THE NEXT BEST THING

In this paper the author states that an experiment in Hawaii proves that alternative earthen landfill caps can effectively increase runoff and decrease leachate production even in humid climates. The percolation in his field plots was 1.5 inches (38 mm) in the 20-IR plots and 0.9 inches (23 mm) in the 40-IR plots over a 28-month period. He used the HELP model to estimate the percolation through a RCRA Subtitle C and Subtitle D cap and claims that the expected percolation is comparable to that of his alternative earthen covers.

However, the analysis he used is flawed and the HELP model estimates of percolation are greatly exaggerated. Dr. Robert Koerner, in his Letter to the Editor, states that the HELP model assumptions with respect to defects in geomembrane are obsolete due to advances in the state-of-the-art. Also, the Subtitle D cap cross section on page 63 does not have a low permeability clay layer under the geomembrane. A geosynthetic clay liner under the geomembrane would greatly reduce the percolation. With these changes to the input of the HELP model the Hawaii alternative earthen cover plots would not be comparable to percolation through a composite Subtitle C or D cap. Thus, as Dr. Koerner states in his Letter to the Editor, this article is better stated as “Not Nearly the Next Best Thing”.

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The Next Best Thing

An experiment in Hawaii proves that landfill caps designed as alternatives to those prescribed by law can effectively increase runoff and decrease leachate production, even in humid climates. By Chittaranjan Ray, Ph.D., P.E.

Most older landfills in the United States are unlined, meaning that they feature an open floor, which makes it possible for the leachate produced from the refuse to find its way to the groundwater below. Even leachate produced in more modern landfills—which are lined—can filter down to the groundwater. But the amount of leachate can be reduced if the infiltration of rainwater is controlled while the landfills are being filled and after they are closed.

One way to reduce infiltration into landfills is to install a surface cap or cover that is impermeable or has very low hydraulic conductivity. But it has been difficult to design and construct caps that can meet this requirement in humid climates. A recent demonstration project, however, shows that such covers can be successful.

The Resource Conservation and Recovery Act (RCRA), passed in 1976, gave the U.S. Environmental Protection Agency the authority to promulgate regulations governing the generation, transportation, treatment, storage, and disposal of hazardous waste. Subtitle C of the act covers the requirements for hazardous waste landfills, and subtitle D sets forth the requirements for municipal (nonhazardous) solid waste landfills. Caps delineated in subtitle C—often referred to as subtitle C caps—feature a layer of compacted clay atop the refuse and three layers of material above the clay. In ascending order these are a drainage layer of sand, a geotextile layer, and a soil layer. Vegetation is often planted in the soil layer. (See the figure on page 63.) The drainage layer acts as the capillary barrier formed when a

To make 40 percent of the area impervious, *opposite top*, the gutters had to be more closely spaced than on the plot where only 20 percent was impervious, *opposite bottom*.

Martin Sanda and Cliffton Miyasaki, all photos

Theoretically, the performance of a vegetated soil cap or any other alternative cap with runoff-enhancing structures would be similar to that of a RCRA subtitle D cap.

layer of low-permeability media is kept above a layer of high-permeability media. Typically, water does not enter the high-permeability media layer until the low-permeability layer is near saturation. The cap is designed with a sloping configuration so that water reaching the high-permeability layer is drained to one side of the landfill.

Compared with the subtitle C cap, the subtitle D cap is much simpler. Once a subgrade has been prepared above the compacted refuse, a geomembrane is placed on its surface and then a geotextile is placed atop that. Above the geotextile is 18 in. (45.7 cm) of compacted native soil, and above the native soil is 6 in. (15.2 cm) of topsoil, which is generally vegetated with grass. (See the figure on page 63.) A sprinkler system is often installed in the topsoil of both types of caps to water the vegetation.

Because of the high costs and some inherent problems associated with the RCRA caps—particularly the subtitle C caps, which sometimes crack or settle—the RCRA regulations allow the state or federal regulatory agencies in charge of landfills to approve alternative caps that have been shown to allow less infiltration than RCRA caps. In other words, these alternative covers must meet the performance standards of the RCRA caps.

Vegetated caps designed to serve as alternative landfill covers have been successfully tested in arid areas, where annual evapotranspiration exceeds annual precipitation. But in humid areas, where annual precipitation can significantly exceed annual evapotranspiration, it has been widely believed that vegetated soil caps may not be suitable for infiltration control. However, a theory has been advanced that, if some of the precipitation could be diverted in the form of runoff so that the infiltrating precipitation would be less than the evapotranspiration, leachate production might be as low as in less humid regions. Theoretically, the performance of a vegetated soil cap or any other alternative cap with runoff-enhancing structures would be similar to that of a RCRA subtitle D cap.

In early 1995 the Naval Facilities Engineering Service Center (NFESC), based in Port Hueneme, California, and Los Alamos National Laboratory (LANL) built an instrumented group of demonstration landfill caps near the Marine Corps Base Hawaii, in Kaneohe, to determine if a vegetated cap with runoff-enhancing structures would be effective in controlling infiltration in the tropics. The test ran for slightly more than two years. The 0.125 acre (0.05 ha) site had six test plots: two "control" plots, which had no impervious areas; two plots on which 20 percent of the area was impervious (referred to as 20-IR plots); and two plots on which 40 percent of the area was impervious (40-IR plots).

Each plot was 20 ft (6.1 m) wide and 30 ft (9.1 m) long and had a surface slope of 4 percent. Prior to the construction of the plots, the top 2 ft (0.6 m) of soil was removed and stockpiled on a pad at one end. After marking each plot area, a leachate collection area measuring 10 by 27 ft (3.1 by 8.2 m) was marked in each plot. This collection area had a 5 ft (1.5 m) gap on two sides and a 3 ft (0.9 m) gap on the downstream end. Cutoff walls were installed on the upslope areas to prevent rainwater from entering the plots from the area above them.

Excavation in the leachate collection areas then removed 1 ft (0.3 m) more of soil. A liner was placed in each leachate collection pit, and the liners were connected to a 4 in. (102 mm) diameter leachate collection pipe. After proper installation and sealing, the leachate collection areas were filled with uncrushed smooth stones 0.75 to 1 in. (19 to 25 mm) in diameter. The plots were then backfilled with the 2 ft (0.6 m) of excavated soil from the pad, layer by layer, to achieve 95 percent of the soil's optimum density. After this, garden edging material was used to form the boundaries of the six plots.

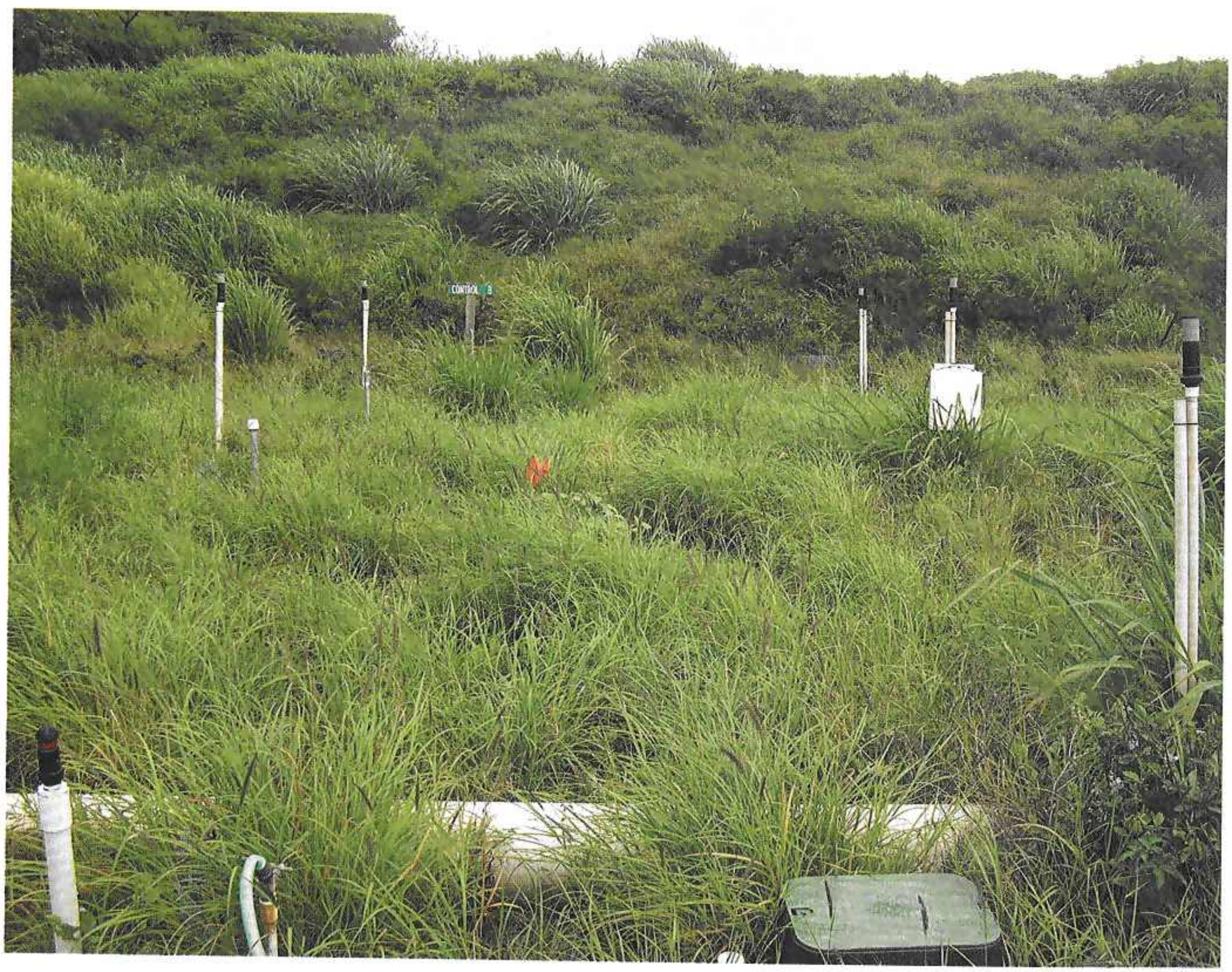
The control plot had no impervious area. The researchers concluded that covers on which at least 20 percent of the area is impervious can perform almost as well as those prescribed by the Resource Conservation and Recovery Act. Of the two test cap designs, the one with the higher percentage of impervious area did not perform significantly better.

Since the site had no electric power, the sump pumps and flowmeters were operated by deep-cycle batteries charged by solar panels.

Rain gutters 4 in. (102 mm) wide and 30 ft (9.1 m) long were installed in the test plots. On the 20-IR plots, 12 gutters were spaced 20 in. (508 mm) apart on centers; on the 40-IR plots, 24 gutters were spaced 10 in. (254 mm) apart on centers. Each gutter was filled with 0.75 in. (19 mm) diameter gravel. The downstream end of each plot was fitted with a 12 in. (305 mm) diameter pipe cut along its length and flush with the soil so that it could receive runoff. The collected runoff was routed through an outlet to tanks—two for each plot—via a 6 in. (152 mm) diameter pipe.

The runoff and the leachate tanks were instrumented with pressure transducers, sump pumps, and flowmeters to monitor the amount of water collected over a period of time. Additionally, the leachate tanks were equipped with tipping-bucket rain gauges to measure leachate production when the rate was small. Since the site had no electric power, the sump pumps and flowmeters were operated by deep-cycle batteries charged by solar panels.

A meteorological station monitored rainfall, wind speed and direction, relative humidity, temperature, and solar radiation. In addition, time-domain reflectometry probes were used to monitor moisture in the top 8 in. (203 mm) of the soil. All data were stored in three data loggers and were downloaded to a remote computer via a cell phone located at the test site. The plots were seeded with native vegetation—



The variation in percolate production, most of it from four or five storms during the study period, was significant among the plot pairs.

including buffle grass, star grass, guinea grass, and koa haole—prior to the start of the experiment.

For the 28 months between November 1995 and March 1998, the total measured rainfall at the site was 62.55 in. (1,589 mm). That amount was much lower than the 98.15 in. (2,493 mm) that would have been obtained for this period using the 30-year average rainfall for the Marine Corps Base Hawaii airfield, which is located about 0.9 mi (1.5 km) southwest of the site. Three months experienced rainfall in excess of 4 in. (102 mm): November 1995 (15 in. [385 mm]), January 1996 (7.87 in. [200 mm]), and January 1997 (4.9 in. [126 mm]).

During the 28-month study period, the two control plots produced an average of 5.4 in. (137 mm) of runoff, whereas the two 20-IR plots had 10.78 in. (274 mm) and the two 40-IR plots 13.3 in. (338 mm). The average amount of percolation from the two plots with soil covers was 3.4 in. (87 mm), whereas the average for the 20-IR plots was 1.5 in. (38 mm) and that for the 40-IR plots was 0.9 in. (23 mm). The variation in percolate production, most of it from four or five storms during the study period, was significant among the plot pairs.

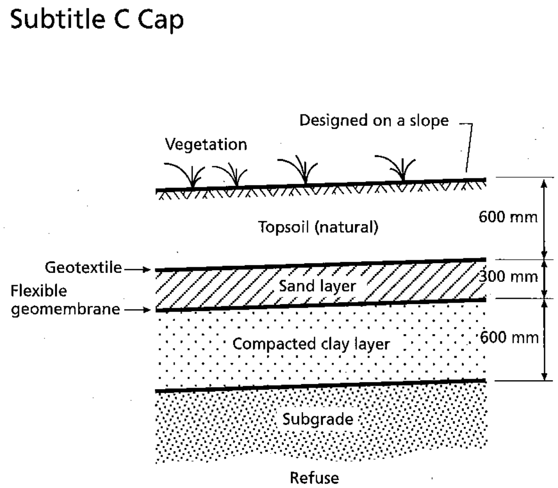
Using version 3.0 of the computer program Hydrologic Evaluation of Landfill Performance (HELP), developed by the U.S. Army Corps of Engineers, a water balance model was created and used to simulate leachate production from a hypothetical RCRA subtitle D cap at the site. The model incorporated typical rainfall events over the course of 28 months, and the program predicted a total of 0.67 in. (17 mm) of leachate, which is close to the amount actually produced by the 40-IR plots.

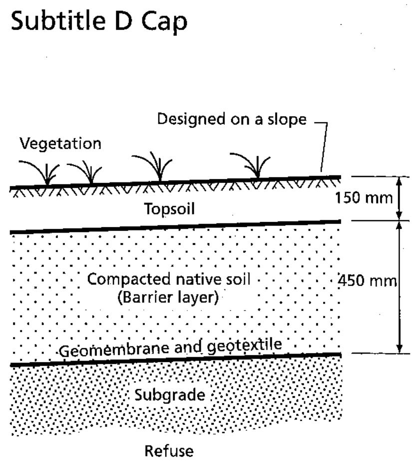
Upon gaining access to the demonstration site in 1999, the author of this article and a team of researchers began two separate studies of water balance to examine the effect of storm type and the stage of growth of the vegetation on the caps on the amounts of runoff and leachate produced. A reexamination of the effect of the pattern and amount of rainfall on runoff and leachate production was needed because part of the 28-month NFESC-LANL study was during a period when a weather pattern known as El Niño occurred. (The National Oceanic and Atmospheric Administration defines El Niño as a disruption of the system formed by the ocean and the atmosphere in the tropical Pacific that has important consequences for weather around the world.) El Niño caused the site to receive only 13.38 in. (340 mm) of rainfall from February 1997 to March 1998, compared with an annual average of nearly 40.16 in. (1,020 mm). The author's first study was conducted from 1999 through 2000 on the two control plots and the two 20-IR plots. A second, more detailed study was conducted from 2003 through 2004 on three plots, one of each type. For the latter study, an irrigation system was established to apply water at a constant rate for various durations to each of the three plots.

These studies revealed several interesting facts. One is that plant growth on the covers depends to a marked extent on the season, and these stages influence the effectiveness of the caps. During the rainy season (November through March), plant growth results in significant vegetation coverage of the caps. And while the gutters can be very effective in the early stages of vegetation growth, they may lose their effectiveness to some extent once the vegetation is fully established and covers them.

Additionally, from March 1999 to February 2000, the total rainfall was just 14.6 in. (371 mm). Combining the data from the NFESC-LANL study with the author's data, the research team found that the control plot produced 2.9 in. (74 mm) of runoff and 2.7 in. (69 mm) of leachate, while the 20-IR plot produced 6.7 in. (170 mm) of runoff and 0.9 in. (23 mm) of leachate. These results must be viewed in light of the fact that rainfall over this one-year period was roughly a third of the historical average. Lingering effects from El Niño appear to have played a role.

Rainfall totals for 2002 and 2003 were respectively 17.6 and 20.4 in. (447 and 518 mm). Although these figures represent an increase over the previous years, they were significantly lower than the 50-year annual average of 40 in. (1,016 mm). One of the reasons for establishing the irrigation system was to permit the effects of





April Kan, both

rainstorms and vegetation growth—as well as of various soil and water conditions—on leachate and runoff generation to be evaluated. Because rainfall was lower than expected, irrigation was employed; the irrigation intensity was 0.71 in. (18 mm) per hour, the durations lasting from 3 to 12 hours. Irrigation was used on nearly 20 occasions, some in combination with rainfall events.

At the beginning of the 2003 study, all vegetation was cut from the plots. The grass began to grow as the irrigation water was applied. On eight occasions, each lasting three hours, irrigation coincided with rainfall, and the runoff totals here for the control, 20-IR, and 40-IR plots were respectively 0.09, 2.17, and 2.61 in. (2.3, 55.3, and 66.3 mm). Leachate was produced in all episodes except the first. The average percentages of rainfall appearing as leachate were 46.0 for the control plots, 29.3 for the 20-IR plots, and 33.9 for the 40-IR plots. It became apparent from these data that the 20-IR and 40-IR plots were achieving similar results.

In 2004 Hawaii began receiving rainfall that was above average. However, because the rainfall was sporadic, three large irrigation applications were required, each lasting 12 hours, in both July and August. After the three applications in July, leachate production from the 40-IR plots varied from 7 to 44 percent of the total water applied. At the same time, the fraction of rain and irrigation water that became runoff varied from 11 to 15 percent. For the 20-IR plots, leachate production varied from 6 to 33 percent and runoff varied from 5 to 8 percent over the three events. The August rain and irrigation events showed the same general trend. It became obvious that runoff was greater in plots having a 20 percent impervious area. However, increasing the impervious area to 40 percent did not enhance runoff by a corresponding amount. The interception of rainfall by the plants, the antecedent soil moisture conditions, and the types and durations of the storm events all played roles in the runoff-to-leachate water balance.

The NFESC-LANL study and the author's study proved that by making a portion of the cap impervious, leachate production can be reduced and surface runoff enhanced. In the case of the 40-IR plots, the plants reduced the effectiveness of the gutters. This is an area that needs further research. The results further showed that the runoff rates from the 20-IR and 40-IR plots were not significantly different from each other for several events, suggesting that runoff can be enhanced by putting more gutters in one place or by placing an impervious swale on the surface.

After examining the results so far, the author believes future research should focus on accurate measurements of water storage within the soil in the cap, with attention also given to improving the water balance. Funding is being sought for a study that would determine if a different design or placement of impervious surfaces, including rain gutters, would further enhance runoff and reduce infiltration. ■

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Clarifying the Assumptions

Some major assumptions are necessary in evaluating such soil-only covers as evapotranspirative and capillary barriers for landfill closures in humid areas. For example, Chittaranjan Ray, Ph.D., P.E., in his article "The Next Best Thing," which appeared in the July issue, states in the second paragraph, "It has been difficult to design and construct caps that can meet the [Resource Conservation and Recovery Act] requirement in humid climates." Yet last year 24 million lb of high-density polyethylene geomembranes were used for this specific purpose, as were 34 million lb of linear low-density polyethylene (LLDPE) geomembranes. Polyvinyl chloride geomembranes also are being used for this purpose, along with other polymer types. Thus the regulatory, owner, designer, and contracting communities appear to be following the regulations quite well.

The presence of a geomembrane in a landfill cover essentially stops surface water from making its way into the underlying solid waste material. In fact, one must assume holes to be in the geomembrane to obtain and measure leakage rates. When one places a geosynthetic clay liner beneath the geomembrane (as required in modern landfills since, by regulation, the cover must be as impermeable as the liner), the leakage rates are essentially nonexistent. Such data are presently available, and corroborating experiments can be conducted in a laboratory at nominal cost and effort.

Ray also compares his leakage rates with those provided by the Hydrologic Evaluation of Landfill Performance (HELP) model, which also must assume holes in the geomembrane to obtain any results. The default values in the model are now 15 years old, and the placement of geomembranes has progressed tremendously since that time. Interestingly, the author states that a liner (presumably a geomembrane with no holes in it) was used to capture the leakage in the various soil-only plots.

While the title of the article, "The Next Best Thing," is indeed provocative, this writer feels it is better stated as "Not Nearly the Next Best Thing."

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