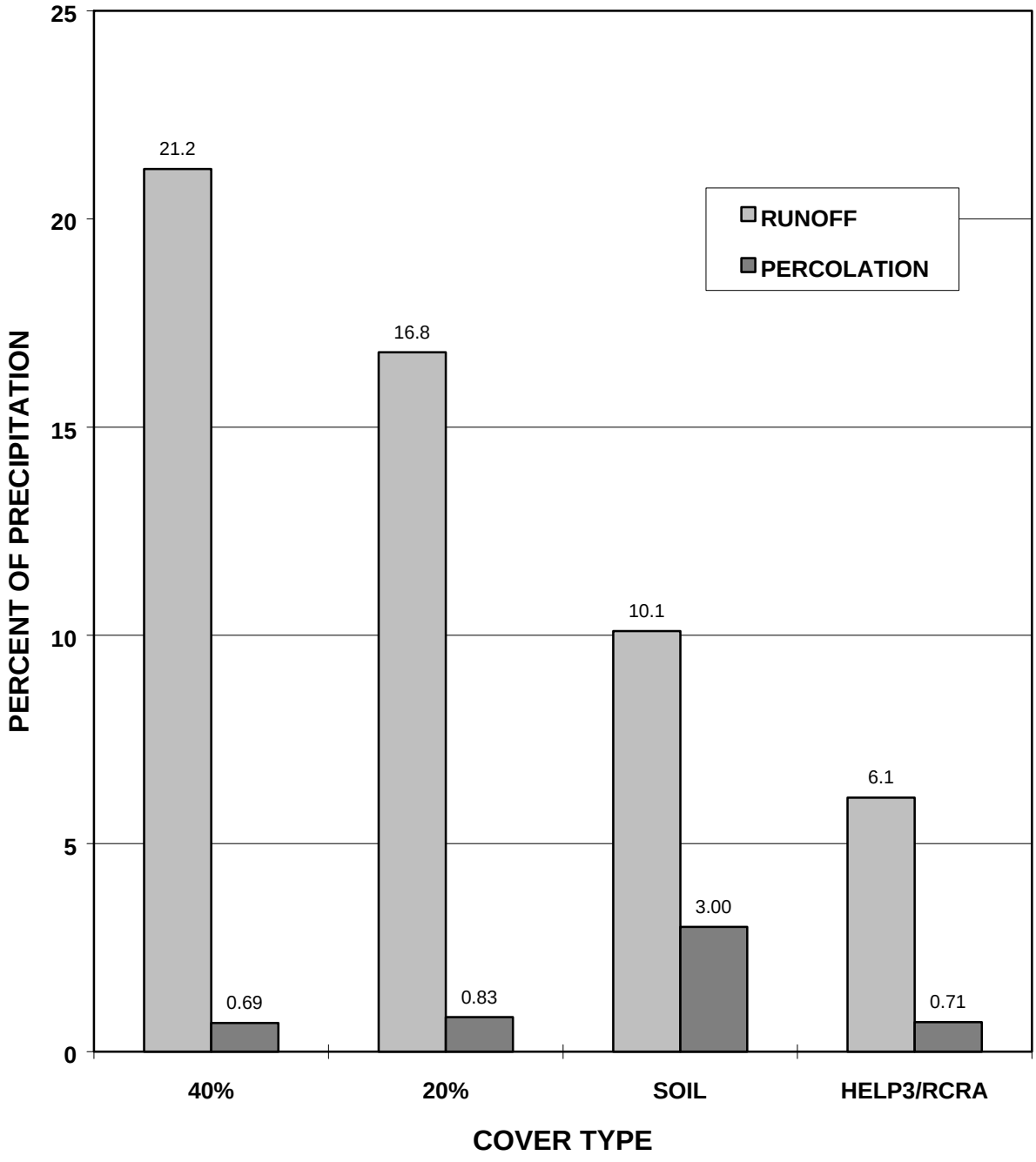


Fig. 8. RELATIVE AMOUNT OF PERCOLATION FROM VARIOUS COVER DESIGNS AT MCBH
40% RES
20% RES
CONTROL
HELP3/RCRA
PERCENT PERCOLATION
0
1
2
3
4
5
6
7
Nov-95
Dec-95
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
MONTH

Fig. 9. RELATIVE AMOUNT OF RUNOFF AND PERCOLATION PRODUCED FROM RUNOFF ENCHANCEMENT, SOIL, AND HELP3 SIMULATED RCRA COVER DESIGNS AT MCBH FOR PERIOD 11/95 - 7/96



the RES 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.

Summary

In summary, preliminary results from the RES designs appear encouraging in that they are producing results in line with the technical theory behind them. 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.

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