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TITLE STATUS OF CORRECTIVE MEASURES TECHNOLOGY FOR SHALLOW LAND BURIAL AT ARID SITES

AUTHOR(S) Willy V. Abeele, HSE-12
John W. Nyhan, HSE-12
Barry J. Drennon, HSE-12
Edward A. Lopez, HSE-12
Wilfred J. Herrera, HSE-12
Gary J. Langhorst, HSE-12

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

STATUS OF CORRECTIVE MEASURES TECHNOLOGY FOR SHALLOW LAND BURIAL AT ARID SITES

W. V. Abeele, J. W. Nyhan, B. J. Drennon, E. A. Lopez,
W. J. Herrera, and G. J. Langhorst
Los Alamos National Laboratory

ABSTRACT

The field research program involving corrective measure technologies for arid shallow land burial sites is described. Soil erosion and infiltration of water into a simulated trench cap with various surface treatments was measured and compared with similar data from agricultural systems across the United States. Report of field testing of biointrusion barriers continues at a closed-out waste disposal site at Los Alamos. Final results of an experiment designed to determine the effects of subsidence on the performance of a cobble-gravel biobarrier system are reported, as well as the results of hydrologic modeling activities involving biobarrrier systems.

INTRODUCTION

The corrective-measures technology for shallow land burial at arid sites mainly involves application of corrective measures to field-size situations. Our modified trench cap design, as derived from modeling and small scale studies, was applied to an area of 0.65 ha for validation against a conventional design.

The water balance and erosional behavior of burial trench caps of several cover conditions exposed to simulated rainfall was also studied. Subsequent infiltration, runoff, and erosion will be, to some extent, dependent on permeability.

Quanitative studies involving the physical and mechanical properties of soils having direct application on the design or the construction of waste disposal facilities include hydraulic conductivity, consolidation, and shear strength. Long-term soil consolidation and shear failure will result in subsidence. Subsidence is very likely to affect the integrity of the cobble/gravel biointrusion barrier present in our modified trench cap designs.

USE OF CREAMS FOR THE DESIGN OF SHALLOW LAND BURIAL FACILITIES

Data from two experimental caissons each 3.05-m diameter and 6.1 m deep is presented. One caisson contained topsoil and crushed tuff; the second was filled with a mixture of topsoil, cobble, and gravel. The field site was decommissioned in 1948 and has laid fallow for 32 years (Area B). Experimental field plots at Area B are 40 m x 40 m. Various combinations of topsoil, backfill, gravel, and cobble were monitored at each site.

Observed soil moisture data was obtained for the 1982-1984 period using a Campbell Pacific Model 503 neutron moisture gauge for comparison with CREAMS predictions. Moisture content was monitored 20 and 50 cm from the soil surface in both the caissons and at Area B.

The observed soil moisture averaged over the rooting depth and CREAMS-simulated soil moisture is presented for two field scales in Fig. 1-4. Daily precipitation and snow data are also included in these figures. Supplemental moisture was added to the caissons bringing the annual precipitation to about 80 cm/yr (as opposed to about 45 cm/yr for natural precipitation). An annual precipitation of that magnitude at Los Alamos has a probability of occurring about once every 100 years.

Generally at both sites, observed increases in topsoil moisture are correlated with periods of snow cover (although caissons were irrigated). During the summer growing season, soil moisture is relatively constant or decreases slightly despite the occurrence of summer precipitation. Figures 1-4 show that the CREAMS model predicts observed soil moisture best in the summer and fall; maximum divergence between observed and predicted soil moisture occurs in the winter with snow cover, snowmelt, and freeze/thaw. The two main descriptors of the plant component--leaf area index (LAI) and rooting depth--are estimated and, therefore, may be subject to significant uncertainties.

The caisson data (Figs. 1 and 2) show the closest agreement of field data and model predictions. CREAMS simulates the major increases and decreases in soil moisture. The observed soil moisture on the experimental and control caissons is comparable except for spring 1983 when the experimental volumetric soil moisture is approximately 0.05 units higher than the control plot. This may result from the soil/rock barrier design serving as a capillary barrier preventing the downward flow of water. Previous studies (3) have shown that the moisture content of topsoil over a rock barrier often measures several volume per cents higher than topsoil moisture over a tuff barrier.

At the larger field scale of Area B, there is more variability between the observed and CREAMS-predicted soil moisture (see Figs. 3 and 4). However, CREAMS still tracks increases and decreases in soil moisture. The greatest discrepancies between observed and predicted soil moisture occur in the winter.

Determination coefficients between predicted and observed water content for caisson data for the experimental and control plots are 0.73 and 0.48, respectively. The determination coefficients for Area B data are considerably lower than those for the caisson data--0.42 and 0.21 for

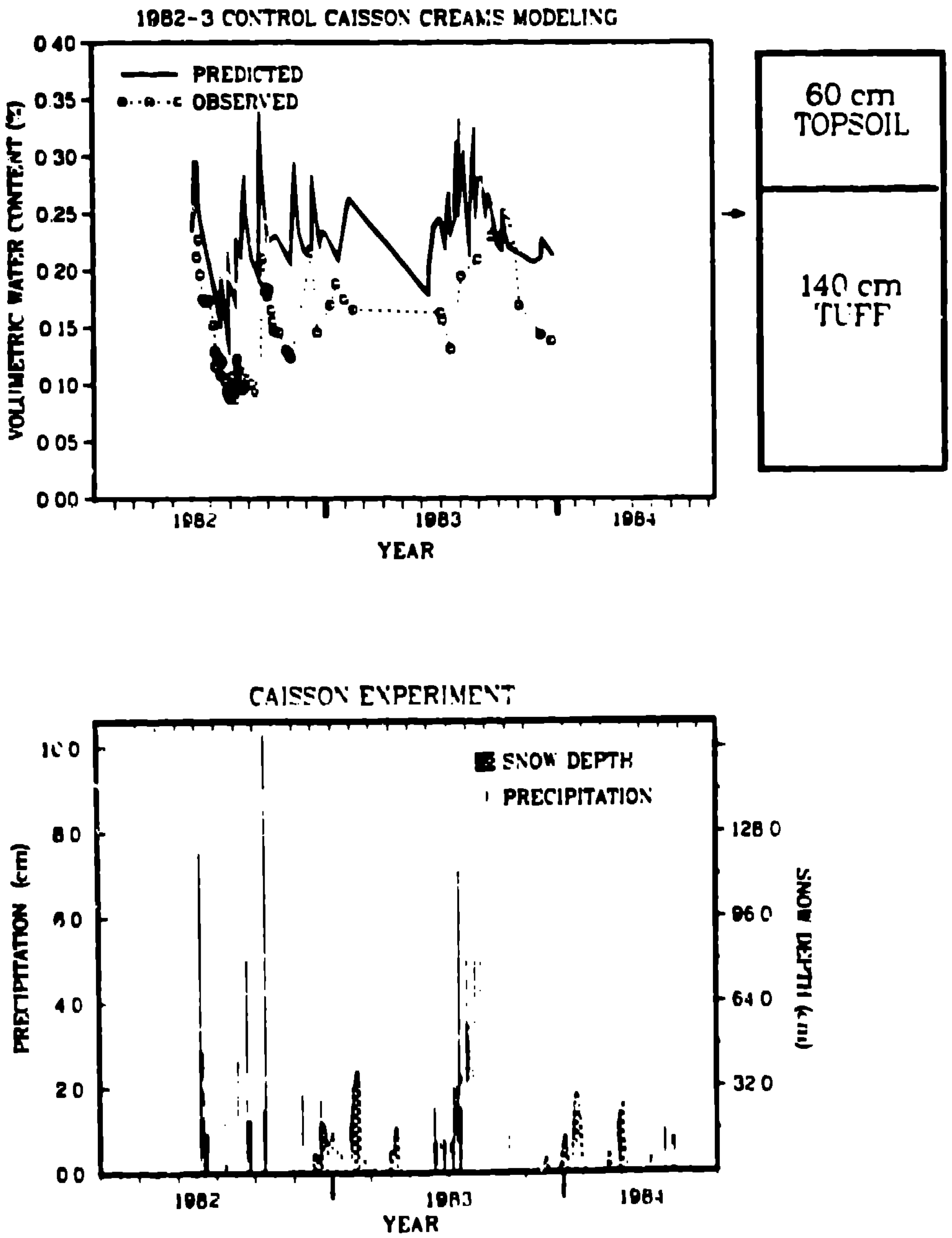


Fig. 1. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given control caisson profile (top right).

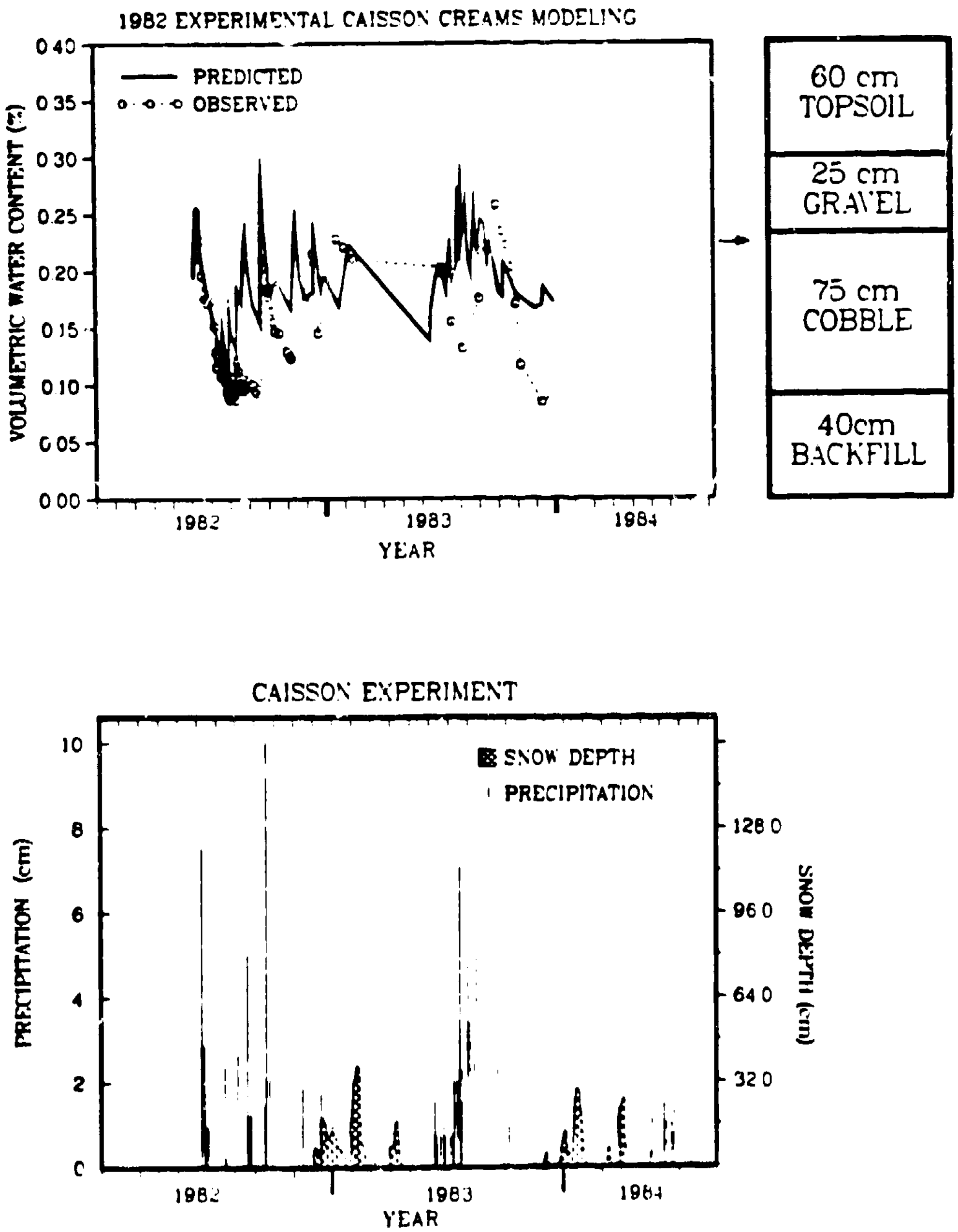


Fig. 2. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given experimental caisson profile (top right).

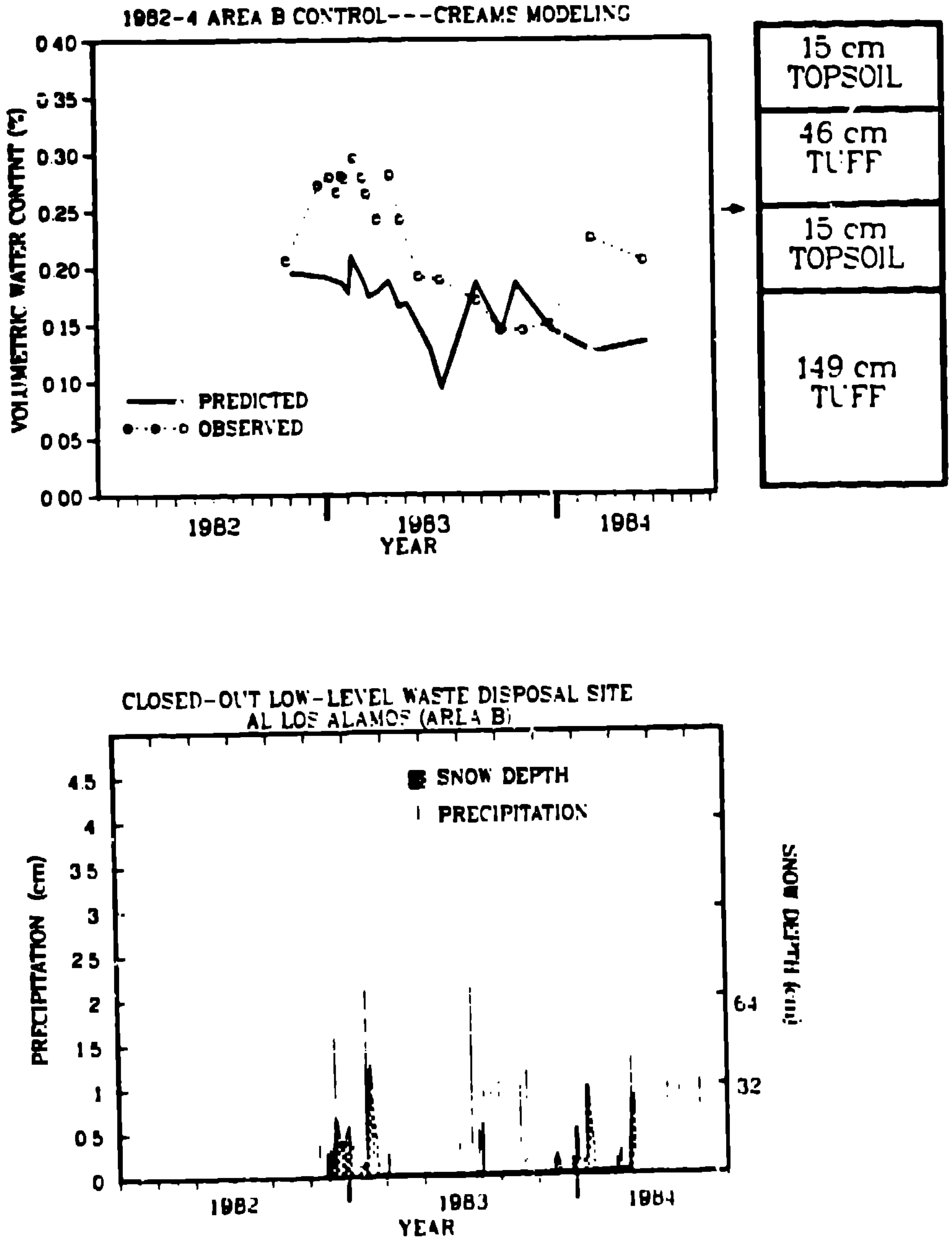


Fig. 3. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given Area B control profile (top right).

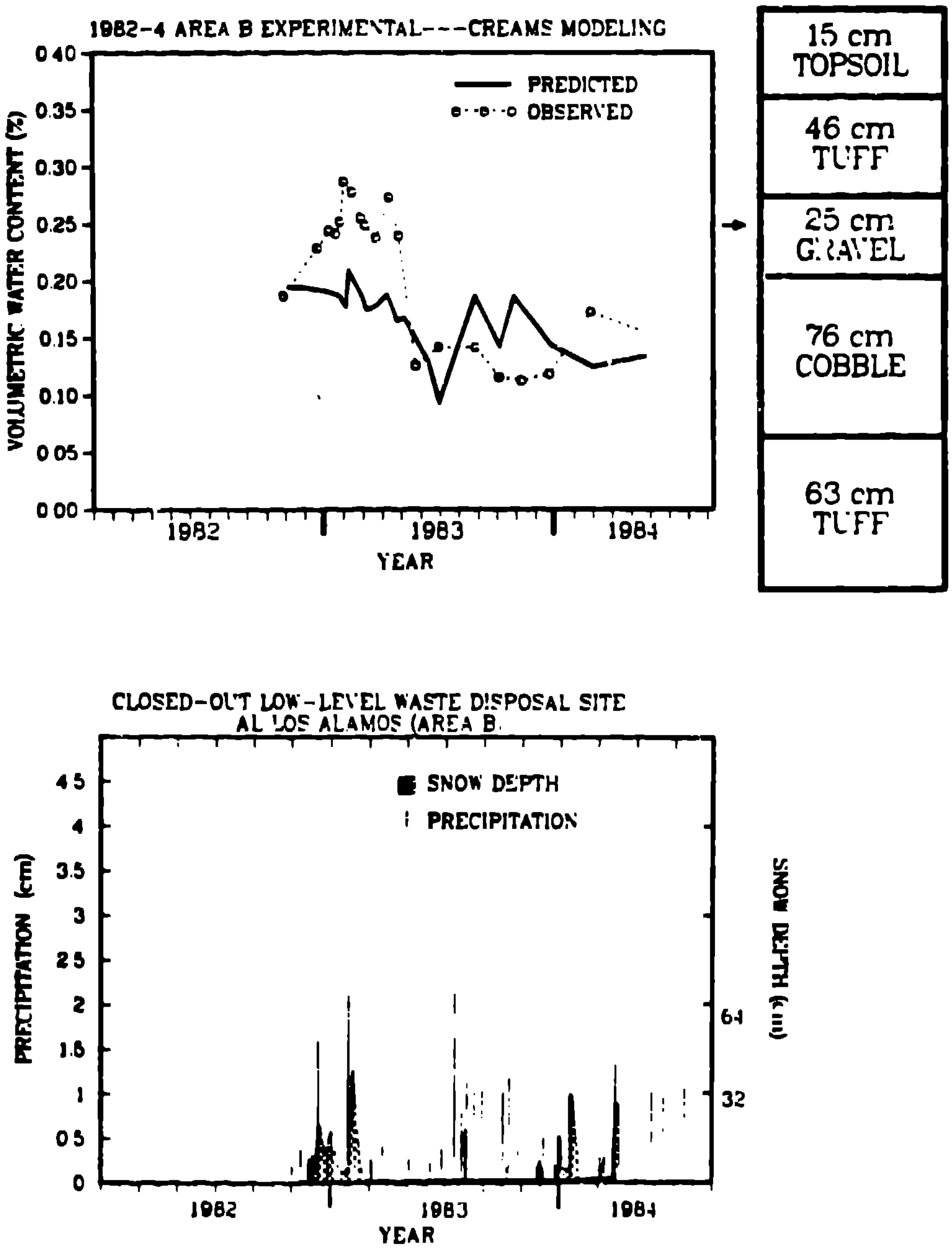


Fig. 4. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given Area B experimental profile (top right).

experimental and control plots, respectively. These results show that CREAMS predicts soil moisture better (higher R^2) for the experimental plots. It also indicates that for Area B, less than 50% of the variation in observed soil moisture is explained by CREAMS.

The results presented here suggest that consideration of the effects of frozen soil and snowmelt on the water balance should be incorporated in CREAMS. Secondly, since the CREAMS model has only recently been applied to waste disposal sites under arid and semiarid conditions, additional research is required to quantify model parameters (especially LAI and rooting depth) under these conditions. Thirdly, rock barriers have been shown to act as capillary barriers preventing downward flow of water. Whether CREAMS can accurately model soil moisture through a soil/rock intrusion barrier design requires further investigation. Finally, lateral subsoil movement of soil water toward and through the wastes below the trench cap should also be considered.

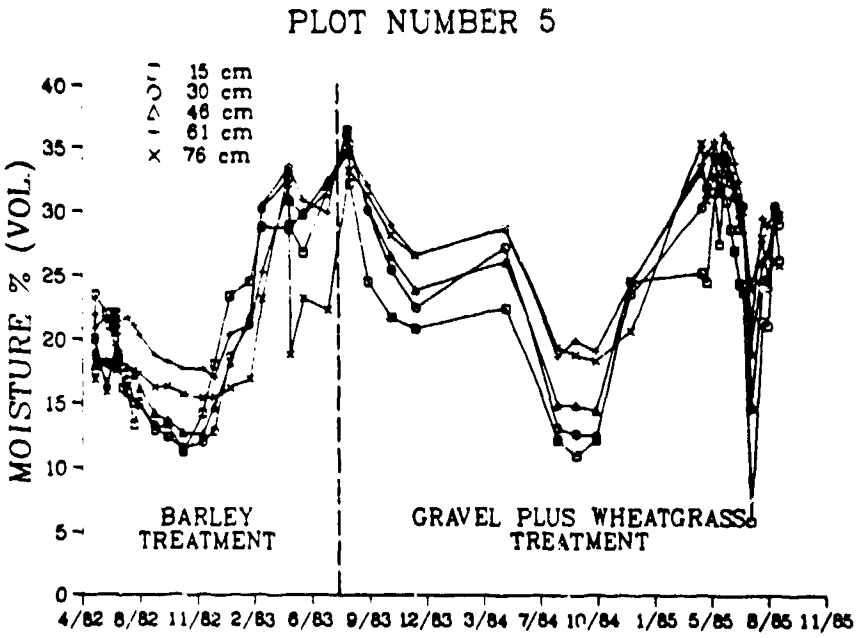
EROSION

The objective of this subtask was to investigate the water balance and erosional behavior of burial trench caps of several cover conditions in erosion plots established at the Los Alamos Experimental Engineered Test Facility. These plots were exposed to simulated rainfall to generate infiltration, runoff, and erosion during the simulated rainfall events as previously described.

Four treatments were imposed on the eight erosion plots by the end of July 1983. As in 1982, two plots received a new up- and down-slope disking (cultivated treatment). Both standard tilled plots were thus again comparable to the standard USLE plot used to determine the soil erodibility factor. A second year's data were collected on the two plots that were not tilled in 1982 and had no vegetative cover (bare soil treatment). To determine the influence of partial gravel cover on soil erosion, two plots were prepared as the bare soil treatment and then received a gravel (<13-mm-diam application rate of 15 kg m^{-2} (gravel cover treatment). The influence of partial gravel covers plus vegetation on soil erosion was determined on two plots that were first seeded with Western Wheatgrass, which then received the same gravel application rate as the gravel cover treatment (gravel and plant cover treatment).

Since the hydrologic processes at the surface of a SLB trench cap influence the management of the subsurface hydrologic processes, we decided to monitor the soil water content beneath the erosion plots. Soil water determinations were performed at sampling depths in the topsoil (15 cm), in the crushed tuff (30, 46, 61, 76, 91, and 107 cm) and in the undisturbed tuff beneath the simulated trench cap (122, 137, and 152 cm).

Over three years worth of neutron moisture gauge data (average values for three locations per erosion plot) are presented in Figs. 5-7. After the snowmelt and late winter rains had time to percolate into the trench cap, almost all of the erosion plots exhibited either saturated or near-saturated conditions within the trench cap. By May 1985, the average volumetric water content within the trench cap under all three treatments ranged from 32 to 33% This represents a 45-46% increase in the water content of the trench



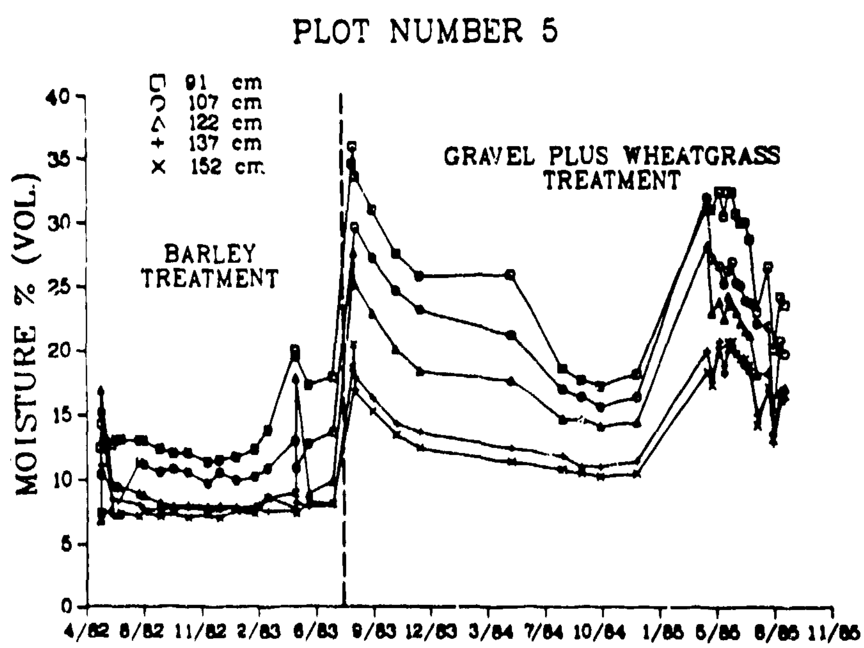
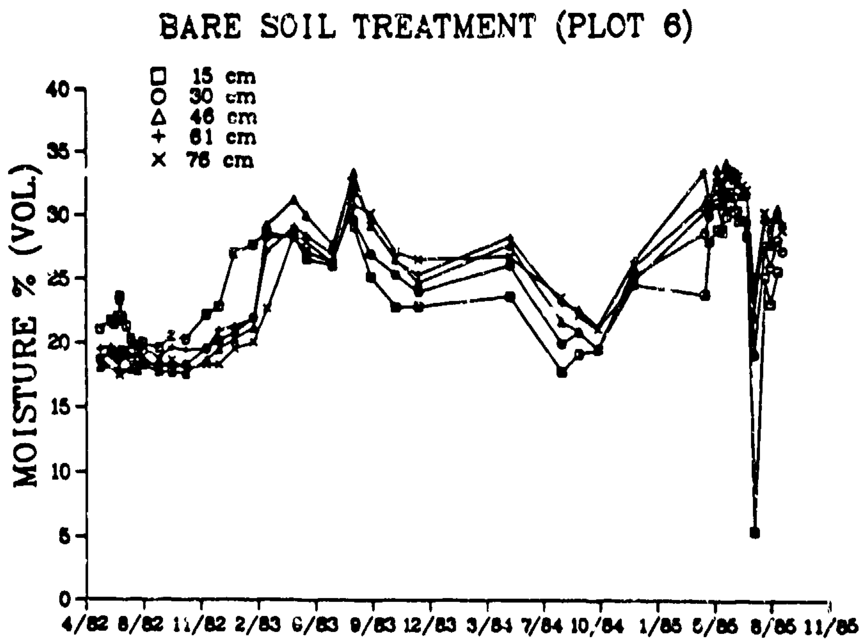


Fig. 5. Moisture contents in Plot 5.



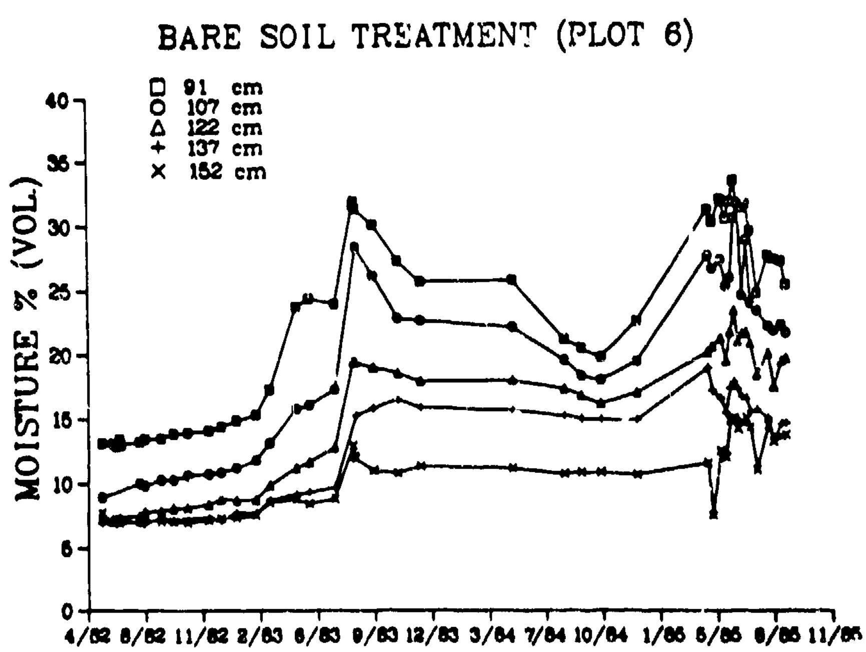
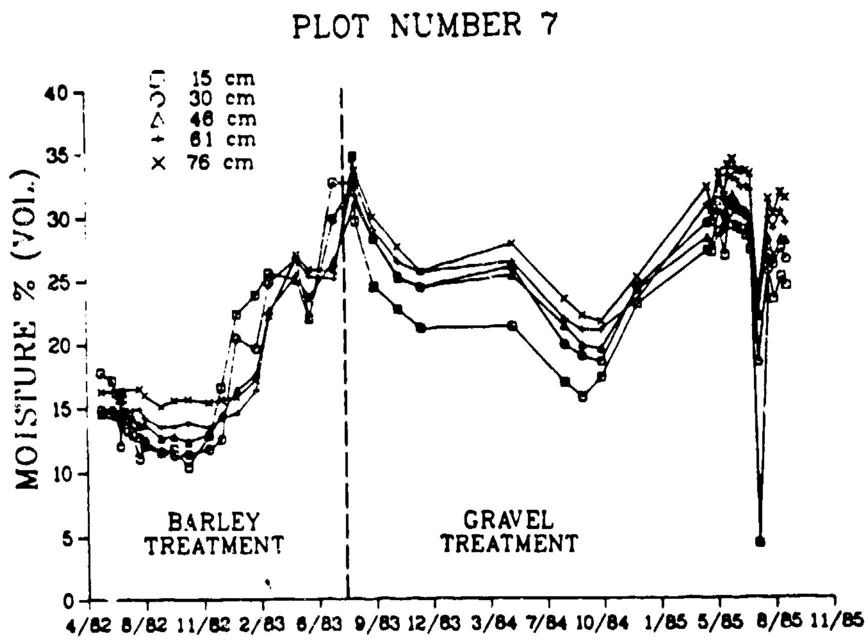


Fig. 6. Moisture contents in Plot 6.



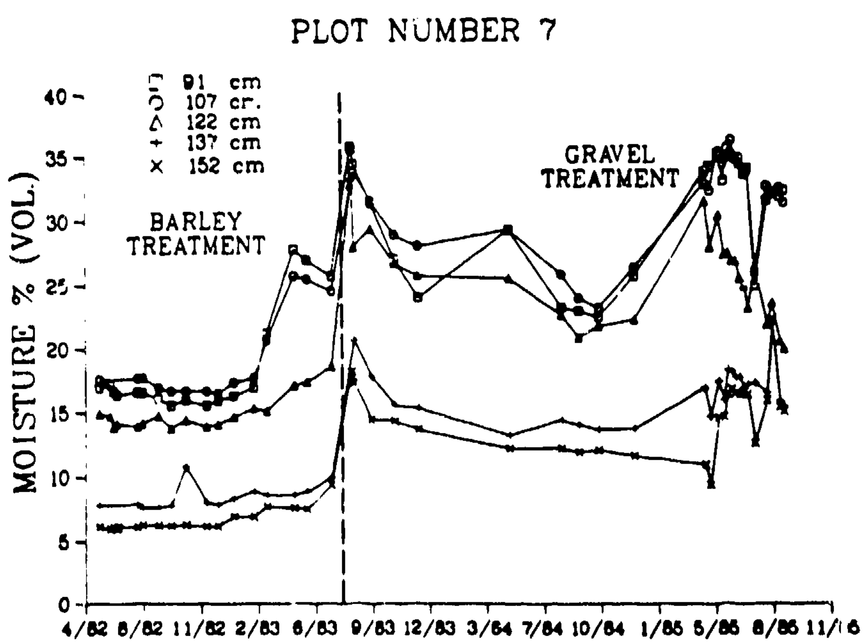


Fig. 7. Moisture contents in Plot 7.

cap since August 1984 in the bare soil and gravel cover treatments, with a corresponding 95% increase in water content observed under the erosion plot with the wheatgrass and gravel cover treatment.

After the late winter and spring rainstorms, the soil moisture content of the gravel cover and gravel plus wheatgrass cover treatments again changed dramatically between May and August 1985. The volumetric water content in the trench cap with the gravel cover remained at 33% between May and August, but the water content beneath the trench cap increased from 20.6% to 25.7% in this time period. Just as in 1984, the gravel plus wheatgrass treatment exhibited decreased water content between May (33%) and August (26%) within the trench cap due to transpiration water losses. It is also interesting to notice that a more long-term trend is starting to develop--the water content beneath the trench cap with the gravel plus wheatgrass is remaining drier than that beneath the gravel cover.

One needs to realize that these are unusual events due to unusual climatological circumstances that, averaged over a period of 6 months, amounted to precipitation of as much as 241% of normal.

MODIFIED TRENCH CAPS

Area B, a Los Alamos low-level radioactive waste disposal site, was closed in 1947 when waste operations were moved to another location. In 1982, as part of scheduled remedial action on a 0.65 ha portion of Area B, Waste Operations presented us with the opportunity to fieldtest our modified trench cap design as derived from the modeling and plot studies already described, along with a conventional design that was applied to Area B as a part of the remedial action.

The monitoring study designed for Area B addressed two questions:

1. Does the cobble/gravel biointrusion barrier cap design perform any better than the soil/crushed tuff cap at field scale under natural precipitation regimes and native grass cover?
2. Does the cobble/gravel trench cap design act as a capillary barrier to percolating water?

The remedial action performed by waste operations consisted of applying a new trench cap on top of the existing cap in order to cover radionuclide contamination present on the ground surface. All tree and shrub cover was removed prior to beginning construction activities.

Two plot areas were established on Area B as shown in Fig. 8. The performance of the two designs in limiting root intrusion was evaluated with the cesium tracer method described previously. About 16 kg of cesium chloride was applied to a 6 m x 40 m area in each plot on top of the existing trench cap for an application rate of 240 g/m^2. After the tracer was applied, a 15-cm layer of uncontaminated soil was spread over the entire area to prevent cross contamination of the earth-moving machinery.

Neutron access tubes were installed at four locations along the slope in each plot (Fig. 8). The tubes extended 100 cm into the old trench cap to provide access for measuring the moisture content of soil underlying the new caps.

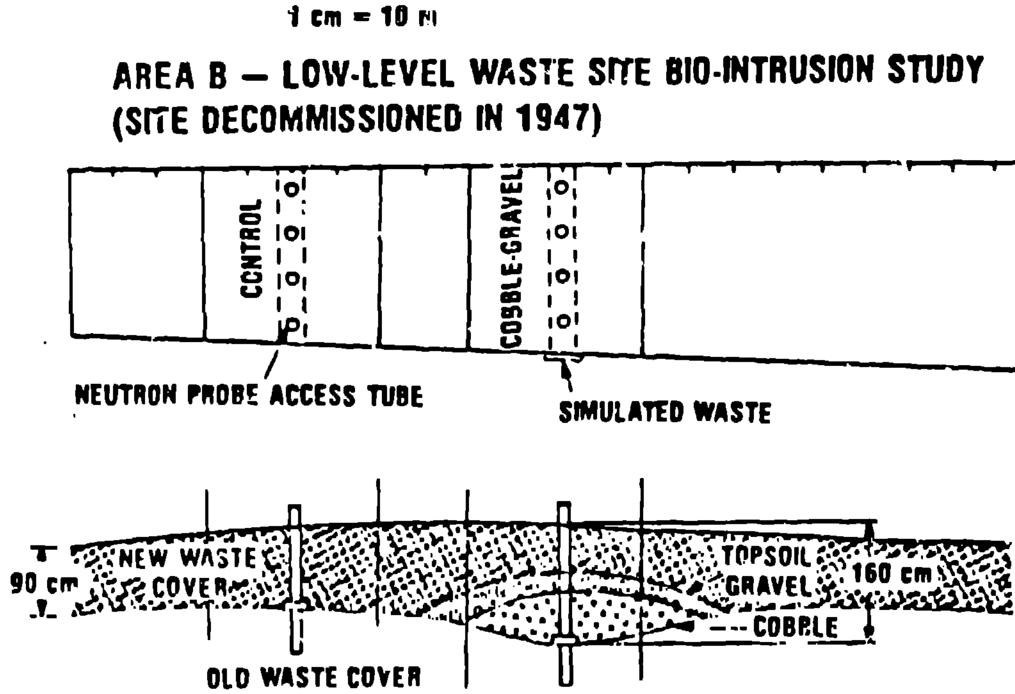


Fig. 8. Schematic of plot configurations for the Area B biointrusion barrier study initiated in the fall of 1982. Control treatment represented the conventional cap design constructed on Area B. The intrusion barrier design consisted of topsoil over layered rock.

The cap profile in the control plot consisted of about 75 cm of crushed tuff covered with 15 cm of topsoil. The improved cap design consisted of 75 cm of 10- to 30-cm-diameter cobble covered with 25 cm of 2-cm gravel all covered with 60 cm of Hackroy series clay/loam topsoil. Both plots had a surface slope of about 2-3% to allow for some surface runoff.

The surface of the entire area was seeded with a mixture of native grasses and covered with straw mulch used to minimize erosion during establishment of the plant cover. Because the plot was constructed late in 1982, plant cover did not become established until the spring of 1983. The dominant plant species covering the site in 1983 was wheat (*Triticum aestivum*) whose seeds were present in the straw mulch. In late 1983 and during the growing season of 1984, perennial grasses and yellow sweet clover dominated the plant cover.

The cesium concentrations in plant samples collected during the growing seasons were reported in last year's biobarrier report.

The most interesting feature of the soil moisture data from Area B is that snowmelt dominated over rainfall in recharging topsoil moisture and in contributing to percolation through both cap designs. For example, major increases in topsoil moisture during the winter (Figs. 9 and 10) were all correlated with periods of snow cover, whereas rainfall, which occurred primarily during the summer, produced no measureable increase in topsoil or backfill moisture. In fact, during the period from May 1 to November 1, 1983, when 18.5 cm of rain fell on Area B, topsoil moisture steadily declined from about 15-18% volume to 7-10% volume depending on the cap design. The decrease in soil moisture, as we have previously shown to be due to evapotranspiration, not only completely used that part of the 18.5-cm rainfall that infiltrated into the topsoil (i.e., all that was not runoff), but also used significant amounts of soil water in storage before May 1, 1983. As previously mentioned, major increases in topsoil moisture were sometimes followed by smaller increases in the soil underlying the trench caps. This was especially apparent during the winter when a very sharp increase in backfill moisture occurred following the rapid rise in topsoil moisture due to snowmelt.

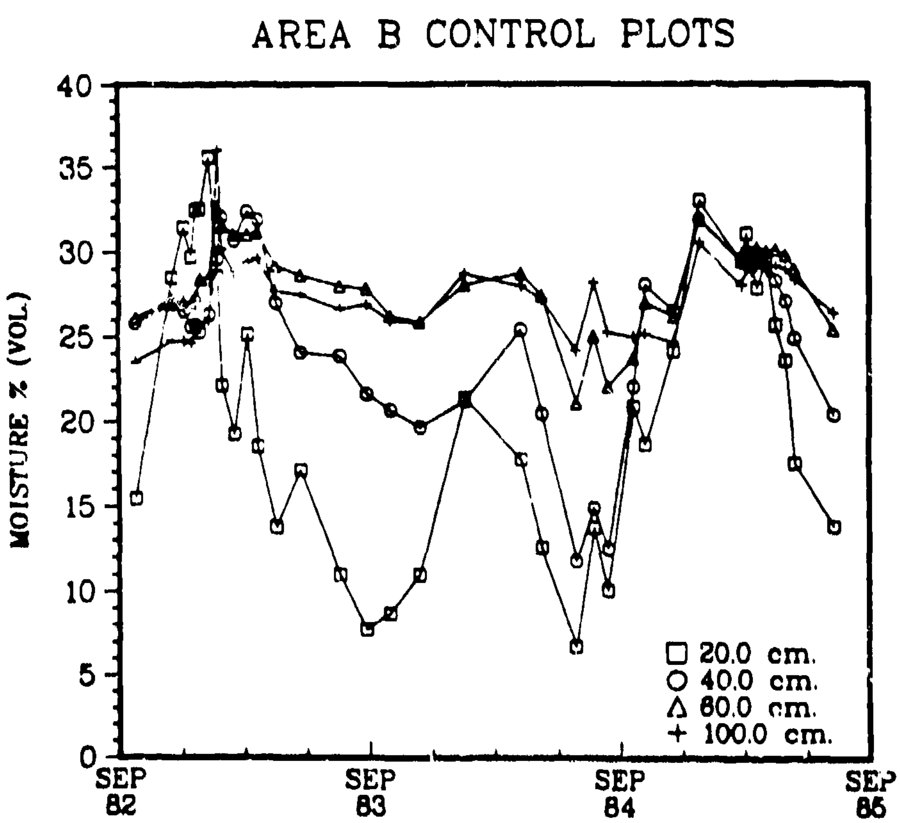


Fig. 9. Moisture contents in control plots.

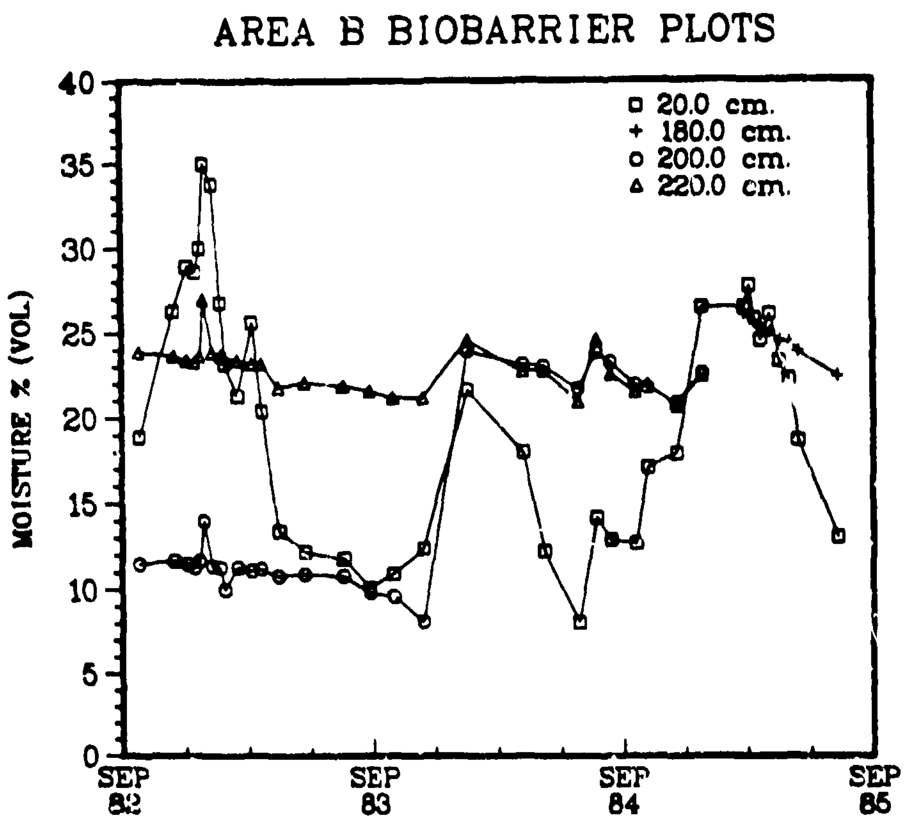


Fig. 10. Moisture contents in biobarrier plots.

The data for the backfill underlying both cap designs (Fig. 9: 100 cm for control plots; Fig. 10: 200 and 220 cm for biobarrier plots) also supports the latter statement in that backfill moisture under the soil/tuff cap design increased after all but one of the several snow storms occurring during the study suggesting that percolation through the soil/tuff cap design had occurred. In contrast, backfill moisture under the rock barrier did not respond to most of these snowmelts. For example, snowmelt from storms occurring in December 1982, January 1983, February 1983, late March and April 1983, and several times during last winter, all resulted in observable changes in backfill moisture under the soil/tuff cap design. However, only one measurable increase in backfill moisture under the soil/rock barrier occurred during the same interval. The lack of percolation through the rock barrier, when it had occurred through the tuff barrier, should result in higher topsoil moisture over the rock barrier. As mentioned, the data in Figs. 9 and 10, where topsoil moisture over the rock barrier was higher than that over the tuff barrier, lends some support to the potential use of the soil/rock cap design as a capillary barrier to percolation.

FIELD SUBSIDENCE EXPERIMENT

Test Plan

Subsidence cavities measured on actual burial trenches vary widely in both size and shape from broad, shallow depressions to narrow pipes that may extend to the waste. Burial site surveys indicate that about 85% of the measured cavities are less than 2.75 m in diameter and 95% are less than 4.25 m in diameter.

To stress the biobarrier, cavities of four sizes were created. There are two replicates of each and two control plots. The experiments are conducted in a trench 38 m long, 15 m wide, and 3 m deep. In the bottom of each 58-m^2 experimental plot we augered a 0.9-m-diam hole to a depth necessary to equal the desired volume of the subsided cavity (1.4, 3.4, 6.4, and 11.5 m deep). Over each of these drawholes was a 2.25-m^2 steel plate with a hinged trap door, which was fastened by explosive closures. One side of the drawholes was cut away flat to a depth of 1 m to allow the door to open fully. The entire trench was backfilled to a depth of 2.2 m with crushed tuff and screened to remove particles larger than 5 cm to prevent clogging. The backfill is overlain by 0.9 m of cobble/gravel biobarrier material and soil. A layer of cesium chloride tracer was placed at the backfill/barrier interface. Alfalfa was planted uniformly on the surface.

When the explosive closures were released, the trap doors fell downward, allowing the backfill to drain into the drawholes causing subsidence at the surface.

Plant root penetration is being monitored by routine sampling of plant leaves. Cesium concentrations in the leaves will be mapped as a function of time and location relative to the subsided cavities. Root penetration (if any) can be expected to occur first at the cavity rims--regions of maximum tensile stress and elongation.

Results

The resistance to subsidence should be equal above all eight drawholes since the main parameters influencing subsidence are unchanged in the backfill overlying the eight drawholes. The uniform backfill thickness--drawhole diameter ratio (t/d)--was high enough to prevent subsidence at any of the eight locations.

From this experiment it is obvious that the crushed tuff and/or the soil have some cohesiveness as was demonstrated in the laboratory.(6) The lab results also show that, even for crushed tuff, a higher degree of consolidation or compression is at the origin of an increase in soil strength. (It is well known that densification causes soil stabilization.) The bottom of the landfill, which is submitted to a pressure averaging 50 kPa, could consequently be fairly well stabilized when dry.

A completely cohesionless porous medium (Ottawa sand, for example) would have undergone immediate subsidence into the 0.9-m-diam drawholes when the trapdoors were released. This was obviously not observed when the trapdoors, overlain by crushed tuff, were opened.

As stated earlier, the presence of excess water reduces the effective stress responsible for the friction between solids. Therefore, it was decided that by increasing the water content of the backfill, the shear strength may decrease enough to cause failure or subsidence while preserving the "natural" setup. This action could in no way be considered to be totally undisturbing to the environment because it was suspected that the amount of water needed would far exceed the amount of water available through natural precipitation in Los Alamos.

Flooding of the area immediately overlying the drawholes caused subsidence in two 1.4-m deep holes, two 3.4-m deep holes, two 6.4-m deep holes, and one 11.5-m deep hole.

The shape of the subsidence holes was, at the start, far from resembling an inverse cone with regular slope. Instead, it had, in most cases, a vertical wall where the cohesive materials are located (Hackroy series soil) and extremely irregular angles where the diameter of the unstable moving material is not small compared with the height of the slope (gravel and cobble in our cases). The ratio of the diameter of the unstable moving material to the total slope has to be small to satisfy the demand for identification of the angle of repose, which represents the angle of internal friction and/or maximum slope angle of a granular material at its loosest state. The ratio diameter/length of the slope is too high in the case of gravel and cobble and the compression is too high in the crushed tuff for their slope angle to be representative of the angle of repose. Cohesion prevents the Hackroy series soil from adopting an angle that is indicative of what the angle of repose might be.

Principles based on relationships between surface deformation and underground cavities can be applied to predict fundamental quantities such as maximum possible subsidence. Generalization of these empirical relationships can lead to calculation of complete deformation profiles, provided

1. The stratification is horizontal (soil, biobarrier, tuff).
2. The subsidence reached its final stage.
3. The cavities are geometrically simple.

Because the above conditions are fulfilled, final deformation is characterized by the following facts:

1. The surface subsidence boundaries extend beyond the edges of the cavity.
2. Concurrent with subsidence, horizontal displacement-producing stresses occur. Those movements are larger than would be expected from the subsidence curvature.
3. The cylindrical nature of the cavity causes maximum subsidence over the center where there is no horizontal movement, whereas the vertical and horizontal stresses and subsequent displacements should be symmetrically distributed over the subsidence area.

The vertical component, whose upper limit is defined as "maximum possible subsidence" is only present if the cavity has a minimum "critical area."

In case a critical area is present, the central maximum possible subsidence is coupled with zero curvature and strain. Prediction of maximum subsidence is based on the fact that it is correlated to cavity thickness or S = at, where a = subsidence factor. If the displacements caused by any cavity on our plot are affected by displacements caused by neighboring cavities, then we would witness a superposition of surface displacements. Since this was not the case, we can assume that every cavity was unaffected (through distance) by the presence of any other.

Maximum subsidence is also dependent on the subsidence factor, which, in turn, depends on the depth of the cavity, its lateral dimension, and stability of overlying soil layers. Because these three parameters are the same for all cavities, the only variable remaining in our plot is t. The subsidence factor would be very difficult to determine for our heterogeneous over-burden, but one would expect it to decrease with increasing depth. The General Institute of Mining Survey (7) suggests

$$S = \frac{25m}{25 + \sqrt{h}} \cos \alpha \quad ,$$

where α = angle of dip. and h = backfill thickness. This formula does indeed point to a decrease of subsidence with depth of drawhole.

The National Coal Board, Mining Department (9) tried to predict maximum subsidence based on curves empirically derived from actual measured occurrences that appear under certain conditions. However, those curves are not drawn for cavities of less than 10 m in diameter or at depths of less than 50 m.

Biointrusion

Statistical analysis of data from the short-term, small-scale bio-intrustion studies conducted in lysimeters (10) revealed that a trench cap design consisting of 60 cm of topsoil over 25 cm of gravel (2-cm diam) over a 75-cm layer of cobble (7.5- to 13-cm diam) effectively limited both plant root and burrowing animal intrusion into a simulated waste emplaced beneath the cap. Although the results from this initial screening experiment were encouraging, a number of additional questions remained concerning the long-term performance of a soil/rock intrusion barrier cap design. Those questions are

- How does the soil/rock cap design affect water balance, particularly percolation?
- How does the soil/rock cap design perform at larger scales?
- How does the soil/rock cap design perform over extended time?
- How much subsidence can be permitted and still maintain the effectiveness of the soil/rock intrusion barrier design?

The design and construction of the plot to address the question of intrusion barrier performance under various degrees of subsidence is described in detail in a previous section.

Evaluating the effectiveness of the soil/rock intrusion barrier design under various degrees of subsidence was accomplished throught the use of a tracer emplaced at the interface of the trench cap and underlying backfill. A total of 73 kg of CsCl was spread uniformly in a thin layer on the crushed tuff backfill before placement of the soil/rock trench cap. Because cesium is plant available, time series analysis of the cesium content of vegetative samples can be used to indicate root penetration through the trench cap.

Although the entire plot area was seeded with a mixture of native grasses, the only plant that was successfully established on the plot was a common invader (or weed) of the genus Euforbia. Plant cover during the height of the growing season in 1983 was about 50%. The lack of success in establishing native grass cover stems from our decision not to supplement precipitation by irrigating the plot.

Vegetation sampling on each of the plots was begun in July 1983. Samples were oven dried and submitted for neutron activation analysis to determine cesium content. Cesium concentrations in excess of 1 ppm (background levels in plants are <1 ppm) were considered indicative of root penetration to the cesium layer.

SUBSIDENCE ESTIMATION

Phillips (11) devised a method to estimate geomechanical subsidence. If we consider that the total drawhole volumes are 0.89 m^3, 2.16 m^3, 4.07 m^3, and 7.32 m^3, respectively, and that they all occurred at 3.1 m below grade, prediction for subsidence depths and diameters could be attempted.

Using the subsidence feature estimation curves from Phillips, the predicted maximum subsidence depths for the 2.16 m^3 and 4.07 m^3 drawholes amount to 0.3 m, 0.6 m, and 0.8 m as compared to the measured values of 0.3 m, 0.8 m, and 1.3 m, respectively. Only the cavities of 2.16 m^3 and 4.07 m^3 were completely surveyed. The curves were derived from soil mechanics studies in idealized noncohesive, isotropic and homogeneous porous media and the morphology of the voids used herein by Phillips are idealized, i.e., a cylinder equivalent in diameter and length. The closer the voids studied at Los Alamos resemble the idealized void, the better the match between the predicted and the measured maximum subsidence (the smaller void depth is the one that most closely matches the "idealized" void).

Our subsidence feature appeared at the rim as a somewhat near vertical depression that is slowly being transformed to a more shallow depression of bigger diameter as the particulates form increasingly stable slopes.

The estimated maximum subsidence diameter according to the Phillips subsidence feature estimation curves for the surveyed cavities of 2.16 m^3 and 4.07 m^3 are 4.75 m and 5.2 m, respectively. This compares to measured values of 3.7 m and 4.25 m.

It has to be realized, as was stated in the procedure's limitations that the predictions were valid in idealized, noncohesive, isotropic and homogeneous porous media. This is obviously not the case in our experiment. Neither are most the studied drawholes anything near an "idealized" void.

This last point, more than anything else, is probably at the origin of the noted discrepancies.

RESULTS AND DISCUSSION

It can be seen that regardless of the fact that our drawholes have far from an idealized void or medium, the shape of our cavities is slowly approaching the one predicted by Phillips. Indeed, the depth of the cavity is decreasing as the diameter is increasing, mainly through factors such as erosion. (Phillips's depths are more shallow and his predicted diameters are larger than the ones measured to date). Our depth measurements average between 133% and 163% of prediction, while our diameters measure 78% and 82% of prediction. As of this date, no cesium uptake is apparent over the subsided areas. The biobarrier may have lost some of its integrity in some cases, but so far (two years) naturally occurring vegetation has been unable to penetrate it.

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